A Study of Intergenerational Equity and the Optimal Depletion of a Finite Resource: Canadian Natural Gas

by

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INTERGENERATIONAL EQUITY AND OPTIMAL DEPLETION OF CANADIAN NATURAL GAS

ABSTRACT

This thesis is a study of the problem of intergenerational equity and the optimal depletion of finite resources. A review of the economics literature on the subject precedes an interdisciplinary study of equity in static and intertemporal contexts. Reasons for the use of non-market rules for depletion policies are examined. A simulation model of the Canadian natural gas industry, which integrates non-market rules similar to those used for Canadian gas exports for the last thirty years, is developed to assist in the evaluation of these types of rules, focusing on their intergenerational impacts.

Résumé

Cette thèse examine le problème de l'équité entre générations et l'épuisement optimal de ressources naturelles limitées. Un compte rendu de la littérature sur ce sujet en économie politique précède une étude interdisciplinaire de l'équité dans des contextes statiques et entre générations. L'auteur examine les raisons pour l'utilisation de règles qui n'obéissent pas au marché, pour les politiques sur l'épuisement. Un modèle de simulation de l'industrie canadienne de gaz naturel, qui incorpore des règles qui n'obéissent pas au marché semblables à celles utilisées pour l'exportation de gaz canadien depuis trente ans, est développé pour aider l'évaluation de ce genre de règles, en concentrant sur leurs effets entre générations.

INTRODUCTION

A STUDY OF INTERGENERATIONAL EQUITY AND THE OPTIMAL DEPLETION OF A FINITE RESOURCE STOCK, CANADIAN NATURAL GAS

The topic of this thesis is intergenerational equity and the optimal depletion of finite resources stocks, with particular attention to Canadian natural gas. The thesis is organized in six chapters. Chapter One reviews the economics literature on finite resource use. Chapters Two and Three examine the concept of equity in static and intertemporal contexts respectively, from the viewpoints of different disciplines. Chapter Four presents a simulation model of the Canadian natural gas industry, and Chapter Five reports on results from simulation experiments. Chapter Six is the summary and conclusions. The following offers a more detailed description.

Chapter One begins with an historical overview of the way finite resource use has been treated by economic analysts from the time of the classical economists. These authors include among others, Smith, Ricardo and Mill, up to and including Gray. The latter's work in comparative

statics suggests that he be considered as marking the boundary between classical and neoclassical economics. The classical economists focussed primarily on mines. Most of their examples are drawn from studies of the operations of coal mines, and the mines for precious metals, although the principles they espoused were intended to be general. It was not until the neoclassical work of Hotelling that one finds a clear dynamic analysis of finite resource use. This work is reviewed at length, as it is generally considered to be the seminal work for the vast literature which has evolved on the subject. Hotelling also explicitly considered the social optimality of alternative patterns of finite resource use.

Curiously, interest as represented by journal articles in the subject seems to have died out for a period of some thirty years after Hotelling, to be revived in the 1960s. From that point onward, hundreds of papers appeared, enhancing and extending Hotelling's work in many ways. An overview of this vast literature is also presented in Chapter One. Within this literature, very few works focus on the issue of equity in finite resource use, and those that do are reviewed more critically. The literature review is interspersed with descriptions of the general analytic

techniques used in the various historical periods. This is done for two reasons: first, to enhance the clarity of the exposition as, for example, the meanings of particular terms such as rent and royalties have changed over time; second, to make the thesis more intelligible to all of those participating in the natural gas industry even if they are not economists.

Chapter Two begins with a discussion of the role of equity in economic analysis. In most cases where the term is used, it is either left undefined, or is poorly defined. The meaning of the term is generally taken for granted. In some areas, however, attempts have been made in the literature of welfare economics to ascribe specific meaning to the term, and these attempts will be carefully reviewed. The term equity also arises in other literatures, such as psychology, sociology, and law, in ways that have meaning for the issues at hand.

It is clear that issues involving equity raise questions of morals, and ethical analysis. Chapter Two continues with a discussion of the utilitarian ethics which form the basis of most of neoclassical welfare analysis and for the neoclassical economists' conceptions of equity.

This is contrasted with the alternative approach of Rawls, the intutionists, and other ethical schools of thought that are relevant to the problem of equity in finite resource use.

The preceeding leads to a discussion of the ethical neutrality of economic analysis and how economic science might be used to encourage particular moral judgments. This discussion is especially important because some economists take the position that their analysis is "value-free" and can be used as objective input to political and ethical debates on the choice of economic systems, as well as the distributions of initial endowments and rewards obtained under the economic system. The market system in particular is often thought of as a sort of value-free transformation system, or tool for a society and its economic analysts. The ethical neutrality of the economic analysis with respect to the use of finite resources in particular, and other resources in general must be carefully analyzed. The logical priority of economic or ethical analysis in the study of the problem of finite resource use and the use of the concept of equity as an "extra-economic" criterion are next discussed.

Chapter Three describes the special character of problems involving intertemporal and intergenerational choice. This explicit inclusion of time creates special problems in ethical analysis and moral choice, as well as in economic analysis. The economic and ethical areas relating to intergenerational choice also have perhaps the least well-developed literature of the issues discussed thus far, although they are most germane to the thesis. However, on the basis of the exposition in Chapter Two, it becomes clear that insights from earlier thought on inheritances, preservation of the environment, dynasties, etc., are all relevant to these issues. Ideas and concepts based on this wider literature are presented in relation to the problem of intergenerational equity and finite resource use.

Chapter Four focuses on the applications and use of the ideas and concepts presented in the previous chapters to the problem of natural gas use in Canada. The National Energy Board (NEB) and the Alberta Energy Resources Conservation Board (AERCB) are the key institutions that can regulate the use of natural gas over time. These boards and their functions and decisions are described in detail.

The NEB and AERCB are charged with the protection of

the interests of present and future generations of Canadians, and they have elected certain non-market rules in fulfilling their charges. This chapter describes the development of a simulation model of the natural gas industry. Since the model includes the aforementioned rules, it should be able to identify the likely impact that these rules have on the industry and on depletion patterns for natural gas, in contrast with "more market-oriented" solutions, for which the literature is more complete. In this thesis the review of world and North American energy markets suggests that Canadian supplies of natural gas are likely to be a relatively small part of the gas substitutible energy supply in those markets. Thus, for the modelling exercise, prices for gas are assumed to be determined exogenously, in the world and North American markets. In the case where the border is closed to exports, it is argued that a reasonable scenario is based on the idea that the same political regime which would cease exports would also be likely to price the resource at or near world levels.

Chapter Five presents the detailed simulation model results for a number of scenarios involving the use of "more market-oriented" and non-market rules including the

possibility of preserving all natural gas for domestic consumption i.e. cutting off all exports. The effects of these various policy alternatives on the intertemporal patterns of industry investment, rates of return, depletion, and terminal dates for exhaustion are all considered.

Chapter Six integrates the simulation model results with the earlier chapters' discussions on equity in finite resource use to draw conclusions regarding the equity of natural gas use in Canada. The chapter offers suggestions regarding the equity of finite resource use in general, in Canada and in the rest of the world as well. The thesis does not deliver firm conclusions as to what is equitable use and what is not, but rather offers direction on the factors which must be accounted for if one wishes to promote one pattern of resource use over others, in the interest of equitable resource use. While no single definitive statement is made about what equity is, the thesis attempts to develop an understanding of equity through argument. Thus the thesis does not offer, for example, an alternative objective function for the microeconomists, but it does offer useful input to the policy debate on equitable finite resource use for the economist, the businessman, the politician, the philosopher, and all other interested

parties.

Several appendices conclude this paper. The first offers a fairly complete overview of the elements of the natural gas industry in Canada, in the interest of making the discussion of the industry in the text understandable to the layman. This is considered essential for this thesis because the industry is very complex, and the technical aspects of the resource from discovery to final end use must be understood in order to appreciate the economic analysis of the resource use.

The second appendix lists the evolution of the National Energy Board and the Alberta Energy Resources Conservation Board rules for the evaluation of exportable natural gas surpluses.

The third appendix lists the simulation program that is used to study the various scenarios of Chapter Four.

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DEDICATION

...to my family and friends

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CHAPTER ONE

LITERATURE REVIEW

INTRODUCTION

The purpose of this chapter is to describe the basic nature of the problem of intergenerational equity and the optimal use or depletion of finite resources. The focus of this chapter is on the economic analysis of the problem, and the organization of the material is historical. The economic analysis of this problem may be said to begin with the classical economists although there are some relevant comments in earlier literature. Interspersed throughout the following literature review, the reader will find descriptions of economic models, methods, and tools of analysis. Such an approach seemed useful, first because throughout the historical period of interest, there have been changes in the way in which economists have performed their analyses, and changes in the meanings of, and usages of, particular concepts. The second rationale for explaining the tools of analysis is to try to make the overall presentation accessible to those relatively unfamiliar with economic analysis. The chapter concludes with reviews of the most recent and generally accepted models in economics relating to intergenerational equity and the optimal depletion of finite resources.

LITERATURE REVIEW SEQUENCE

The problem of the optimal depletion of finite resource stocks and a variety of related problems, such as protection of the environment, the value and use of inheritances, consideration for the needs of future generations, etc., have been addressed from ancient times. Thus, the problem at hand may be considered to be ancient, at least in some respects, and from biblical times many authors have made statements which have strongly affected how people thought about the problem. True "economic analysis" of the problem did not come until much later. There is therefore a line of demarcation between early "thought" on this problem and the subsequent economic analysis. Thus, the first division in the literature review is between preclassical thought and classical economic analysis. The second division is then between classical and neoclassical economics, which differ on a number of bases, especially methodology.[1]

The paper which provides the ending point in the review of classical analysis is Lewis Gray's "Rent Under the Assumption of Exhaustibility", which many consider to be a seminal and transitional article to "Neoclassical Economic Analysis".[2] The Gray paper contains many elements commonly identified with both the classical and neoclassical schools of thought, in content and methods of analysis.

The cornerstone work, however, for the bulk of modern Neoclassical Analysis came seventeen years later with Harold Hotelling's "The Economics of Exhaustible Resources", published in 1931.[3]

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[1] See P.J. Crabbe (1983), p. 195 for a discussion of some of these differences.

[2] Lewis Cecil Gray, "Rent Under the Assumption of Exhaustibility", Quarterly Journal of Economics, 28 (1914), 466-489.

[3] Harold Hotelling, "The Economies of Exhaustible Resources", Journal of Political Economy, 39 (1931), 137-175.

While the immediate response to this paper was modest, thirty years later this paper gave rise to a stream of literally hundreds of papers published in the sixties, seventies and eighties which follow the partial equilibrium approach of Hotelling. The literature is so vast that it is necessary to be selective. To this end, particular attention is given in this thesis to the seminal article by Hotelling (1931), and to the Scott (1967), and Herfindahl (1967) papers which together provide overviews of the basic work in this area.

The analysis of this chapter will pursue a second stream of research based on macro production function models that include resource sectors. The use of this class of models, and the accompanying methodologies, forms the second major stream of modern neoclassical economic analysis relating to the problem. This approach was outlined by Solow in 1974 and this and other related papers are reviewed later in this chapter.

ECONOMIC THOUGHT AND ANALYSIS

The primary purpose of this section is to trace the development of economic analysis relating to the use of finite resources. To this end, it is useful to consider what is generally accepted as economic analysis. Schumpeter (1954) distinguishes between

> "...Economic thought -- the opinions on matters that prevail at any given time in any given society and belong to the province of economic history rather than to the province of the history of economics -- and Economic Analysis -- which is the result of scientific endeavour..."[4]

He also states:

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[4] Schumpeter, History of Economic Analysis, p. 52.

> "what distinguishes the "scientific" economist from all the other people who think, talk, and write about economic topics is a command of techniques that we class under three heads: history, statistics, and "theory".[5]

If one accepts such a conceptual framework for the identification of economic analysis, or economics as a science, then there appears to be no analytical contributions made to the problem of natural resource economics prior to those of the classical economists. Finite resources were discussed, but were not subjected to explicit analysis. However, as was mentioned earlier, pre-classical thought is relevant to questions of value, equity, provision for future generations, etc. They will not be neglected, but will be more appropriately discussed in later sections which treat equity, value, intertemporal time preference, and intergenerational distribution; matters that are not the sole prerogative of economists.

PRE-CLASSICAL THOUGHT

How was the problem of finite resource use approached?

As has just been noted, there was a great deal of thought relating to the problem at hand, but very little in the way of analysis as we think of it today. Such matters as optimal resource use were presented more in the manner of opinions or judgments or as models for behaviour.

1. For example, there is the Biblical lesson of "The Prodigal Son". The precept is clearly that future generations have 'rights', and that these rights must be preserved and cannot be eliminated even by "riotous living".

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[5] Schumpeter, History of Economic Analysis, p. 12.

2. Another example is the "Dynasty Concept", keeping power in the hands of generations of members of the same family. Power is preserved by maintaining economic sources of wealth intact. This encouraged such things as the practice of leaving the land to the oldest son in part to keep it from being broken up into small parcels, but also to encourage the care and maintenance of the land. The English and the Scots called this method of preserving the dynasty the "Primogeniture Concept". The oldest son held the land interest for the preservation of the family, and selling it off was one of the worst things imaginable. In England, primogeniture practice was encouraged in part by the "Law of Entail". One had clear duties toward children, and the preservation of a way of life. This attitude was reflected later in the Bostonian concept of capital preservation - never eat into the capital, and do not sell the IBM stock.

There are many other examples indicative of attitudes toward discounting future pleasures and pains, the importance of family, providing for future generations, preserving the basis of wealth, preservation of a world belonging to God, and duties toward culture, nation, and state. Many princes of church and state, and many philosophers and essay writers commented on intergenerational subjects and exhaustible resources. Historically, economic thought was heavily intertwined with political and religious thought, and though it fell short of being analytical, it still offered some useful insights.

CLASSICAL ECONOMIC ANALYSIS

The classical economists' discussions relating to finite resources focused [primarily] on mining activities, especially coal and the precious metals, with a particular interest on the matter of rent. For example, Adam Smith wrote:

> "Whether a coal mine...can afford any rent depends partly upon its fertility, and partly on its situation. A mine of any kind may be said to be either fertile or barren, according as the quantity of mineral which can be brought from it by a certain quantity of labor is greater or less than what can be brought by an equal quantity from the greater part of other mines of the same kind."[6]

Thus, for Smith both fertility and location are important, with labour a factor to be applied to mines and paid the labour rate. The return to capital is contrasted with the landlord's rent in the following passage:

> "There are some of which the produce is barely sufficient to pay the labour, and replace, together with ordinary profits the stock employed in working them. They afford some profit to the undertaker of the work, but no rent to the landlord. They can be wrought advantageously by nobody but the landlord, who, being himself undertaker of the work, gets the ordinary profit of the capital he employs in it."[7]

Rent will not always arise, according to Smith, and it would be absent in the highest cost mine in production, based on fertility and location. Smith discusses the role of substitution between wood and coal, in suggesting the maximum price to which either could rise.[8] He also presents a discussion of the role of fertility, in relation to price,

> "The most fertile coal-mine, too, regulates the price of coals at all the other mines in its neighbourhood. Both the proprietor and the undertaker of the work find, the one that he can get a greater rent, the other than (sic) he can get a greater profit, by somewhat underselling all their neighbors. Their neighbors are soon obliged

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[6] Smith, A., The Wealth of Nations, pp. 269-270.

[7] Smith, A., The Wealth of Nations, pp. 269-270.

[8] Smith, A., (1776), p. 271.

> to sell at the same price, though they cannot so well afford it, and though it always diminishes, and sometimes takes away altogether both their rent and their profit. Some works are abandoned altogether; others can afford no rent, and can be wrought only by the proprietor."[9]

The lower cost mines tend to displace the higher cost mines, when the lower cost resources are discovered. The marginal mine may now be a lower cost mine, given demand at that time. The marginal mine determines market price. In Smith, the price of substitutes provides an upper limit on price, and lowest cost resources are used first, and describe the resources which could be sold, were the price to drop to its lowest possible level, transportation cost aside. For several precious metals, Smith notes that production from new low cost mines causes older mines to shut down altogether in some cases.

Robinson (1980) refers to the above quotation from Smith as evidence of "a dynamic factor involving the displacement of high- cost mines by low cost ones."[10] While Smith seems to be emphasizing the low-cost mines first rule, the dynamic process of exploration and exploitation described by Smith seems to me to have more dimensions than just that. Robinson uses the above type of argument to suggest the following summary of Smith,

> "The mineral industries, therefore, have a decreasing cost - which results, not from changes in technology, which decrease costs for all mines, but from the lower costs of exploiting new more fertile mines vis-a-vis the cost of exploiting existing, less fertile mines." [11]

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[9] Smith, A. (1776), p. 272.

[10] Robinson (1980), p. 280.

[11] Robinson (1980), p. 281.

There seems to be an implication in Robinson (1980), that coal is not an exhaustible or finite resource, which ceteris paribus faces ever increasing costs due to increasing scarcity. Rather, the process may be one where more fertile, lower cost supplies can be found regularly as exploitation continues.

I think that the above quote does not correctly reflect Smith's views on mining industries, and although Smith later (in the context of a discussion of precious metals) suggests that exploration can result in larger, more fertile finds he also describes it as a most uncertain activity, and not one which leads in the direction of ever decreasing costs.

Ricardo disagreed with Smith, on several points, one being his use of the concept of rent. Ricardo gives the following definition.

> "Rent is that portion of the produce of the earth which is paid to the landlord for the use of the original and indestructible powers of the soil."[12]

This poses an interesting puzzle as this thesis is concerned with destructible (exhaustible) "powers" of the soil. Ricardo notes that Smith sometimes uses the term rent in a more popular sense - and he emphasizes this - for payments other than for the original and indestructible powers of the soil – and this Ricardo objects to. Ricardo notes,

> "The laws which regulate the progress of rent are widely different from those which regulate the progress of profits, and seldom operate in the same direction."[13]

Robinson (1980, p. 282) notes that there is a clear contradiction between the definition of rent described above

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[12] Ricardo (1817), p. 33 [1948 edition].

[13] Ricardo (1817), p. 34.

and the discussion of rent in the following chapter of Ricardo (1817), where Ricardo states,

> "The return for capital from the poorest mine paying no rent would regulate the rent of all the other more productive mines. This mine is supposed to yield the usual profits of stock. All that the other mines produce more than this will necessarily be paid to the owners for rent. Since this principle is precisely the same as that which we have already laid down respecting land, it will not be necessary further to enlarge on it."[14]

The first definition states that "rent" should only refer to payments for indestructible qualities, the second states that it may be used to refer to payments above the price paid to the marginal mine. Robinson states that the explanation for the contradiction does not appear in Ricardo's text, but suggests that Ricardo may have been emphasizing not the use of the term rent in the two contexts, but the different bases for rent in agriculture and mining. Cannan suggests that it may have merely reflected the evolution of Ricardo's thought on the similarities between mines and agriculture.[15]

Robinson notes that although there is clearly confusion regarding the Ricardian concept of rent and Ricardo's criticisms of Smith, Ricardo's presentation of the analysis of the mine is "less contentious". Ricardo emphasizes the role of the marginal mine (similar to the farm at the extensive margin). He claims that,

> "After Adam Smith has declared that there are some mines which can only be worked by the owners, as they will afford only sufficient to defray the expense of working, together with the ordinary

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[14] Ricardo (1817), p. 46; quoted in Robinson (1980), p. 282. See also Ricardo (1817), pp. 220-221.

[15] Cannan (1964), pp. 246-248, cited in Robinson (1980), p. 283.

> profits of the capital employed, we should expect that he would admit that it was these particular mines which regulated the price of the produce from all mines. If the old mines are insufficient to supply the quantity of coal required, the price of coal will rise, and will continue rising till the owner of a new and inferior mine finds that he can obtain the usual profits of stock by working his mine. If his mine be tolerably fertile, the rise will not be great before it becomes his interest so to employ his capital; but if it be not tolerably fertile, it is evident that the price must continue to rise till it will afford him the means of paying his expenses, and obtaining the ordinary profits of stock. It appears, then, that it is always the least fertile mine which regulates the price of coal." [16]

The term "regulation" has causal implications here; true, the number of mines of a given fertility affect price and the existence of marginal (no rent earning) mines in an industry, but also true is that were it not for the marginally fertile mines, the price would be higher ceteris paribus. Ricardo also notes,

> "If the demand for coal should be diminished, or if by new processes the quantity should be increased, the price would fall, and some mines would be abandoned; but in every case, the price must be sufficient to pay the expenses and profit of that mine which is worked without being charged with rent. It is therefore the least fertile mine which regulates price."[17]

This static analysis, and the emphasis on a progression from more to less fertile mines essentially summarize the view of Ricardo.[18]

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[16] Ricardo (1817), p. 222.

[17] Ricardo (1817), p. 222.

[18] Robinson notes this, and also presents the contrasting view of Carey (1847) regarding land. Robinson notes that Carey suggested a progression from less to more fertile lands as the (continued...)

Mill (1895) suggests that diseconomies of scale, as well as several other factors, explain why one fertile mine can not supply the market. Robinson (1980), states, that Mill

> "...introduced a fundamental difference between mining and agriculture - that in mining present production and future production are antagonistic and thus optimization may involve adjustment of the time profile of exploitation. But Mill goes further than this. He allows that minerals may, by virtue of their approaching exhaustion, permanently yield a scarcity rent (or royalty)."[19]

Mill also notes that temporary payments of rents (due to population increases, changes in demands, etc.) may be paid to the least fertile sources. He also notes, along with Smith, that the discovery of new, more fertile sources of supply will tend to depress market value. This is clear in the following passage,

> "If the superior mines or fisheries, with the addition of the one newly opened, produce as much as is required at the lower value corresponding to their lower cost of production, the fall of value will be permanent, and there will be a corresponding fall in the rents of those mines or fisheries which are not abandoned."[20]

His conception of rent, however, for agricultural commodities is rather different from our modern conception, as is made clear below:

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[18](...continued)
population is more able to bear the higher initial development costs of the more fertile lands. Such a proposition is clearly in opposition to the approach of Ricardo (1817).

[19] Robinson (1980), p. 284.

[20] Mill (1871), Book III, ch. 5.

> "Rent, in short, merely equalizes the profits of different farming capitals, by enabling the landlord to appropriate all extra gains occasioned by superiority of natural advantages."[21]

Price is determined by the cost of production of the highest cost farmer supplying the market. Were the price to be lower, eliminating some rent, a part of essential supply would be lost, according to Mill. Mill claims that consumers would therefore, be no better off by elimination of rent. However, there is always the possibility of taxes on rent, which is not explored in that context. Mill notes, however, that a land tax would replace private good with public advantage, but he does not explicitly examine discriminating taxes.

As a general rule, Mill[22] follows the Ricardian argument for a progression from more to less fertile mines. Robinson (1980, p. 285) notes the "natural order" of Mill which dominates the current neoclassical literature.

> "Both in the case of mines and of fisheries, the natural order of events is liable to be interrupted by the opening of a new mine, or a new fishery, of superior quality to some of those already in use."[23]

Robinson (1980, p. 285) emphasizes that Mill asserted that the marginal mine may earn a scarcity rent, and that optimization may require the adjustment of the time profile of exploitation for a mine.

Mill notes a number of specific items relating to the fertility and rate of production possible from mines, where, for example only a limited surface of a vein is exposed, and notes,

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[21] Mill (1871), Book III, ch. 5.

[22] Robinson (1980), p. 284.

[23] Mill (1895), quoted in Robinson (1980), p. 285.

> "In some instances, the owners limit the quantity raised, in order not too rapidly to exhaust the mine: in others there are said to be combinations of owners, to keep up a monopoly price by limiting production."[24]

Gray (1914), The Profit Maximizing Mine Owner

Gray's work has been noted as being transitional between classical and neoclassical analysis by a number of authors including Crabbe (1983), who states the following:

> "Even though Gray's analysis still carries some traces of classical influence, his method of analysis is definitely neoclassical. Allowance for substitution between factors of production, clear distinction between the law of variable proportions and Ricardian decreasing returns, between profit and interest, abandonment of rent as the specific income of land, the use of marginal analysis, etc., are all neoclassical features. Some traces of classical influence are still present in Gray's analysis, e.g., the merge of labour and capital into a composite factor, the distinction between intensive and extensive margin, etc."[25]

In "Rent Under the Assumption of Exhaustibility", Gray presents a number of the basic elements of finite resource economics.[26] His primary example describes the behaviour of a representative profit maximizing mine owner.

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[24] Mill (1871) Book III, ch. 5.

[25] Crabbe (1983), p. 195.

[26] Lewis Cecil Gray, "Rent Under the Assumption of Exhaustibility", Quarterly Journal of Economics, 28 (1914), 466-489.

Zero interest rate, constant costs, no taxes

Gray initially disregards the influence of the interest rate and assumes a case in which the per unit costs of removing coal at different points in time and at different rates at these points in time are constant, and there are no taxes. His analytical approach is similar to partial equilibrium analysis.

> "The owner of a valuable coal deposit, for instance, desires to derive the maximum benefit from the limited supply which he owns. If, for any reason, less benefit can be derived by immediate removal and sale of the coal than by waiting until some future time, it may be profitable to postpone utilization."[27]

> "...If the price is rising and the prospect is that the rise will continue, the owner of the mine will find it to his interest to take out but little coal in the present."[28]

Ceteris paribus, a rising price scenario would tend to result in the postponement of the sale of the coal, as compared to a constant price scenario.

Cost changes

Gray next considers the influence of changes in the costs of production of the coal, holding other variables constant. He states:

> "...a lowering of the prices of those factors which enter into the expenses of production will make profitable a postponement of removal."[29]

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[27] Ibid., p.470.

[28] Ibid., p.470-471.

[29] Ibid., p.471.

The lowering of costs per unit is apparently assumed to be a continuing change as was the price increase scenario. Conversely, he states:

> "...a decrease of the prices of the product or an increase of the prices of the factor of expense, in as far as such changes are continuous or anticipated, will create motives for rapid utilization."[30]

Diminishing returns, zero interest rate, no taxes

He then examines the nature of the production process, and notes that diminishing factor productivity will influence production plans. Gray states that:

> "According to the Ricardian theory of rent, the landowner will find it to his interest to add units of labor and capital to a given surface of land up to the point where the last unit applied just equals the product which might be derived from its employment on marginal land."[31]

> "The owner of the mine may well hesitate to proceed beyond the point of maximum average returns per unit of expense."[32]

Thus, if one assumes a zero rate of interest and assumes the price of coal to be a constant over time, one should choose an output level where average productivity is the highest and average cost per ton is lowest. This maximizes net benefit per unit of input at any time.[33]

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[30] Ibid., p. 471.

[31] Ibid., p. 471.

[32] Ibid., p. 471.

[33] This plan may be altered in the case where only a relatively small amount of coal is left for removal in a final year, possibly at high cost. In this case earlier period plans may be adjusted above or below the previous minimum cost per ton output estimates to minimize the intertemporal cost per ton of coal.

Influence of the interest rate

Gray then considers the influence of the interest rate, in his summary, he states:

> "...the removal of all coal in the present, beyond the point of maximum net returns per unit of coal, is subject to the competition of future uses; it might be considered that the value of all coal extracted beyond this point is subject to an opportunity cost measured by the present value of the net return which would be derived from the coal if extraction were postponed until the future."[34]

He presents a numerical example which illustrates the use of:

> "...the theoretical method of determining the rate of utilization (of a known stock of coal) as a resultant of the two antagonistic factors: diminishing productivity and the discount on the returns from future removal..." [35]

The influence of the discount rate, is to bias production toward the present, and to increase production in the early years beyond the point of minimum (undiscounted) cost per unit of output. He does note that this implies that a larger capital facility may be required in the early years, and that it would be under-utilized in later years. The high investment cost of a rapid rate of extraction would tend to levelize annual output. Also, he assumed that the quantity extracted in the first year in no way affects the costs of removal in subsequent years, this based on the assumption of constant returns. He indicates that due to the physical structure of the mine in question, the mine may be

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[34] Ibid., p. 485.

[35] Ibid., p. 475.

characterized overall by increasing returns, diminishing returns, or both according to the conditions encountered.[36]

As discussed earlier, the influence of intertemporally increasing prices is to bias production toward the future. However, Gray has noted that a change in the overall price level (e.g., a doubling in all prices except interest i) uniformly through time does not affect the optimum output decision in each period, so long as the discount rate is zero. There is a bias toward the present when the (assumed constant) discount rate is greater than zero and the price level increased.[37]

Taxes

Gray also discusses the likely influences of different kinds of taxes.

> "An annual tax on the value of the mine, provided the tax is expected to be permanent, will increase the tendency for the mine owner to remove the coal in the present rather than in the future. For, since the mine must pay the tax as long as it is operated, the tax may be evaded by increasing the rapidity of exhaustion."[38]

The overall effect of this tax, he claims, would be to increase the output in early years, and if demand is constant, tend to lower the price of coal. As 'value of the mine' is not defined here, one cannot be sure what is meant, but it seems that a constant annual lump sum tax is implied, as tax is avoided by accelerating output, and shortening mine life. Alternately, he states:

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[36] Ibid., p. 476-477.

[37] Ibid., pp. 477-480. Gray does not treat the case where the interest rate increases along with all other prices.

[38] Ibid., p. 486.

> "...a tax on the annual surplus from the operation of the mine...will not create an inducement for the mine owner to alter the adjustment of utilization between present and future."[39]

This tax proportionately reduces the surplus in each year and makes an adjustment of output unnecessary. He notes, however, if the tax is thought to be temporary, it would tend to bias production toward the future.

A uniform tonnage tax will tend to bias production toward the future.[40] The future tax is more heavily discounted, and the owner presumably would tend to reduce present annual tonnage in favour of future tonnage.

Summary

Thus, Gray has set out many of the elements of exhaustible resource usage, looked at in terms of the behaviour of the mine owner. He has described the reactions of the mine owner to intertemporal changes in price, different factor productivity scenarios, different interest rate scenarios, and various tax scenarios. The bulk of his discussion is based on the ideas of "average expense of removal per ton" and with the influence of price, the "average net return per ton". Presumably, all factors, labor, and capital are paid their opportunity cost, and the owner is maximizing economic profits. Gray does not, however, discuss the nature of price equilibrium for the industry, an equilibrium price or output path, or whether a tax could be large enough for the owner to consider another line of business.

Most of these questions are addressed in more elaborate theoretical models developed by later economists. Gray was very insightful and it will be clear that most of his results

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[39] Ibid., pp. 486-487.

[40] Ibid., pp. 487-488.

are consistent with those of later economists.

Three works which appeared in the time between Gray (1914) and Hotelling (1931) were King (1916), Cassel (1923) and Ise (1925).[41]

King (1916) Population Growth and Conservation Policy

King (1916) describes "the usual line of argument" regarding the burden the present generation must bear for the sake of future generations, due to conservation of natural resources. He states:

> "if we set aside forest reserves today, it makes lumber dear. If we insist that in mining coal as little waste as possible be incurred, it means high-priced fuel. If we required that the low-grade ore in an iron mine be fully utilized in place of being wasted, it means dearer iron and steel products. In every case, the present generation is called upon to make a sacrifice in order to benefit the people of the future centuries. Conservation; then, resolves itself into a question of altruism; of the amount of sacrifice we are willing to undergo for the sake of generations yet unborn."[42]

King (1916) notes, however, that despite the strength of the above argument, population growth is not taken into account, and the laws governing that growth are critical factors to consider. King (1916) states:

> "In any nation, population tends to expand through excess of births over deaths until a certain degree of tension or pressure upon the available natural resources is reached. When this degree of tension is attained, the birth rate and death rate become equal and population remains stationary so far as internal forces are concerned. The degree of

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[41] See Crabbe (1983,1986), G.A. Smith (1982,1986) for interesting notes, review and argumentation on Gray (1914) and also Hotelling (1931).

[42] King (1916), p. 595-6.

> population density at which equilibrium for the native-born population is attained varies directly with the advancement in those phases of scientific knowledge which teach the ways and means of extracting the greatest annual product from the available natural resources and inversely with the number of comforts and luxuries included in the standard of living of the lower classes of the population. If the standards of comfort are firmly entrenched in the minds of the masses of the people, any exhaustion or diminution in the natural resources will be accompanied by a falling birth rate and a contraction of population corresponding to the decrease in the resources available."[43]

He gives several examples in support of the above assertion, including China, India, and the American Indians. The basic model states that equilibrium is a function of desired living standards for a society. A conservation policy, then would have the effect of reducing family size now so that future family sizes could be larger, and this loss would be the disutility of the conservation policy. I could see neither King's tongue nor cheek, so I am not sure of the sense in which the following was intended, but he states:

> "It is doubtful, however, whether the extra numbers in a large family do not, on the average, cause as much sacrifice as pleasure. If this is true, the supposed conservation policy involved no cost whatever."[44]

Thus, in that author's opinion, the setting aside of resources does not affect any particular sacrifice, but merely hastens the day of a particular population equilibrium. The ultimate decision on conservation policy he suggests, is determined by military needs - sufficient resource must be used to maintain a sufficiently large size population to

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[43] King (1916), p. 596.

[44] King (1916), p. 599.

defend itself. The conservation/family size/population considerations do, of course, have much to do with other related items, such as immigration policy, and the likelihood of foreign aggression.

Cassel (1923), Pricing of Natural Materials

Cassel (1923), a contemporary of Gray, later extended the Gray (1914) analysis in relating some of the factors which would produce equilibrium price paths. Cassel discussed the operations of a representative mine, in the context of his presentation of argument regarding the factors effecting the present and future prices of natural materials in the market. Cassel differentiated between the part of price required to cover the costs of capital and labour used in bringing the resource to market and that part of price which reflected the scarcity value of the underlying resource alone. He refers to the resource alone as one of the "free gifts of nature",[45] and to the extent that there is a part of price above capital and labour costs, there is a rent or royalty, and he makes no distinction between the two in this context. He stated that increasing scarcity drives up prices thereby generating surpluses (whether considered as royalties or rents). Cassel states that it is the general pricing process which determines the price of the resource itself, based on the general principle of scarcity. The natural forces of present and future supply and demand determine present and future prices.[46]

Cassel specifically refers to the present value decisions made by mine operators and the influence of the interest rate, and the influence of uncertainty about future income due to changes in the value of the resource due to a variety of factors. Some of these are possible displacement of the

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[45] Cassel (1923) The Theory of Social Economy, p. 290.

[46] Ibid., p. 290.

resource by substitutes (as wood was replaced by coal in many uses), discoveries of new deposits which reduce the scarcity value of the known deposit, and improvements in production processes which could make known but otherwise uneconomic resources available and again reducing the scarcity value of the resource. He also notes that changes in expectations of future prices affect present output decisions directly.[47] It is in this sense that Cassel explicitly considers dynamic elements in pricing, although he does not offer a formal mathematical model similar to that of Hotelling, nor does he state that the royalty or rent must grow at the rate of interest. The basic elements of later economic arguments regarding equilibrium intertemporal price paths are however implicit in his work.

Cassel specifically focuses on a number of items somewhat unique to mining, which were in some cases ignored by later economists, such as the need for steadiness in production. He made explicit references to the time frames required to bring ore to market (known reserves generally cannot be brought to market like an inventory of tins of beans), and to the general issue of supply elasticity and price stability. Cassel also mentions a relation between trade cycles and movements in mineral prices and the start-up and shut-down of marginal mines. Cassel states that the monopolist plays the role of the conservationist in postponing consumption and perhaps shows "greater regards for the needs of the future".[48] Thus the work of Cassel does in many ways, reflect that of Gray and anticipate the later neoclassical analysis of Hotelling.

Ise (1925), Pricing at the Cost of Substitutes

Ise (1925) in "The Theory of Value as Applied to Natural Resources", argues that prices for natural resources, whether

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[47] Ibid., p. 290-292.

[48] Ibid., p. 293.

arrived at by competitive or monopolistic forms of market organization are too low. In coming to an estimate of how high prices should be, Ise (1925) identifies several major items. First, he states the obvious point that,

> "present prices will determine the rate of consumption and the amount of the resource left for the future, and therefore will determine future prices."[49]

Then, in the context of a decision about how present wants would be compared with future wants, he suggests that the appropriate distribution of consumption over time will determine the prices we should now charge, and the prices which will be charged in the future. He claims that the policy the U.S. has been following (to 1925) was one of very low pricing, and this he argues, will likely result in very high prices in the future. He also states

> "Doubtless future wants should be discounted somewhat, because of various contingencies and uncertainties, but it is doubtful if the wants of the next generation, for instance, should be rated less than one half as important as our own."[50]

This, he notes, implies approximately a two percent per year growth rate, or a doubling in price each generation if no substitutes can be found. We note that this gives information on the rate of price increase, but not on a starting or ending price.

One of the more important ideas introduced by Ise was the existence of substitutes in the future for the resources and for the products made from those resources.

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[49] Ise (1925), p. 284.

[50] Ise (1925), p. 285.

Regarding the situation where there are forthcoming substitutes, Ise (1925) states:

> "The answer here is clear. Prices of the resources, or of the products derived from these resources, should be fixed at a point approximating the cost of producing adequate and satisfactory substitutes."[51]

The above policy statement would appear to describe an intertemporal allocation rule, in which marginal utility per unit is equal in all time periods to the time of exhaustion of the resource and its replacement by a substitute for the society. This would also, perhaps imply that the prices for a group of substitutes would have to be set at the highest priced member of that group, as most of the substitutes are themselves exhaustible resources. He claims that prices fixed at the prices of substitutes would stimulate the search for other substitutes. This discussion by Ise can be interpreted as a forerunner of the idea of the "backstop" technology that will be encountered later in the thesis.

Partial Equilibrium Analysis

As the next works reviewed rely on the use of partial equilibrium analysts, a brief introduction to that framework for analysis is presented here for the benefit of readers who are not economists.

The "Law of Demand" states that the lower the price per unit of a product, the more of the product consumers in an economy will want to purchase and consume at a point in time. This relationship is graphically represented by the familiar downward sloping demand curve, DD pictured below.

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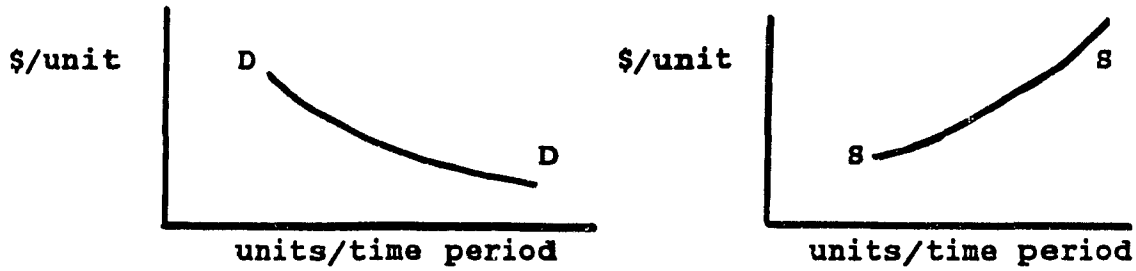
[51] Ise (1925) p. 285.



The usual supply function is assumed to be upward sloping and it shows that the higher the market price, the more suppliers are willing to sell in the market. The quantity a supplier will put on the market usually is a function of many variables, the costs of capital, labor, raw materials etc., not just price. Similarly for the consumer, the quantity demanded is a function of tastes, initial wealth, income, the prices of other goods, etc., not just price. In general equilibrium analysis, one is concerned with all the supply and demand functions for all goods and services in an economy. In a state of general equilibrium, supply equals demand in all markets, and an equilibrium quantity is produced and consumed at the equilibrium price in all markets.

In partial equilibrium analysis, the analysis is focused on only one market (or small set of markets). In partial analysis not only are other markets ignored but it is customary to invoke a ceteris paribus assumption that allows the analyst to examine a relationship - between say price and quantity of a particular good - on the assumption that all other variables in that market remain constant. The economist assumes that all other markets are in equilibrium, and that they will not be affected or at least not be affected to a significant degree by events in the particular market under consideration. Partial equilibrium analysis considers the effects of price changes, taxation, etc., on a particular market. The ceteris paribus assumption here implies that other variables influencing supply and demand can be treated as constants in the analysis. In a perfect market, the demand curve represents the marginal social benefits associated with

the consumption of a good, and the supply curve, the marginal social cost of producing the good, both in the absence of externalities. Since supply equals demand in all markets, marginal social benefits equal marginal social costs in all markets.[52]

All consumers have made their demand decisions in such a way as to maximize their own benefits, and all suppliers have made decisions which maximize profits. When all markets are in a competitive equilibrium, there is no reallocation of resources, change in production, or reallocation of purchases, or change in consumption which can increase the total social benefit. In an intertemporal framework, this relation holds for all goods and services over the relevant time horizon provided that markets approach the perfectly competitive market ideal at least in the long run.

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[52] Anderson and Bishop state:

"Economists are often asked to determine the values of commodities as part of cost-benefit analyses. Many goods and services are traded in organized markets, and it is reasonably straightforward to derive values for these commodities. Consumer surplus is given by the area under the inverse Marshallian demand curve and above the good's market-clearing price. This so-called "welfare triangle" is an estimate of what consumers would be willing to pay for incremental units of the good (X_i) up to the actual level (X^*_i) minus the amount they actually pay, which in turn equals X_i^* multiplied by the market price, $P_x^*_i$.

Marshallian consumer surplus is not an ideal welfare measure because a change in the commodity's price involves a change in the real purchasing power of consumers. If the price of X_i falls to $\hat{P}_{xi}$ from $P_x^*_i$, the consumer can continue to purchase X_i^* units and subsequently increase utility by purchasing additional units of X_i or other goods with the residual income $[(P_x^*_i - \hat{P}_{xi})X_i^*]$. If more accurate measures of willingness to pay are needed, utility or income compensated welfare measures can be obtained from the Hicksian compensated demand functions [Deaton and Muellbauer 1980] or by making use of Willig's result to adjust Marshallian consumer surplus measures (see [Willig 1976; Just, Hueth, and Schmitz 1982])." Bromley, D.W.(1986)pp. 89-90.

EARLY NEOCLASSICAL ANALYSIS

Hotelling (1931), Exhaustible Resource Dynamics

Harold Hotelling (1931) uses the partial equilibrium approach in studying the markets for exhaustible resources, in what is considered to be the seminal purely neoclassical analytical work in the area.[53] Hotelling was interested in describing the intertemporal equilibrium price and output paths for exhaustible resources under conditions of free competition and monopoly, and in comparing social welfare under those conditions. He also evaluated the influence of various changes in assumptions regarding production costs, taxation, and market structure.

Net price demand function

Hotelling assumes that there is a demand function for a mine resource over time given by the equation

$$q=f(p,t)$$

The variable p is not equal to the market price paid by consumers, however, it is rather the net price received by the mine owner after paying the costs of extraction and placing the resource on the market. This presumably includes the costs of capital as well. This is an unusual formulation of the demand function, as consumers are really interested in the price they pay, rather than the net return the mine owner receives.

Fundamental theory of exhaustible resources

The equilibrium rate of interest available in the economy is denoted by r. Thus, a mine owner is assumed to be indifferent between receiving Po at time o or Po(e(rt)) at time t. Thus, it is the net return which is expected to

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[53] Harold Hotelling, "The Economics of Exhaustible Resources", Journal of Political Economy, 39 (1931), 137-175.

exponentially increase at the rate of interest, not necessarily the market price paid by the consumer. The intuitive appeal of this observation on the supply side under conditions of certainty and rationality is very strong, and has been referred to as the fundamental theory of exhaustible resources.[54]

In terms of market price (Pm), constant costs (C), and interest rate (r), this may be written as the following for any two periods.

$$[Pm(t) - C] = [Pm\ (t + k) - C]\ (1 + r)^k$$

or

$$\frac{[Pm\ (t + k) - C] - [Pm(t) - C]}{[Pm(t) - C]} = r$$

Per unit rent or royalty must grow at the rate of interest.

Constant costs

The rate of change of the market price will vary of course, depending on the cost assumptions which are used. For example, ceteris paribus the market price would increase at a rate less than the rate of interest if there are constant costs. The rates may be the same under increasing costs.[55]

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[54] Solow 1974.

[55] A numerical illustration of a constant cost example is the following:

Suppose P=10, r=.10, t=3

$(10)e^{(.10)(3)} = 13.4985$

if costs equal 2, market price = 12 at time zero and solving

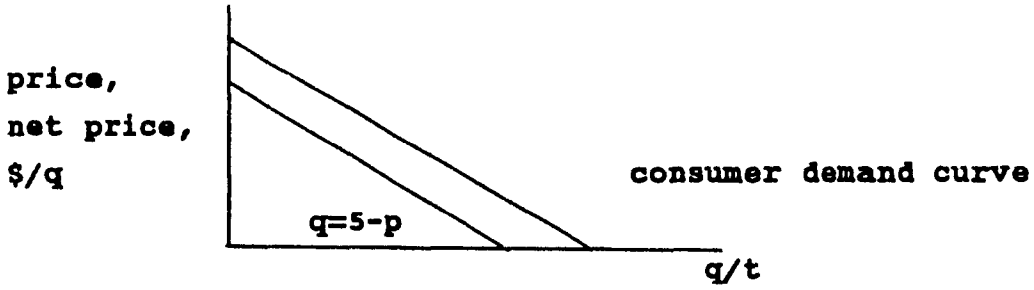
$12e^{(x)3} = 15.4985$

(continued...)

A numerical example

Hotelling uses an example in which his specific demand function is given by $q = 5 - p$ where $(0 < p < 5)$ and $q = 0$ for $p >= 5$, and does not change over time.

The diagram below pictures a possible consumer demand curve, as a function of net market price. $q=f(p)$. We will use the symbol p to mean net price, as Hotelling did, and Pm to mean market price.



If cost is greater than zero, the true consumer demand function for the good lies above the function $q = 5 - p$.

If the object of the exercise was to find an optimal output at a point in time, then the calculus may be used, if the object is instead to find a series of output points through time, (an optimal function), then the calculus of variations is an appropriate approach. Hotelling uses the calculus of variations to approach the problem of the optimal quantity and price for the exhaustible resource over time.

The initial value of Po will depend on actual demand and the total supply, α. The time of final exhaustion is denoted

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[55](...continued)

where x is the growth rate of market price
$3x = \ln (1.2915)$

gives $x = .0852$, or market price growing at 8.52% p.a., a rate less than the rate of interest.

A consumer who wishes to maximize intertemporal pleasure, could refrain from purchasing at time To, invest 12 at 1.10 to obtain 15.972 by period 3, and purchase the same unit for 15.4985, and have a surplus. We will return to this point later.

by T, where Hotelling assumes q will be equal to zero. The assumption, then is that the mine must be exhausted at some time, perhaps in an infinitely long time period. We note that Hotelling does not specify conditions on the cost of producing any of the stock α. We also note that as demand is written as a function of net price, even very high cost units of α are included in the usable stock and it does appear to be a curious way to represent demand for the stock at various points in time. No consumer decisions are based on 'net price to mine owner' demand curves. If substitutes are available at low cost, there is no reason to believe that the mine need ever be exhausted, but then the assumed demand curve would not apply. It would, indeed be difficult to identify the consumer demand as a function of consumer price, unless equilibrium in all other (including substitute) markets is assumed.

Hotelling writes

$$\int_0^T q\,dt = \int_0^T f(P_0 e^{rt},\ t)dt = \alpha$$

Thus, the entire stock α is exhausted by time T, at which point q is equal to zero.

$$f(P_0 e^{rt},\ T) = 0$$

We note, however, that the possibility remains that q may well go to zero before the entire stock α is exhausted. The consumer demand function, $q = f(Pm, t)$ has been rewritten in terms of net return, $q = f(P, t)$ and presumably reflects all of the different costs of units of stock α. If the demand function is $q = 5 - p$, then when $p = 5$, $q = 0$. The market price may be, say 12 at that point, but it is not clear why the mine would have to be exhausted at that time. If extraction costs were nil, and the demand curve were to

hold for all time, then if one accepts the demand curve q = 5 - p, then one would expect that the mine would be exhausted when p = 5. All that the demand curve q = 5 - p tells us is that if the owner charges a price guaranteed to provide a net price of $5, then the amount demanded will be zero. It <u>does not</u> tell us that the mine will be exhausted. The question is why would the mine owner set the net <u>profit</u> (all costs are excluded) at 5 and have zero profit <u>unless</u> the mine was exhausted. In fact, it would seem that the initial reserves are defined, such that only reserves in a certain cost range are included in total supply. The last drop of oil will never be removed from a well. Also, it would appear that the independence assumptions required for the partial equilibrium analysis are critical here. It must be assumed that all substitution possibilities are reflected in the demand curve for all points in time. The empirical estimation and verification of such an assumption are difficult to imagine.

Suppose there are substitutes for which there is an inexhaustible supply at market price Pm = 10, and that the costs of mining the first half of stock α is 5 while the cost of producing the second half is 8. The demand function is always q = 10 - Pm for the consumer, but is q = 5 - p for the first half of α, and q = 2 - p for the second half of α for the firm. For a producer demand function of the form q = 5 - p to hold for all α, for all time, then it must be assumed that there are compensation changes in the consumers' demand curve q = f(Pm, t) over time in order to ensure exhaustion of the resource stock. This does seem to be a rather curious requirement.

Solution; pricing, depletion, time of exhaustion

Those problems of interpretation and anticipated operationalization aside for the moment, the example continues as follows. At time T, Po(e(rT))=5, and we have two unknowns, Po and T described in the following relationship:

T

$$\alpha = \int_0^T 5 - P_o e^{rt}\, dt = 5T - \frac{P_o e^{rT} - 1}{r}$$

Hotelling eliminates P_o to obtain the following:

$$e^{-rT} = 1 + r\,((\alpha/5) - T),$$

Hotelling then plots e^{-rT} and $1+r((\alpha/5)-T)$ for trial values of T to find the time of exhaustion.[56]

Social value of the resource

Hotelling next discusses the idea of maximum social value of the resource. He states that at a point in time, the maximum social value is defined as

$$u(q) = \int_o^q P(q)\, dq$$

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[56] A numerical example of this problem follows, using $q = 5 - p$, $r = .10$, $\alpha = 10$.
Assume $r = .10$ $\alpha = 10$ $P_0 e^{rt} = 5$ (at time T)

T	$Y_1 = e^{-rt}$	$Y_2 = 1+r\,(\alpha/5 - T)$	P
0	0	1.20	2.48
1	.90	1.10	2.74
2	.82	1.00	3.02
3	.74	.90	3.35
4	.67	.80	3.70
5	.61	.70	4.08
6	.55	.60	4.51
7	.49	.50	4.99
		(crossover at T = 7)	
8	.45	.40	
9	.41	.30	
10	.37	.20	
11	.33	.10	
12	.30	0	
13	.27	-.10	
14	.25	-.20	
15	.22	-.30	

$$P_0 e^{.10(7)} = 5$$

$$\text{---} \quad P_0 = 2.48$$

"...where the integrand is a diminishing function and the upper limit is the quantity actually placed upon the market and consumed."

Here, Hotelling presumably intends that p still be viewed as the net return to the mine owner. The present value is

$$V = \int_0^T u[q(t)]e^{-it}\,dt$$

where V is the present (social) value of the resource, u is the one period equivalent of the former, and i is the rate of interest. Hotelling states that:

"Since $\int_0^T q\,dt$ is fixed, the production schedule q(f) which makes V a maximum must be such that a unit increment in q will increase the integrand as much at one time as at another."

This is given by

$$\frac{d}{dt}\ u[q(t)]\ e^{-it} = p(e^{-it})$$

This right hand side constant is taken to be Po which yields the result from the free competition scenario.

$$p = p_o e^{it}$$

On p. 143, Hotelling uses

$$V = \int_0^T u[q(t)]\ e^{-it}\,dt$$

as the present value of the future enjoyment obtained from the consumption of the resource. Here, Hotelling seems to be maximizing the areas under the demand curves, and it seems he is equating the discounted marginal benefits in each time period. This would seem a reasonable approach if price is

rising with the interest rate, but it is not clear that it gives a social optimum if it is net price which is assumed to rise with the interest rate. Hotelling states on p. 141 that "the most cheaply available first" describes the order of extraction, and seems to imply increasing costs. Thus, if the producers equalize marginal profits in each period, net price would rise with the interest rate, but under constant costs, consumer prices will rise more slowly, as their base year value is higher. Under increasing costs, it is possible that the rate of increase of net price could equal the rate of increase of consumer price, but such equality would only be coincidental. Thus, only in the case where extraction costs are negligible does the Hotelling rule

$$P = P_0 e^{rt}$$

hold for consumer prices and the social value calculations which were made.

Discount rate and social value

Hotelling considers the issue of whether the same discount rate used by the entrepreneur should be used in determinations of social value in the following passage:

> "... the rate of interest is set by a great variety of forces, chiefly independent of the particular commodity and industry in question, and is not greatly affected by variations in the output of the mine or oil well in question. It is likely, therefore, that in deciding questions of public policy relative to exhaustible resources, no large errors will be made by using the market rate of interest."[57]

Another important note, is that in the Hotelling analysis, future social benefits are discounted by the rate of interest, an ethical position which is not uniformly

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[57] Hotelling (1931), pp.144-5.

supported by economists. Hotelling was aware of these conflicts, and responded with the following:

> "The discounting of future values of u may be challenged on the ground that future pleasures are ethically equivalent to present pleasure of the same intensity. The reply to this is that capital is productive, that future pleasures are uncertain in a degree increasing with their remoteness in time, and that V and u are concrete quantities, not symbols for pleasure. They measure the social value of the mine in the sense concerned with the total production of goods, but not properly its utility or the happiness to which it leads, since this depends on the distribution of wealth and is greater if the products of the mine benefit chiefly the poor than if they become articles of luxury."[58]

Thus Hotelling would seem to be implicitly using a model which assumes uniform declining marginal utility of income for all the population. He also makes an explicit judgement about interpersonal comparisons. Also, by implication the resource, a capital type input, is providing other capital inputs for future generations in an optimal way. The discounting of future pleasures is not described as an irrational or wrong thing in itself. These issues of utility discounting, and appropriate social discount rates that are raised by Hotelling will be reintroduced and discussed in detail in the following chapter of this thesis.

Monopoly

The next case considered by Hotelling is that of a resource which is owned by a monopolist. Hotelling concludes that the likely path of price is such that the initial rate of exhaustion or rate of use of resources per time period is slower than that under free competition, and the terminal date further in the future. The two situations were represented

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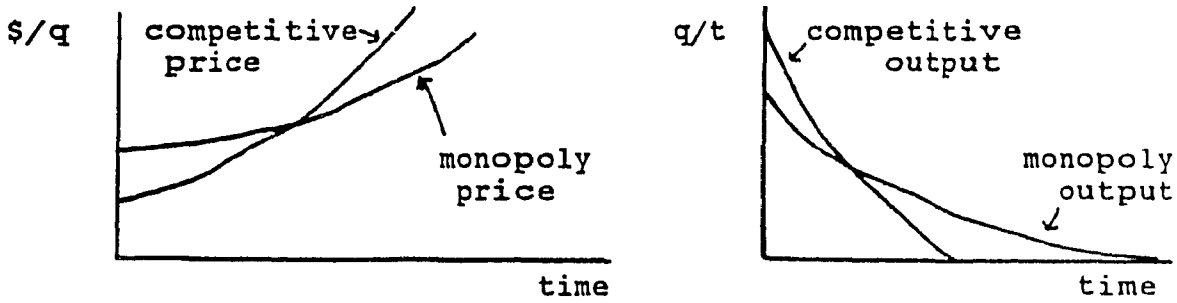
[58] Hotelling (1931), p. 145.

graphically in Devarajan and Fisher (1981) in their review of Hotelling's paper, and are presented below.

Competitive and Monopoly Price and Output Paths



[The comparative results are also based on the assumption of negligible extraction costs.]

Costs increasing with cumulative production

The more interesting (and complicated) case which Hotelling considers is one in which cumulated production affects net price. Here x is cumulative production, $dx/dt = q$ is the current rate of production, and α is the total stock originally in the mine. P is taken as a function of t, as well as x and q in this case for several reasons. First, "durable substances, such as gold and diamonds by their accumulation affect the market."[59] Also, "...growth of population and the rising prices to consumers of competing exhaustible goods...", "...the progress of science [which] might lead to the gradual introduction of new substitutes for the commodity in question", and "...exhaustion of complementary commodities", are all factors which tend to make price a function of time. Thus, the present value of the mine at time zero may be described by Hotelling's equation

$$\int_0^{\infty} P(x,q,t)\, qe^{-rt}\, dt$$

[59] Hotelling (1931), p. 152.

Hotelling states that "if exhaustion is to come at a finite time T, we may suppose that q=0 for t>T, so that T becomes the upper limit. We put

$$f(x,q,t) = pqe^{-rt}".$$

Hotelling notes that the owner of the mine (monopolist) cannot do better than adjust his production so that

$$\sigma f/\sigma x - d/dt\ \sigma f/\sigma q = 0,$$

(...where σ indicates the partial derivative)

if f does not involve x, the former case of monopoly is obtained. He then offers computational examples under these assumptions.

Hotelling is, of course interested in examining the 'optimum ccurse' of exploitation under these more elaborate assumptions, as a generalization of the earlier social optimum analyses. It is shown that the monopolist tends to draw down the stock of the resource more slowly than is socially optimal, and therefore terminal exhaustion of the mine comes later than it should. He identifies the optimum course, as before, as that which maximizes the present discounted value of social benefits.

Steadiness in production

Hotelling later considers an issue, some aspects of which are important for natural gas, "the need for steadiness in production", where price p is a function of the rate of production q, but also the rate of change of quantity, q'. He notes that some say that the amount of a commodity that can be sold is a function of the rate of change of price, as well as the level of price;[60] therefore p = f(x,q,q',t).

These issues, though outlined, are not resolved in the Hotelling paper.

Taxation

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[60] C.F. Roos(1927) and G.C. Evans(1924) in Hotelling, p. 162.

The remainder of the paper is primarily given over to consideration of the effects of various taxes on depletion patterns. Hotelling shows that:

> "An anticipated tax at the rate of σ per year and payable continuously will have the same effects upon the value of the mine and the schedule of production as an increase of the force of interest by σ.[61]

The above tax is an income tax, at rate σ to be applied to the producers gross revenue. He also examines the effect of a severance tax, described as:

> "...so much per unit of material extracted from the mine, [which] tends to conservation."[62]

Hotelling shows that under such a tax early prices tend to be higher, and future prices lower, resulting in what might be called more conservation; the severance tax postpones exhaustion.

Hotelling also briefly considers the then current approach to depletion allowances by tax authorities and concludes that the practice seemed to be overly gracious to owners. Finally Hotelling turns to duopoly, and to cases intermediate between perfect competition and monopoly where he comments on the relations between the usual static formulations and the dynamic finite resource case, but he does not produce an analytic model here. He closes with comments on price wars and the nature of dynamic competition.

LATER NEOCLASSICAL ANALYSIS

Scott (1967) The Individual Profit Maximizing Mine Owner

The next major paper to be considered is that of Scott (1967). Scott presents the theory of the operation of a mine

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[61] Hotelling (1931), p. 164.

[62] Hotelling (1931), p. 165.

and focuses on the decisions regarding rates of production, investment in capacity, and the life of a mine. He refers to the distinguished literature which precedes his work, including that of N.J. Busschau (1956), L.C. Gray (1914), Harold Hotelling (1931), William Vickery (1967), F.W. Paisch (1938), Donald Carlisle (1954), and Orris Herfindahl (1955, 1959). He also suggests the following as valuable references, David B. Brooks (1964), Paul Davidson (1963), Allyn O. Lochner (1962), James W. Mckie and Stephen L. McDonald (1962), and Dino J. Tessaro (1960).

Further bibliographic information on this period is offered later by Cummings and Pearse (1986), which responded to Heal's (1986) statement that there was a barrenness in the literature between the nineteenth century economists and those of the sixties. Heal (1976, p. 2) attributes this dirth to "the fact that for the first two-thirds of this century, exhaustible resource constraints have not been important for industrialized countries". The response of Cummings and Pearse (1986, p. 22) is that:

> "This view ignores substantial literature in both the economics of conservation - the "home" for concern with exhaustible and other resources problems through the 1960s - and in agricultural economics, a distinct subdiscipline in economics since the early 1900s with whose literature Heal is seemingly unfamiliar. Classic examples of the former literature include works by Ciriacy-Wantrup (1942, 1944, 1952), Gray (1914), Hess (1917), Renner (1942), Hammar (1942), Scott (1955), O'Neill (1940), and Van Hise (1910). An historical overview of conservation economics in 1937 is given in Pinchot (1937). Earlier twentieth century interests in valuing/ managing mineral and other exhaustible resources are seen, e.g., in Ise (1925) and in Tyron and Berquist (1932). Economists in agricultural economics have long been concerned with soil and water as exhaustible resources; as examples, see Gray (1914) and also Crabbe's (1983) assessment of Gray's contribution to the theory of exhaustible resources, Ciriacy-Wantrup (1938), Bunce (1942), Shepard (1945), Bartz (1949), Milliman (1956), and Weitzell (1943). We might also note concern with exhaustible resources in the late 1940s reflected

> in the Paley (1952) report which provided the impetus for the later formation of Resources for the Future, Inc. (See Howe [1979, 48- 49]). Finally, we might acknowledge earlier twentieth century concern with minerals - Logan (1930), Osgood (1930), Watkins (1937), Wallace and Edminster (1930), Barnett (1950), Harberger (1955), Herfindahl (1955), Scott (1953), Tyron and Berquist (1932), O'Neill (1940); with water development - see particularly Maass et al. (1962), and Eckstein (1958); and the fishery - e.g., Scott (1955) and Gordon (1954)."[63]

Scott claims that "much of the writing uses the mine as a step on the way to deducing the properties of the industry supply curve."[64] The final position of the firm (an equilibrium position), he claims, has been presented in tabular form,[65] calculus form[66] and figures.[67] He claims that Paisch (1938) and Carlisle (1954) "provide a reasonable sketch of the equilibrium plan of a stable firm imbedded in a stable industry." He goes on,

> "But these reasonable approximations neglect the important Marshallian task[68] of examining the rational reactions of the mine manager to his problems to see whether these reactions do provide a path or process to the theoretical equilibrium. The use of a diagram, maximizing function or example, certainly suggests a final program of mine operation - but is it the program that is achieved by the day-to-day decision-making of the company?"[69]

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[63] Cummings and Pearse (1986) also refer to Faustman (1849) on optimal forest rotation paths and Worming (1911) on common pool problems.

[64] Scott (1967), p. 25.

[65] Gray (1914).

[66] Hotelling (1931).

[67] Busschau (1956).

[68] Alfred Marshall (1920), Book IV.

[69] Scott (1967), p. 25.

It is that latter path which Scott proposed to examine in his paper. He notes that his step-by-step approach uses assumptions, and confronts problems which, in general, have appeared in the literature, with one exception. There is

> "...at least one widely accepted assumption that needs examination: that it is a good approximation to mine-planning to assume that the decision-makers are trying to decide upon a constant (italics) rate of output over the years."[70]

He states,

> "the observed tapering-off of production in many mines can be explained independently of the fact that the ore is running out, that the workings are becoming more remote from the plant or mill, that the machinery or workings are wearing out, or that prices or wages are becoming disadvantageous. Even without such events, it will pay to tilt the production profits to the present." ..."It is missing, for example, from Hotelling's (1931) model of the competitive mining industry and eventually emerges explicitly in the theory only because of changing market price, not because of the maximizing behaviour of the competitive firm."[71]

Certainty

He assumes that certainty prevails, and he defends this on three grounds:

> "...first, it follows the tradition of the authors mentioned above; second, it provides a framework for deciding, in subsequent work, how uncertainty can be introduced into the various parts of the model; third, it should be capable of providing testable propositions which may cast some light on the effects of uncertainty. The divergences of its

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[70] Scott (1967), p. 26.

[71] Scott (1967), p. 26.

results from those observable may suggest how uncertainty does influence decision making."[72]

At first blush, these latter grounds seem appealing, however, the elimination of competing hypotheses for the divergences may well pose very serious problems.

Short run focus, other assumptions

He also assumes that the manager

> "... is making short run decisions. Long run investment is dealt with summarily in the final section. Brevity is appropriate because, apart from uncertainty, mine investment is broadly similar to any other type of industrial investment, so that familiar theoretical approaches apply without modification. On the other hand, exploration, discovery, and development obviously raise entirely different questions, concerned with probability and certainty, that are the province of a different branch of the theory."[73]

The elimination of the above elements of the operation of the mine, uncertainty, investment components, etc., seriously constrains the scope of the analysis.

Scott's assumptions are the following:

A. The contents (reserves) in the mine are completely known.

B. The owner invests, borrows, and lends at the same rate of interest or return.

C. The owner's objective is to maximize the present value of the asset, both initially and in every period in which he must make decisions.

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[72] Scott (1967), p. 26.

[73] Scott (1967), pp. 26-27.

D. In order to accomplish (C) he may adjust only the rate of extraction, measured in tons per period and, in the long run, the amount of investment in size (capacity) of mine and mill.

E. Conditions are constant through time. This assumption has three aspects: (1) The reserves are of uniform grade throughout their known total volume. This assumption is later relaxed. (2) Supply prices of all inputs (except the resource itself) delivered at the mine and selling prices of all products f.o.b. the mine are given, fixed, and unchanging through time. The manager is always a price-taker, but the assumption that outside prices are constant is later relaxed. (3) The owner knows the costs and prices in (2) with complete certainty.[74]

The uniform grade assumption is quite strong, and Scott appeals to Marshall's (1920) use of the example of pumping fluid from a well as a rationale for this. In the absence of such an assumption for ore grade, extraction costs would usually rise over time, (there may be exceptions) greatly complicating his basic analysis. This leaves the law of diminishing returns intact at each point in time.

The above assumptions are combined with an appeal to parallel production arguments to explain the use of the standard U-shaped AVC (average variable cost curve), which has its associated U-shaped MC (marginal cost) curve. These factors, combined with firms facing a (perceived) horizontal AR (average revenue) function in the short run, and at all points in time, produce a profit function (pictured below).

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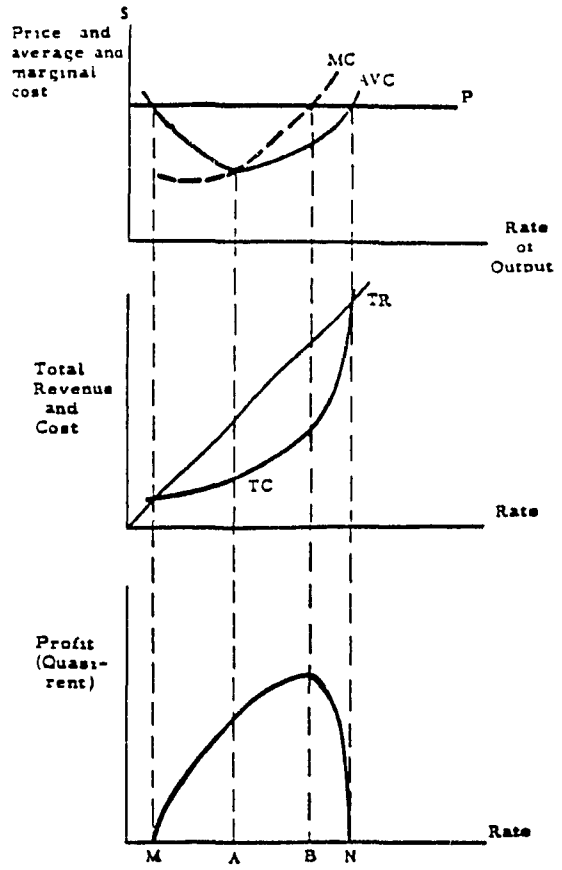
[74] Scott (1967), p. 27.



Scott notes[75] that he has essentially removed all the non-standard characteristics of the mining firm from the analysis, and proceeds then to argue for modifications to the solutions to the standard theory of the firm problem to obtain the optimal (profit-maximizing) solution for the competitive mining firm.

The role of discounted present value

The usual profit maximizing output level is, of course, B on the previous picture. However, this is with no intertemporal constraints on resource use, or terminal date for exhaustion. He suggests that the only reason a mine owner would produce at the usual output level where MC = MR is if the owner anticipated a mine shut down prior to the exhaustion of the resource, else the owner should choose the output point where the profit per unit is a maximum, which would maximize the total mine profit. This would be output

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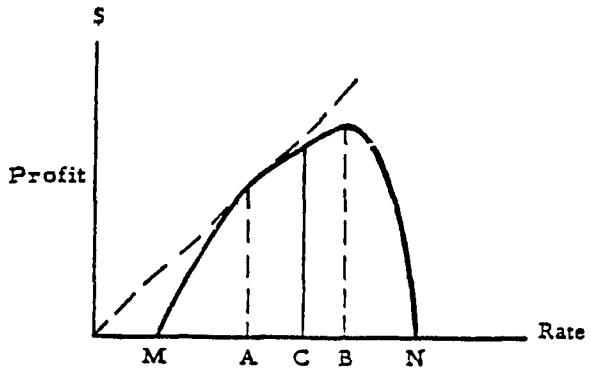
[75] Scott (1967), p. 31.

level A on the figure below, and consequently, with the lower per-period output level, mine life would be longer. However, this disregards the discounting process. Essentially, the discounting process tilts the preferred output profile toward the present. He claims any interest rate greater than zero will do this, and will consequently shorten mine life, as output level is increased toward B (in the below figure) in earlier periods.



Scott notes that generally speaking the larger the rate of discount, the stronger the bias to present production and profits, the shorter the mine life, the higher the annual rate of extraction, and the higher the mining cost per ton in each period. Also, the upper limit on the rate of production is given by the output rate where MR = MC.

The optimal rate, a first approximation

The first approximation to the optimal rate which can be found with the calculus, is what Scott calls "the tentatively chosen rate of production" (t.c.r.) which is selected as a constant rate of drawdown. Hence mine life equals total reserves divided by the t.c.r.

Thus far in his analysis, Scott assumed that all periods have identical output rates, depending on the rates selected, the terminal period of exhaustion is changed by periods, as the time of final exhaustion is moved forward or backward in

time. However, he states, it may be that rates of output would best, or optimally vary over time for the individual owner. He notes that in the Hotelling (1931) analysis, it is the rate of output for the industry which varies over time, but little, save in the case of monopoly is said about the behaviour of individual operators.

Scott argues, that assuming an individual owner has found an extraction rate per period which maximizes profit, contemplation of the influence of the discounting process would encourage the reallocation of output to achieve a still higher profit. The direction of the reallocation of output would be toward the present. The loss in profit from output in the distant future is relatively small compared to the incremental profit of that unit sold today, up to the point where MR = MC for the individual, as present and future cost and revenue curves (undiscounted) are assumed to be identical. The actual limits of the intertemporal transfers, however, will be constrained by the shape of the particular profit functions (discounted). He states that the calculus of variations could be used by the individual owner to determine the optional intertemporal output plan.

Cost and price changes, changes in the resource stock

Scott next considers the effect of three items on the output plans of the individual firm. They are:

> "(1) cumulative extraction...over time changing the working conditions in the mine;
> (2) resource growth or decline with time;
> (3) wage and price change."[76]

He notes that each of these three items destroy the heretofore profit curve identified in the previous analysis. The first, he suggests, has the effect of shifting the production cost curves for the firm upward as the resource

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[76] Scott (1967), p. 40.

is extracted. He emphasizes that this is independent of time. The second item, resource growth or decline for a particular site is a function of time.[73] Items one and two may interact, but are two distinct forces. The resultant series of profit curves is probably one which declines with cumulative output, going out into the future. Regarding a revised output sequence, he states:

> "Given that all the material is ore, capable of being removed profitably, the deterioration probably leads to a stretching - out of the removal process in excess of the time that would be required if the same amount of material were available under constant conditions."[74]

After an allusion to some possible effects of uncertainty, he concludes with the following (somewhat inconclusive) statement:

> "It is clear therefore that if the mine can be operated only by taking smaller amounts in the later periods, cumulative deterioration must produce a new source of tilt in the production sequence."[75]

Here I believe that Scott is referring to the situation where at some point in the future the mine owner finds that there is less stock of resource in the mine than previously expected. Less is therefore removed in the future, characterizing a tilt over time, but is not the result of a conscious prior decision on the part of the mine owner.[76]

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[73] Only because new information is acquired over time.

[74] Scott (1967), p. 42.

[75] Scott (1967), p.42.

[76] One would, however, imagine that as often as not the surprise about the amount of revenue would be pleasant rather than unpleasant.

Scott continues with detailed discussion of the influence of the "Recourse to Lower Grades" (p. 42). This, Scott states, can result in greatly increased complexity for analysis. There are two extremes, at the one extreme, all the ore is mixed together where there is little possibility for the miner to choose between grades; at the other extreme different grades may be mined separately. In the latter case one may choose between working them simultaneously, or in some sequence.

The work of Carlisle (1954) is referred to by Scott in the latter's work on the problem of intermixed grades of ore, the problem between the two extremes, where the richness of the grade varies within the mine, but in sizeable "chunks". Scott refers to Carlisle's (1954) presentation on several counts, and states:

> "His exposition is not clear on whether the decisions are assumed to be made before or after the mine is set up and ready for working..."

and

> "Carlisle's discussion suffers from difficulties that are inherent in the subject. Because stopes differ, there are no input units available for defining the problem in a general way; Carlisle is forced to discuss grades chiefly in terms of percentage of lifetime recovery potential. Thus, although his paper distinguishes between rate-variable and grade-variable costs, the items that make up these two types of cost are unidentifiable in that an outlay for drilling, say, cannot be imputed to the maintenance of the grade or of the rate.."[77]

He does credit Carlisle for identifying "what may be called short-run economies of scale." This is the possibility of using low grade ore in combination with higher grade ore, to provide a relatively uniform grade for a mill, which could

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[77] Scott (1967), p. 43.

yield economies underground as well.

Scott refers to a model by K.F. Lane (1964) which describes these economies. He quotes Lane (1964) p. 812 as follows:

> "...decisions about cut-off grades, which are decisions of major economic significance, cannot be taken by the application of some simple cost formula such as, for example, that which equates marginal revenue to marginal cost. In fact, the optimum cut-off grade is influenced by the economics of present value, the capacities of the several stages in the mining operation, and the grade distribution of the deposit. These three influences can interact in complex ways, with the result that the optimum cut-off grade changes, sometimes widely, during the life of the operation."[78]

Scott goes on to detail the factors which would encourage the selective extraction of a resource by grade, emphasizing the role of various possible bottleneck factors at different stages of processing.

His summary conclusions regarding varying grades of ore are the following with respect to the optimal output program:

> "...(a) Insofar as the mine, or any part of it, has a constant grade, the rate will be tilted over time. (b) Insofar as the contents of the mine or of its separate parts can be selected into chunks of separate grade, the best grades will be taken before the poorer; the best areas before the poorer; and the best mines before the poorer. (c) If the mine has a fixed capacity, in ore per day, a gradual deterioration of ore will mean a reduction in the output of metal per day: output is tilted toward the present. The same tilt would result if the mill capacity were fixed in terms of tons of feed. Finally, if for some reason the capacity of the mill were fixed in tons of metal (concentrate of given grade) the output program would, by definition, be

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[78] Scott (1967), p. 44.

> fixed over time; but the input program would be tilted toward the future."[79]

On the second item, "Growing and Decaying Resources", (p. 46) Scott focuses on the growth or decay of a unit of the resource, which enables a discussion of the user cost of a unit of the resource at different points in time. These factors will affect the future profits picture, and the user cost calculations, although the specific technical relationships would have to be known in order to come to specific conclusions on their effect on the production profile.

In the "Changing Wages, Costs, or Prices" section, Scott combines argument with a numerical example to come to the following conclusions:

> 1) Large expected price increases, and therefore profit increases encourage managers to postpone output.
>
> 2) Mines in existence, are unlikely to shut down, but the expectation of future price increases will likely cause possible new mines to open.
>
> 3) The mines which do shut down would reopen only if the future profit curve series levels out. Lower future profits encourage present production. Higher future profits encourage postponement of production.
>
> 4) Prolonged real increases in prices and costs would tend to be associated with increases in real interest rates, and this would bring production closer to the present.
>
> 5) Conversely to the above, expected declines in prices, and profits would draw production closer to the present. Also, however, a large fall in costs would have the effect of raising future profits, and shifting the production further to the future.
>
> 6) Lastly, a rise in costs (wages) would also have substitution effects, - he claims even in the short run. Although Scott ignored capital costs in his

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[79] Scott (1967), p. 46.

> analysis, he states that if capital were included, substartial effects between capital and labour would tend to offset to some extent the influence of wage changes.

This last item seems somewhat confusing, unless two different definitions for short run are used.

> Taxes and interest rate and price expectations
>
> On the subject of taxes Scott notes the following:
>
> "...a progressive income tax, for example, will change the shape of the profits curve directly; other taxes, such as royalties and severance taxes will work indirectly through their effects on revenues. Property and other flat-rate taxes will leave the shape unchanged; producing no change in the shape of profit curves, but reducing user cost and marginal user cost via their carrying-charge effect (similar to a rise in the rate of discount)."[80]

In considering the influence of future interest rate changes, Scott notes (p. 56) that the expectation of some future interest rate decline will reduce the current discount rate but by less than the entire future change. Other things equal, a drop in the rate encourages postponement, while increases encourage acceleration of production.

Scott credits (pp. 56-57) a colleague of his, Professor Milton Moore with showing that changes in the interest rate may cause firms to switch production from a high grade resource to a lower grade. The required interest change is described as drastic.

Scott also analyses Gray's (1914) price problem, and draws the following conclusion for a once and for all price increase:

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[80] Scott (1967), p. 55.

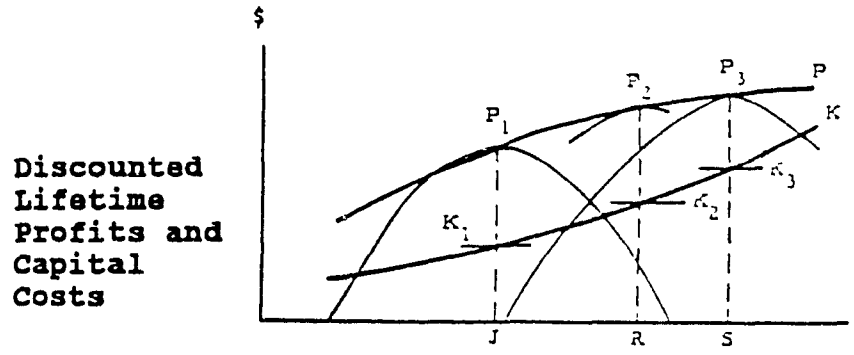
"...higher future prices would tend to tilt the series toward the future, but a higher present profit at each rate of present output, undiscounted, is more attractive than an equal future profit, discounted. At given discount rates, the absolute loss of present value from discounting future profits is greater the larger is future profit."[81]

Optimum plant size

The final section of Scott's analysis deals with the selection of the optimal plant size for the firm. He states:

"Although it is the first decision to be made in time , it cannot be made optimally without knowledge of the life of the reserves and the annual (daily) output to be expected."[82]

He uses the following diagram to assist in the analysis:



Discounted Lifetime Profits and Capital Costs

Capacity in tons per year

For each plant, initial cost is given by a horizontal line, and labelled K1, K2, K3, with the curved line K indicating the cost of running plants of various sizes. The curve P passes through the maximum points of the (discounted) profit

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81 Scott (1967), p. 58.

82 Scott (1967), p. 58.

curves for running the plants of different sizes (P is not an envelope curve).

Scott notes that "Paisch's solution is that the best size of the plant (as measured on the horizontal axis) is that which has the maximum distance P-K, such as J." (p. 59). He notes further, that "This approach is suitable when capital is in elastic supply. If capital is limited to a given sum to be invested by the company, the criterion would select the maximum benefit over cost and would be biased toward large investments." This statement as it stands is somewhat confusing as larger plants undoubtedly cost more and are therefore subject to the constraint of the capital that is available. The Paisch solution seems to yield a higher Benefit-Cost ratio than most of the larger plants. A smaller plant, Scott notes, might be associated with a plant other than J, and he suggests minimizing the difference between the two solutions.

Summary

Scott's (1967) work is useful for many reasons, possibly first among which is that he takes the first steps towards an integration of the decisions of individual firms with the macro behaviour of the industry. Scott refers to his paper as "work in progress" and suggests further lines of research, including an empirical test of the declining production rate hypothesis for individual producers, the development of long run supply curves for minerals, the extension of the individual firm framework to encompass the exploration decision, and lastly, an evaluation of the impact of uncertainty on all of the previous considerations.

Herfindahl (1967), A Graphical Approach to Exhaustible Resource Dynamics

Orris Herfindahl (1967) presented his paper "Depletion and Economic Theory" at the same conference as Scott, however he takes a different tack, pursuing the Hotelling (1931) line of research more closely. Herfindahl states:

> "The essence of the concept of depletion is not a sudden running out of something but rather a progressive change in the quality of a resource, or in the current costs (outlays made approximately at the time of production of the mineral product) of producing the resource product."[83]

He notes this, in the context of a description of the "standard analysis of a static economic system [which] deals with flows of commodities and services that are uniform through time." (p. 63). The extent of the uniformity he refers to, however, is not clear, because generally, it is not assumed that all goods whether resource or otherwise, must always be produced, or demanded at all points in time. He refers to the changes in the quality of a resource as being based in, or related to a change in cost. On the other hand, in the world of perfect competition, at a point in time, supply of goods is deemed to be infinitely elastic from the point of view of consumers, and demand infinitely elastic from the point of view of suppliers at market-clearing prices; however, this is not necessarily the case in intertemporal problems. The price of goods need not be identical through time, and all goods need not be demanded through all time. Thus his initial statement can hardly be assumed to apply to natural resources unless they exist in virtually unlimited volumes.

Assumptions

Herfindahl begins his analysis with the following assumptions. First demand is known, for all time, by all participants, and the demand function remains fixed. Second, production functions are assumed to remain fixed. Also, Herfindahl will pursue the problem of price and industry output for the depletable resource, rather than focus on the decisions of the individual firm, as Scott (1967) did, and

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[83] Herfindahl (1967), p. 63.

his time period of analysis, is taken to be the life of the average mine. This time period he states is short compared with the time over which a mineral is mined in an area. This latter item, I believe, is debatable, some mines have very long lives indeed; however, I will not pursue this point here.

Herfindahl notes:

> "The basic theoretical ideas discussed here are not new. They are all embedded in the basic and definitive treatment given this subject by Harold Hotelling in 1931..."[84]

His presentation does, however bridge the gap between the then standard economic analysis of algebra, graphical analysis, and logical argument, to the calculus of variations approach of Hotelling.

Known reserve, constant costs

In analysing his first case, that of all deposits known and current costs constant, with quantity demanded equal to zero at some finite price, he concludes as Hotelling did, that the royalty must rise at the rate of interest, and that a mineral deposit should be "viewed as a piece of capital that can yield a flow of services which represent its consumption, just as with a machine that wears out." (p. 67).

He used the diagrams below to help to show, that with demand fixed, and firms in the industry behaving like profit maximizers, there is one depletion program i.e., production profile, which will maximize the industry profits.

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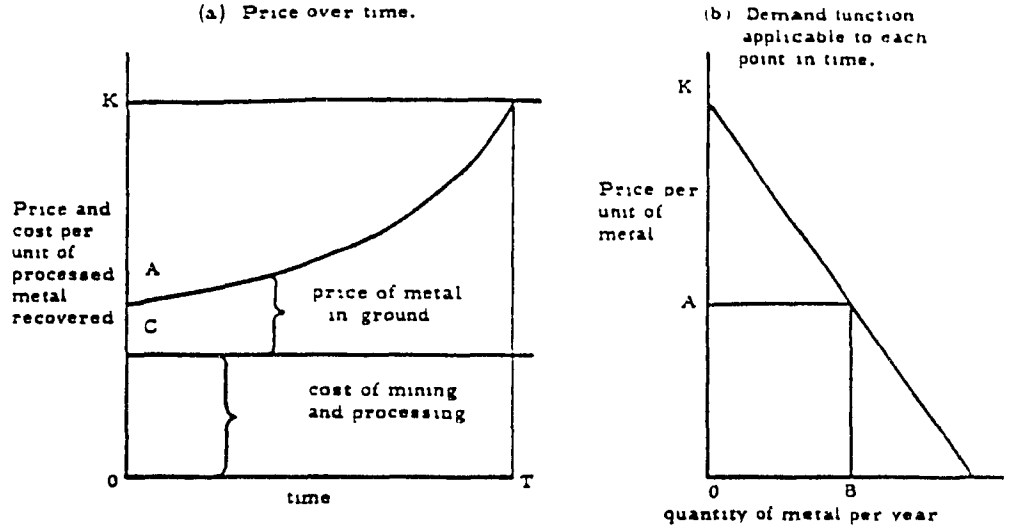
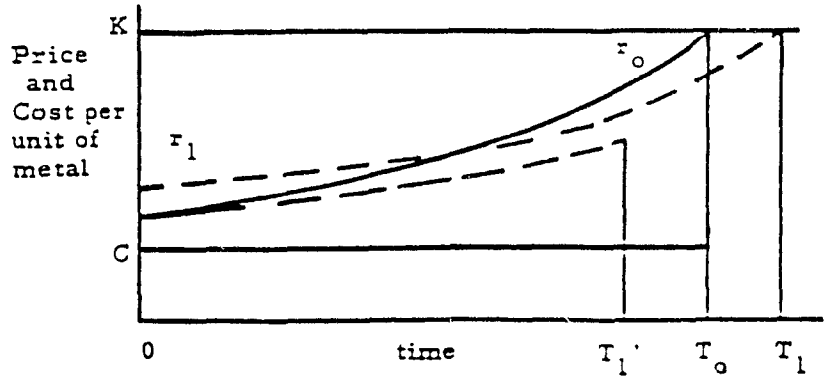
[84] Herfindahl (1967), p. 64.



Since the royalty must rise at the rate of interest, the only question is, what should the initial price be? The answer is that initial price must be chosen, such that with the royalty growing at the rate of interest, gross price produces a sequence of demands which exhausts the resource precisely at price K. If price K is reached prior to exhaustion, initial price was too high, if never reached by exhaustion, the intial price was too low.

The initial solution was described by Herfindahl as the solid line with exhaustion date To on the graph below.



Interest rate effects

He then considers the likely influence of a change in the rate of interest. If the rate of interest drops, then

the rate of increase in the royalty declines, the price change series declines to the dashed line connected to T_1'. However, at the rate of price increase, the resource is exhausted before price can rise to K, therefore the starting price must be higher. A possible solution is given by the dashed line connected to exhaustion time T1. Thus compared with the initial interest rate ro, prices under r_1 are higher initially, and lower finally, indicating a lesser interest in the more rapid drawdown policy under ro.

Changes in the size of the reserves, costs, taxes, and demand

On the effect of an increase in the quantity of deposits, Herfindahl simply states

> "The effect of an increase in the quantity of deposits is obvious: price is lower at each point in time, royalties are lower, quantities consumed are higher in all periods, and the period of exploitation is lengthened."[85]

If costs per unit decline, i.e., if C on the preceding figure were to drop, then earlier prices must be lower, with an earlier time of exhaustion at price K. Conversely for higher costs, we have a higher initial price, but later time of exhaustion, again at price K.[86]

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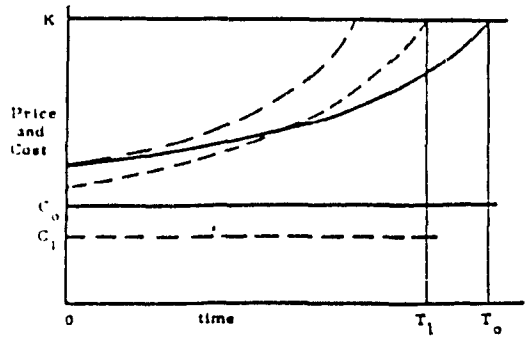
[85] Herfindahl (1967), p. 68.

[86] The effect of a change in current cost, is presented on the following diagram.



(continued...)

The effect of a severance tax could be illustrated (fn. 86) by an upward shift in the horizontal line C_1 to Co (costs plus severance charge). At the higher cost (plus severance), the exhaustion time would be To. One tax which Herfindahl notes would have no effect on production plans is a tax which takes a constant percentage of the realized royalty. Such a tax equally affects present and future values of the royalty stream, and offers no inducement to shift output from one period to another.

Three main cases for changes in demand are presented. In the first, there is an increase in the quantity demanded (at all time periods) at each price by a constant percentage, which Herfindahl notes (p. 70) leaves elasticity of demand the same at all prices, and leaves the maximum price K unchanged.[87] If price was not changed, this increase in demand would result in premature exhaustion, and thus price must rise so exhaustion occurs at price K in an earlier time

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[86](...continued)

Initial costs, rate of price increase, and time of exhaustion, are given by Co, the solid line "S" and To respectively. If costs decline to C1, then at the existing interest rates, the royalty would grow such that K is reached prior to exhaustion, thus the initial price must be too high. If early prices must be lower, later prices must be higher if exhaustion is to occur at price K. A solution is given by the dashed line connected to exhaustion time T1 at price K.

[87] This may be pictured as below

period T_{11}. The second case assumes that price increases by a uniform amount for each quantity demanded, which results in a uniform upward shift in the demand curve. The effect of this increase in demand is that at the initial price, which has also increased with the entire price sequence, the associated rate of increase of royalty would be too low. Thus, production would be shifted forward in time, initial prices lower, and final exhaustion time earlier, with the new initial royalty growing at the rate of interest.

The last case is the opposite of the first, price associated with each quantity increases by a constant percentage, the demand curve pivots upward to the right.

Herfindahl states (p. 72) with price higher by a constant percentage, the royalty increase rate would be less than the interest rate. Thus, in this case also, the initial price would have to be lower, and the final prices higher, with exhaustion time earlier to obtain an equilibrium.

Different grades, no uncertainty

Herfindahl (p. 72) turns to the problem of limited quantities of different deposits, with all deposits known with certainty. He states that at this point in the analysis:

> "We are exposed to the full complexity of the problem of exploiting minerals over time under conditions of certainty."[88]

In a case in which there are two grades of ore of different size he states that an optimizing solution demands that the final product must sell at the same price, and that the royalties of the two different grades must grow at the rate of interest. These conditions are impossible however, for so long as $r > 0$, the equation:

$$Pt = (Po - Ca)e^{rt} = (Po - Cb)e^{rt}$$

implies that

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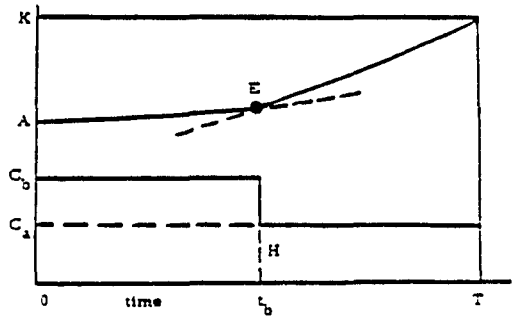
[88] Herfindahl (1967), p. 72.

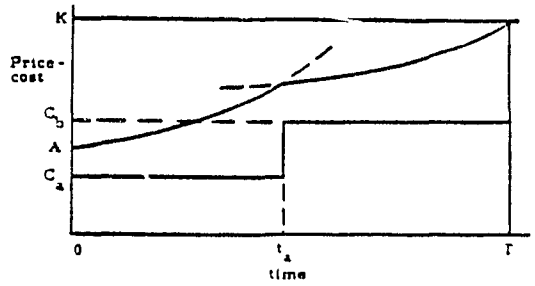
$$e^{rt} (Cb - Ca) = (Cb - Ca)$$

which cannot hold.

Herfindahl shows two possible cases, only one of which, depicted as the lower of the two following figures, is stable. It is the case where the better grade is exploited first, followed by the poorer grade, which in a world in which all things are known, is the sequence of development that one would expect.

If the poorer grade was exploited earlier, the owner of the superior grade could always get a higher royalty by displacing the lower grade supplier. In the second picture, if the production at time ta, of the worse grade were shifted to time to, the royalty rate would be lower, and there would be no gain to shifting the production.





Backstop technology

Herfindahl (p. 75) seems to develop the idea of a "backstop technology" in the following passage.

> "An important special case of this situation is that in which the quantity of metal in the lower-grade deposits producible at a current cost of Cb is extremely large, for example, a metal extracted from sea water. In this case Cb is the price reached at the end of exploitation of the better deposits. Thereafter price stays at Cb and does not rise. Production and consumption are higher while the

better deposits are being exploited than if the quantity of poorer deposits is limited..."[89]

This is presented in contrast with the previous figure. The larger the quantity of the poorer but ultimately exhaustible deposit, the longer the time of its exhaustion, and the earlier the crossover point, from the better to the poorer grade. The point here is that there is a longer period for the use of the higher cost resource, due to the larger quantity of the resource available, which changes the price sequence, shifting the introduction of the resource closer to the present, and reducing the size of the initial royalty for the inferior grade. The superior grade is used faster to accomodate this change in availability. This, of course, assumes that royalty for the inferior good was not equal to zero initially, before the large discovery.[90]

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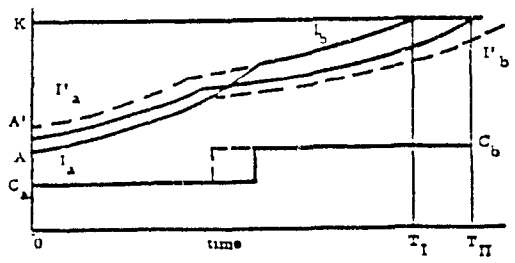
[89] Herfindahl (1967), p. 75.

[90] On the subject of a change in the relative quantities of grades, Herfindahl starts with an initial situation given by the price curve Ia to Ib in the following diagram.

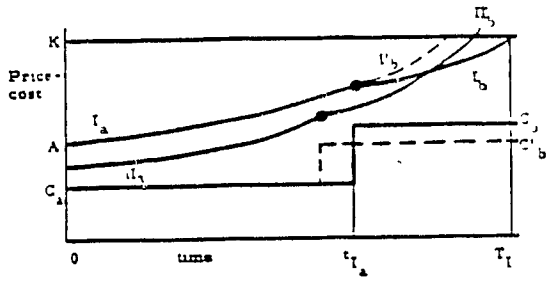


The change in the model involves an increase in low grade deposit, and decrease in high grade deposit of equal amounts in recovered ore. With the increase in the amount of lower grade ore it will come into production earlier, in which case when the smaller royalty grows at the rate of interest, price will not rise to K by the time of exhaustion. Thus, the initial price for the higher grade ore would have to be higher initially, and the new price line I'aIb would lie above the original price line, prior to exhaustion since that line would lie uniformly above or equal to IaIb. The final solution curve, he states, would have its initial price between A and A', with exhaustion occuring at price K at some time TII. Earlier prices are higher, and later prices

(continued...)

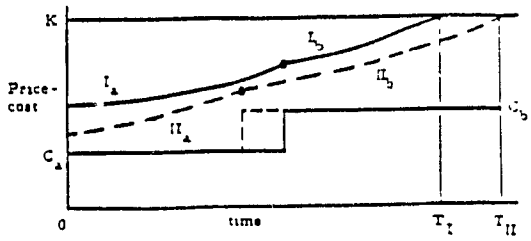
[90](...continued)
are lower compared with the initial solution, with associated production being shifted from the present to the future. The royalties on the higher grade is increased while that for the lower grade are reduced, on a per unit basis.

A reduction in the current cost of the poorer grade would have the effect of raising the per unit royalty at time tIa, when it would have initially come on stream, pictured in the graph below.



He states that if initial price A were kept, the new b price line I'b would apply, and price K would be reached prior to exhaustion. Thus, he argues, the initial price must be below A, however final price must be higher if exhaustion is to coincide with price K. The lower initial prices accelerates the introduction of B, and the time of exhaustion as well.

The final case considered by Herfindahl involves quality. It is assumed that the average quality is lowered because of an increase in quantity of lower grade deposits [described below].



The figure shows that from the inital price, Ia, K would be reached prior to exhaustion at TI. With a lower initial price IIa, the introduction of b is accelerated, however with the larger deposit, the price K is reached at a later terminal time TII, the final price curve lying everywhere below the first curve.

Exploration

The next major section of Herfindahl's paper is devoted to exploration. His first case deals with the situation where one can choose to look for a particular mineral, and find it and nothing else. Exploration may not always be successful, however, if the mineral is found, it is always of a uniform quality. Herfindahl states:

> "If the dispersion of returns to expenditure on exploration is small enough to enable the investors and/or firms in the field to effectively consolidate risks, there will be an economically effective cost of exploration. By effective, I mean that an increase in the price of mineral properties above this level will bring additional exploration effort and success and vice versa. Furthermore, if we take a very long view, the outlays on exploration can be thought of - at least for the purpose of developing some usable analytical apparatus - as being made approximately at the time of production. In this case, the conclusion is that exploration outlays can be regarded as part of current costs. No modification of the preceding analysis is called for."[91]

Regarding deposits of different quality, Herfindahl states, there are two alternatives if they are found in a fixed ratio.

> "1. Work both grades of deposit as they are discovered.
> 2. Increase the exploration effort so that the production schedule can be met from only the higher-grade deposits so long as any remain to be discovered. From then on, work the lower-grade deposits."[92]

Clearly, the second option has higher costs for exploration associated with it, as they are shifted toward the present relative to the second option. However, he notes

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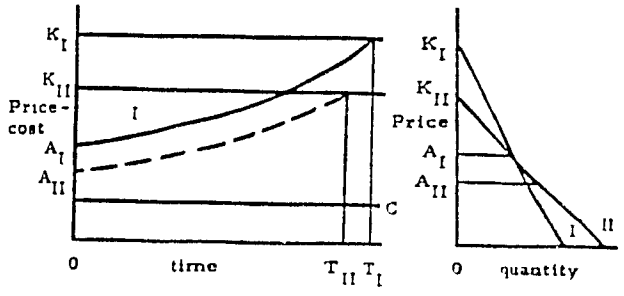
[91] Herfindahl (1967), p. 78.

[92] Herfindahl (1967), p. 78.

which option ultimately has the higher overall present value of net revenue will depend on several factors: the relative frequency with which the two grades are found, the rate of discount, and the total amount of ore to be found. No general solution is offered however, for a case where mineral output is constant, the total period of exploitation is "long", and the rate of discount is "not extremely low", and the fraction of deposits of the better grade "is not very small", a case for simultaneous production is made. He states, however, that if the quality of deposits is continuously distributed, exploitation will always be sequential, in the sense that some deposits will always be held for later production. This is not argued in detail.

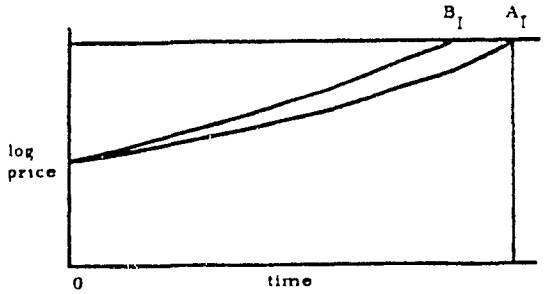
On substitution

On the influence of substitution possibilities of one metal ore for another, where A is in great abundance, and B is exhausted earlier on, and where the price for A is expected to stay constant for a long period, an increase in substitution possibilities of A for B will make B's demand curve more elastic at all prices. This is pictured below:



Initial price was OA_I, with the given rate of income in royalties, the new terminal price K_{II} would be reached prior to exhaustion, hence the initial price must drop. Early consumption is increased while later consumption is decreased.

Herfindahl also discusses the more complex case where two metal prices increase at "rates of the same order of magnitude", pictured below.



He concludes that in general, the prices will tend to move more closely together, as substitution possibilities increase, the limiting case, perfect substitutes would show both prices moving identically.

Joint production is mentioned only in passing, where it is noted that it

> "poses no special problems for the long run theory of minerals; standard economic theory applies."[93]

Long run price behavior

In his final section "Mineral Supply in Light of the Theory", Herfindahl seeks to explain possible real world supply, and market price behavior using elements of the theory he has examined. He attempts to "categorize" some types of long run price behavior.

The first category refers to price behavior in a situation where dedicated exploration is not done because the sum of current costs (exploration and production) is greater than price. If the resources are found accidently (no exploration costs), then production of the established mines will be interrupted as the accidental finds are exhausted, each exhaustion occuring of prices near the previous maximum price if the finds are infrequent. If frequent, there would

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[93] Herfindahl (1967), p.84.

be fluctuating prices around some long term price trend based on long term finding estimates. "In the case of by-products, supplies are connected with the supply of the major metal" (p. 84). There seemed to be a number of these by-products he claims.

Category two, is characterized by increasingly rapid rises in price until the maximum price is reached, and this category, he believes was empty at time of writing. He does not believe that these types of changes never occurred; he states that they have, but they have not been of a long term nature. In most cases, he states, changes in price level or trend are accounted for by technological progress. In sum, he states there seems to him to be little or no evidence that there have been persistent price rises that have indicated exhaustion.

The third and fourth category seem to Herfindahl to be most closely associated with the mineral industries. The prime influences for this behavior he sees as large expected supplies, and the expectation of technical progress (as well as past technical progress). We note that neither of these elements were explicity described in the theoretical sections of his paper. In support of his arguments he cites data on the recent estimates of mineral supply at less than a doubling in real cost, some trends in recovery as the grade of various resources decline, and change in historical costs for minerals which indicate technological progress.

Fossil fuels he cites as one item which could require major increases in long term supply due to the high rates of consumption, although the resource figures he cites indicated that these changes in sources of supply might be only over the very long term.

His last section considers the issue "Shall We Run Out in the Very Long Run?" Here the idea of cost limit (the early statement of backstop technology) is emphasized. He writes:

> "The notion of cost limits is very useful in thinking about energy commodities over the very long run. The current supply situation not withstanding, demands now met by petroleum products from the usual source will have to be met comparatively soon (decades?) from other sources, that is, from shale, from tar sands, coal, atomic energy, and to a limited extent, from sources related to the current flow of sunlight such as rivers, tides, and plants. As we move toward the higher-cost sources, quantities available become large, and the question of the cost of exploiting the more plentiful source is all important in shaping the course of price to that level."[94]

He also discusses the role of scrap for metals, and the fact that demand can't be expected to grow indefinitely, as population growth rates must level off. For fossil and other energy fuels, he emphasizes that we must move to some steady state consumption.

Other Contributions at the Time of Herfindahl (1967)

The Steele (1967), McDonald (1967), and Wunderlich (1967) papers which appeared at the same time as Herfindahl (1967) are directed toward the issue of optimal taxation for extractive resources, and oil and gas in particular. Their analyses are microeconomic, and as they are policy oriented, tend to focus attention on particular behavioural items in the industry. Some of these items refer to business risks in exploration, development cycles etc., while others refer to financial considerations more related to the then current institutional environment in which the firms operated.

It does not appear that these research works offer a great deal in terms of advancing the state of theory for extractive resources per se. For this reason the analysis of these papers will not be pursued, as taxation policy is not the specific subject of this thesis.

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[94] Herfindahl (1967), p. 88.

Solow (1974) Summary to Date, and a Commentary

One of the best appreciations of the work of Hotelling is that of Robert Solow in his 1973 Ely Lecture, "The Economics of Resources or the Resources of Economics". Solow begins with the following quotation from Hotelling (1931), noting that it "...could have come from yesterday's newspaper, or from the most recent issue of the American Economic Review."

> "Contemplation of the world's disappearing supplies of minerals, forests, and other exhaustible assets has led to demands for regulation of their exploitation. The feeling that these products are now too cheap for the good of future generations, that they are being selfishly exploited at too rapid a rate, and that in consequence of their excessive cheapness they are being produced and consumed wastefully has given rise to the conservation movement."[95]

Solow used this quotation to note that the subject was one which appeared to him to be a perennial one. Solow had a number of ideas to add to the Hotelling evaluation of the exhaustible resource problem along with his appreciation of Hotelling.

Resources as capital assets

Solow notes that exhaustible resources should be thought of as capital assets, which ultimately draw their value from sale in the marketplace. Solow states that asset markets are only in equilibrium when all assets in the same risk class earn the same rate of return, which is the interest rate for that risk class. He states that as long as a resource deposit remains in the ground, in equilibrium, the value of the deposit must be growing at the rate of interest. Also,

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[95] Solow, R.M.,"The Economics of Resources or the Resources of Economics", American Economic Review, 66 (2), pp. 1-14.

> "Since the value of a deposit is also the present value of future sales from it, after deduction of extraction costs, resource owners must expect the net price of the ore to be increasing exponentially at a rate equal to the rate of interest."[96]

Stock equilibrium

Thus Solow deduces the 'Hotelling Rule' as a condition of stock equilibrium in the asset market, rather than as a flow equilibrium condition as Hotelling did. Solow refers to net price for these assets growing at the rate of interest as "the fundamental principle of the economics of exhaustible resources," and he states, "It is hard to overemphasize the importance of this tilt in the time profile for net price."[97] Price rising too quickly or too slowly would result in subnormal and supranormal profits for the owners of the resource.

The asset market equilibrium condition refers to the idea that a stock of natural resources, S, at some time, t, has value $P_t S_t$. Now we may think of this (non-deteriorating) stock of resources as an asset, and for asset equilibrum to hold in a competitive market, the value of all assets of similar risk must rise at some rate of interest r. The only way for this to happen is for P_t to increase, S_t to increase, or P_t and S_t to increase. As S_t is fixed, P_t must rise by r, for asset equilibrum to hold. Thus

$$P_{t+1} = P_t(1 + r)$$

Flow equilibrium

The flow equilibrum approach focuses on the stream of service the stock offers. A competitive resource owner would be indifferent between putting some units of the resource on the market at price P_t at time t, or at price P_{t+1} in time t

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[96] Solow (1974), p.2-3.

[97] Solow (1974), p.3.

+ 1. If $P_t(1 + r)$ is not equal to P_{t+1}, the owner would rearrange sales such that he earns a rate of return in excess of r. If by holding units off the market the owner cannot in present value (P.V.) terms earn more than P_t per unit, the owner will sell the units at P_t. If the owner can earn more than P_t in P.V. terms by selling in the future, the owner will reduce present sales, increase future sales, until $P_{t+k} = (1+r)^K P_t$ for all periods K = 1,2,...

An analogy would be to the value of a home held for investment purposes. If the home is assumed non-deteriorating like the resource stock, and therefore can offer, say, thirty years of service at any point in time, then the owner of the house should be indifferent between selling the house today for $P_t H_t$, (where H_t are units of housing) or K_t years from now for $P_{t+K} H_t$ if $P_{t+1} = (1 +r)^K P_t$. This would describe the asset equilibrium.

Focusing on the flow equilibrium, the stream of services, perhaps rental offered by the home, the owner would be indifferent between renting the house for a year today at Price P_t or K periods from now for $P_{t+1} = P_t(1+r)^K$, then the owner could earn more than r by shifting services from period t to period K, or vice versa for any period t, K. House owners would continue shifting services between time periods until this flow equilibrium, where $P_{t+K} = P_t(1+r)^K$ for all K, was obtained.

The two equilibrium should hold simultaneously, as the value of the capital asset, i.e. the house held for investment purposes, is equal to the present value of the flow of services it provides.

High versus low cost producers

After reiterating the Hotelling approach to the influence of costs on the gross price path for the resource, through argument, he offers an extension to the consideration of a multi-site problem. Presumably, the different sites contain deposits differing in the cost of extraction, and he argues

in terms of the fundamental principle (rents growing at the rate of interest).

> "At the beginning, if the high cost producer is serving the market, the market price must cover high extraction costs plus a scarcity rent that is growing exponentially. The low cost producer would refrain from undercutting the price and entering the market only if his capital gains justify his holding off and entering the market later. But just the reverse will be true. Any price high enough to keep the high cost producer in business will temp the low-cost producer to sell ore while the selling is good and invest the proceeds in any asset paying the market rate of interest. So it must be that the low cost producer is the first to enter the market."[98]

Thus the sequence of production is from low cost to higher and higher cost resources, until all of the stock has been exhausted, and price has risen sufficiently to reduce quantity demanded to zero.

Backstop technology

Demand will also be reduced to zero for a particular resource if the gross price has risen sufficiently to bring a higher cost (including normal profit) resource on stream. Solow refers to the work of William Nordhaus in the energy industry, relating the idea of a 'backstop technology'. This is

> "...a technology capable of producing or substituting for a mineral resource at relatively high cost, but on an effectively inexhaustible resource base. ... The nearest thing we have to such a thing is the breeder reactor using U-238 as fuel."[99]

Stability of equilibrium

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[98] Solow (1974),p.4.

[99] Solow (1974), p.4.

Thus the order of usage for the various resources is from low cost to high cost, with the highest cost resource preceeding the introduction of the backstop technology. At the equilibrium, market-clearing prices for the resources, there is an assumption that not only are present markets for the resources in equilibrium, but also all future markets are in equilibrium as well. If the futures markets actually existed, it might be easier to accept the conclusions regarding equilibrium asset pricing, and the stability of that pricing. Solow notes,

> "...natural resource markets work with a combination of myopic flow transactions and rather more farsighted asset transactions. It is legitimate to ask whether observed resource prices are to be interpreted as approximations to equilibrium prices, or whether the equilibrium is so unstable that momentary prices are not only a bad indicator of equilibrium relationships, but also a bad guide to resource allocation."[100]

It does seem that Solow is leaning toward an argument that says that whereas the decisions of those in the asset markets (perhaps stock markets) are made with a long view in mind and tend to stabilize prices, those in the flow (commodity) market tend to emphasize the short run, and are associated with price instability. It is not at all clear why stock analysts should have a superior long term view than those intimately involved in the flow markets - i.e., producers, and why the former tend to stabilize prices more than the latter. The asset market versus flow market participation becomes fairly difficult to separate when one considers that the producer of a well (asset) usually plans to be a part of a long sequence of flow markets. Generally, wells are drawn down over long periods of time. I will

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[100] Solow (1974), p. 6.

continue the discussion of specific types of return in the gas market in Chapter Four.

Solow notes that the flow markets may tend to instability, but the asset markets tend to provide a corrective force. He gives the following example:

> "Suppose net prices are expected by producers to be rising too slowly. Then resource deposits are a bad way to hold wealth. Mine owners will try to pull out; and if they think only in flow terms, the way to get out of the resource business is to increase current production and convert ore into money. If current production increases for this or any other reason, the current price must move down along the demand curve. So initially pessimistic price expectations on the part of producers have led to more pressure on the current price. If expectations about future price changes are responsive to current events, the consequence can only be that pessimism is reinforced and deepened. The initial disequilibrium is worsened, not eliminated by this chain of events. In other words the market mechanism I have described is unstable."[101]

A symmetrical argument holds for the reverse case. The long run view associated with the asset market equilibrium, however, counterbalances the tendencies toward instability inherent in the flow market. Investors aware of the long run value of the resource are aware that increasing short term output results in capital losses for the example above. If prices are actually rising at too slow a rate, then the increased short term flow reduces prices, which serves to write down the capital value of the resource (correctly) and helps to establish the correct asset value, associated then with prices rising at the proper rate. Solow notes that it is

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[101] Solow (1974), p. 6.

in such an operation that "the two stories can be made to merge..."[102]

Social discount rate

Solow next turns to the issue of the social discount rate. The context of this discussion is the theoretically optimal usage rate for the resource described on the basis of partial equilibrium analysis. In that analysis, the interest rate which governs the rate of growth of net prices in the resource sector, is given by the market, as is the demand for the resource. Solow notes:

> "...the fundamental principle of the economics of exhaustible resources is, among other things, a condition of competitive equilibrium in the sequence of futures markets for deliveries of the natural resource. This sequence extends out to infinity, even if the competitive equilibrium calls for the resource to be exhausted in finite time....Like any other competitive equilibrium, this one has some optimality properties. In particular, as Hotelling pointed out, the competitive equilibrium maximizes the discounted consumer-plus-producer surpluses from the natural resource, provided that society wishes to discount future consumer surpluses at the same rate that mine owners choose to discount their own future profits."[103]

Solow notes that there are a number of possible problems here, some of which Hotelling was aware of as well. The model is only as good as the assumptions, the first being that there are a number of externalities, involving individuals' common access to particular stocks of a resource (slant drilling). Also there are externalities in the individual evaluation of exploration risks and the usual rush to exploit the resource, and the influence of monopoly and oligopoly.

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[102] Solow (1974) ,p. 7. Again, this implicitly assumes that the financial analysts are better informed than those working in the industry, an assumption that is certainly questionable.

[103] Solow (1974), p. 7.

Finally, society may wish to discount future pleasures or consumer surpluses at a rate different from the rate at which the market offers interest returns, an item which Hotelling dismissed.

Solow notes that "if the market rate of interest exceeds the social rate of time preference, then scarcity rents and market prices will rise faster than they 'ought to' and production will have to fall correspondingly faster along the demand curve."[104] This implies a faster than socially optimal rate of depletion. Solow cites two classes of reasons why private discount rates might exceed the 'correct social rate of discount.'

Risk and return, individual and societal

The first class of reasons has to do with the fact that individuals in society face different risks and returns than does society as a whole. Two examples illustrate the first class:

> "...society ought to discount utility and consumption at the same rates as reflective individuals would discount their own future utility and consumption...there are reasons why this might not happen...individuals can be expected to discount for the riskiness of the future, and some of the risks for which they will discount are not risks to society but merely the danger of transfers within the society. Since there is not a complete enough a set of insurance markets to permit all these risks to be spread properly, market interest rates will be too high."[105]

On the return side:

> "...since individuals care about the after- tax return on investment and society on the before-tax return, if investment is carried to the point where

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[104] Solow (1974), p.8.

[105] Solow (1974), p. 8.

> the after tax yield is properly related to the rate of time preference, the before-tax profitability will be too high."[106]

Individual choices versus societal choices

The other class of reasons has to do with claims that individual rates of time preference should not be used as the presumed 'correct' basis for intertemporal decision making. Solow states,

> "Frank Ramsey, for instance, argued that it was ethically indefensible for society to discount future utilities. Individuals might do so, either because they lack imagination (Bohm-Bawerk's 'defective telescopic faculty') or because they are all too conscious that life is short. In social decision-making, however, there is no excuse for treating generations unequally, and the time-horizon is, or should be , very long."[107]

This implies a zero discount rate on future utilities, or consumption, and it is one which Solow finds appealing. Solow also states,

> "If the whole infinite sequence of futures markets for resource products could actually take place and find equilibrium, I might be inclined to accept the result (though I would like to know who decides the initial endowments within and between generations). But of course they cannot take place. There is no way to collect bids and offers from everyone who will ever live."[108]

There are several points here. First,there is the voting issue and the problem of representing the preferences of future generations. The second issue, is dealt with in detail

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106 Solow (1974), p. 8.

107 Solow (1974), p.9.

108 Solow, 1974, p. 9.

in chapter three, and is concerned with initial endowments. Solow assumes that various generations should use their initial endowments of capital (physical, intellectual, etc.) and labour to bid on resource products. This approach bypasses the issue of whether or not it is correct to think of the finite resources as a component of an initial endowment itself, and whether it should not be subject to bidding.

Solow points out that in the present market situation, the preferences and interests of future generations are only represented by our opinions, and by the fact that the interest that previous generations have shown for us (care for children etc.) have left us relatively well off. He suggests that it might perhaps have been better if they had saved less and consumed more; it is a problem worthy of serious study.

> "...the future may be too important to be left to the accident of mistaken expectations and the ups and downs of the Protestant ethic."[109]

Macroeconomic growth models

These views of the future motivate an interest in macroeconomic growth models. These models present several economic aggregates: capital, labour, and in some cases finite natural resources. This class of models bypass market response issues, dollar voting etc. They present idealized, or theoretical economies which combine units of the aforementioned inputs using theoretically acceptable technologies, to produce outputs. The outputs of these models may either be consumed or saved at each point in time. While consumption has utility or satisfaction associated with it at given points of time, postponed consumption is imagined to make possible increased investment and the enhancement of the future capital stock, which should enable increased future consumption.

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[109] Solow (1974), p.9.

At any given point in time the factors are all presumably characterized by decreasing marginal returns. Also it is generally assumed that the marginal rate of substitution of one factor for another is decreasing as well. The labour force is generally assumed to be given initially, and subject to an exogenous rate of growth. Thus, given assumptions on initial labour stock and its growth rate, available technologies, and initial endowments of capital and natural resources; output, and associated consumption and savings-investment paths are produced according to assumptions on the elasticity of factor substitution, etc. Clearly a great number of diverse paths may be generated, and one would wish to have a way of choosing among them. Generally an optimum is found by using some rule for evaluating the different consumption paths. A social welfare indicator is usually some transformation of consumption per capita, and the present value of the social welfare indicator is taken as the measure of the social optimality of each given path. These are then compared, and the path with the highest present value is taken to describe the optimal path. The choice of the social discount rate to be used in the present value analysis is critical in the evaluation of different paths in this type of modelling. Solow notes an important aspect to this type of modelling, and that is

> "...the future brings no endowment of its own to whatever markets actually exist. The intergenerational distribution of income or welfare depend on the provision that each generation makes for its sucessors. The choice of a social discount rate, is in effect, a policy decision about that intergenerational distribution. What happens in the planning parable depends very much - perhaps dramatically - on that choice; and one's evaluation of what happens in the market parable depends very much on whether private choices are made with a discount rate much larger than the one a deliberate policy decision would select. The pure theory of exhaustible resources is trying to tell us that, if exhaustible resources really matter, then the balance between present and future is more delicate

> than we are accustomed to think; and then the choice of a discount rate can be pretty important and one ought not to be too casual about it."[110]

There are a number of points to be made. First that none of the stock of natural resources is deemed to 'belong to' any future generation per se. Second, the models that are used to evaluate the problem are not models of markets but rather of an idealized system with its own unique characteristics, leaving one to question the policy value of the whole class of models. Possibly this issue of external validity can only be addressed on a model by model basis, by examining assumptions and market parallels, and by running empirical tests before drawing critical conclusions. One may also wonder whether individuals do value anything besides consumption and whether the procedure for identifying an optimum is one which regardless of whether anyone would actually choose it (which is yet another complication) is one which anyone should want to choose on moral grounds. Yet another complication involves the twin issues of whether individuals really do choose what is really best for them, and when if they pick what they want they pick what they should want. What an individual chooses may not be what is best for the individual, and neither of the two may be what the individual perceives as the morally correct choice. This is straying a bit from the problem of the social planner, but the notion of the optimum is central to every policy choice.

Maximin criterion

Solow, perhaps in the interest of conservatism, and perhaps because he believes it to be the most appropriate criterion, imposes the requirement that total consumption per head be constant through time so that no generation be

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[110] Solow (1974), p. 10.

favored over another. To this is added the requirement that this consumption per head be the largest that can be maintained forever, given all the constraints including the finiteness of resources. The criterion has been referred to as the maximin criterion, and the Rawls' criterion.[111] Solow notes that this criterion he uses has 'its pluses and its minuses', and he claims not to be committed to it by any means, however, he notes that good reasons for using it are that it does pick a path that is efficient, and that it has 'the advantage of highlighting the importance of certain crucial technological assumptions'.

Technical progress, substitution possibilities

Solow notes that technical progress affects the outcome of the modelling effort in two ways. First it may effect changes that result in savings that can be made in resource use and it may make it easier for other productive elements, capital and labour to be substituted for the finite resources in production. Solow, however, chooses to analyse the 'zero-technical-progress' case, because 'it is easy to see how technical progress can relieve and perhaps eliminate the drag on economic welfare exercised by natural resource scarcity'.[112] He notes that substitutibility is the key factor, if there is no strict dependence on the finite resources, i.e., there is substitutability, then there is 'no problem'; alternatively, if there is no substitutability 'then catastrophe is unavoidable'. These are the extremes, and he concludes with the following:

> "Fortunately, what little evidence there is suggests that there is quite alot of substitutibility between exhaustible resources and renewable or reproducible resources, though this is an empirical question that

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[111] The evaluation of these and other criteria appear in chapters two and three.

[112] Solow (1974), p. 11.

could absorb a lot more work than it has had so far."[113]

Solow concludes his discussion of growth models with a paragraph which marks a departure from the preceeding, more intuitive style, and which is reproduced below.

> "In the simplest, most aggregative, model of a resource-using economy, one can prove something like the following: if the elasticity of substitution between exhaustible resources and other inputs is unity or bigger, and if the elasticity of output with respect to reproducible capital exceeds the elasticity of output with respect to natural resources, then a constant population can maintain a positive constant level of consumption per head forever. This permanantly maintainable standard of living is an increasing, concave, and unbounded function of the initial stock of capital. So the drag of a given resource pool can be overcome to any extent if only the initial stock of capital is large enough. On the other hand, if the elasticity of substitution between natural resources and other inputs is less than one, or if the elasticity of output with respect to resources exceeds the elasticity of output with respect to reproducible capital, then the largest constant level of consumption sustainable forever with constant population is - zero. We know too little about which side of that boundary the world is on - technological progress aside - but at least the few entrails that have been read seem favorable."[114]

In moving to the conclusion of his talk, Solow returns to the discussion of the theoretical market model, and it would appear that this latter discussion is presented as being more germane to the discussion of policy issues,

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[113] Solow (1974), p. 11.

[114] Solow (1974), p.11. The entrails to which Solow refers appear on pp. 60-70 of Nordhaus, W.D., and J. Tobin (1972).

although he cautions the reader that he is not directly confronting 'concrete current problems'.[115]

A role for a regulatory body?

The two key market factors which Solow focuses on are the possible divergence between market interest rates and the social rate of time preference, and the problem of assuring that the 'long view' be sufficiently pursued by the members of society. The former problem which may tend to result in too rapid depletion, may be alleviated he suggests through the use of conservation subsidies, or a system of graduated severence taxes, falling through time. The latter problem, he suggests, may be eased, if sufficient effort is put into the production and wide dissemination of good information about the likely long term prospects for the economy and the exhaustible resources, 'reasonable information about reserves, technology, and demand in the fairly far future'.[116] He states that organized long term futures trading might help, as might organized indicative planning governed by professional standards to help eliminate major errors and help to resolve uncertainty. The NEB forcasts should provide an interesting example in this context. Solow states, "it is also likely that a certain amount of conspiracy against the public interest might occur in such sessions, so perhaps they ought to be recorded and the tapes turned over to Judge Sirica, who will know what to do with them" (p. 14). This does seem to be rather like the NEB process, and provides further motivation for placing more emphasis in this study on the NEB.

RECENT EXTENSIONS

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[115] Solow (1974), p.13.

[116] Ibid., p. 13.

The following discussion of "recent extensions" is not intended to be exhaustive, but rather is intended to give a flavour of the directions recent economic research has taken in this area, and some of the main results. The books and papers in the general area of this thesis probably number in the thousands, but there is a great deal of duplication and one must be very selective.

General Surveys

There have been a number of recent survey papers and books on finite resource economics, energy modelling, and energy policy modelling. They include Pearce and Rose (1975), Blank et al.(1977), Peterson and Fisher (1977), Manne et al. (1979), Dasgupta and Heal (1979), Howe (1979), Devarajan and Fisher (1981), Fisher (1981), Julius (1981), Anderson (1985), Hartwick and Olewiler (1986), Bromley (1986), Smith (1979, 1982), Pearce (1984), Kemp and Van Long (1980, 1986), Gordon et al. (1987), Pindyck (1979), Lecomber (1986) and Scott (1985).

Literature on Supply, Demand, Technology and Costs

Later extensions to Hotelling's partial equilibrium analysis include Cummings (1969), Weinstein and Zeckhauser (1975), Heal (1976), Schultze (1974) Lasserre (1985) and Hoel (1983). Hoel (1983) also examines the influence of changes in supply and demand factors as they affect marginal extraction, user costs and techological progress. Hartwick, Kemp and Van Long (1986) examine the influence of start up and shut down costs on finite resource use.

Extensions to the case of many deposits include Weitzman (1976), Solow and Wan (1976), Sweeney (1977) and Hartwick (1978). In these studies, the rule persists that cheap deposits should be used first. Other recent papers include Kemp and Van Long (1980) who show some conditions under which the aforementioned rule will not hold. Van Long (1974) examines the concept of user cost, Hansen (1977) the concept

of scarcity rent, Salant (1983) presents the effects of depletion on costs, Johnson, Bell and Bennett (1980) examine scarcity, costs, and prices, and Banks (1977) examines resource scarcity. Hansen (1977) examines the case of cost uncertainty, Burness (1978) considers price uncertainty, and Sundareson (1984), price behavior. Farnsworth and Norgaard (1976), Copp (1976), Ayers and Miller (1980), and Smith (1973) examine the effect of technological change on costs. Cairns (1986) examines a case in which the firm cannot choose to mine in order of grade, and in which the optimal cutoff grade changes at different points in the mine's life. Conrad and Hool (1984) consider extraction with ore variation and endogeneous reserves. Krantkraemer (1988) studies the influence of technical problems in the use of certain grades from highest to lowest order, and its influence on extraction, and the resulting industry price path. Cairns and Laserre (1986) examine optimal investment in mineral production, in the presence of mines of varying ore quality, to try to explain some of the "stylized facts" of the mineral industry. Heaps (1985) examines the effects of different taxes on exploitation in the presence of different cost structures. Yucel (1986) examines further the effects of severence taxation in a competitive resource industry. Lucke and Todfer (1987) attempt to estimate the burden of the U.S. Federal income tax on oil and gas extraction. Kalt and Otter (1985) examine the influence of price ceilings and excise taxes.

Other general models along the lines of Hotelling (1931), but in optimal control formats include Sierstad and Sydsaeter (1983), Sethi (1979), and Fisher (1981).

Monopoly

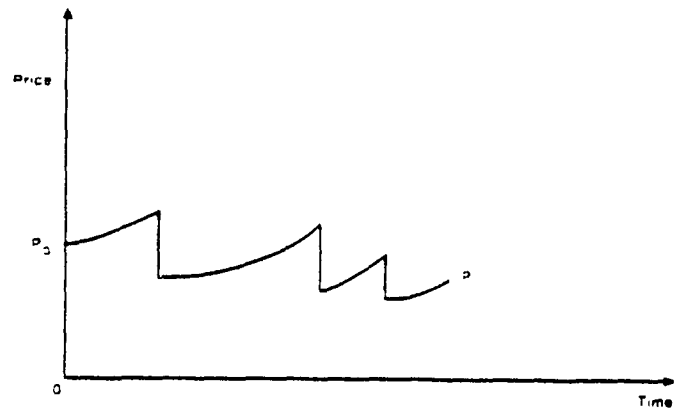
Further studies of the case of monopoly include Peterson (1977), Weinstein and Zeckhauser (1975), Sweeney (1977), Stiglitz (1976), Kay and Mirlees (1975), and Solow (1977) where generally 'Hotellings (1931) conclusions' for

retardation of production under monopoly is supported, although some counterexamples have been cited. Pindyck (1987) examines monopoly power in extractive industries with fluctuations in demand, rents, and reserves. Moussavian and Samuelson (1984) follow the work of Stewart (1980) and Levhari and Pindyck (1981) in examining monopoly extraction of a durable, exhaustible resource. Eswaran and Lewis (1984) examine imperfectly competitive markets for finite resources, where the reserve base is not fixed, but determined exogeneously.

Exploration

Exploration has been further studied in Fisher and Krutilla (1975), Solow (1977), Adelman (1970), Adelman (1972), Peterson (1975, 1977, 1978), Herfindahl and Kneese (1974), Uhler (1975), Burgess and Davisdon (1977), Schjanchi (1982), Mason (1986), Nilssen and Nystad (1986) and Fraser (1986).

Since exploration is a particularly important aspect of the natural gas industry and since Fisher had some significant things to say on this subject, we will treat his 1980 and 1981 work in somewhat more detail. The basic Hotelling resource model treats the underlying stock as known. The simplest conceptualization of the impact of exploration, is that it increases the known stock size in an unexpected manner. Fisher (1981, p. 55) claims that it has the effect of reducing the expected future prices, because that is when the impact of production is likely to be significant. The effect of this would be to depress expected future prices, causing suppliers to expand current production, which results in the depression of current prices. Fisher presents the following diagram to describe the effect of sequential discoveries on the price path of a finite resource.



The size of the discovery will of course influence the rate of decline in the price, and the degree of risk aversion will influence the rate of increase in price between discovery shocks.

Fisher differentiates between unanticipated discovery and exploration which is "purposeful activity". Fisher takes a very wide view of exploration, such that it encompasses research and development, and technological change. He states,

> "Exploration can be defined quite generally as an activity that increases the stock and thereby lowers extraction cost. Obviously, discovery of a new deposit will do this, but so can research and development of a new process that makes profitable production of the resource from materials formerly considered too poor in quality."[117]

The model which Fisher develops includes exploration, but in a deterministic fashion, where discoveries are a function of costs, and profits are a function of production and revenues from the stock, as well as the costs of production and exploration. Thus, there is no uncertainty in the exploration process per se, if one spends the money, one finds the resource. Still, Fisher claims that "the sense

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[117] Fisher (1980), pp. 55-56.

of the results will not be affected by introducing uncertainty.[118]

According to the Fisher model, increases in the stock size reduce extraction cost, so exploration and extraction costs are balanced against each other in the competitive equilibrium, "...the royalty or shadow price of a unit in the stock is just equal to the cost of finding another to replace it..." Fisher notes that in the basic model (without exploration) "...the royalty was interpreted as the benefit of having an additional unit in the stock."

According to the Fisher model, the royalty should be equal to the marginal cost of exploration. However, he mentions that royalty can therefore be estimated by the marginal cost of extraction for that reason. If this is the case, then it seems royalty is being redefined, as contrasted with the conventional use of the term, i.e., price minus average cost per unit - else a joint hypothesis is tested. A joint hypothesis implies that if marginal cost of exploration does not equal royalty (conventional usage) - then either price is not in equilibrium, exploration is not in equilibrium, or the underlying model which Fisher proposes is incorrect.

Fisher also mentions that there is still another adjustment to be made to exploration cost, which is that it should be affected by cumulative output. He mentions that this can have two possible effects on the level of marginal cost of exploration, depending on whether the better deposits are found early or late in the exploration sequence. He states,

> "If the better deposits are found first, the shadow price will be negative, and the royalty will exceed the unadjusted marginal exploration cost. If, on the other hand, the early finds provide information which will reduce the cost of future finds, the

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[118] Fisher (1980), p. 57.

shadow price will be positive, at least initially."[119]

Thus, the royalty equals the adjusted marginal exploration cost, the adjustment equals " (minus) the shadow price of a unit added to the stock of cumulative finds."[120]

Uncertainty and information

Fisher (1981) notes that there is not yet a substantial literature in this area, and "the effect of uncertainty on exploration is just beginning to receive attention from theorists."[121] First, it was noted that uncertainty about the size of the resource stock, other things equal, tends to slow the rate of useage. He states the following,

> "If we do not know what we have left, it makes sense to proceed cautiously, to reduce the risk of suddenly running out. But if the uncertainty is not so much about the size of the stock at any time as about what remains to be found, then depletion need not be slowed. In this case there is a tendency for the uncertain exploration activity to be restricted, whereas the rate of depletion may actually be increased."[122]

Fisher notes that there may be another reason to explore rather than just to hold down extraction costs - to reduce uncertainty concerning the size of the stock, and in this context he notes that a dry hole imparts as much information as a gusher. Here, the boundary line between uncertainty on the presumed stock versus what is to be found ultimately is

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[119] Fisher (1981), p. 59.

[120] Fisher (1981, p. 59). Fisher refers to Fisher (1977), Pindyck (1978), and Brown and Field (1978) for further discussion of this point.

[121] Fisher (1981), p. 63.

[122] Fisher (1981), pp. 63-64.

blurred. The information provided in delineating a current stock, or field, may reduce the cost of future finds. Thus, development drilling, and wild catting, though distinct activities in many ways, are similar, in that they are both information generating activities. This leads to Fisher's discussion of problems of market failure associated with information generation, an area I will not pursue here.

Duopoly, oligopoly

Studies of alternative market forms to competition and monopoly include Lewis and Schmalensee (1982), Pindyck (1978), Folie and Ulph (1980), Ulph and Folie (1980), Giesen and Bennett (1979), Salant (1976), Newberry (1981), Schmalensee (1976), Dasgupta and Heal (1979), Heal (1976) and Peterson and Fisher (1978), Eswaran and Lewis (1985), Rauscher (1988); supply shocks and their influence on prices for similar models are treated in Hubbard (1986).

International aspects

The behavior of multinational resource firms, which has been given scant attention in the literature, is treated in Lee (1984) and Lee (1986). Djahc (1988) presents a model of trade in exhaustible resources. Anderson (1986) examines resource valuation in an open economy. Asheim (1986) derives a rule, analagous to, but different from Hartwicks rule for open economies. Kemp and Van Long (1980) present a number of papers on trade and exhaustible resources.

Externalities

Forester (1980) examines the influence of pollution on depletion policy, Khalatbari (1977) problems of common pools and property rights, Simpson (1979) problems of political externalities, and Simmons (1977) on taxation.

Uncertainty

The effects of uncertainty are further pursued by Grayson (1960), Kaufman (1963), Allais (1957),Slichter (1959), Uhler and Bradley (1970) and Solow (1977). Weinstein and Zeckhauser (1975) focus on the case of uncertain demand, and conclude that whereas risk neutral firms are unaffected, risk averters tend to draw down the stock too rapidly. Fisher and Peterson (1977) note that the latter conclusion is dependent on the use of a model without investment or exploration sectors. Dasgupta and Heal (1974) focus on uncertainty in the arrival of a backstop technology, and biases are introduced by this exogenous element. Other recent papers include Dasgupta and Stiglitz (1981) and Henry (1974), Koopmans (1974), Heal (1975), Long (1975), Dasgupta and Stiglitz (1975), Kemp (1976), Gilbert (1978), Hoel (1978), Loury (1978). Hoel (1984) considers the case where there is a backstop for only some of the uses of a resource, but not all. Yeung and Hartwick (1988) study industry equilibrium under price and interest rate uncertainty. Kamien and Schwartz (1978) examine optimal resource depletion with uncertain endogeneous technical change. Krautkraemer (1986) treats the case of optimal depletion in the presence of resource amenities and a backstop technology, the author solves for the optimal useage pattern for the environment as well as the resource.[123] Bhattacharya (1984) pursues the issue of ignorance or uncertainty regarding the nature of the technology which would make a particular resource obsolete.

On uncertainty, Anthony Fisher notes two "easy answers". The first was the context of the Arrow-Debreu economy, where uncertainty will not affect depletion since there are perfect markets for futures in all commodities and for all risks, and perfect insurance is available. However, such markets do not exist in reality. The second easy answer involves the use of

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[123] The amenity services referred to include scientific, recreational, and aesthetic values associated with preserved natural environments. See Krunthraemer (1986).

a higher discount rate to evaluate future decisions. For finite resources, according to the Hotelling rule, ceteris paribus, a higher discount rate implies a more rapid rate of growth of price, a lower initial price, more rapid depletion, and an earlier terminal date for exhaustion. Fisher notes[124] that while this is possible for certain kinds of uncertainty, it is not the case for all types of uncertainty, especially when considering the role of exploration and development in expanding the resource stock.

Fisher's approach is to try to use intuitive approaches, as well as theoretical results from the recent literature in order to describe the problems of uncertainty of different kinds in resource markets. His stated intention is to try,

> "...to answer a positive question about the behavior of resource owners. There is also a question of whether or not that behavior continues to be consistent with allocative efficiency. This turns out to be more difficult in that it involves first determining what we mean by efficiency in these circumstances."[125]

It would appear that Fisher would like to first determine what resource owners are likely to do, on the basis of his own intuition, and then see if it is consistent with some model or theory-based concept of efficiency, assuming such a concept can be identified.

Fisher presents the following summary table which relates his suggested effects on depletion of different kinds of uncertainty apart from exploration uncertainty.

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[124] Fisher (1981), p. 45.

[125] Fisher (1981), p. 46.

Table 1

Effects on depletion of different kinds of uncertainty[126]

Kind of uncertainty	Effects on depletion
Uncertain demand for the resource, with degree of uncertainty related to distance in time from the depletion decision.	Shifts depletion toward the present
Uncertain demand for the resource, with variation in expected returns related to quantity of output.	Shifts depletion toward the future
Uncertainty regarding date of event that will destroy the value of the resource to the owner (e.g., expropriation, discovery of a cheaper substitute).	Shifts depletion toward the present
Uncertain size of resource stock	Shifts depletion toward the future

A higher discount rate, Fisher claims, is appropriate for the first kind of uncertainty, uncertainty about future demand, with the uncertainty concerning distance in time from the depletion decision. This is meant to imply that uncertainty about future demand increases the further out into the future the potential future demand is, and hence the further out into the future the depletion decision should be.[127]

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[126] Fisher (1981), p. 48.

[127] Fisher refers to the work of Koopmans (1974) and Weinstein and Zeckhauser (1975) on this point.

Fisher suggests an alternative case, where price is random, with the random component identically distributed in each period. This he states (so long as demand is not increasing (shifting out) over time as price rises), will result in decreasing quantities sold, and the variation in returns would be falling throughout time. Fisher notes that this will cause the resource owner to shift extraction toward the future.[128]

The third kind of uncertainty, is related to problems such as expropriation, or the possibility that at some point in the future the market will be lost to some low cost substitute. Either one of these events would reduce the value of the resource to the owner - the uncertainty is focused on the date of occurence. These types of uncertainty cause the owner of the resource to try to sell more of the resource in the near term to maximize the expected present value of the resource, which has a similar effect on depletion patterns as an increase in the discount rate.[129]

The final type of uncertainty considered is that of uncertainty about the stock of the resource, which Fisher refers to as "uncertainty on the supply side."[130] Here Fisher considers the optimal exploitation of a stock of uncertain size, and he suggests that the only thing that the owner is concerned about, is running out too fast. He states that a risk averse owner will,

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[128] Fisher refers to Lewis (1977) on this point.

[129] Fisher refers to Heal (1975), Long (1975), Dasgupta and Heal (1974), and Dasgupta and Stiglitz (1975). See also Davidson (1978).

[130] Fisher (1981), p. 47.

"wish to slow depletion to husband the resource against the (unknown) day when it will run out."[131]

His overall conclusion is that uncertainty per se, will "... not necessarily speed up depletion and therefore is not always appropriately reflected in a higher discount rate."

Fisher considers another type of risk as well, that associated with large investment projects like exploration and development, and he notes that higher discount rates would tend to reduce the levels of these activities. This seems fairly reasonable, other things equal, if there is a rise in the discount rate, the levelized cost of the capital expenditure increases - the cost of the capital equipment used for exploration and development is increased and the present value of the gas flow is reduced, raising the levelized cost of gas per unit. However, the effect of the increase in the discount rate so proposed should probably be evaluated as well, in terms of its impact on other sectors of the economy where, ceteris paribus, the effect of an increase in the cost of capital goods is to increase the demand for labour and energy services (but delivered gas is an energy service itself, not a capital good). Should such an outcome arise, the increased demand for energy must be evaluated, and two possible cases arise, the increase in demand is seen as a temporary phenomenon, or as a permanent phenomenon. In the former case, one would expect little reaction on the part of the industry, as an exploration or development expenditure leads to a long term revenue stream, not a short term stream. In the latter case, with demand increasing throughout time, depletion patterns may or may not be altered. The relative value of current and future sales would have to be compared.

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[131] Fisher refers to Kemp (1976), Gilbert (1978), Hoel (1978), and Loury (1978) for this result.

Reactions of companies with respect to exploration and development and depletion in the context of possible expropriation have been viewed in different ways, depending on the view one takes of the nature of the underlying resource. If the resource is viewed as say tins of oil and cannisters of natural gas, then a company would try to sell off its stock as rapidly as possible, and would be relatively reluctant to expend capital in finding more of the resource that may be expropriated. Alternatively, if the nature of the product is such that rapid drawdown requires accelerated expenditures on development, those sorts of expenditures would quite possiblly increase, while other types of investment, say new-field wildcats might tend to be reduced. Fisher refers to Peterson (1978) who he notes finds an increased depletion, followed by reduced depletion relative to a base case simulation because of the influence of expropriation or threat thereof on industry behavior. Rapid drawdown increased early period depletion, while early cutoff in exploration reduced later period depletion.

Fisher and others[132] have noted that uncertainty is generally presumed to lead to instability in resource markets, and has the consequence of producing inefficient depletion. He further notes that the existence of an equilibrium may be in question as well, due to (a) the absence of a complete set of forward markets, and (b) reliance on expectations on the parts of the owners of the resource and the consumers. Herein lies one very important role for a government agency: by collecting and dissiminating information on future supplies and demands to establish possible bounds on future prices and volumes, the agency should help to keep markets fairly orderly. Fisher notes that "one condition for the existence of a sequence of spot-market equilibria (temporary equilibria) is that each individual's expected future prices lie within a closed bounded interval," and he suggests that

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[132] For example, Solow (1973) reviewed earlier on.

information on demands and costs would lead to this result.[133] This line of thought is, intuitively, very appealing.

If such an arrangement can yield such an equilibrium, then one must consider whether it is efficient, and pareto-optimal. Fisher notes that very restrictive assumptions on consumer preferences, especially with respect to risk, and markets for sharing risk are necessary. Fisher notes the results from Samuelson (1964), Vickery (1964), and Arrow and Lind (1970), "that social decisions might appropriately be made on the basis of a neutral attitude toward risk, even though individual members of society are risk averse."[134] This is the argument for lower social discount rates on public projects than the private discount rates of individuals evidenced in private capital market rates. Fisher refers to the work of Rogerson (1980) who, he claims, shows that all of the stochastic variation in price must originate on the supply side in order for the social planner to obtain the efficient outcomes desired. If there are random fluctations in income or preferences, expected consumer surplus will not accurately reflect welfare.[135]

Focusing on the behaviors of private owners of resources, Fisher notes that the situation is different, because complete markets for sharing risk do not exist, and some degree of risk aversion will be in evidence. He states,

> "Recent analyses of firm behavior under uncertainty have suggested that even in an economy with a stock market, which permits risk sharing and spreading, simple expected- value maximization by the firm's manager is not in the interest of risk-averse shareholders."[136]

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[133] Fisher refers to Grandmont (1977) for these results.

[134] Fisher (1981), p. 53.

[135] Fisher (1981), p. 53.

[136] Fisher (1981), p. 54.

In conclusion, Fisher (1980, p. 54-55) notes that even if a planner wanted to maximize the expected value of consumer surplus, it is not clear that he could do a better job of estimating demands, than could the individual firm. I feel that we are still left with the difficult problem of determining, from the point of view of the members of society, the role of a regulatory authority. The literature does not seem to suggest that there is any practical way that a government regulator could estimate what the risk preferences of all individuals, present and future would be.

Empirical studies

There have been a number of recent empirical studies, that have tested the Hotelling rule, and that have examined the use of costs and prices to indicate scarcity. They include Stiglitz (1975), Marshalla (1977), Smith (1978a, 1978b), Cairns (1981, 1982a, 1982b, 1986), Heal and Barrow (1981), Solt and Swanson (1981), Netschert (1983), and Miller and Upton (1985), Stollery (1983), Liverivois (1987), Hall and Hall (1984), Jorgenson (1986), Gately and Rappoport (1988), Farrow (1985), and Griffin and Jones (1988), Laserre (1985), Slade (1985), Mueuer and Gorn (1985), Livernois (1987), Livernois and Uhler (1987), Rowse (1986a, b, 1987, 1988), Stocks and Musgrove (1986), Beltramo, Manne, Weyant (1986), Broadman (1987).

Growth models with resource sectors

The optimal rate of usage literature focuses primarily on neoclassical economic growth models with natural resource sectors. Anderson (1972) appears to have made one of the earliest attempts, followed by Vousden (1973), Banks (1974), Beckman (1974), Dasgupta and Heal (1974), Ingham and Simmons (1975), Miller (1977), Stiglitz (1974a), Solow (1974), Phelps and Riley (1977), Sweeney (1977), Dasgupta and Heal (1979),

Solow (1986), and Mäler (1986). Hartwick (1978) extends the Solow model to a many resources case, using the maximin criterion. Cairns (1986) focuses on cut-off grade decisions where mines have resources of different qualities, a modified Hotelling rule is required for intergenerational equity, and Hartwick's rule for reinvestment of rents applies.

A clear and concise review of an economic growth model with a finite resource sector is given in Hartwick and Olewiler (1986). They use a Cobb-Douglas functional form, and show that the Hotelling rule for finite resource use must hold within this model. They also explore the possibility of reinvesting the rents from the use of finite resources, in pursuit of intergenerational equity.

Intergenerational Equity and Resource Use

Solow and the Rawlsian fairness principle

Among the recent papers written on finite resource economics, there are several papers which directly consider intergenerational equity. Solow (1974) presents an economic growth model, which uses an intertemporal maximum objective function to present a Rawlsian approach to distributive justice, and in fact claims to be "plus Rawlsien que le Rawls", in that Rawls himself directly applies the maximin function only in an intragenerational context. The use of this alternative objective function emphasizes the need for an initially large capital stock to support a reasonable standard of living, else he notes, poverty will be perpetuated, also Solow notes (p. 41)

> "...it seems to give foolishly conservative injunctions when there is stationary population and unlimited technical progress."[137]

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[137] Solow (1974a), p. 41.

Otherwise the results are rather as expected for other growth models given reasonable estimates (> 1) of the elasticity of substitution of natural resources for labour and capital goods. We will return to a detailed discussion of some of the ethical content of this paper in Chapter three.

Riley (1977) and the Rawlsian fairness principle

Riley (1977a) also examines an application of the Rawlsian fairness principle in an economic growth model, and notes that the previous approaches in this direction required a consumption plan which equalized consumption over time, and he notes,

> "It is a trivial matter to show that the optimal investment plan is simply to maintain the capital stock at its initial level."[138]

Riley offers a reformulation which utilizes intergenerational trading, as generations overlap in his formulation. He notes that such trades lead to a "monotonic increase in the capital stock while the utility of all generations are equalized. (p. 5). Under the assumption of risk (time of arrival of a "backstop technology") or certainty, where initial generations are "poorly endowed" in relation to later generations, the earlier generations have only obligations to the generation to which it is tied by sentiment, else they should maximize expected utility. In the case where the early generations are relatively well endowed in the initial state (prior to backstop), a slower utilization rate for the resource than that associated with expected utility maximization is called for. The author states, that under certain conditions, risk and relatively large initial endowment, both expected utility maximization

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[138] Riley (1977a), p. 4.

and government intervention may be required to obtain the "just" rate of depletion, even in the presence of complete forward markets.

In a later paper, "The Just Rate of Depletion of a Natural Resource", Riley explores a concept of justice related to the ideas of Rawls (1971) and Varian (1974), that avoids the use of a social discount rate. He states

> "The basic notion is that the current generation is unfairly exploiting its earlier point in time if, by choice, it leaves some future generation t* with assets that would make the current generation worse off, were it compelled to exchange places with generation t*."[139]

The above definition was earlier stated in Phelps and Riley (1978), and Riley would improve on it because he notes that it

> "...fails to take account of the possibility that, because of the nature of the technology, the future is inevitably worse off in the above sense."[140]

He corrects this by assuming that each generation chooses the plan which maximizes its own utility, subject to the constraint that it not choose an exploitative plan. An exploitative plan is one in which a generation t chooses a consumption plan which would result in a generation t* (t* > t) having a strictly lower utility level, when generation t could have chosen an alternative plan which could have increased the welfare of generation t* without decreasing the perceived welfare of any of those generations worse off than t*. Here we note that there are no interpersonal or intergenerational comparisons of utility, each generation evaluates its consumption plan using its own preferences.

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[139] Riley (1980), p. 292.

[140] Riley (1980), p. 292.

The model is a macroeconomic growth model with a natural resource sector, which he works with as a control model. The author concludes as he did in the previous paper, that there is a case for government intervention (taxation) to slow the rate of depletion of the finite resource, to achieve a just rate of depletion. Calvo (1978) and Leininger (1985) present results on time consistency in the application of the Rawls maxmin criterion in growth models. Leininger (1986), Abel and Warshawsky (1988), and Bernheim and Ray (1987) although not concerned with natural resources, treat intergenerational altruism. Krautkraemer (1985) treats finite resource use, and natural resource amenities in the context of an economic growth model.

Other papers on topics related to equity

Two other related papers, involving in the one case the problem of environmental pollution and in the other altruistic preferences, are also growth type models with natural resource sectors, Asako (1978) and Lane and Mitra (1981).

Dasgupta and Heal (1979) devote a considerable part of Economic Theory and Exhaustible Resources to the problem of intergenerational equity and include an extensive bibliography. Both Fisher (1981) and Hartwick and Olewiler (1986) offer notes on recent research results in this area as well.

CHAPTER TWO

ON EQUITY

INTRODUCTION

The purpose of chapter two is to examine the concept of equity. The chapter begins with dictionary definitions and common usage, and then progresses to its use in the economics literature. Finally, consideration is given to its relevant uses in related literatures: political science, philosophy, psychology, sociology and law.

The chapter continues with comments by some of the most outspoken of economists on the concept of equity. Hewlett (1977) notes that most economists carefully avoid policy issues related to equity, and she is critical of the reliance of economists on the Pareto optimal aspects of market outcomes. Some brief notes on efficiency, pareto optimality, and social welfare functions are introduced at this point. Dasgupta and Heal (1979) emphasize, however, that a variety of preferred distributions of income can be generated by the market mechanism, and the market model can be used to find the most efficient lump sum transfers (changes in initial endowments) which would, through the market mechanism, most efficiently produce those preferred distributions. Notes on the competitive market model, welfare analysis, and frequently cited problems with the model are briefly presented. We continue with Musgrave et al. (1987) who contrast factor price theory for distributional shares or returns to classes of land, labour, capital, etc. with equity which is an individually based standard.

Issues related to equity have long been the subject of study in "Welfare Theory", in the theory of optimal taxation, and "Income Distribution Theory". For example, economists contrast the "ability to pay" principle with the "benefit" principle. Recent contributions by Arrow and Kalt (1979) and

Smith (1981) are reviewed because they use the primary economic constructs relating to equity, to evaluate the policy issue of oil price decontrol in the United States. These economic constructs are standards based on efficiency, volunteerism in exchange, horizontal equity, vertical equity, and regional equity. The use of distributional weights in resolving equity-efficiency trade-offs is briefly evaluated. Next, utility theory for welfare analysis and interpersonal comparisons is reviewed in greater detail. Factors relevant to equity evaluation are listed, and alternative criteria are examined. This is followed by a description of social welfare functions, and Varians' (1978) descriptions of some microeconomic approaches to the problem of equity and fair allocations.

The concept of ideology is introduced to assist in a conceptualization of why a purely efficiency based standard, which essentially ignores distributional issues, has been viewed as an equitable standard, and why ideology plays an important role in the acceptance of possible standards of social justice. The fact that the choice of an economic system reflects an ethical judgement is discussed. The issue that certain research programmes regarding equity in economics are chosen to be pursued, rather than others, is considered.

The chapter continues with a description of what ethics is and how the problem at hand, equity in finite resource use, forms a part of ethical analysis. The "logical priority" of ethics or economics in this problem is discussed. Several ethical theories, especially utilitarianism, intuitionism, and Rawls theory will be presented, and a limited discussion of justification in ethics is included. A discussion of the ethical neutrality of economic analysis and economic research follows. It is suggested that appeal to a wider conceptual base, a values base, may be useful and perhaps necessary in

exercising judgement of the equity of a process or of an outcome. The review of some recent research in psychology and sociology, and the use of the concept of equity in law, widen the perspective on equity in process and outcomes. A summary and overview section concludes the chapter.

EQUITY, JUSTICE, FAIRNESS

It is certainly not the opinion of this author, that the statement of the definitions of equity and related terms solve the problem of what equity is, or that it allows an easy solution to the problem of what an equitable use of a finite resource could be. Definitions, however, provide a convenient point of departure.

Dictionary Definitions

The term equity has a number of common meanings. It has been defined as:

> "a free and reasonable conformity to accepted standards of natural right, law, and justice without prejudice, favoritism, or fraud and without rigor entailing undue hardship: justice according to natural law or right:[1] impartiality[2]...: something that conforms to the principle of equity (as an equitable act): an instance of equity[3]..."[4]

Equity is closely related to fairness and justice, the

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[1]Prompted by considerations of (equity) to honor claims not legally valid.

[2]Tax adjustment for the sake of (equity).

[3]The inequities produced by the system being outweighed by the equities.

[4]Websters Third New International Dictionary, 1981.

first term being the widest of the three, the last the narrowest.

Justice is defined as:

> "the maintenance or administration of what is just: impartial adjustment of conflicting claims: the assignment of merited rewards or punishments: just treatment...: the quality or characteristic of being just, impartial or fair: fairness, integrity, honesty...the principle or ideal of just dealing or right action...the quality of conforming to positive law...the quality of conforming to positive law and also to divine or natural law..."[5]

The term justice generally connotes adherence to principle, or precept, to be applied on a similar basis to other citizens. Where precedent would be inappropriate to a particular case, on the basis of equity, one may look beyond the normal application of rules or principles, taking account of the individual's particular circumstances. Traditionally, for example, courts of equity have been the higher court of appeal when normal judicial procedure is deemed inappropriate.[6]

Fairness is defined in many ways, the most relevant to the present discussion are:

> "...characterized by honesty and justice: free from fraud, injustice, prejudice, or favoritism...: conforming to an established commonly accepted code or rules of a game or other competitive activity...:equitable as a basis for exchange: reasonable[7]..."[8]

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[5]Websters Third new International Dictionary, 1981.

[6]See Walker (1980), Oxford Companion to Law.

[7]A (fair) valuation; a (fair) wage.

[8]Websters Third New International Dictionary, 1981.

Two final, related definitions which may be useful to the presentation are for the words "equitable" and "equality". Equitable is defined as:

> "characterized equity: fair to all concerned:[9] without prejudice, favor or rigor entailing undue hardship..."[10]

Equality is defined as:

> "sameness or equivalence in number, quantity, or measure...: likeness or sameness in quality, power, status, or degree[11] was accepted in spite of physical inequality..."[12]

The preceding definitions are all related, and do serve to enlighten the conventional use of the terms. We must pursue the concept and construct of equity further, however, if we are to understand what an equitable distribution of, or rate of use of, finite resources might be. The definitions alone do not offer sufficient insight, to answer our questions.

Some comments by McCormick[13] have influenced my approach to the problem of equity.

"It is candidly accepted that there are here no

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[9]An equitable pay scale; an equitable price.

[10]Websters Third New International Dictionary, 1981.

[11]Legal (equality) of states.

[12]Websters Third New International Dictionary, 1981.

[13]His review "Access to Goods" of the book The Morality of Freedom by Joseph Ray, Times Literary Supplement.

> value-neutral definitions of terms such that having set up the definition, one can proceed independently to decide what it defines as good, bad or indifferent; rather it is to theorize; to propose an understanding of the idea as it is to be defended or supported, or, I suppose, attacked."

It is my opinion that while one may attempt to define a term like equity, as a way of helping to develop some understanding of the idea of equity, it is more likely that only through study, analysis, and debate that one will come to a good understanding of the concept or idea of equity. A number of theories of equity, theories in the above sense, will be explored.

The issue of whether equity is a term that can be used in a value-neutral sense more or less objectively, such as red or tall, or only in a value-laden or moral sense is relevant to this thesis. This forms a part of an important and current debate in philosophy and a review of some of the basic issues will help to focus the discussion of equity as it relates to economics. This discussion, however, is postponed to the section titled "Ethics and Equity".

Why Worry About Equity?

Why should we be concerned with equity anyway? Why worry about "equity" in the use of finite resources?

Equity is almost always seen as a "good thing" in North American society...at least it is generally so promoted in public discourse. It seems to carry almost universally good connotations in both economic and ethical theory, but does not have equally universally acceptable prescriptions for action. There are, for example, differences across societies. Some societies prefer that power be distributed in a way which would, from our North American cultural perspective, be deemed inequitable but which from their perspective is quite equitable. The accepted use of the term equity may indicate

cultural relativism; what would be equitable to the Samauri warrior may not be equitable to the Benedictine monk. For example, most western societies would think it inequitable that a great deal of power should reside in the hands of a "religious monarch" whereas some Middle-Eastern societies would consider such an allocation of power quite equitable.

The term equity, as it is generally seen as a laudable or praiseworthy characteristic of a situation or process, seems to be implicitly a prescriptive term. Whenever it is used in a comparative context, it compels the choice of the more equitable outcome. Further, there are as many theories about the meaning of the term equity, as there are about the meaning of the terms good or right. Discussion of the term equity brings to the forefront one area of overlap of the fields of ethics and economics, the question of the "goodness" of our economic system. It may be that a theory of equity could be grounded in economic reasoning or vice versa, economic reasoning and thought may claim to be based on many of the dimensions of the concept equity.

ECONOMICS AND EQUITY (the experts are likely to disagree)

Donald W. Moffat[14] defines equity in the following way: "the standard meaning of this word - fairness -is carried into economics, especially the social aspects of economics." He further states "...one of the main goals of our economic system is EQUITABLE DISTRIBUTION OF INCOME." The latter is described as follows:

> "Proportions of some income measure (such as NATIONAL INCOME) which go to different groups or individuals is the distribution of income. Some say that those who receive most have contributed most to the nation's productive effort and therefore the existing distribution is equitable; some say that there is need for a few modifications; some say the

[14]Economics Dictionary, 1976, New York: Elsevier.

> distribution will be equitable only when it is identical for everyone. There is no universally acceptable understanding of what is meant by 'equitable', except that only a small minority feel that equitable should mean equal."

If we accept the above, it seems that the economic "experts" are likely to disagree on equity, or what is an equitable distribution of income. It seems that part of the problem may be that the dimensions and meaning of "equity" are not clear, and if some progress can be made in this area, perhaps some conflicts can at least be clarified. Carification of the problem of equity alone, I believe, would offer a significant contribution to knowledge in this area.

Should Economists Be Concerned With Equity?

Sylvia Ann Hewlett in "Inequality and Economic Growth" states,

> "Modern economic theorists have not been a great deal of help in defining equity, a term that denotes the preferred shape of the distributional curve, or just distribution of economic resources in society. ...As far as the mainstream of the discipline is concerned, much of contemporary welfare theory is concerned with issues that carefully avoid judgements on the distribution of economic rewards altogether."[15]

This view seems, to me, to be quite accurate in its appraisal. Further it seems to be representative of many of the critics of the 'received neoclassical theory' in that the focus is on the equity in the distribution of rewards alone. Standard welfare analysis focuses on the distribution of income among individuals, but does not really "pass judgement" on the goodness of the distribution as compared to all other

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[15]Sylvia Ann Hewlett, "Inequality and Economic Growth", in Horowitz, I.L., Equity, Income and Policy, (New York: Praeger, 1977), p. 31.

possible distributions based on alternative initial endowments of resources. Hewlett notes, as many others have, that very unequal distributions of income can be Pareto optimal, and she appears to be disturbed that so many economists spend so much time with Pareto optimality.[16]

Some brief notes on efficiency, pareto optimality, and social welfare functions may be useful at this point. Meade (1976) states the following on efficiency:

> "It is not very difficult to define perfect efficiency in an economic system. A stationary economy may be said to be in a perfectly efficient state if it is impossible to move to another feasible state in which someone is better off without anyone else being made worse off. A growing economy may be said to be moving on an efficient time path if it is impossible to shift it to another time path on which someone over his life span would be better off without anyone else being made worse off over his life span."[17]

In graphical terms, the meaning of this can be explained using an "Edgeworth Box", focusing on the stationary economy at this point.

The "Edgeworth Box" offers a clear presentation of the contrast between distributional fairness and pareto optimality. The analysis ignores the role of production and focuses on initial endowments of goods, and final distributions of goods after trade takes place between two individuals. We may have the two individuals A and B whose indifference curves representing their preferences for two goods X and Y appear below:

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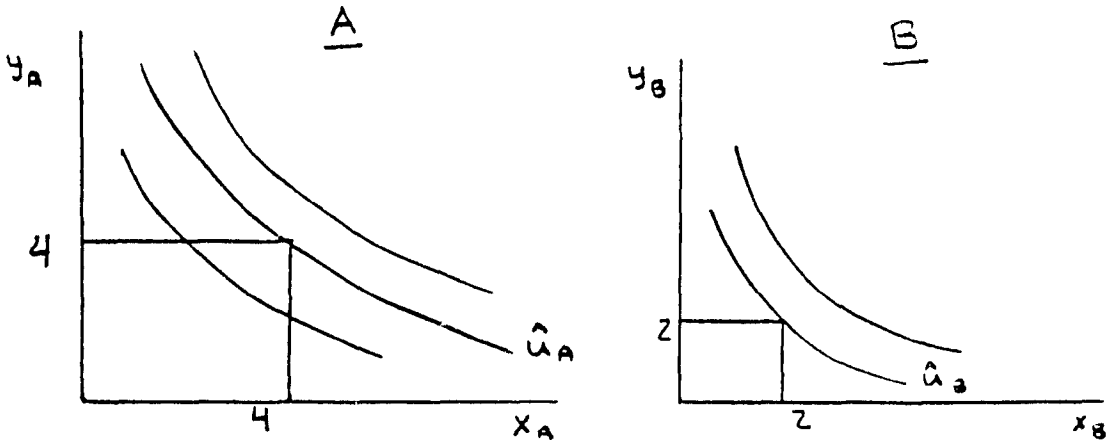
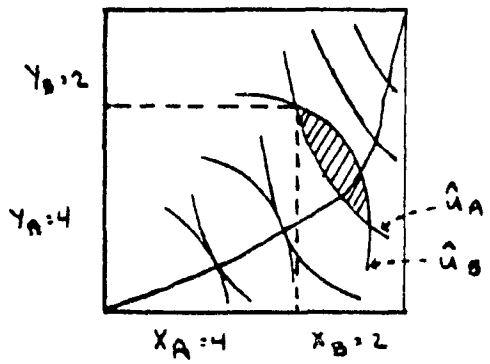
[16]Ibid., pp. 31-32.

[17]Meade (1976), p. 30.



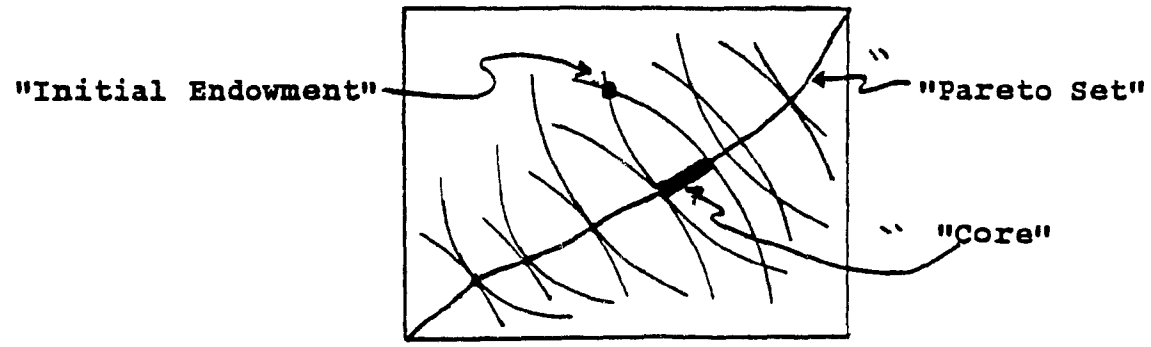
We may assume that they have the above preference structures, so it seems that A is probably better off than B in terms of the initial endowment. The endowments and preference structures of both A and B are captured below, with B's endowment being rotated 180 degrees and added to A's endowment, to yield the "Edgeworth Box" below.



Thus both A and B can get to higher indifference curves by exchanging X and Y. The way the preference functions are drawn, A has a slightly stronger preference for more X, and B for more Y. Any new point they move to within the shaded lens-like area is a pareto optimal point, since at least one person would be made better off without anyone being made worse off. Clearly, the final distribution could be quite unequal and perhaps unfair in total equity terms, and still be "pareto optimal". The critical factor here is that the result may be strictly conditional on whether or not the initial endowments were equitable.

To find the set of points where gains from trade and exchange are exhausted, we should take a closer look at the Edgeworth box. The set of points where the sets of indifference curves for A and B are tangent define the set of "Pareto efficient" points, since a movement from any point on that locus of tangencies which defines the "Pareto set" to another, or any other point reduces the utility of at least one of the two participants.

Given the initial endowments of agents, the core defines the part of the "Pareto set" which is preferred by at least one member of the economy, and does not reduce the utility of others in the economy, as compared to their initial utility.



We also note that since agents are free to trade, we would expect that a market equilibrium, if it exists, is in the "core", in the above diagram. This result has been proven, given certain assumptions on the nature of the market equilibrium process. Similar results (in general equilibrium theory) have been proven for theoretical transactions involving production and investments, and the same general results hold, and are likely to hold for a price system, or for some other arrangement.[18]

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[18]See Varian (1978), pp. 178-9.

Social Welfare Analysis

Social Welfare Function

Most economists prefer to think of themselves as scientists, doing value-free analysis, and offering choices to a public, who can use the analysis to make better moral decisions. One of these efforts involves the idea of a social welfare function.

A social welfare function is the one that accumulates in some way the utilities of individuals in an economy to produce an overall measure of "social utility". Usually, it is assumed that individual utilities are additive, so that total social utility is the sum of individual utilities, and is referred to as a classical utilitarian or Benthamite welfare function. The philosophical discussion of this will be dealt with in a later section. Other social welfare functions which have been proposed include a weighted average of individual utilities, and the maximin function of individual utilities, among others.[19] There is an extensive literature in this area, and an overview of the major results will be presented.

One may think of social utility, or social welfare, as some function of the individual welfares or utilities of the individuals in a society. In the simple two person economies (i and ii) graphically represented below, the total social utility curves U_1, U_2, U_3 represent the utility to society of different combinations of (consumption and) utility for persons A and B.

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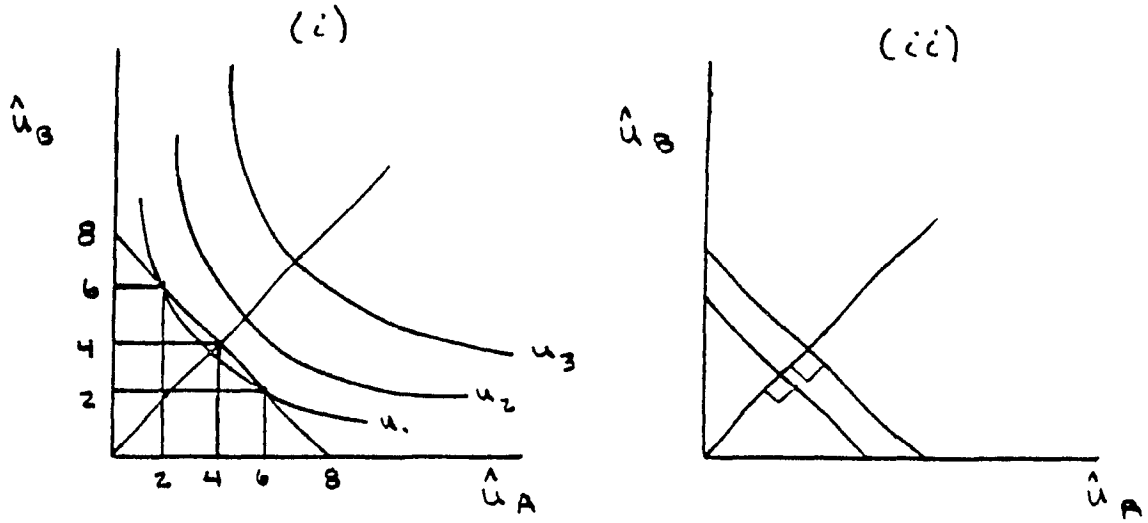
[19]The maximin is often promoted as the "Rawlsian" social welfare function, although it is not, as will be shown later in this thesis.



In the above picture (i), there is a social preference for equality in distribution, as $\hat{U}_B = \hat{U}_A$ is preferred to $(\alpha)(\hat{U}_A) + (1 - \alpha)\hat{U}_B$ for any α, and any other state $\hat{U}_A + \hat{U}_B =$ some constant. On the right (i) society is indifferent between the distribution of utility, but merely wants to attain the highest utility. Gain for A, or a gain for B increases social utility and welfare equally.

Before going further with distribution, it is useful to set out the basic assumptions of the perfectly competitive market model, and the welfare approach taken, as well as some of the most frequently cited problems with the model. This listing is general, and indicative only, because in the thousands and thousands of books and papers written on the market, and market models, a host of variations on the following assumptions are presented.[20]

The general characteristics of the market model include the following:

1. Individual preferences are taken as given. They are exogenous to the market and the satisfaction of these preferences is deemed to be a good thing. These preferences are assumed to be the correct inputs for social decision making.

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[20]This outline is based on a description offered by Lecomber (1979).

2. Individuals will act on their preferences - they are not influenced by the preferences or behaviors of others in the market. Consumers do not fail to adequately satisfy preferences due to habit, ignorance, etc.

3. All individuals are price takers in the marketplace - that is to say no one is a monopolist, and everyone must pay the market price for goods, and receive the market wage for labour. The interactions of large numbers of buyers and sellers, reflected in market supply and demand curves in each market determines these prices and wages.

4. All costs and benefits are subject to the market (or some equivalent mechanism). Everything is priced - pollution, the enjoyment of the natural environment in parklands - etc., as well as the usual market type goods we see conventionally bought and sold in our economy.

5. Preferences and production constraints are well behaved. This is a more technical requirement needed for the solution of the market model. Generally, it is assumed that consumer preferences are convex, or there is a positive marginal rate of substitution between goods , and that production function input-output relations are concave.

6. The distribution of income and consumption as a result of the use of the market should be acceptable.

Among the problems or failures cited with the market are the following:

1. Wants are often created endogenously, and the preferences of individuals are often strongly influenced by the market.

2. The preferences themselves, if satisfied, will not always result in improved social welfare. For example, satisfaction of a drug addiction may not be a preferred social goal. To paraphrase Mishan (1977), the preferences structures that are the source of welfare for the economist are the source of the problem for the psychotherapist.

3. Individual behaviors often reflect the influence of others' preferences rather than one's own.

4. Externalities in pollution, abuse of the natural environment, etc., abound in the economy. There are many cases when there are significant divergences between Marginal Private Costs and Benefits, and the associated Marginal Social Costs and Benefits.

5. The "regularity" assumptions required frequently are not satisfied, economies of scale, government and other social restrictions, monopolies, etc., are prevalent in our society.

6. There are frequent challenges of the "fairness" or acceptability of resulting distribution which is usually based on the Pareto criterion alone.

Similar criticisms are leveled at the intertemporal analogues of the market model as well, and these will be mentioned in Chapter Three. In this chapter, our primary focus is on the static conceptualizations. We now return to

the discussion of distribution and equity.

In Public Finance, Musgrave et al (1987) begin their chapter on Optimal Distribution with a section title :Does Equity belong in Economics?"[21], and they note:

> "Economists, over the last fifty years, have increasingly held that a theory of just or equitable distribution is not within the purview of economics but should be left to philosophers, poets, and politicans."[22]

They note that factor price theory is usually applied as a theory of distribution, but note that whereas factor price theory focuses on the distribution of shares to classes of factors, land, labor and capital; distributive justice and equity focus on the distribution of shares among individuals. Factor price theory is an important element in a competitive economy because it promotes the efficient use of resources, it does not, however, by itself guarantee a just or equitable distribution of output.

> "In the market economy, the distribution of income is determined by the sale of factor services. It thus depends upon the distribution of factor endowments. With regard to labour income, this distribution involves the distribution of abilities to earn such income, as well as the desire to do so. With regard to capital income, it involves the distribution of wealth as determined by inheritance, marriage patterns, and lifetime savings. The distribution of labour and capital endowments is linked by investment in education, which in turn affects the wage rate which a person can command."[23]

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[21]Musgrave, R.A., et al, Public Finance, (Montreal: McGraw-Hill Ryerson Ltd.), 1987.

[22]Musgrave, R.A. et al (1987) p. 76.

[23] Ibid., p. 76.

Dasgupta and Heal (1979) show that the relevant inverse theorems for the market model can be very useful.[24] The inverse theorems have to do with the following idea. If one can decide what the desired outcome (final distribution) should be, then the neoclassical market model can be used to identify the appropriate lump sum transfers or changes in initial endowments which would generate that outcome. While this does offer an analytical solution to the problem of how to use the market to achieve any desired set of rewards as an outcome, it does not offer insight into the question of what the equitable outcome should be. Also, as Lecomber (1979) states,

> "In practice, however, lump-sum redistribution is infeasible and redistributive taxes/ subsidies inferfere somewhat with allocative efficiency (for example income taxes are a disincentive to work and acquire higher skills. Thus, in practice there is likely to be some conflict between allocative efficiency and distribution."[25]

I will return the the "conflict" cited above later in the chapter.

Regarding the issue of final distribution, we return to the work of Hewlett. Hewlett's earlier cited remarks imply that economists should be more involved in the judgements regarding desired outcomes, and the optimal lump sum transfers. Most other economists either imply or directly state that those judgements are outside, or should be outside the purview of the economic analyst as an economist. Perhaps it is for this very reason that economists have not focused a great deal of attention on the concept of equity from the general equilibrium point of view. It is almost universally

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[24]Dasgupta, P.S. and G.Heal (1979), pp. 34-37.

[25]Lecomber (1979), p. 85.

accepted among neoclassical economists, that issues relating to equity are primarily issues relating to the distribution of society's output. Equity in opportunity is generally ignored, as is equity in property, or initial endowment, or equity in lifestyle choices- industrial societies pass on industrial systems to following generations which otherwise (if reared differently) might have preferred a non-industrial lifestyle. Similarly, one generation might pass nuclear power generation to another which would rather it were passed gas, a low risk energy source. Economists today do not have any way to evaluate this preference; however, from a reading of the literature, if the low cost energy source is nuclear, it would be used, period. Economists generally do not point out that their models neglect these potential value and preference divergences. Equity undoubtedly has many dimensions- and finite resources have value on many dimensions, lifestyle, endowment, energy, by-products, propensity to pollute, effect on lifestyle, productivity, etc. To better understand the use (and misuse) of the term, examples must be drawn from the literature. Such an examination is necessary because it would be desirable to know if the economists' understanding of equitable resource use is the understanding that non-economists have or that they would find to be reasonable.

Income Distribution Theory

There is a vast literature in welfare analysis and income distribution theory, which deals with the measurement of income inequality, changes in income distribution over time, and the effects of income distribution on the economy. This area, however, is more relevant in the intertemporal and intergenerational contexts, and discussion is postponed to

Chapter Three.[26]

Taxation

Equity is also used extensively in the taxation literature, which is another aspect of welfare analysis. In this context, equity is seen primarily as a relative, interpersonal measure. However, its meaning in this context is not entirely clear. Musgrave R.A., et al (1987) state:

> "Everyone agrees that the tax system should be equitable, i.e., ...that each taxpayer should contribute his or her "fair share" to the cost of government. But there is no such agreement about how the term "fair share" should be defined...a variety of approaches may be taken."[27]

The term equity is usually used in terms of equality in tax payments in the "ability to pay" literature. Horizontal equity refers to individuals in similar income circumstances paying similar taxes. Vertical equity refers to the idea that individuals with relatively higher incomes should bear a relatively larger burden of the taxes. Equity is sometimes interpreted to mean equality in income tax payments for all who are in similar income circumstances but identifying "similar income circumstances", is not easy. An individual with a spouse and several children or relatives to support may be thought of as having a lower ability to pay taxes (a lower disposable income) than another individual with the same income but who does not have to support others. The idea of "ability to pay" is often implicit in discussions of both horizontal and vertical equity. The use of raw income

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[26]See, for example Martin Bronfenbrenner, Income Distribution Theory, (Chicago: Adeline Atherton, 1971).

[27]Musgrave R.A. et al (1987), p. 209.

levels, as opposed to an adjusted income level based on "ability to pay", has an important impact on individual decisions for family size, care of children etc. It is perhaps equally difficult to decide how the tax payments should rise with relative differences in income. And although income is generally used as the basis for ability to pay measures, some argue that consumption or wealth or some combination of the three are the more appropriate basis. Ideas of income equality, consumption equality, or taxation equality are far less cumbersome than ideas of equity, fairness, and equally burdensome taxes, and for that reason the former approaches relating to increases of equality, etc., are often emphasized. The other main body of taxation literature focuses on the "benefit principle", an appealing but still more difficult approach to apply in practice.

Standards of Social Justice for Policy Evaluation

One recent study which focuses on equity (in a relative sense) and national economic policy is Arrow and Kalt (1979), a study which uses five standards of social justice. In his review of Arrow and Kalt (1979), Rodney Smith (1981) describes and evaluates those five standards.[28]

The Arrow and Kalt standards which are used in evaluating alternative proposals for oil price decontrol in the United States are the following.

(1) an efficiency based standard,
(2) a voluntarism in exchange standard,
(3) a horizontal equity standard,
(4) a regional equity standard,and

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[28]Rodney T. Smith, "In Search of the "Just" U.S. Oil Policy: A Review of Arrow and Kalt and More," Journal of Business, 54 (1981), pp. 87-116. Kenneth J. Arrow and Joseph P. Kalt, Petroleum Price Regulation: Should We Decontrol?, (Washington D.C.: American Enterprise Institute for Public Policy Research, 1979).

(5) a vertical equity standard.

Smith states that the efficiency based standard focuses only on total changes (increases) in national income, and "balances efficiency against equity by ignoring the latter". "Voluntarism in Exchange" focuses on "freedom of contract", and Smith claims, "as with the former one [it] solves the efficiency-versus-equity problem by ignoring equity." Smith quotes Arrow and Kalt in describing the horizontal equity standard as one which "holds that those who were alike before a change would be alike after a change."[29] (The equity of the initial situation is also implied here.) Smith notes that proponents of this view do balance efficiency against equity, but he implies that difficulties in making it operational (designing appropriate compensation schemes) could preclude the use of the criterion.[30]

Smith states that "The vertical equity standard provides the most promise for analysing the conflict between efficiency and equity."[31] Distributional weights are assigned based on marginal utility of income, and measured equity gains can be measured against efficiency losses in this scheme. Smith refers to Pigou in noting, "the vertical standard would imply taxation and subsidization until everyone received the same income if there were no efficiency losses from government policy."[32] Smith notes that Arrow and Kalt show how the regional equity standard is ultimately related to the vertical equity standard.[33] The analytical

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[29]Smith (1979), p. 97.

[30]Ibid., pp. 97-98.

[31]Ibid., p.98.

[32]Ibid., p. 99.

[33]Ibid., p. 97.

vehicle for the analysis is cost-benefit analysis, and the focus of equity theory is clearly only on income transfers.

The approach of using distributional weights in evaluating projects involving equity and efficiency is now quite common and representative of the neoclassical approach to those problems.[34]

Utility Theory and Distribution

Utility theory forms the basis for most modern consumer analysis in the economics literature, and is critical to the usual economic approach to distribution. Two authors whose work is reviewed in the following section are J.E. Meade and Abba Lerner, who are well known for their research in issues relating to distributional equality. Their approaches to a solution of the problem of distributional fairness, given similar attitudes toward the basic institutions of economic theory are indicative of two main alternative lines of thought that are evident in economic literature. The first author suggests that in the absence of evidence that utility functions are identical, we should treat them as different, and perhaps pursue a non-egalitarian income distribution policy. The second suggests that in the absence of evidence that the utility functions are different, we should pursue a more egalitarian income distribution policy.

In The Just Economy, J.E. Meade presents many of the basic problems which one would face in attempting to develop a structured analysis for distributional policy. As the literature has been dominated by ethical positions which stress either the maximization of total utility or conditional equality (the Pareto criterion), the objective functions based on these two ethical criteria are center

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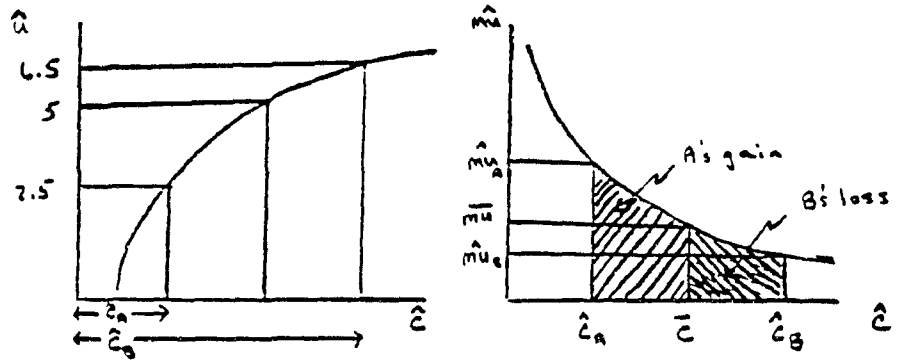
[34]See for example, Lyn Squire and Herman G. Van der Tak, Economic Analysis of Projects, (Baltimore: The John Hopkins University Press, 1975.

stage for analysis. At the outset, Meade notes that since a "utilometer" does not exist, it does not appear that it is possible to make any direct empirical comparisons of utility.

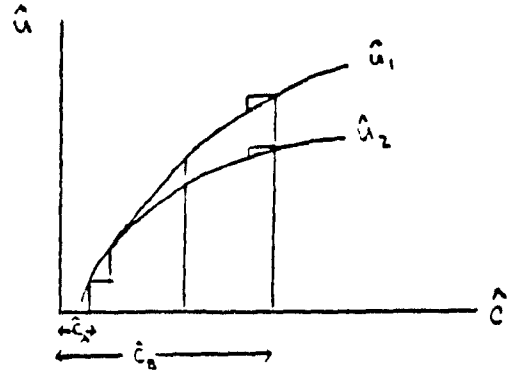
Beginning with a most stringent assumption, it may be assumed that all individuals have the same utility function, with diminishing marginal utility in consumption. For simplicity, we may also assume that a single good is produced and consumed in this economy. With this assumption in place, one simply observes the level of consumption of individuals, say A and B (to keep the Meade notation) and identifies directly their levels of utility. In the A-B economy, equality and total utility maximization will, of course, be obtained at the point where A and B consume equal levels of the good (or else the marginal utility of one would be greater than that of the other).



Given differing individual marginal utility, the gains from redistribution will always exceed the losses to society in this type of situation. But alas, life is much more complicated than this.

Meade also presents an interesting idea regarding differences in interpersonal total utility as it relates to distribution. As shown in the diagram below, the <u>less</u> the differences in total utility for given differences in consumption, the greater the social value of redistribution towards equality. Redistribution from rich to poor is greater

if the total utility function in U_2 will result in greater gains than if the total utility function is $\hat{U}_1$.[35]



Work and leisure, a note

This simple situation regarding consumption alone can be easily complicated. Assume work is not homogeneous and leisure is, then if A has a worse job than B and in an efficient market is paid more, would B ever begrudge A a larger salary and consumption or wish to trade places with A? Quite possibly not. Alternatively, suppose work is homogeneous as well as leisure, and income is unequally distributed between A and B such that A earns more, and A and B together save more than they would in a regime of perfect income equality, or rather perfect distributional equality. (The last qualification is suggestive of the difference between equality of income opportunities and equality of income distributions.) Further, suppose (as Bronfenbrenner suggests) that this situation (higher savings) encourages rapid growth in an economy, such that B is better off in several periods and forever after, than if A and B received equal income shares. Even with identical utility functions, would A and B prefer a policy which encourages equality, or total utility maximization, or a sort of Pareto type situation where B is at least as well off as under equality, but A is better off? - Another judgement call. There are

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[35] Meade (1976), p. 44.

other alternatives, for example A and B might agree to equal consumption over their lifetime, however, they would take turns doing the horrible job. Even this would be confounded if we were to admit differences in innate abilities which could make the job less horrible to one than the other, however, this would probably be reflected in their utility functions which we have thus far assumed to be identical.

The issue of how individuals perceive and value differentials, giving rise to problems of inequality is important. This, however, seems to create a problem of circular reasoning of very small diameter, to use Professor Ayers's phrase. If we posit identical utility functions such that we can identify equal utility situations, then all differences can be equally perceived by A and B. A and B will choose among all different prospects in exactly the same way, and for all intents and purposes, one might as well be simply a clone of the other. If they are not identical, then in the absence of a utilometer, we shall never be able to compare their levels of perceived utility. One other way out of this dilemma would be total brainwashing, to the point where individuals with previously different utility functions and value systems, find themselves agreeing about everything and always making identical selections. If their lives do not then proceed identically, we must ensure that they are brainwashed to ignore random differences which could arise in, for example, a case where nature may offer one opportunity which both cannot take advantage of.

Utility theory and Meade on distribution, continued

Professor Meade notes that since any direct comparisons of the utilities of various individuals are impossible, "we must rely on the policy makers to allot marginal utilities

to the spendable incomes of individuals".[36] At first, this might seem a rather arbitrary policy, and it is, but it is usually implemented at least implicitly whenever a government enforces any redistributive measure. Again, in a situation where there is no "utilometer", the justice of such a system must be in doubt.

The preceding argument makes it seem reasonable to suggest that in the absence of scientific evidence to show that individual marginal utilities of income are identical, we could assume that they are different. A slightly different point of view was taken by Abba Lerner in The Economics of Control.[37] That author argues that we have little scientific basis, if any, to assume that the marginal utilities of income for individuals in a society even if different at a point in time would remain different under an equal income distribution policy over time. He admits the possibility that some of those with high incomes may have become accustomed to the pleasures that income can provide, and the marginal utility of a wealthy person's last dollar may be equal to that of a poor person's last dollar, but he believes that the appreciation of the things that great wealth can buy can be acquired. Since sentiments and perhaps perceptions of utility acquired can be forgotten slowly in time, slow redistribution of income dynamically can perhaps still raise the total utility of a society.

Arrow on Utilitarianism

I have chosen to review some works of Arrow, because I think that in his review of Rawls, A Theory of Justice, we see a very clear statement of the view of a modern welfare economist, as regards fairness and equity. Arrow contrasts

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[36]Meade (1976), p. 46.

[37]See Chapter Three.

utilitarian psychology used as a description of the motivation of agents behaviors with the utilitarian ethical approach used in the evaluation of the economic system.

I think that Arrow gives a very balanced picture of the utilitarian approach in contrasting it to 'Rawls' theory. Arrow notes,

> "The basic theorem of welfare economics: that, under certain conditions, the competitive economic system yields an outcome that is optimal or efficient (in a sense that requires careful definition), depends on the identification of the utility structures that motivate the choices made by economic agents with the utility structures used in judging the optimality of the outcome of the competitive system."[38]

This leads to criticisms like that of Mishan (1977):

> "...for the economist the choices revealed by the individual are assumed to be the expression of his wants, for the psychotherapist they are assumed to be the expression of his problem."[39]

The above can lead to different types of arguments. One may argue that only the individual knows what is best for himself, and the use of any other measure of welfare than one's own utility leads to fascism or totalitarianism. Or, one may argue that (similar to Mill) only enlightened individual's judgements should be used to direct society - not all individuals really know what is best for themselves, and not all individuals are able to act on that knowledge. Most economists do not spend much time on these aspects. As Arrow notes regarding utility functions,

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[38]Arrow (1973), p. 246.

[39]Mishan (1977), p. 384.

> "There has been more emphasis on their operational meaning but perhaps less on their specific content; philosophers have been more prone to analyse what individuals should want, where economists have been content to identify "should" with "is" for the individual (not for society)."[40]

This is again related to the points made by Hewlett (1977), and also explains some of the arguments in Baumol (1977)[41] and may also explain why the approach of the economist tends to encourage the acceptance of the status quo.

The preceeding utility and distribution approaches of Lerner and Meade were presented in a cardinalist perspective, which implies that utility structures are measureable (the use of the utilometer etc.). Arrow refers to his own utilitarian approach as "ordinalist (i.e., epistemologically modest)." The ordinalist approach requires that individuals be able to rank their preferences for consumption bundles, but not necessarily be able to assign absolute numbers to the satisfaction or utility they would derive from the consumption of particular bundles of goods. Ordinalists tend to rely even more on pareto optimality as absolute levels of utility are not identified.

Arrow notes that the application of a "productivity principle" to explain and justify distribution is "widely and unreflectively held" - it states that "an individual is entitled to what he creates."[42] He states that on the contrary, he shares the value judgement with Rawls, that all natural talents should be regarded as a common asset - that

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[40]Arrow (1973), p. 246.

[41]See p. 501 on the rationale for the use of the pareto criterion, and pp. 526-527 on some of the key limitations.

[42]Arrow (1973), p. 248.

> "...even natural advantages, superiorities of intelligence or strength, do not in themselves create any claims to greater rewards."[43]

Arrow notes that most utilitarians emphasize the "sum of utilities" approach to the choices among distributions of income and the choices of structures of institutions. He notes that utilitarian theory requries that social institutions or their creators must have access to certain kinds of knowledge. He asks whether they can "in fact or even in principle"[44] have access to such knowledge. He states that the only access we have to individual utilities is what we can infer from behaviors, which are presumably done to maximize the individual's utility. There is no unique quantitative (absolute) measure for the individual's utility, so any utility function compatible with that ordering is valid, and

> "If the utility of an individual is not measureable, then a fortiori the comparison of utilities of different individuals is not meaningful. In particular the sum-of-utilities criterion becomes indefensible as it stands."[45]

One then is left to decide whether or not one wishes to take account of potential individual differences in capacities for satisfaction associated with different utility functions, or to ignore the possibly different functions and assume all utility functions are identical. This, Arrow notes, dispenses with the problem of having to find income

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[43]Arrow (1973), p. 247.

[44]Arrow (1973), p. 252.

[45]Arrow (1973), p. 253. Arrow notes that the ordinalist position was introduced by V. Pareto and I. Fisher and has become fairly orthodox in the (then) last thirty years.

sensitive people and redistribute income to them.

Arrow presents a discussion of the Vickery-Harsanyi utilitarian position, which Rawls refers to as "average utilitarianism."[46] He states,

> "As Ramsey and von Newmann and Morgenstern have shown, if one considers choice among risky alternatives, there is a sense in which a quantitative utility can be given meaning. Specifically, if choice among probability distributions satisfies certain apparently natural rationality conditions, then it can be shown that there is a utility function (unique up to a positive linear transformation) on the outcomes such that probability distributions of outcomes are ordered in accordance with the mathematical expectation of the utility of the outcome."[47]

Arrow notes that on its own the theorem does not do much for social welfare, but he notes that

> "the Vickery-Harsanyi argument puts matters in a different perspective; if an individual assumes he may with equal probability be any member of society, then indeed he evaluates any policy by his expected utility, where the utility function is specifically that defined by the von Neumann-Morgenstern theorem."[48]

Arrow notes that individuals may, in fact, incorporate risk aversion in the utility function they use to choose among policies. He also notes that

> "the maximin criterion, far from being opposed to average utilitarianism, can be regarded as a

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[46]Arrow (1973), p. 256.

[47]Arrow (1973), p. 256.

[48]Arrow (1973), p. 256.

limiting case of it."[49]

Arrow notes that average utilitarianism does not solve all problems, he notes,

> "Rawls very properly points out that each individual may have a different utility function, so that, although each wishes to maximize a sum of utilities, each individual has a different utility function in his maximand...in addition, the use of equiprobability in this case is certainly not beyond cavil."[50]

Utilitarianism, is said, by Rawls to use some men as means, rather than ends, because their greater talents are used to provide for those less fortunate. But Arrow claims that this is true of Rawls and other systems as well. There doesn't appear to be an easy way around this criticism. A final criticism is that utilitarianism makes an "illegitimate

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[49]Arrow (1973), p. 256. Arrow gives the following example: "... let U be any utility function, in the sense of a function that represents preferences without uncertainty. Then, for any a > 0, $-U^{-a}$ is an increasing function of U and is also a utility function. Any member of this family could be the von Neumann- Morgenstern utility function, i.e., that utility function for which it is true that the individual seeks to maximize expected utility. It is easy to see that the larger the a, the higher the degree of risk aversion. Then, according to Vickery, the value of a policy to an individual with a random stake in society would be:

$$V = \Sigma(-U_i)^{-a} = -\Sigma U_i^{-a}$$

But a social welfare function is only an index of choice and can itself be subject to monotonic transformation; hence, another criterion that would yield the same choice is

$$W = (-V)^{-1/a} = (\Sigma U_i^{-a})^{-1/a}$$

It can. however, easily be proved that, as "a" approaches infinity, representing increasing degrees of risk aversion, W approaches min U_i."

[50]Arrow (1973), p. 257.

analogy between individuals and society."[51] This, Arrow claims is an essential formal requirement of any theory of justice. Arrow claims that he and Bentham, and Rawls, all agree that "justice should reflect individual satisfactions", and the combination of individual desires into a system of desires, is formally the way it is accomplished in most theories of justice. Arrow notes, however, that perfectionist theories or religious theories would be exceptions.

Some of the problems associated with the use of the political system to correct shortcomings in the economic system outcomes are presented in K. Arrow, Social Choice and Individual Values. Professor Arrow proves that a set of statements which seem reasonable amd characteristic of a democratic society are inconsistent. This area has become itself a major area of research in the economics, applied mathematics, and political science areas, and will be briefly reviewed later in the paper, especially as it does have relevance to the formation of social welfare decisions.

Distributional Weights

The problem of distributional weights may be approached in terms of the following. Suppose that we have two individuals, A and B, with utilities U_A and U_B. If we are indifferent regarding the distribution of the total social utility ($U_A + U_B$), then the social utility functions may be represented by indifference curves which are perpendicular to a 45 degree ray from the origin as below.

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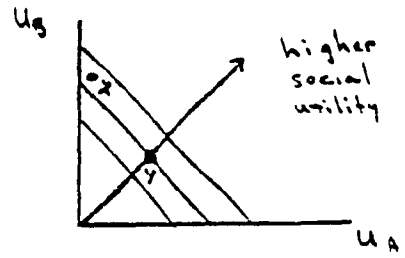
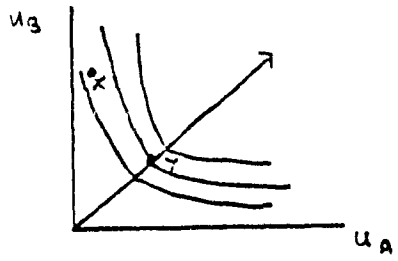
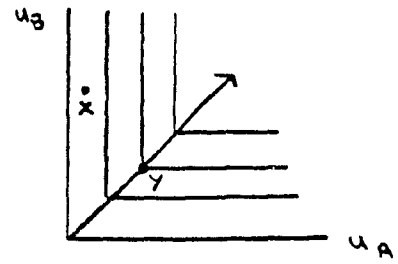
[51]Arrow (1973), p. 257.



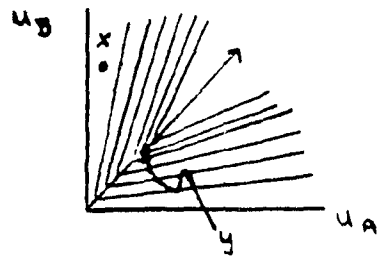
Thus, a point like X would be (socially) preferred to a point like Y, regardless of how the relative utilities of A and B are affected. In the picture below, the social planner, or the assumed social utility function is more responsive to relative differences in utility:



Under this assumption a point such as X at which utilities are unequal could be shown to be socially inferior to Y. If the utility function showed an extremely high preference for equality the indifference curve would be as described in the following diagram:



In this case, if A's utility is as shown by the point Y then no matter how much U_B increases, there is no increase in the perceived level of overall social utility. Meade refers to this as an "egalitarian" criterion. Inequality could even be discouraged, and penalized in social utility, and this may be pictured as below:



Here an improvement in B's utility from Y to X reduces social welfare, because it increases the inequality in distribution, as compared to Y. Meade (1976) refers to the above as a "super- egalitarian" criterion.

Meade (1976) also suggests an "anti-poverty" criterion which cannot be represented graphically, as it involves a two-stage process. He assumes a rich and a poor class. In stage one, the set of all possible policies is examined to find the one or ones which are best for the poor. In stage two, then, the program selected is either the one, or among the set of the ones which were selected in stage one, which is best for the rich.

In the simplest case, distributional weights may be related to marginal utilities if it is assumed that marginal utilities decline. Thus the higher one's relative level of income and consumption, the lower one's marginal utility, and the lower one's weight in social utility. Social utility would increase by shifting increments of consumption from low MU curves (high income consumers) to higher MU curves (lower income consumers).

If we presume that the government wishes to maximize total utility, then the distributional weights used are the marginal utilities of the individuals or classes of individuals. Distribution, or rather redistribution (and a great deal of it) can occur on this basis alone. However, even if the marginal utilities of income are numerically the same for rich and poor, without redistribution government could ignore utility functions and decide to equalize income,

if that is the government policy. Clearly, the selection of such a policy for redistribution is of great political and ethical consequence. However. in a technical or scientific sense, the redistribution process is likely to be based on extra-economic rather than economic criteria. Redistribution is not likely to be irrelevant for economic analysis because redistribution is generally expected to produce a variety of "economic" consequences - e.g., promotion or discouragement of luxury cars. While it seems reasonable to assume that a government might undertake to redistribute income in the interest of equalizing total utilities for individuals, such a policy may have negative consequences for other government objectives such as encouragement of growth, productivity, etc. It is interesting that Professor Lerner presented his chapter on the optimum division of income prior to a discussion of production or incentives to production. This last item, I suspect, ranks with equity as a most critical issue in income distribution theory. Stephen Leacock in The Riddle of Social Justice claims that it is just this question of incentive which motivates individuals, which makes the great difference between capitalist and collectivist socialist systems, and it is this incentive which Professor Lerner would wish to maintain in the "controlled" economy while equalizing income.

Thus when we come back to these matters in our explanation of intergenrational equity, we will have to consider not only the foregoing individual and social utility function, but the related issues such as economic growth and development.

Interim Summary

The preceding discussions contain many descriptions, comments and criticisms about the approach economists have taken to social justice. First, and if we accept the usual utilitarian approach, there is the issue of whether one should

assume that individuals have identical utility functions. Relating to this issue, it was noted that economists have had little success in measuring utility and thereby providing support for the theoretical constructions. This, really, offers no evidence either way, for concluding that utility functions are identical or different. The importance of assumptions about utility depends on the factors considered to be of importance in questions of equity, and therefore, a function of the criterion for equity selected (i.e., if Pareto optimality alone is sufficient for equity, measurability of equity is not important). If utility functions cannot be measured at least we might enumerate some of the relevant factors that one might wish to include in questions of equity. Possible factors include the following:

A) Initial endowment
   1) Inherited assets
   2) Innate ability, physical and mental, psychological profile
   3) Family position or social status
   4) "Connections" in certain income/wealth producing businesses
   5) Access to education

B) Ability to enjoy consumption of any kind

   1) Ratio at which utility increases for increases in income
   2) Absolute utility - income relationship
   3) Health, freedom from stress, anguish, etc.

C) Ability to enjoy work of any kind, or of specific kinds

   1) Physical ability differentials
   2) Mental ability differentials
   3) Labour-leisure tradeoffs

D) Role of incentive effects

   1) Motivational factors, positive and reinforcing
   2) Negative factors and moral hazard elements

E) Treatment of family size choices, population changes

1) Family size as an individual value and choice
2) Family size as a social value

Clearly, one will get very different assessments of the equity of an economy, depending on which of the above factors are emphasized, and which are ignored. It must be noted here, that the fact that economists pursue one or another program of research which emphasizes certain factors, and ignores others, reflects a moral judgement on the part of the researchers. We now continue our discussion of equity in a static context with endowment based criteria.

Distribution Criteria

Endowment Based Criteria

Musgrave, et al. (1987) list four "endowment based" criteria for distributive justice,

> "a) Keep what you can earn in the market; b) keep what you could earn in a competitive market; c) keep labour ("earned") income only; d) keep what you could earn in a competitive market, given equal positions at the start."[52]

They claim that the foundations for the above criteria are found in the work of natural law philosophers, including Hobbes and Locke who

> "postulated a person's innate right to the fruits of his or her labour, thereby giving ethical support to distribution by factor endowment, and the pricing of factors in the market."[53]

Criterion C) is particularly relevant to this thesis, because it suggests that income from material resources which

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[52]Musgrave, et al. (1987), p. 79.

[53]Musgrave, et al. (1987), p. 79.

belong to society, and produce rents should be used for the benefit of all members of the society, and not just to the benefit of specific individuals who might have found the resource, especially if the finding was based on luck rather than effort. The criteria listed above go from the most "conservative" view, where one "deserves" whatever one can "get" from the free market system, to very "liberal" view where adjustments are made for differentials in initial endowments. The latter, may have various interpretations depending on which factors one would wish to count as "relevant" and which one would wish to ignore. Still, as liberal as d) may appear at first blush, the influence of a variety of "after the start" factors should not be ignored.

Population Decisions and Distribution

Utilitarians, whose work will be discussed further in a following section on ethical approaches to equity, focus directly on the valuation of social output, as determining optimal distribution. They do ignore, however, certain other factors such as those relating to incentives and moral hazard, that are usually associated with redistribution. The two most common goals of utilitarians are maximization of total utility, or maximization of average utility. Here the aforementioned problem of utility functions and the different implications for redistribution depending on the assumption used (identical functions, or not) comes to the fore, and the approaches of Meade and Lerner seem to be representative. The use of the average welfare criterion is an attempt to bring population decisions into the valuation of actions. That is to say, if marginal utility schedules are declining, should we not prefer under the maximization of total utility criterion, to increase population indefinitely?

Alternative Criteria

Three other criteria which Musgrave et al. (1987) note are the following:

> "...Egalitarian criteria
> a) Welfare is equalized; b) welfare floor is set with the endowment rule applicable above it; c) welfare of the lowest group is maximized."[54]

The authors associate the first with the thought of Rosseau, Marx, some recent Christian ethicists, and at times with writers in the tradition of the Protestant Ethic such as Max Weber. Clearly, the above rule would have different implications, depending on assumptions made about utility functions, however the comments of Musgrave et al. (1987) on Marx and Rosseau summarize the general tenor associated with this criteria.

> "It is doubtful, however, whether egalitarians such as Rosseau or Marx would have recognized differences in the level of utility schedules as legitimate reasons for income inequality. When Marx postulated, 'From each according to his ability, to each according to his need', he evidently referred to differences in need due to objective factors such as family size or health, and not to subjective differentials in the capacity to enjoy income. Although enjoyment capacities may differ, most egalitarian philosophers would have interpreted the "equal worth" doctrine as calling for society to proceed as if utility schedules were the same, thereby arriving at an egalitarian distribution, qualified only by an allowance for objective differentials."[55]

Pigou, for example was an economist who came to the conclusion that welfare should be equalized, and income

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[54]Musgrave et al. (1987), p. 79.

[55]Musgrave, et al. (1987), p. 83.

equalized through taxation, because of identical utility schedules. There is no country which pursues such a redistribution procedure today. The second criterion is probably the closest to North American norms. The third criterion reflects the work of John Rawls, which suggests, that after asserting the priority of liberty, the choice among social institutions is made (as if behind a veil of ignorance regarding who one would be in a society) is such that the worst off individual is the best off. This recalls the familiar "Maximin" criterion of decision analysis. The detailed discussion of these criteria, and issues regarding justification will be deferred to the section on ethics and equity.

Fair Allocations, Envy, and Equity

One of the few streams of research which goes beyond the assumption of a social welfare function is presented in Varian (1978).[56] Varian (1978) states, in his chapter on welfare analysis, that what is being used by the economist is a welfare function which incorporates all value judgements, and uses mathematical analysis; he claims that the welfare analysis as a whole can be called "more or less value free". He uses the term "fair allocations" to refer to the study of the economic consequences of some specific value judgements, going beyond the usual general framework referred to previously. He does, however, maintain the same general perfectly competitive market paradigm, although with a few modifications.[57] Varian assumes a situation of pure

[56]Sen (1988) notes that this work forms a general stream of research which includes publications by Foley (1967), Kolm (1969), Feldman and Kirman (1974), Varian (1975), Suzumura (1983), Archibald and Donaldson (1979), and others.

[57]His presentation is based on earlier papers by Faby (1967), Schmeidler and Yaari (1971), Pazner and Schmeidler (1972, 1974), and Varian (1974, 1975).

exchange, and asks "What is a 'just' way to divide this bundle of goods?"[58] and he notes

> "Of course in general the answer to this question will depend on the particular circumstances involved so we seek a criterion depending only on the information we do have, namely the tastes of the agents involved."[59]

The notion of "internal symmetry" is basic to Varian's "equitable allocation", where the latter term is defined as follows:

> "An allocation is equitable if no agent prefers the bundle of any other agent to his own."[60]

This is connected to fairness through the following definition,

> "An allocation is fair if it is both equitable and efficient."[61]

The notion of internal symmetry has to do with some symmetric division of goods which takes account of the "tastes of the individual agents involved". Simple equal division of goods, Varian (1978) notes, while symmetric "from the outside", is unlikely to be pareto efficient, and he states, "We would hardly want to divide goods in an inefficient manner".[62]

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[58] Ibid., p. 225.

[59] Varian (1978), p. 225.

[60] Varian (1978), p. 226.

[61] Varian (1978), p. 226.

[62] Ibid., p. 225.

He proves a theorem which shows that any Walrasian equilibrium with equal wealth involves a fair allocation. Any agent in this exchange equilibriuim situation would only "envy" another agents' bundle when it costs more than his own, and this contradicts the equal wealth assumption.

Varian (1978), however is not very satisfied with this problem which he refers to as "rather trivial", as he states:

> "Fair division when all agents are symmetric does not seem so difficult; what is hard is deciding what a fair division is when all agents are not fundamentally symmetric."[63]

Varian goes on to consider such a case, where agents preferences are known, technology is known, and individuals have different abilities to produce, so agents have different amount of "labour power" although their number of hours worked might be identical. Here, if envy covers number of labour hours (labour-leisure combination) and consumption bundles, a "far from trivial" problem is encountered, and "fair" allocations do not always exist. Varian states "There may be no feasible, pareto efficient allocations in a productive economy that are "envy-free".[64] This is unfortunate, because a most common day-to-day problem is between two workers who put in an equal day's work, and between whom "envy" exists.

The problem according to Varian is with that "envy" comparison, so another comparison is tried, where rather than having a consumption-labour hours comparison, a consumption-output measure is used. In this case the question to be asked is would you "envy" another if you could have his consumption bundle and work as many hours as you have to (accounting for differential abilities) to produce

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[63] Varian (1978), p. 226.

[64] Ibid., p. 227.

what the other does? This he shows to provide pareto efficiency, and an equitable outcome (based on this alternative "envy" definition). Varian still is dissatisfied with this, as there is no correction for the initial distribution of abilities, which he notes are "after all, arbitrary".

He next considers the Pazner and Schmeidler (1972) concept of distributive justice, which is an "income equitable allocation". This is based on the idea of individuals valuing their leisure time at their own personal wage rates, which are associated with their own differential abilities. The "constructive proof" Varian offers requires that agents' endownment of leisure be divided up evenly, along with all other physical endowments, among all members of the economy, so all have an identical initial endowment. Thus, agents may sell other agents labour (the unable may exploit the able), and after trading to a Walrasian equilibrium, all agents hold bundles of equal value. Varian states that the differentials in initial ability are compensated for by the fairness of the income equitable allocation employed.

In summarizing his welfare section on "fair allocations", Varian (1978) states

> "Although neither wealth fair nor income fair allocations seems completely desirable, they do seem to illustrate clearly the trade-offs and problems concerning distributive justice when abilities differ."[65]

Thus the potentially enormous interpersonal variations in abilities, valuation of different levels of income and different consumption bundles, and their differences in the

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[65]Varian (1978), p. 228.

valuation of the freedom of choice of consumption bundles[66] plague the viability of this approach.

Belief Systems and Ideology

Rodney Smith began his article on the work of Arrow and Kalt with the following quotation from Monty Python, "Gosh, justly distributing income is tricky business". One might well ask, what decides a "just" distribution? What one deems to be just or equitable treatment or equitable distribution, is intimately a part of one's belief system, ideology, culture and moral perspective. Belief system, though probably the most general conceptual idea, is concerned with all that one believes about the world. While beliefs lie at the basis for perceptions of equity, I have not encountered any studies of equity which begin at such a general level. At a more specific level, some recent, and very relevant work has been reported on the topic of ideology which relates to the problem of equity, and may help to better understand ideas of equity in individual and group decision making.

Ideology and Equity

Portes and Ferguson (1977) quote Mannheim (1966) who defines ideology as "an integrated set of ideas for systematically ordering and evaluating social reality."[67]

Portes and Ferguson use the term ideology loosely, in the sense that in their discussions they avoid "written ideologies of political parties and codified religious doctrine."[68]

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[66]See Sen (1988), p. 76.

[67]Alejandro Portes and D. Frances Ferguson, "Comparative Ideologies of Poverty and Equity: Latin America and the United States," pp. 70-105 in Irving Louis Horowitz (ed.), Equity, Income, and Policy (New York: Praeger), p. 71.

[68]Ibid., p. 71.

They seek to describe ideologies that have gained wide acceptance. In their discussion of the application of the term, they state:

> "It is by now commonplace that dominant ideologies reflect the interests and concerns of dominant groups. Ideologies do not tend to challenge common knowledge; they place different weights on its different truths."[69]

Cultural and moral perspectives, in this context, may be seen as components of one's ideology, and may assist in the understanding of what a group of individuals might value as equitable. It is a general concept, however, and may not be especially useful in understanding a particular individual's decision at a point in time.

One ideological theme which Portes and Ferguson identify:

> "...arose in the nineteenth century as the need grew to justify early industrial capitalism. It revolved around the ultimate benefits of free markets and the evolutionary requirements of selection. The first notion dated back to classic economics and evolved around the more humanitarian view that in the long-run, operations of the market would yield the greatest benefit for the greatest number."

They include the following epigraph from William Graham Sumner who they claim "reflects the thoughts of an entire generation of British and U.S. scholars."[70]

> "Under the names of the poor and weak, the negligent, shiftless, inefficient, silly, and imprudent are fastened upon the industrious and prudent as a responsibility and a duty."[71]

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[69]Ibid., p. 71.

[70]Ibid., p. 74.

[71]Ibid., p. 70.

Portes and Ferguson relate this to the ideas of "evolutionary selection, survival of the fittest, organicism," and state that these ideas are well known. Redistribution policy would hardly be a major issue under this ideology, one only deserves what one can get from participation in the market economy. This ideology stands in sharp contrast to that which later generated the "New Deal" policies in the U.S. for twenty-five years, and again in sharp contrast to that which later generated the recent conservative policies for deregulation and encouragement of the laissez-faire economy. Ideology clearly seems to be a central component in discussions of the equitable distribution of income. It also appears, in this light, that equity is not a hard and fast standard, but rather, at least with respect to income distribution policies, is one which evolves over time. It seems that ideologies do not die out, and several major ideologies may be maintained by different groups in a society or country. It seems rather unlikely that one would find universal acceptance of any single redistribution policy as equitable in a society of competing ideologies, each emphasizing different values of an economic and social system.

Ideology may have specific relevance to issues relating to natural resources. Should the natural resources be viewed as belonging to those members of a society who can go out and stake their claim, or to the larger subset of individuals who are participants in a national economy generally, or to those who can afford to go out and purchase them? Do they really belong only to those living, or to those unborn as well?

While ideologies are of interest in themselves, they should not be uncritically interpreted as defining the goals of a society. This statement is partly justified on the basis that ideologies have often been described as constructs developed by elites to enable them to pursue selfishly their

own interests at the expense of others.

Ideology may therefore help to explain the world view and/or the self-interest of groups of individuals. All individuals can make value judgements regarding all aspects of the economic system in which they participate, as well as about those in which they do not participate. To come from the general to the particular, there are specific elements which are of particular interest in this paper. Individuals make general statements about what is "good" about various economic systems, as well as specific processes and outcomes. In a sense, then, ideologies may be seen as prescriptive as well as descriptive entities, when they are used to promote certain goals.

Neoclassical Ideology and Equity

It is useful here to consider the debate on the use of analytical versus value judgement type statements, as value conflicts are often mistaken for analytical and factual conflicts in this area.[72] Little states that value statements do more than describe- that is why it is so hard for individuals to agree on the meanings of ethical words and on the truth or correctness of ethical statements.

Ethical and moral statements have at least an implied element of 'one should' or 'one ought' when they are made. They often have the purpose of influencing, suggesting, or persuading. Little notes that it is not only ethical and moral statements which do this, but others do as well - aesthetic statements for example, often have these properties. He notes that the key problem in the assessment [in the context] of discussions such as the present one, is to be able to differentiate between economic statements that are purely descriptive, and those that are value-laden, or

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[72] I.M.D. Little, (1950), A Critique of Welfare Economics, p. 70.

based on value judgements.

It does seem that when neoclassical economists make statements about equity, or pareto optimality for that matter, they are doing more than making a descriptive statement. At least implicitly their pronouncements usually imply an endorsement of the market model, which reflects a value judgement in itself.

As a purely formal model, used by economic investigators, its use per se does not imply a value judgement relating to a moral or ethical problem - perhaps except to note once again that it is a value-based decision to pursue one research programme rather than another.

The fact that the model is used as a part of a long research and policy tradition in theoretical and applied economics is very significant. There are two issues here:

1) Economists as scientists use the market model because they feel that it best fits the subject of study, and they feel that as a descriptive model it is superior to all others. In general, of course, one can always question how well the model fits the real world and more particularly, while one might agree that it is a reasonable description of most aspects of reality that it is of little help in studying some questions such as intertemporal policies.

2) Economists use the market model, because they have made value laden decisions, that this is how the world should work, and the prescriptive results generated are to be targets or goals for society.

Market, Command, and Traditional Systems

The market may be considered as one of three main systems that have been observed throughout history, as a possible solution to the economic problems. The other two main systems

are traditional and command.[73]

The selection of one or another system implies a value judgement, or a moral decision. The different economic systems have different power structures and in practice render different benefits and abuses to various participants.

In the discussion in the previous section on redistribution criteria, we found that one definition of equity is "receiving what one is due." In the context of the market model, if one believes that one's initial endowment is all that one is due at the outset, and that the results of participation as per market rules are all one is due then the resultant rewards must be all that one is due even if another person receives a greater reward. Under these assumptions the competitive equilibrium outcome is also an equitable outcome. The market system, however, does not have to be accepted as an all or nothing system. A person may, on value grounds, accept some parts of the market system but reject the equity of initial endowments, or the market participation processes, or the exchange processes or the final unadjusted rewards. Furthermore, to add to the complexities of the problem, some people might accept virtually all aspects of the market system as it is applied to some products or markets and yet judge that it is inappropriate, inequitable or unpractical if applied to other products or markets. These value judgements and similar considerations may apply to any alternative economic system as well.

Generally, it seems that in Canadian society the use of the market system (regulation apart) is taken as a given, and equity issues arise as exceptions only when the moral

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[73]Heilbroner (1963). I will not pursue discussions of these alternative systems here except to note that they have been very sucessful in bringing the human race through most of its history. The use of the market system is a relatively recent phenomenon.

dimensions of economic solutions are deemed inappropriate. It must be emphasized that the decision to select a market system, rather than a command or traditional system itself reflects a moral decision on the part of society and the decision to accept market solutions for all economic problems is no less a moral decision. Moreover, we must examine the proposition that when economic welfare is maximized, human welfare is also maximized.

There are many questions to consider: when individual wants are maximized, are "good" or beneficial results obtained? Is is uniformly accepted that individuals are always capable of making the best choices for themselves, or do clinical psychologists really serve a useful purpose in our society? When economic welfare is maximized for an existing population is human welfare for future generations also maximized? When individuals in other societies express preferences for non-market systems, are they making moral errors in judgement, or behaving irrationally in accepting a system which according to economic theory should not produce a higher level of economic welfare than the market system? What is it that makes the market system so appealing to North Americans? Does it go beyond the benefits suggested by economic theory alone? What moral force or ethical system is behind the use of the market system? Are there criticisms of utilitarian ethics and utilitarian psychology and are these the only possible bases for the election of the market system? Are other ethical theories also compatible with the market system? These are some of the important questions which must be examined in the thesis, particularly as these relate to intergenerational matters.

So we turn to a discussion of some elements of ethical theory, not to expect to find the answer to the problem of equity in finite resource use here, but to enlighten and inform the discussion of the problem.

We are faced with the problem, of whether to begin with an economic or ethical discussion. For the problem of equity in finite resource use, is it sufficient to use the standard neoclassical market model, or a growth theory model, and examine the utility of various depletion patterns? It would seem then that economic analysis has some "logical priority" in the solution of this problem, because moral choice is taken, based on the economic choices offered. It may alternatively be the case that morality should inform our scientific and economic theorizing about human problems, possibly eccouraging the development of other economic systems. For now, having introduced some key elements in the economic analysis of the problem, I will present some elements of ethics. It is my opinion that no such "priority" rules are essential.

ETHICS AND EQUITY

The scope of ethics is very wide indeed and a complete review of ethical theory is not practicable or necessary since only a small subset of ethical theory is relevant to this thesis. However, to find that subset, an overview of ethical theory and a brief exploration of some of the subject matter of ethics relevant to the problem at hand is desirable. The following draws heavily on the presentation of ethics offered by John Hospers (1961) in Human Conduct[74], and on several other authors, who address themselves to an identification of the subject matter of ethics.

Subject Matter of Ethics

Ethics is concerned with many problems, but a workable definition is approached by Hospers through his consideration of six major questions.

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[74] Hospers (1961), pp. 4-22.

First, "What things are good (or desirable or worthwhile)?" That author suggests that the word "good" be reserved for "things (objects, processes, events, states of mind. goals)...", whereas the word "right" be reserved for actions which are desirable. One should also distinguish between statements such as "This act is right" and "You ought to do this", as the second is the stronger of the two. The author notes that it would be not wrong to do the former, whereas it would be wrong not to do the latter, and ethical thinkers are most frequently concerned with the latter in the theory of obligation or right. The theory of deserts is concerned with the reward or punishment (or blame) due a person for some action.[75]

Second, ethics may be seen as a study of morals which are the beliefs which people have about "right and wrong, good and bad, punishment and desert, and so on, together with their actions in consequence of these beliefs..." "Ethics uses them as material for study..."[76] A purely scientific description lies in the realm of the sciences of anthropology or psychology, whereas ethics seeks a prescriptive analysis of the raw material of morals.

Third, ethics also has been described as not only the study of what is, but a study of what ought to be as a future oriented prescriptive analysis. Thus, ethics is concerned with what ought to be-- what would be the good, as well with what actions should be taken to bring such a state(s) or world about.[77]

Professor Hospers emphasizes the distinction between

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[75] Ibid., pp. 4-5.

[76] Ibid., p. 5.

[77] But Hospers notes--the study of right and wrong (what one ought to do) is the study of what is-- because the word "is" is so all inclusive that everything that is studied, every study about anything is, in a sense, about some aspect of what is.

judgements of fact and judgements of value. "Ethics is concerned not only with what a certain individual or group considers right, but with what is right"[78]. Professor Hospers notes that here we see the difference between ethics and empirical science. The author suggests that statements about good and bad, and right and wrong cannot be verified empirically--yet seems to suggest that they can be verified in other ways.

He claims that the terms "good", "right", etc must be well defined before we can attempt the "how do you know?" type of questions.

> "Where is the line between moral and non-moral questions to be drawn?" ..."Some say that a question or a problem is a moral one if it concerns behavior that affects the happiness or well-being of any other person (or sometimes, of any other living creature). Others say that it is a moral question only if it concerns behavior that can be universilized, behavior of which one can legitimately ask whether everyone else in the same position ought to do the same. In any event, moral questions are very inclusive..."[79]

Also,

> "...it will not do to define moral questions as those employing moral terms, since all those terms are also used in non-moral contexts. We still haven't answered the question 'When is the term being used in a moral way?" It would be circular to define moral questions in terms of their use of moral words, and then distinguish the moral sense of these words by referring back to moral questions."[80]

Hospers fifth note emphasizes that

> "...ethics is concerned to find the truth about (these) moral questions, not to try to make us act upon them." "Perhaps doing right is more important than discovering what is right, but at least the second is a necessary

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[78] Ibid., p. 6.

[79] Hospers, p. 8.

[80] Ibid., p. 8.

> means to the first. Unless you know what is right, how will you know what to do, or what to persuade others to do. You cannot act on knowledge unless you first have knowledge. Of course, you may act without knowledge at all; many people act ignorantly, and many do not even care what is right, but just do as they please. Nevertheless, acting in moral matters without knowledge is surely just as dangerous as an engineer's trying to build a bridge without knowledge of the principles of engineering. Before you drink what's in a bottle, it's wise to know what the bottle contains"[81].

In this sense also, one cannot discuss the morality of finite resource exhaustion without knowledge of the consequences of various patterns of and possibilities for resource use.

"It (ethics) is concerned not directly with practice, but with finding true statements about what our practices ought to be--statements which, it is hoped, will then be acted upon." Nevertheless,..."It is difficult to think of questions which, in the long run, are more practical than questions about how to live, how to conduct oneself, how best to spend the few short years that are the most anyone can enjoy in this world."[82]

Lastly, ethics does not seek to prescribe a code for behavior for every specific instance of behavior or every moral action, ethical philosophers search for moral principles[83] or rules of behavior having to do with matters of right and wrong. In order to do so, we would not only have to understand true moral principles, but also a vast array of empirical facts about a particular case.

When one considers the concept of equity, ideas about

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[81] Ibid., p. 9.

[82] Ibid., p. 9.

[83] A.P. Griffiths (pp. 177-182) discusses justification and ultimate moral principles in his report in the Encyclopedia of Philosophy.

what is right, good, just, fair, or morally correct come to mind. Sahakian, in his book, Systems of Ethics and Value Theory, states:

> "Ethics has been defined as the study of the right and the good, i.e., right conduct and the good life; whereas morality is the practice of what one believes to be right and good. Ethics is a study, hence is theoretical, whereas morality is pragmatic; it involves doing, acting, behaving. ...Summarily, ethics applied becomes morality; and morality theorized or studied is ethics."[84]

Frankena describes ethics as

> "...a branch of philosophy; it is moral philosophy or philosophical thinking about morality, moral problems, and moral judgements."[85]

He states

> "Moral philosophy arises when, like Socrates, we pass beyond the stage in which we are directed by traditional rules and even beyond the stage in which these rules are so internalized that we can be said to be inner-directed, to the stage in which we think for ourselves in critical and general terms...and achieve a kind of autonomy as moral agents."[86]

Equity as a Moral Term

To the extent that we are concerned with the use of the term equity, and its meaning as a moral term, we are engaged in moral philosophy especially if in argument on the basis of equity, we wish to find "right" ways of behaving,

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[84]William S. Sahakian, Systems of Ethics and Value Theory, (New York: Philosophical Library Inc., 1963). pp. 2-3.

[85]Frankena (1973), p. 4.

[86]Frankena (1973), p. 4.

utilizing resources, or more generally, arranging or structuring our social institutions to achieve a social "good". To the extent that we might be concerned, not only with the formation of certain normative judgements, but wish to go beyond this to a justification of these judgements, we are doing "analytical", "critical", or "meta-ethical" thinking, and are engaging in a further branch of moral philosophy. It seems that when we make decisions which are influenced by considerations of equity, we are making moral decisions, and the question of what to do to promote equity in most situations involves an issue in morality. Hence, it is my position that equity cannot really be discussed without considering the philosophical dimensions of the problem.

It might be useful to offer an introductory comment to the field, however, stated by Warnock (1967) in his concluding chapter to Contemporary Moral Philosophy.

> "...we must start from the recognition that there is something peculiarly puzzling and problematic, particularly arguable, about the whole phenomenon of morals. Not everyone, naturally, feels this, but even if one does not feel it the record shows it to be so. So much is unclear; so many different views have been taken - and not only, of course, about what is right or wrong, but about what it is to be morally right or wrong."[87]

Much, if not most of the field of ethics is concerned with problems that are of a different kind than most of those which scientists face. Moral theories may be justifiable, but appear to require rather unique kinds of justification. The field offers little in the way of hard facts, as physics may offer laws, that have been discovered and proven by scientific methods. The positive and negative aspects of various ethical theories may be argued, and as a result

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[87]Warnock, G.J. (1967), p. 73.

opinions, and attitudes toward the many theories change over the years, but all of this study and reasoning does not appear to be having a consensus on which is correct.

Teleological Theories

The usual form of utilitarianism promoted by economists, is one of a class of teleological ethical theories. In teleological theories,

> "the basic or ultimate criterion or standard of what is morally right, wrong, obligatory, etc., is the non-moral value that is brought into being."[88]

For a teleologist, moral value is dependent on the comparative non-moral value which obtains as a result of an action. This avoids circular problems which would arise if moral value was dependent on some other moral entity. The non-moral value which utilitarians use is our old friend "utility". Thus, depending on how utility is defined, and whose utility is relevant, one can identify many versions of utiliarianism, ethical egoism, ethical universalism, ethical altruism, and those based on valued items such as hedonistic pleasure, or power, or perfection or self-realization. Clearly, there are many possible versions of utilitarianism consistent with different theories of value. Most commonly, neoclassical economic theory makes use of two versions. The first is that ethical egoism or a utilitarian psychology guide the actions of individuals. The second, is in welfare theory, where ethical universalism, the maximum social utility, the maximum utility per capita, etc is promoted.

Deontological Theories

The other main class of ethical theories, are the

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[88]Frankena (1973), p. 14

deontological theories, which either deny that right actions, obligation, or the morally good, are determined by the amount of non-moral value brought into being, or claim that there are also other "right making characteristics as well".[89] There are other considerations besides the consequences of the action. Frankena states,

> "...certain features of the act itself other than the value it brings into existence, for example, the fact that it keeps a promise, is just, is commended by God, or by the state."[90]

There are also many different versions of deontology, two classes generally identified refer to act deontologists and rule deonotologists. The former focus on situation specific judgements or "situation ethics", and the latter on general rules to be followed. Frankena includes Caritt and Pritchard in the former group, and Sidgewick, Clarke, Price, Reid, Ross, Kant, and Butler in the latter group.

There are many competing ethical theories, including ethical egoism, psychological egoism, divine command theory, Kant's theory, Rawls theory, etc. The "opening up" of the discussion in this way, regarding what can or should be considered when one is contemplating "optimal" or best resource use, suggests that what is often referred to by neoclassical economists as "optimal use of resources" is only one of many possible conceptions of "optimal". Clearly, researchers, it seems to me, have a responsibility to pursue these other alternatives rather than merely accept a single ethical paradigm merely because it is associated with a class of mathematical-economic models with convenient properties.

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[89]Frankena (1973), p. 15.

[90]Frankena (1973), p. 15.

Rawls' Theory

A major alternative theory to utilitarianism is Rawls (1971) Theory of Justice, which Arrow (1973) states

> "...has been widely and correctly acclaimed as the most searching investigation of the notion of justice in modern times."[91]

It certainly stands as a strong challenge to utilitarian theories which have formed the basis for the recommendations of neoclassical economic analysis, and a careful review of the theory, and its implications for action in the context of the present problem is useful. One interpretation of Rawls theory appears in Solow (1974) which is discussed in Chapter One. Here I focus on the review of Rawl's work in Arrow (1973).[92]

Arrow on Rawls Theory of Justice

Arrow had a number of questions about, and criticisms of Rawls'theory. He saw Rawls' theory as a system of axioms which would be elected by rational potential members of society, which are justified by Rawls on the basis of argument from the contractarian tradition. The system of axioms has implications for the structure of social institutions (and morally right behavior).

Arrow notes that Rawls' general point of view is "a strongly affirmed egalitarianism, to be departed from only when it is in the interest of all to do so."[93] This refers to the "generalized difference principle" of Rawls.

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[91]Arrow (1973), p. 245.

[92]See also Feinberg (1973), pp. 272-275 for a discussion of acts versus rules in the context of Rawls' theory.

[93]Arrow (1973), p. 247.

Arrow notes that, asset egalitarianism ("...that all the assets of society, including personal skills, are available as a common pool for whatever distributive justice calls for...") is an implication of the "original position contract." This contract is described by Gordon (1973) as

> "the principles of justice that would be adopted by rational self-interested persons who find themselves in an 'initial situation' characterized by a 'veil of ignorance' which conceals all factors relevant to the determination of their individual fortunes in an operating society."[94]

Rawls argues that the two principles which would be accepted are first, the priority of liberty, and second, the "generalized difference principle." The individuals elect these two from a choice situation where they have "full general knowledge of the world, but do not know which individual they will be."[95] There are two important notes which Arrow (1973, p. 249) emphasizes

> "(1) The principles of justice are intended to apply to the choice of social institutions, not to the actual allocative decisions of society separately. (2) The principles are supposed to characterize an ideal state of justice. If the ideal state is not achieved, they do not in themselves supply any basis for deciding that one non-ideal state is more or less just than another."[96]

Arrow notes that we may suppose the characterization of the ideal state, as a first step toward the characterization

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[94]Gordon (1973), p. 275.

[95]Arrow (1973), p. 247.

[96]Arrow (1973), p. 249.

of all alternative states.[97]

Rawls emphasizes the priority of liberty, and states that no amount of compensation by other goods can compensate for the loss of an individual's liberty.[98] Arrow notes that this is a lexicographical ordering of all goods, with more liberty being preferred than less, and this dominates the choices among possible states of existence for all individuals. However, the quotation of Rawls which Arrow selects makes this seem somewhat more doubtful.

> "The supposition is that...the persons ... will not exchange a lesser liberty for an improvement in their economic well-being, at least not once a certain level of wealth has been attained...
>
> As the conditions of civilization improve, the marginal significance for our good of further economic and social advantages diminishes relative to the interest of liberty."[99]

Arrow responds to this with the following:

> "The argument is clearly an empirical judgement, and the reader can decide for himself how much weight it will bear."[100]

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[97]See Feinberg (1973), p. 267-268 for a description of the ideal (strict compliance) versus non-ideal (partial compliance) states of Rawls.

[98]Sen (1988) notes that Rawls provision of primary goods can be seen as an index of freedom, as the primary goods allocation provides a means to ends the individuals are choosing- individual responsibility is not to be abdicated. The ability to convert these goods to achieve the individually chosen ends would then be a variable, and Sen (1988) notes that Rawls has become more sensitive to this issue recently in Rawls (1982) which appears in Sen and Williams (1982), Utilitarianism and Beyond.

[99]Rawls (1971), p. 542, quoted in Arrow (1973), p. 250.

[100]Arrow (1973), p.250.

Arrow also notes, that if there is, in fact, such a lexicographical ordering, the sum of utilities criterion would yield the same ranking of social states as Rawls' theory, and this is as far as the discussion of Rawls' views on liberty goes. The bulk of Arrow's review focuses on the maximin rule, which has become synonymous with Rawls' theory for most economists. Arrow notes that Rawls' maximin rule is to be applied separately to liberty and "the non-priority goods." He notes that the original position argument had also been put forth by Vickery (1945, 1960), and Harsanyi (1953, 1955) who he claims used it "to supply a contractarian foundation to a form of utilitarianism (discussed at considerable length by Rawls)."[101] Rawls starts with the same premise and argues that society should choose the set of social institutions such that the worst off individual's utility or satisfaction, is the highest, this is the maximin rule. The acceptance of the maximum criterion is motivated by two arguments, first, that where quality of life is at stake high risk aversion is justified (Arrow notes, however that Vickery and Harsanyi measured utilities in such a way to capture the influence of risk aversion). Second, Rawls notes that the probabilities are ill-defined and should not be used in such calculations. Arrow notes that different viewpoints have been taken on the question of whether all uncertainties are expressible by probabilities, with Ramsey (1931) and Savage (1954) on the pro side, and Knight (1921) on the con. Maximin is only one of a fairly large number of decision criteria currently studied by decision analysts.

Some of the problems with the maximin criterion are well known, Arrow offers the following example,

> "...any benefit, no matter how small, to the worst off member of society, will outweigh any loss to a

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[101] Arrow (1973), p. 250

better off individual provided it does not reduce the second below the level of the first. Thus there can easily exist medical procedures which serve to keep people barely alive but with little satisfaction and which are so expensive as to reduce the rest of the population to poverty. A maximin principle would apparently imply that such procedures be adopted."[102]

Arrow notes that Rawls rejects this argument on the grounds that it won't occur in practice, although clearly, many such choices exist today, and could equally well plague the ideal system. The role of "close-knittedness" is problematic as well, and Arrow claims that it could be used to further diminish the difference between Rawls theory and the sum of utilities approach to social choice.

Arrow also notes that Rawls' theory faces the same problem as utilitarians, in determining who would be the worst off individual. Arrow raises this as an epistemological issue - how can interpersonal satisfaction be judged - how well can we know the satisfactions of other human beings? Where utilitarians sidestep the issue by assuming identical utility functions, Rawls introduces the idea of "primary goods" which Arrow argues[103] does not effectively evade the problem of interpersonal comparisons.

Arrow next turns to the issue of knowledge in the initial position. Individuals know all physical and social laws, but not who they'll be, to this, Arrow responds,

"But empirical knowledge is after all uncertain, and even in the original position individuals may disagree about the facts and laws of the universe."[104]

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[102]Arrow (1973), p. 251.

[103] Ibid., p. 254

[104]Arrow (1973), p. 255.

Arrow, it seems to me, would not be of the opinion that those in the original position would be capable of suppressing intolerance for things they believe to be untrue. For example, tolerance for other faiths than the "one true faith" is hard to expect, if one believes that one could end up being a person believing in a faith other than the "one true faith".

Arrow also notes that Rawls takes all of his actors to be egoistic, and asks why there should be no benevolence or envy in the original position, which he says would cause the "no disagreements in the original position" to disappear. In a sense, I think there would be at least some self-benevolence for the egoistic actors behind the veil of ignorance, as no one knows who they will be. This self-benevolence could also be viewed as altruism, from the point of view of the implied decision consequences.

On Rawls and voting, Arrow quotes Rawls (1971, p. 356) in the following,

> "There is nothing to the view, then, that what the majority wills is right."[105]

Arrow notes that Rawls' leanings toward majority rule, a pooling of opinions by experts in justice, where the workings of justice are not always clear, is shared with many other political philosophers. Arrow disagrees with Rawls where he asserts that

> "...the expression of one's own interests in voting seems to me an essential part of the information process needed for voting. Unless voters express their interests, how is anyone going to know if the

[105]Arrow (1973), p. 257.

ends of justice are in fact being carried out?"[106]

Rawls, he claims, was of the position that individuals acting only in self interest, could never have a political process which leads to perfect justice. Other-regardedness is important, and Arrow continues,

> "...I would hold that the notion of voting according to one's beliefs and then submitting to the will of the majority represents a recognition of the essential autonomy and freedom of others. It recognizes that justice is a pooling of irreducibly different individuals, not the carrying out of policies already known in advance."[107]

Arrow notes that Rawls' rule would have radical implications for the redistribution of income, as would the sum of utilities rule if it were accepted that all utility functions were identical, and displayed decreasing marginal utility for income. He notes that,

> "Rawls, however, holds that the close- knittedness of members of the society means that perfect equality of income is not to the advantage of the least well off, but that typically they will benefit by an increase in income to some higher up in the income scale."[108]

A fundamental issue of the maximum approach whether perfect equality of income is desirable or not, depends a good deal on the assumption we make about the theory of production

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[106]Arrow (1973), p. 258.

[107]Arrow (1973), p. 258.

[108]Arrow (1973), p. 258.

(or class) that we carry about with us in the backs of our minds. To a Marxist who believes strongly that wealth (or high income) is the result of exploitation, then the redistribution of income is little more than the stopping of exploitation. The rich need (and exploit) the poor. The rich are rich because they exploit the poor.

According to those who accept the explanation of the market and/or who accept some aspects of the work ethic, predestination, etc., it may be held that those who are rich would be relatively well to do on a desert island, one-person economy whereas the poor (the halt, the lazy, the incompetent, etc.) would starve. The poor need the rich (the competent, the hard-working, the entrepreneurs, etc.) to organize them, to give them jobs, to give them charity, to organize society so that there are resources created that will make it possible to "subsidize" the poor.

According to the latter view of the rich, "the least well off will also benefit through an increase in income to those higher up in the income scale." There may be a tendancy when we think of endowments to emphasize inherited wealth - but of course "original position" and "endowment" will include desire or willingness to work hard, cleverness and a host of other characteristics.

If these personal (as opposed to material wealth) endowments are thought of as inherent, inseparable dimensions of the individual, then 100% ownership of these traits by the collectivists and 100% tax on the earnings thereof will smack of slavery. The details and meaning of close-knittedness should be pursued more thoroughly.

Arrow notes that Rawls was brief on this, and notes that economists tend here to focus on incentive effects. It is not clear to me why close knittedness would need result in income differentials being accepted by those worse or better off, but this is grounded in the generalized difference principle.

Arrow notes that this conflict between incentive and equity in the utilitarian context was

> "...noted by Edgeworth (who was really very conservative and glad to escape from the rigorous egalitarianism to which his utilitarianism led)."[109]

Arrow notes that despite significant efforts by economists, results in this area are dubious due to the uncertainty regarding the magnitude of the incentive effects. Arrow claims, that,

> "The maximin rule would, on the face of it lead to perfect equalization, i.e., 100 percent taxation above a certain level, with corresponding subsidies below it. As far as I can see, it is only the incentive question that prevents us from carrying this policy out."[110]

Arrow also suggests that if we could get people to be honest about their productivity, then we could tax them according to their abilities, not their output, and avoid adverse incentive effects. There does not seem to be much chance of this happening. Gordon (1973) notes that there is an error in Rawls' evaluation of the contrasting differences in optimum distributions of income for utilitarians, as opposed to the use of the generalized difference principle.[111] Also he notes that the Rawls principle may not yield a determinate optimum under certain conditions.

Rawls also includes reviews of other schools of thought in his book, one especially interesting description is that of intuitionism.

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[109] Arrow (1973), p. 259.

[110] Arrow (1973), p. 259.

[111] Gordon (1973), pp. 275-278.

Rawls on Intuitionism

John Rawls describes "Intuitionism" in a "more general way than is customary". He refers to it as:

> "... the doctrine that there is an irreducible family of first principles which have to be weighed against one another by asking ourselves which balance, in our considered judgement, is the most just. Once we reach a certain level of generality, the intuitionist maintains that there exists no higher order constructive criteria for determining the proper emphasis for competing principles of justice."[112]

It would appear that an individual faced with a particular moral decision, would choose a behavior based on an assessment of the situation, whereby one considers all relevant principles relating to good, bad, etc., and strikes a balance among the competing principles, although any such principle, taken by itself, might suggest conflicting directions, on the basis of individual intuition. The appeal to intuition, on this basis, does not suggest irrationality. The individuals' choices may in fact satisfy conditions of rationality and consistency, however, the balance struck in any particular situation may not be explainable by the individual.

Rawls continues as follows:

> "While the complexity of the moral facts requires a number of distinct principles, there is no single standard which accounts for them or assigns them their weights. Intuitionist theories, then, have two features: first they consist of a plurality of first principles which may conflict to give contrary directives in particular types of cases; and second, they include no explicit method, no priority rules,

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[112] Rawls, A Theory of Justice, p. 34

> for weighing these principles against one another: we are simply to strike a balance by intuition, by what seems to us most nearly right. Or if there are priority rules, these are thought to be more or less trivial and of no substantial assistance in reaching a judgement."[113]

Rawls, in approaching intuitionism in this way, goes on to state:

> "Perhaps it would be better if we were to speak of intuitionism in this broad sense as pluralism. Still a conception of justice can be pluralistic without requiring us to weigh its principles by intuition."[114]

While this seems reasonable enough, it does seem to be a departure from the "usual" theory called "intuitionism," and it would appear that this is presented at this point in the book, to suggest an alternative conception of justice. Reliance on intuition is a key element in most versions of intuitionism, and in bypassing that element, a critical change in the theory is effected.

Feinberg (1973) claims that Rawls' main objection to intuitionism is its modesty, the latter author is of the opinion that a moral theory without rigid priority rules is a half-theory. Feinberg (1973) argues,

> "Many intuitionists, however, will be inclined to reply at this early stage of the argument, that "half-theories" are the only kind that can fit the facts of moral experience. Difficult moral decisions and judgements often (if not always) require balancing of conflicting claims, deciding and choosing rather than calculating and applying rules committing oneself and legislating for others

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[113] Rawls, A Theory of Justice, p. 34

[114] Rawls, Theory of Justice, p. 35.

> taking "existential leaps" in situations of "tragic surdity" and so on. To most persons who have struggled with moral dilemmas, I submit the suggestion that reason can provide a ready-made set of priority rules is astonishing."[115]

An analogous argument can probably be set against the use of cost-benefit analysis in the settlement of project decisions in an economy where the values of resource amenities, quality of life, etc. are all at stake. Feinberg's argument appeals to me because it does seem to fit the facts. Examinations of priority rules, often help to evaluate the moral dimensions of a problem, and direct the decision process, but do not seem to offer a clear, unambigous decision criteria in the end.

Feinberg notes that the typical objection to utilitarianism (which Rawls makes as well) is,

> "...that the theory in all its forms would justify too much, ...sacrificing the interests of a few for the greater total good shared by the many."[116]

Feinberg also contrasts normative utilitarian theory of justice with utilitarian analysis of justice. He also questions the contractarian ancestry of Rawls' theory claiming that what really differentiates Rawls' theory from utilitarianism and intuitionism isn't based on a contract at all, it is based on the following general test.

> "A specific principle is correct, he argues, provided it would be chosen over any alternative that could be proposed to a hypothetical group of normally self-interested rational persons, each wearing a "veil of ignorance", gathered together in a state of nature for the specific purpose of

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[115] Feinberg (1973), p. 264.

[116] Feinberg (1973), p. 264.

> designing afresh the institutions that will regulate their future lives. That (italics) criterion is neither utilitarian nor pluralistic, but neither does it make any reference to a "contract". Rawls holds that any (italics) rational person in the circumstances he describes would choose one definite set of principles over all others as the basic ground rules of the society he is to join, and that a collection of such persons, therefore would choose those rules unanimously (italics).[117]

Feinberg notes that the contract of Hobbes and Locke had more to do with the limits of political obligation, and not so much with the truth of principles of social justice. He sees Rawls' theory as more of a system of ultimate justification, and an alternative to utilitarianism and intuitionism as such. He also notes Rawls emphasis on rules, and states

> "Institutions are defined by their constitutive rules which create offices and roles, regulate procedures, and assign rights and duties. Ultimately, then, the principles of justice apply to those rules, and only indirectly or derivatively to the acts and states of affairs that fall under the rules. ...Distributive justice, in Rawls' own terminology, is an instance of "pure procedural justice" insofar as there is no criterion of a just result independent of the fairness of the procedures followed to reach the result. The procedural rules themselves are part of the basic structure, which can be justified only by the principles of justice derived from the contractarian method."[118]

Feinberg notes that Rawls wants to emphasize that we cannot ignore the justice of procedure by focusing only on the justice of outcomes or acts. However, Feinberg notes that similar arguments are used by rule-utilitarians. For Rawls, the fairness of a procedure determines the justice of

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[117] Feinberg (1973), p.265.

[118] Feinberg (1973), pp. 266-267.

outcomes, which Feinberg claims led Rawls to label his conception "Justice as Fairness". On legislation, Feinberg states,

> "The justice of a particular statute, then, is several steps removed from Rawls' initial contractarian criterion: the choice of hypothetical rational persons determines the basic principles of justice, which in turn determines the justice of a political constitution, which in turn determines the proper law-making procedures, which in turn partly determines the justice of a particular legislative outcome. At each stage the fairness of a procedure (hypothetical or actual) determines the justice of a result".[119]

This I quote, not because of an interest in a criticism of Rawls, per se, but because I feel it illuminates one very important possible approach to issues of equity, and a rationale for approaches which are more procedural rather than outcome oriented. One must still be satisfied with the justification of the procedural approach.

Most economists do make statements about criteria for distributive justice and equity, and usually argue in favor of a particular criterion. To the extent that they pursue particular moral standpoints or positions, and attempt to justify their thinking or position, they are engaged in one kind of metaethical analysis, as it is identified by many philosophers.[120]

The Ethical Neutrality of Economics

The purpose of this section will be to consider the questions of the ethical neutrality, first, of economics as

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[119] Feinberg (1973), p. 267.

[120] See, for example, Frankena (1973), pp. 95-96

a science and second, of economic systems.[121]

The first question is related to the issue of how individual or group value judgements can influence the results of scientific economic analysis. The basis for the claim of many, that economic science can be as value free as any of the other natural sciences finds its roots in the work of David Hume, who divided the work of economists into two types, prescriptive and descriptive. These aspects are sometimes referred to as normative and positive elements respectively.

Descriptive statements are logical constructs which have "truth-value" and which can presumably be either proven or disproven, but which imply neither value judgements, nor ethical implications. To the extent that economic analysis uses descriptive statements as such, it is value free, or ethically neutral. David Braybrooke[122] claims that no successful criticism of this view has yet emerged. The thrust of his review, however, seems to focus on the comparison of economic science to natural science and does not go so far as to question whether there can be any value free statements at all. Certainly the questions concerning why certain topics are researched and described as opposed to others, or why certain concepts rather than others are developed and made the subject of the sciences is not resolved.

Values, Attitudes, Valuation

The term value is one of the most elusive, and yet seemingly indispensible terms in the social sciences. Generally, in modern economic usage, values refer to those underlying psychological entities which generate utility.

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[121] The basis of this discussion is David Braybrooke "Economics and Ethical Neutrality" in the Encyclopedia of Philosophy (1972).

[122] Ibid., p. 457

They are reflected, for example, in the market prices which consumers are willing and able to pay for goods. That price reflects value, in this sense, is not a new concept, and it is to be found as value reflected in "just" prices in the middle ages, and principles of fair exchange in biblical times. There have, moreover, been many different approaches to the measurement of value, reflected in price, based on supply and demand, labour hours of input, etc.

As opposed to more specific and measureable concepts such as opinions, attitudes, beliefs, or in some cases utility, "values" is a term which has been used to refer to the more general social and individual underlying phenomena or entities which relate to what an individual conceives to be "good", in the sense, "what is valued". The term "values" is also frequently used to refer to a sort of average of individual values, or social mores. Within a given society, there may well be several classes of values-- technocratic, religious, political etc. Further, within these general classes of values, there are usually subclasses, for example, members of different religions in a larger culture have a different subclass of values. Each of these subclasses will tend to have its own operational morals or moral codes reflecting the preferred values. Frankena (1973), for example, emphasizes the social nature of moral codes.

It can be extremely difficult to attempt to apply the concept "values" in the above sense to an individual, as most individuals (at least in North America) seem to be exposed to several different classes and subclasses of values from early youth. The "group values" of a random selection of individuals from our society may be impossible to define, their individual values may be equally difficult to understand and explain.

By contrast, attitudes which seem to reflect elements of the underlying value systems are more easily identified, more

easily measured, and are popularly deemed to be more useful to researchers for this reason. It is when one wishes to alter attitudes, or seek the roots of attitudes that one must appeal to values. William McGuire defines attitudes as:

> "[those] predispositions to classify sets of objects or events and to react to them with some degree of evaluative consistency. While attitudes logically are hypothetical constructs,] (i.e. they are inferred but not objectively observable), they are manifested in conscious experience, verbal reports, gross behavior, and physiological symptoms."

One should note that although internal consistency is frequently identified, it is much more difficult to establish external validity for attitude measures. As an example, suppose that we were able to construct a scale to measure attitudes of individuals toward future generations. Suppose further that we found a group of people who wished to see the interests of future generations protected as equally as their own. We are interested in knowing these things as clues to their likely behaviors, but until we can actually identify those behaviors, we cannot establish the external validity of our attitude measurement scale.

The difficulty which we face is that equity is probably best represented as a value or in terms of values and not as an attitude. We will explore this concept, value, more fully for this reason - despite the fact that it is used so many different ways in various literatures, and is confusing in that sense. Also, at the level of operationalization, value is likely to be extremely difficult to measure. We may contrast value as a set of ideas or concepts that are the foundation of attitudes, which explain how one feels predisposed toward an object or action, versus how one thinks one ought to feel. This contrast compares the positive element of value, with the normative element of value. Values

are discussed more extensively in chapter three.

PSYCHOLOGY, SOCIOLOGY, AND EQUITY

There has been a considerable amount of research on equity, and applications of equity theories in the field of psychology and sociology. Cook and Messich (1983) describe the general psychological and sociological approach to equity in their opening paragraph below:

> "All social systems evolve mechanisms for the distribution and allocation of rewards, resources, rights, duties, obligations and liabilities or cost. Of fundamental interest to social philosopers and social scientists is the determination of just distributions or allocations of positive and negative outcomes and appropriate mechanisms or procedures for achieving just distributions. Equity theorists are concerned with identifying the principles of distributive justice that evolve under differing social conditions and with specifying when such principles are perceived as fair or just by the members of the social system. Furthermore, equity theorists are interested in investigating the individual and collective social consequences of inequitable treatment or the "sense" of distributive injustice within a social system."[123]

Thus, it would appear that the theorists of both of those disciplines are not seeking some universal, and absolute conception of equity, but rather one which can better be thought of as relative equity. The diagram below is intended to describe the conceptual framework outlined in the above quotation.

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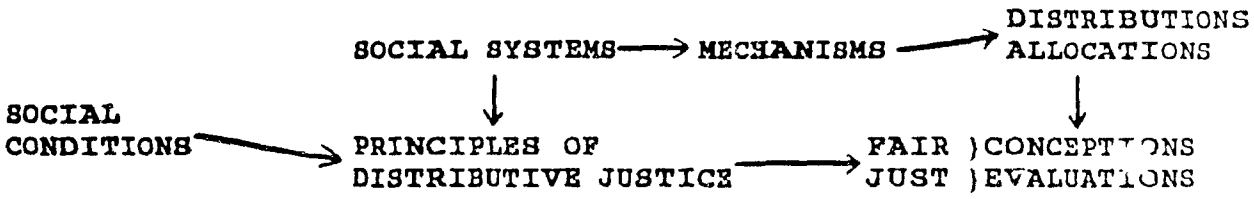
[123] Cook and Messich (1983), p. 1.



Thus, the direction of inquiry would seem to be toward an understanding of the evaluation of distributions on the dimensions of fairness and justice, relative to initial social conditions (and perhaps) within a social system. The relationships between "conditions" and "systems" are not clear.

Cook and Messich describe the collection of papers which form their book Equity Theory as a "smorgasboard" of current research in psychology and sociology[124], however, they see "eclecticism" as a strength. They believe that an interdisciplinary focus is "necessary in combating disciplinary parochialism and in achieving a full and proper appreciation of the pervasive importance of feelings of equity and inequity in our social life".[125]

They note that they can identify no definite line of demarcation between the psychological and sociological perspectives on the subjects of equity or distributive justice. They state that equity theory was the, then currently (1983), dominant "theory of distributive justice, which describes the origins, structure, and consequences of our sense of equity and justice".[126] They refer to the work of Adams (1963, 1965), Homans (1961, 1974), Blau (1964) and

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[124] Ibid., p. 9.

[125] Ibid., p. 1.

[126] Ibid., p. 2.

Walster, Berscheid and Walster (1973) as some of the earliest contributors to the area. The earliest work, they state, focuses on pay inequities and their relation to work productivity and quality, later work focuses on a variety of valued outcomes, beyond wages alone. They add that "...the theory was extended to a diverse set of social relationships and social situations from business to intimate situations and from the workplace to both the home and the society at large".[127]

Some social psychologists focus on the development of fairness values. Keil and McClintock (1983) note two major approaches here.

> "First, some researchers, for example, Piaget (1932), and Damon (1977) have explained children's judgements about fairness in resource allocation, typically by interviewing them about hypothetical resource distributions. The main focus of these studies is on the development of children's reasoning abilities with regard to justice. The second perspective,..., considers how children actually behave when their own self-interest is involved."[128]

Thus the two streams focus on judgements in the one case, and behaviors in the other. The motivation for these approaches, and for the studies undertaken by the above authors' study is given in the opening paragraph to their paper, which follows:

> "The transmission of societal values from one generation to the next constitutes a major portion of the socialization process. One important subject of transmitted values is related to the fair allocation among group members. By having its children learn a common set of fair behaviors,

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[127] Ibid., p. 2.

[128] Keil, L.J. and C.G. McClintock (1983), p. 13.

> acquire the ability to decide when each is appropriate, and eventually internalize generalized rules of fairness, a society decreases the likelihood of conflict among its members and increases its viability."[129]

Several aspects of the above are of interest, in the context of this thesis. First, the focus is on the present generation alone, and constituent members. Second, individual values lie at the base of individual judgements and behaviors. Third, generalized rules are deemed to be the end point of the acquired ability to make judgements on fairness. Fourth, the above values are supposed to be passed from generation to generation.

The rules alluded to above seem to be much closer to ideas of acceptable societal "norms" rather than accepted ethical or moral theory, though there is no doubt, great overlap.

Keil and McClintock (1983) first examine two major assumptions used in their research on interpersonal allocation decisions.

> "The first asserts that fairness can be defined in terms of one or more social rules transmitted across generations by socializing agents. The second states that resource allocation is a social decision-making task in which the options are consistent with fairness rules and/or with other competing values such as self-interest. In such instances the subjective utility of the available options, including fairness, is determined by both personal values and situational constraints."[130]

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[129] Keil and McClintock (1983), p. 13.

[130] Keil and McClintock (1983), p. 14.

Thus, their analysis is based on individual decision making based on utilities, which are themselves based on a number of underlying items, one of which may be fairness which is itself valued on the basis of a number of underlying rules. The authors identify a variety of rules which have arisen throughout history, including "the divine right of kings", "winner take all", "to each according to his need", and two rules commonly studied by social psychologists, "equality" and "equity".[131]

They assert that "Distribution according to an equality rule provides equal shares of available resources to all qualified recipients".[132] It is not clear whether this refers to initial endowments of individuals, or the distribution of social or group output. They refer to Adams (1963) in defining an equitable distribution as one which "requires calculation of the proportions of resources that recipients deserve on the basis of their relative contribution to the group".[133] The latter rule clearly focuses on the output dimension.

They refer to controversy in the literature over whether the various rules proposed are best defined by one generic rule or several more specific ones, citing Walster, Berscheid and Walster (1973), and Leventhal (1976, pp. 211-239) as references for the opposing viewpoints. For their own research, Keil and McClintock (1983) state:

> "While it may be argued that the importance of prevailing fairness rules varies across time and between cultures, the present analysis assumes, as does Leventhal, that conceptually and empirically, fairness is most profitably viewed as more than one rule and that, in Western society today, equality

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131 Keil and McClintock (1983), p. 14.

132 Ibid., p. 14.

133 Ibid., p. 14.

> and equity are the primary fairness rules acquired by children."[134]

The authors do not discuss the nature of the conceptual and empirical "profit" anticipated through the use of this approach.

The second major assumption of their work regards resource allocation as decision-making. The authors begin by noting one implication of the work of Collett(1977) "given rule competence and an accurate perception of the conditions implying the appropriateness of specific rules, a fair distribution of resources represents an intentional choice".[135] Rule competence refers to an individual's knowing the rule; one must "know" or "be competent" with respect to a rule to have "rule competence". Presumably an unfair distribution would reflect an alternative intentional choice. They go on to refer to an assumption typically made in the literature, citing Van Avermaet, McClintock, and Moskowitz (1978), that

> "resource allocations reflect a more or less rational purposive decision process. It is assumed that an allocator recognizes various distribution options and chooses the one with the greatest subjective utility. These options may include fairness rules such as equality and equity, self-interested options which maximize the allocator's own immediate or long term gain, and altruistic options in which benefit is given to another."[136]

This is rather different from the standard neoclassical economic paradigm where decisions are made on the basis of

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[134] Keil and McClintock (1983), p. 15.

[135] Ibid., p. 17.

[136] Keil and McClintock (1983), pp. 18-19.

subjective utility, but are motivated solely by self-interest. Also, the allocation mechanism is generally independent of the actors, the market produces a program for the distribution of rewards, presumably independently of any individual distributional preferences. In practice, however, managers distribute rewards on many dimensions other than wage alone, and this discussion is relevant to those allocations of group rewards.

It is interesting to pursue the authors' comments on fairness and self-interest, because they are relevant to the economic problem of finite resource use. They note that individuals may focus on the 'objective value' of some resource, and if they are a recipient as well, knowledge of that value will affect their allocation decisions. The authors, however, emphasize the use of fairness rules to minimize social conflict, an item which is a lesser issue, of course, in an intergenerational context, where many interested parties are not alive. However, the awareness of these conflicts is important. Keil and McClintock (1983) note[137]:

> "However, use of rules, in general, and choice of a particular rule may also be expected to vary across situations, depending on which rules are salient (Leventhal, 1976, pp. 211-239)."

Thus, the situation affects the choice and use of rules as one might intuitively expect. This flexibility is, however, an alternative to the behavior of the 'principled' turn-of-the-century man, who applied strict rules of moral behavior across all situations. "Thou shalt not steal" meant <u>never</u>! Mitigating circumstances were not given high value.

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[137] Ibid., p. 19.

The above use of fairness rules is also similar in some respects to some versions of intuitionism, discussed earlier in this chapter. This is very relevant to my discussion in a larger sense, because fairness and equity may be judged to be situation and context specific. Further, competence in understanding both the situation and the rules may be necessary before one may be said to behave in an intentionally equitable manner or to promote an equitable allocation. The implied behavior of persons guided by both rules and context may be compared to the individual's behavior in a market economy.

The market outcome may be deemed equitable, yet only very few participants may have an understanding of how or why this is so. In so complex a situation, the acceptable protocol for social psychology experimentation may not be appropriate. The question of the appropriateness of rules for relatively simple social situations, and the means by which individuals may come to understand both the situations and appropriate rules of behavior, is far more simple than that of equity in finite resource use, where even the millenia of existence on a generational time scale, has not yet given us what are considered well accepted norms for behavior in resource use.

The psychological studies, (Marlowe, Gergen and Doob (1966) and Shapiro (1975) cited in Keil and McClintock) also indicate modified behavior on the part of allocators who anticipate future contact with recipients, as opposed to those who do not.[138] The authors Keil and McClintock also note that in cases of outcome interdependency, internalized goods or strategies to influence recipients may be important. Some internalized values are listed as:

"...individualism (maximizing one's own outcomes),

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[138] This is certainly a parallel result to the Roman Empire example in the context of time preference in Chapter Three.

> cooperation (maximizing joint outcomes), competition (maximizing the difference between own and other's outcomes in one's own favor), altruism (maximizing other's outcomes), and aggression (minimizing other's outcomes). In addition, various fairness rules such as equality or equity can function as social values that actors self- consciously pursue (Van Avermaet et al., 1978)."

The situation-rule combination in which equity in distribution is deemed to be the appropriate response in the empirical sections of their paper, (which otherwise is of little relevance to this research), is identified on the basis of task structure and relative inputs. The authors suggest on the basis of previous research (Deutsch (1982) that competitive and individualistic tasks increase the salience of the "equity rule". Unequal inputs are assumed to be the cue for the use of an "equity rule". Conversely, equal inputs and cooperative tasks tend to be cues for an equality rule. The equity rule states that distributions of rewards or the partition of the final allocation should be proportional to relative inputs. There are two types of equity which are described, proportional equity and ordinal equity. We should note that relative inputs refers not to effort where all participants may be deemed to have "tried equally hard", but to successes (e.g., in tossing balls into a box) where the attendent rewards were to be thereafter partitioned among participants.

The authors go on to argue, that,

> "An accurate understanding of allocation behavior thus requires consideration of the function the behavior serves for an actor. Decisions regarding fair behavior may reflect internalized goals or values, but they may also reflect strategic behaviors. Thus, one cannot interpret such decisions at face value but must analyze the context in which they occur for clues to the actor's intention."

Wilke (1983) also notes the proportionality rule for equity, citing the work of Homans (1961),

> "...the equity norm is useful for establishing and maintaining long-term relationships. He suggests that, if outcomes are scarce, people may come into conflict, since they all pursue the maximization of their own outcomes. This potential conflict may be solved by introducing a norm to the effect that one takes in proportion to what one gives."[139]

This is referred to as an example of the "outcome coordination perspective"; an alternative is the "consistency perspective" which stresses the need to consistently organize cognitions. Wilke (1983) cites the following as an example:

> "the 'just world' hypothesis of Lerner, Miller, and Holmes (1976, pp. 133-162) suggests that people assume that one ultimately gets what one deserves, that is, that outcomes are consistent with investments. This notion operates in two directions - if a person makes positive investments, he deserves positive outcomes; and if a person receives positive outcomes, one infers that he has made positive investments. The analagous relationship is assumed to hold for negative investments and negative outcomes."[140]

He also notes, however, that Lerner et al. (1976) assume that the equity principle is not applied unconditionally, but that the more an allocator identifies with a recipient, the greater the tendency to equality. Wilke also refers to the work of Adams (1965) and notes that different perspectives among group members on what constitute "relevant" inputs can lead to problems of inequity. Socialization, Adams (1965) claims should reduce the differences in perceived relevance.

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[139] Wilke (1983), p. 48.

[140] Wilke (1983), p. 48.

Wilke (1963) states, in summarizing his literature overview,

> "... one may conclude that most equity theorists agree that equitable behavior results from a combination of tendencies to maintain certain cognitive consistencies and to maximize outcomes."[141]

Messich and Sentis (1983), in their examination of fairness, state that equality is "at the heart of the concept of fairness". (p. 68). They claim, notably, that

> "The issue is not whether equality is important, but on what dimension the equality should be established. There is a multitude of possible equalities, which gives the study of fairness and equity much of its richness. Some of the various equalities that are important are equality of outcome, equality of outcome per unit of input (equity), equal excess or equality of outcome above a minimum level (Komorita and Kravitz, 1979), equality in psychic profit from an exchange (Cook and Emerson, 1978), procedural equality, or equality in the application of rules and procedures (Thibault and Walker, 1975), equality of opportunity, and so on. The problem of finding fair arrangements is not one of equality versus inequality but one of equality with regard to what."[142]

Thus, these authors appear to take a much wider view on the issues which are relevant to equity and fairness and in extra-laboratory contexts, however, they drop these points to pursue the issue of fairness biases.

They note that some of the more problematic issues with regard to fairness, are that it is difficult for individuals to tell when other individuals are trying equally hard to achieve some outcome, how the difficulty of tasks are

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[141] Wilke (1983), p. 49.

[142] Messich and Sentis (1983), p. 68.

identified, etc. These evaluations usually involve subjective interpersonal comparisons. The authors note that fair rules for dividing a cake (I divide, you choose) between two people may be simple, but n-dimensional generalizations involving psychological entities are not.

The authors cite three reasons for the greater complexity of the psychological problem. The first they state, has to do with information available to make fairness judgements. They note that whereas one has fairly good information about one's own subjective states, one can only infer those of others from their behaviors (including what others say), and they claim herein lies a fundamental asymmetry which makes fairness judgments difficult. They note that differences in the way one views self and others, "may lead to systematic biases in the types of fairness judgments that one makes".[143] The second factor is that others do not have direct information on the first one's subjective states either. This they claim, referring to Adams (1965), may lead to strategic misrepresentation. Finally, one must deal with the suspicion that others are misrepresenting their states, in an effort to reduce inputs or increase outputs. The above points lead to "fairness biases" of different types, detailed in their paper. Strategy misrepresentation is less of a problem in the intergenerational context, since most persons belonging to future or past generations are not able to interact with decision-makers in the present.

Cook and Yamagishi (1983) present a discussion of previous research in the problem of multidimensional inputs in equity theory, and extend the research by examining rule use (single and multiple), inputs (multiple), interaction, and allocation. They conclude "that multidimensional input situations are more complex than currently conceived in

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[143] Ibid., p. 69.

existing theoretical work on the topic"[144]. They suggest the need for more theoretical work in the area of "fixed-reward situations" where models which integrate both multiple inputs, as well as multiple rules are developed.

The work of Martin and Murray (1983) extends the equity discussion more explicitly into the political sphere, in their work on equity theory and deprivation theory. They suggest that these theoretical fields have much in common, although researchers in the different areas do not try to draw on each other's work. They suspect that one reason why so little synthesis has occurred is that "Equity refers to a comparison that is seen as just, while relative deprivation is a perception of injustice".[145] They state "the labels of these theories reflect deep differences in the political roots, theoretical formulations and empirical findings of these two research traditions"[146]. The authors, Martin and Murray take "the position that researchers' political values can influence the content of 'knowledge' in a given area of inquiry"[147]. They state,

> "We undertake examinations of the political roots of seminal formulations of these theories, not because the task of the theories is to support particular political beliefs, but because the political values implicit in some of the seminal formulations of equity and relative deprivation are consistent with and increase our understanding of the effects of the theoretical and empirical limitations in these two research traditions."[148]

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[144] Cook and Yamagishi (1983), p. 123.

[145] Martin and Murray (1983), p. 170.

[146] Ibid., p. 170.

[147] Ibid., p. 170.

[148] Martin and Murray (1983), p. 170.

The authors begin by restating the central proposition of equity theory,(citing Adams (1965)) as:

$$\frac{\text{Outcomes A}}{\text{Inputs A}} = \frac{\text{Outcomes B}}{\text{Inputs B}}$$

> "According to this formula, comparers decide which of their inputs, such as educational qualifications or years of seniority, entitle them to outcomes, such as money. The comparer then calculates the positive or negative value of each input,, sums these, and divides that sum into the sum of the outcomes received. A similar calculation is then performed concerning the inputs and outcomes of a comparative referent. If the two ratios are equal, the relationship is equitable."[149]

They note that unlike many other social science theories, the above is "clear and parsimonious", it also has a "cognitive rational tone"[150]. They claim that it has generated much research, and that it has "considerable explanatory power." In the contexts in which it has been studied (business, exploitation, helping, and intimate relationships) it explains a relatively large proportion of the variance in perceptions of justice. They suggest that the "politically neutral tone of the basic proposition", has encouraged this breadth of application. They offer the following example for two men,

> "...a conservative rich man and a radical poor man. The conservative man might take the position that his wealth is deserved because of two of his input characteristics: a blue-blooded family background and a diploma from one of the appropriate Ivy League universities. A poor man, in the Marxist tradition, might decide that wealth should be distributed to each person according to that person's need. This reduces the number of relevant inputs to one: need.

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149 Martin and Murray (1983), p. 172.

150 Ibid., p. 172.

> **These examples indicate that the basic theoretical proposition can be used to represent widely divergent distributive ideologies."[151]**

The authors state that one beneficial aspect of the theory is the fact that it can be used to reflect very different underlying political motives, nonetheless, they state, the perspective itself has "a distinctly conservative political cast." (p. 173).

The authors refer to Homans' (1974) theory of distributive justice as an example of political "neutrality: in a theory, and cite his comments on "exploitation" as follows.

> "...[Such political theorists as Marx represent] one lone attempt to prove that what employers and owners count as their investments and contributions ought not to be so counted, and that therefore they get more than their fair share of the returns from economic enterprise and exploit the workers. Naturally none of the arguments prove the point; such things are not capable of proof; they are matters, so to speak, of taste. When someone says that one group is exploiting another, all his words mean is that he personally does not approve of the way in which rewards are distributed between the two groups. They mean no more: There is no objective means of determining whether exploitation is taking place. (Homans, 1974, p. 251)."[152]

They claim that the definition of exploitation is neutral, in that both Marxist and anti-Marxist positions are described as "matters of taste", however they note that the term exploitative itself has ethical content.[153]

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[151] Martin and Murray (1983), p. 172.

[152] Martin and Murray (1983), p. 173.

[153] This is an important discussion to keep in mind in the context of the words used to describe items in economics, optima, efficiency, etc.

Martin and Murray state that

"To assert, as Homans does, that the correct epistemological status of ethical language is a 'matter of taste' is to assert that moral statements are really simply personal preferences. Thus, 'bombing children is evil' becomes equivalent to 'I dislike the bombing of children', much like 'I dislike orange sherbet'.

Homans' statement fits within the philosophical tradition of 'emotivist theory'. That theory, in the unequivocal form used by Homans, has fallen into considerable disrepute among philosophers (see Frankena, (1973). One reason for this disrepute is that violation of the two statements, 'Bombing children is evil' and 'I dislike orange sherbet', requires two different kinds of justification. For the latter, no or minimal justification would be required, since sherbet preferences are a private and personal matter of taste. The former statement, however, is a public matter. The public is impacted, and a public justification is required. To imply that exploitation requires no more justification than a food preference is, at the very least, a position that shows little identification with or sympathy for those who consider themselves exploited. Regardless of one's substantive position on exploitation, current ethical philosophy suggests that exploitation is not a mere matter of taste."[154]

The authors note that

"Similar observations can be made about the statement that low rewards are justified because the capacity to perform such a job is probably not rare. This statement implies that the laws of supply and demand should define whether particular inputs deserve reward. The neutrality of the theory has been sacrificed here by identifying as just only one allocation mechanism: the present free-market system."[155]

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[154] Martin and Murray (1983), p. 173-174.

[155] Martin and Murray (1983), p. 174-5.

Their basic point is that theory (i.e., equity theory) though 'potentially politically neutral', can be structured, or used to explore in a biased manner, according to a particular (and in the above case conservative) ideology. Martin and Murray (1983) then go on to evaluate Blaus' (1964) fair exchange theory in the context of the above discussion of political bias.

Martin and Murray (1983) next turn to a more detailed discussion of the theoretical limitation of "original equity formulators", and they find three primary ones. The first is that the level of the analysis is restricted to the individual even in group analyses, which the authors refer to as reductionist. They claim this causes major items such as many relations among groups (powerful versus powerless in a society) to be supressed. The second limitation is that most versions of the theory are restricted to the comparisons of similar individuals, which they claim "excludes a distinctive and potentially challenging class of judgments about perceived injustice".[156] The third limitation is that expectations and what is perceived as fair and just are not sufficiently discriminated. They cite Blau (1964, pp. 155-6) in the following:[157]

> "The going rate of exchange in a group gives rise to expectations that certain returns will be received for certain services. Whereas these standards of expectation are not moral norms but merely anticipations that influence conduct, the normative expectations that a service that required a certain investment deserves a certain return are moral standards, the violation of which evokes social disapproval. (Blau, 1964, pp. 155-156)."

Here the authors are concerned that people's perceptions

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[156] Ibid., p. 179.

[157] Ibid., p. 180.

of what is just may be colored by their perceptions of what is possible. Certainly this is a possible difficulty in the standard neoclassical approach to the analysis of problems. The authors review some empirical results, then turn to relative deprivation theory.

The authors state that

> "relative deprivation theory was developed to explain why some army units with objectively high rewards had lower morale than units with far fewer rewards (Stouffer, Lumsdaine, Lumsdaine et al., 1949),"[158]

and they note extentions of that analysis that are both non-political - Merton and Rossi (1968) and political, Runcimon (1966) among others. They state that a characteristic of all of these studies is that the subject of study is a group which though it appears objectively to be disadvantaged on some dimension, does not appear to perceive itself (if that can be said) to be disadvantaged and/or be associated with a perception of their situation as unjust.

They cite the distinction between egoistic and fraternal deprivation, the former generated by individual to individual comparisons, the latter generated by group to group comparisons, and note that those two deprivations can result in different associated behaviors (individual versus group contrasts - self improvement versus rioting for example). The authors focus in the review of the results of the research, is primarily to contrast it with the previously discussed equity research, focusing on the three conclusions for equity listed below:

> "Comparers display an overwhelming preference for

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[158] Ibid., p. 186.

comparisons to similar referents.

Even when upward, dissimilar comparisons are made, discontent will not be aroused if the referent has sufficiently superior inputs.

If permitted to persist long enough, comparisons leading to a perception of injustice will eventually turn into perceptions of justice. Thus, perceptions of injustice occur primarily when expectations are violated."[159]

Generally, their analysis suggests that the results on relative deprivation theory tend to suggest limitations to those conclusions. They state that there are conditions under which equity theory would not hold, and these instances can be identified using relative deprivation theory. They suggest several reasons for this. First, the egoistic versus fraternal distinction allows the latter theory to encompass some phenomena beyond the former theory. The former is in this sense "wider" in scope, and also avoids the problems of "reductionism", alluded to earlier, and permits issues of "justice" to be established on a wider base. Also the latter focuses on, and can provide useful analysis for, problems of "chronic discontent" with which the former theory is incompatible. The authors then focus on the possibility of integration of the two theories, but identify significant difficulties on political, theoretical and empirical levels, although there are many areas of overlap if not integration.

Cameron and MacCrimmon (1983) offer what is essentially a review of economic theory, which has relevance to equity theory. Their stated purpose was to provoke social psychologists into thinking more broadly about equity theory by describing relevant research from the points of view of various areas of economics, decision theory and related

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[159] Martin and Murray (1983), p. 187.

social science. This research illustrates the broad context of equity that is often ignored in experimental or analytical work in equity theory.[160]

It does seem that if one would go so far as to try to encompass the interpersonal comparisons problem of economists, in the traditional social psychology research programme of equity theory, that it might stop the empirical research cold. Consideration of the equity question on the widest base possible seems to pose unanswerable, and possibly even unposable problems, which the current research program in social psychology ignores. By focusing on relatively simple, testable propositions, equity theory seems to be making some progress, and seems to be leading at least in the direction of the wider perspectives that may be useful to the economist.

In this article Cameron and MacCrimmon use various examples to illustrate fairness situations with regard to wages based on different equity attributes. These examples include the then recently proposed London underground fare hikes, and Gary Carter's salary as a catcher. They consider the problems of contribution and reference group, in contrast, noting that the focus of attention tends to "shift from performance inputs to socioeconomic characteristics or need."[161] They note that an equity evaluation of both examples causes us to focus on "broader concerns" in evaluating the problem, and causes us to consider "dynamic" as well as "static" aspects of the equity problem.

The authors first focus on the models typically used by social psychologists, which they claim, have the following characteristics:

> "Inputs and outputs have one easily measureable dimension.

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[160] Cameron and MacCrimmon (1983), p.322.

[161] p. 296.

A fixed output is available for distribution, and the link between inputs and outputs is ignored.

The output decision is a one-time decision with no dynamic effects, and inputs are fixed or determined with few expectations about output.

Inputs and outputs are either known or equally ambiguous to all parties.

Inputs and outputs are simple enough that participants can rationally process all the relevant information."[162]

Those authors describe these equity interactions as "simple", and explain that they'll "describe protctypical examples of equity situations lying outside the narrow range of these (the above) five asumptions," (p. 297) and their work focuses on the effects of relaxing the above assumptions in various ways (and at times substituting others). They review their analytical objections as follows:

"The implications of increasing from single inputs and outputs to multiple inputs and outputs are discussed, and we note that inputs generate outputs and that output distributions must take this 'production function' into account. We will also describe how expectations about output distributions determine inputs and create various incentives and will study the ramifications of uncertaintly about inputs and outputs, especially when there are asymmetries in information. Finally, in the last section, we will relax the strong assumption of rationality made in the preceding sections and evaluate the effects of limited rationality of individuals on equity judgments."[163]

The major areas the authors review are grouped below, by

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[162] Cameron and MacCrimmon (1983), p. 297.

[163] Cameron and MacCrimmon (1983), p. 297.

their heading weights.

Multiple Inputs and Multiple Outputs
- Linear Modelling and Bootstrapping
- Multiple Attribute Utility Theory
- Ability, Effort and Actual Contribution
- Indivisible Inputs or Outputs

Equity versus Efficiency

Inputs Determine Outputs
- Distributing Outputs or Distributing Inputs
- The Production Function
- Distributing Outputs Based on Inputs
- Outputs = Inputs + Random Effects

Expectations, Incentives, and the Inequity of Externalities
- Tax Avoidance, Brain Surgery, and Incentives
- Free Riding
- Monitoring to Internalize Externalities
- Breaking the Budget Constraint
- Moral Hazard

Information Asymmetries and Incentive Compatability
- Lemons
- Signaling
- Faults and Signaling Complications
- Signaling through Repeated Cooperation

Limited Rationality and Equity
- Situation Framing
- Uncertain Outcomes and Hindsight
- Probability Estimation
- Mixing Values and Beliefs
- Satisficing
- Information Processing Rules versus Discretion

The above listing reads more like a listing of recently developed topics in micro-economics. The connections of equity to the above were, in general, not made at all by the economists working in those areas. Issues of "equity", "fairness" are generally not considered in the bulk of the research reviewed. However, there are equity dimensions there. The reader of Cameron and MacCrimmon (1983) might be

led to believe that the above areas comprise literature associated with some ongoing equity research programme in economics, and decision theory, but that is not the case.

SUMMARY

This chapter has progressed from basic definitions of equity, through reviews of thought on equity in economics, philosophy, psychology, sociology, and law. It is to be hoped that the basic dimensions of the problem of equity are established, in the more or less static context. Although only brief attention is given to the problems of equity in a dynamic context, or in an intergenerational context, such problems will be discussed in Chapter Three.

In general, it may be said that the perspectives of law, psychology and sociology, tried to focus on adherence to various kinds of norms, or evolving standards, and on the identification of those standards. The focus is on what people think is equitable, and how they come to those beliefs. Similarly with values research, and attitude research, the emphasis is on "what is", and less on "what ought to be", or on justification for those values and beliefs. The latter is emphasized in ethical and meta-ethical research, as well as being a subject matter for moralists and religious thinkers. As a result, I have tried to identify the problem of equity, as involving a particular subset of research in ethics. Economists have had a lot to say about the ethical content of the problem of equity. Moreover, they have generally chosen to refer to much of their thinking as scientific, and value-free. It was argued that the fact that only specific research programs containing particular ethical perspectives are pursued, suggests a value based and ideological approach to problems of equity. Also, much of the language used in the context of economic research, "optimal depletion programs", etc. belies the claim

that economic research is free of value-based preferences. When economic reports to government agencies promote programs associated with certain welfare optima, and when only selected criteria are considered, and alternative criteria are excluded, the "scientist" is very likely to be subject to values-based biases.

While the foregoing is indeed a criticism of the approach taken by most economists, it must nevertheless be emphasized that economists have offered, and have examined very critically, a wide variety of ethical criteria, although standard textbooks in microeconomics tend to take a fairly narrow neoclassical perspective. Arrow's (1973) penetrating review of Rawl's Theory of Justice, and comments on utilitarianism offer convincing evidence of some economists' deep concern with the ethical aspects of economic problems and analysis. The work of many other economists could be cited as well.

Chapter Three will use the analyses and surveys of this chapter as a foundation on which to examine the problem of equity in an intertemporal, and intergenerational context. This context, it will be found, creates special problems for ethics, and for economics, especially regarding the use of finite natural resources.

CHAPTER THREE

INTERTEMPORAL AND INTERGENERATIONAL CHOICE

INTRODUCTION

This chapter discusses the special character of problems involving intertemporal and intergenerational choice. The chapter begins with a presentation of some views that economists have taken regarding distance in time as an element of value. Some of these statements concern individual views toward provision for enjoyment of present versus future consumption, the idea of utility discounting, the use of social discount rates, and how individuals and society may confront the problem of an uncertain future. As will be seen, the literatures of ethics as well as economics are not well developed in the area of intergenerational choice.

While there has been limited formal theorizing on intergenerational choice, there has nonetheless from the time of the ancients onward been some thought expressed that is germane to the discussion. Ideas on inheritances, preservation of the environment, dynasties, and endowments are among those presented. It is shown that ideas that are relevant to the problems of intergenerational choice and the use of resources are founded in a plethora of writings bearing on religious doctrine, political ideology, and in moral beliefs. A key issue is this: if there are divergent attitudes toward the use of finite resources reflecting different disciplines, values and attitudes, how can they be resolved if they should be resolved at all? Are these divergent values and attitudes to be expected, do they serve a useful purpose in society, or should consensus be a goal? What are appropriate forums for the evaluations of these

values, attitudes, and goals?

The discussion of alternative ethical and value systems is related directly to equity in the use of resources in the intertemporal and intergenerational context. Equity may be seen as an extra-market and perhaps even an extra-economic criterion or dimension of evaluation. Although the market may in some circumstances be taken as a satisfactory mechanism for the resolution of many competing claims, it may nevertheless be rejected by some people for the resolution of finite resource and environmental issues. Appeal to equity can encourage the adoption of non-market rules for the allocation of finite resources, and can result in dramatically different patterns of usage from that which would arise from reliance on a market system alone.

In this chapter some possible explanations for the use of non-market rules for finite resource and exhaustible resource allocation are set out. This discussion will anticipate to some extent the analysis of the National Energy Board (NEB) and Alberta Energy Resources Conservation Board (AERCB) rules in Chapter Four.

ECONOMICS, AND INTERTEMPORAL PROBLEMS

Economists' Views on Distance in Time as an Element of Value

The early views of economists on distance in time as an element in value were excellently presented by Professor Edgeworth.[1] The following discussion draws on that author's work.

In an early reference, John Rae claims:

> "There is no man perhaps to whom a good to be enjoyed today would not seem of very different importance from one exactly similar to be enjoyed twelve years hence, even though the arrival of both were equally certain."[2]

Of course, the issue of "certainty" is critical and not easily resolved. Also, regarding the acquisition of information to evaluate the above, the asking of hypothetical questions of individuals presents a different situation from one's observations of actual individual decisions and individual patterns of consumption. While statements of individual predispositions to behaviours presently constitute one of the best guides to the future behaviour of individuals, they are still not very accurate with respect to the actual behaviours.

Professor Edgeworth notes that this observed preference for current consumption has attracted the interest of moral philosophers. He refers to Locke:[3]

> "When we compare present pleasure or pain with future, we often make wrong judgements of them,

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[1] Edgeworth, F.Y. (1925).

[2] Ibid., p. 592.

[3] Ibid., p. 592.

> taking our measures of them in different positions of distance. Objects near our view are apt to be thought greater than those of a large size that are more remote; and so it is with pleasures and pains, the present is apt to carry it, and those at a distance have a disadvantage in the comparison."

The references to visual perception seem almost universal. Professor Edgeworth notes that:[4]

> "Jevons expresses the depreciation of future pleasures by a fractional factor (a function of the distance in time). Multiplying the future pleasure by this factor we have its value relatively to present pleasure. The factor expressing the effect of remoteness should be unity, if human nature were perfect."

and states in a footnote, that Professor Marshall claims

> "It is impossible to resist the conclusion, however paradoxical at first sight, that the depreciation of future pleasures at the rate at which they are "discounted" is measured by the rate of discount in the loan market."[5]

By contrast, Sidgwick is quoted,

> "equal and impartial concern for all parts of one conscious life is perhaps the most prominent element in the common notion of the rational - as opposed to the merely impulsive - pursuit of pleasure."[6]

Examples of the way men fall short of this rational ideal are also found in Rae. Mill refers to Rae regarding the failing of rationality, and associates it with the

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[4] Ibid., p. 592.

[5] Ibid., p. 592.

[6] Ibid., p. 592.

behaviours observed by the people of particular nations and classes.[7] The focus of his argument is on the human desire to accumulate the "means of future pleasure"; the extent of intellectual powers is viewed as a critical factor in this accumulation, or building up of personal wealth.

Professor Edgeworth notes that:

> "A wiser ground for preferring present goods is their comparative certainty. The 'bird in the bush' may never come to hand. The uncertainty of the future is greater the lower is the level of civilization."[8]

This seems equally true today, and we note that political uncertainty often greatly increases risk premia on financial investments. Many financial agreements appear to be based on solid legal arrangements. But the legal (inter and intra country) arrangements are only as strong as the civilizations or countries that support the existing legal structure. But governments may fall and the new government or the new order (or disorder) may or may not be able to, or wish to, support the old rules.

Referring to the work of Marshall, Professor Edgeworth states,

> "...some pleasures are more 'urgent' than others. Tastes may change, the sense of pleasure will be dulled in some cases and intensified in others by advancing age. The young man who looks forward to indulging himself in Alpine tours when he has made his fortune would much rather have them now, partly because they would give him much greater pleasure now."[9]

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[7] Ibid., p. 592.

[8] Edgeworth (1925), p. 593.

[9] Ibid., p. 593.

However, we note as well that old age may "require more comforts than youth", and that we may be able to anticipate times in our lives when "certain wants will be more pressing..." Ice will be wanted more next summer than now in winter (Bohm-Bawerk).

This can be interpreted to mean that one should not assign a subjective valuation on ice in the winter for summer goods, using one's winter time value system. We face the important problem that values may change, and perhaps are even cyclical. Intergenerational valuations are introduced when Edgeworth notes:

> "The distance in time over which consumption is thus distributed is extended beyond the lifetime of the individual by his interest in posterity. Rae places the prevalence of the "social and benevolent affections first among the conditions of the effective desire of accumulation."[10]

Another excellent example, which we will later modify to reflect intratemporal income distribution, comes from Mill:

> "If mankind were generally in the state of mind to which some approach was seen in the declining (Roman) empire - caring nothing for their heirs as well as nothing for friends, the public, or any object which survived them - they would seldom deny themselves any indulgence for the sake of saving beyond what was necessary for their own future years."[11]

It is apparent that the attitude towards the distant future will affect the choices individuals will make for schooling or building up what may be called their own "human capital".

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[10] Edgeworth (1925), p. 593.

[11] Ibid., p. 593.

Professor Edgeworth relates this attitude to the capital market:

> "The play of the various motives which have been indicated determines the value of future with respect to present wealth on the loan market, in other words the rate of interest. The spendthrift borrower of capital to be employed in business is moved by the prospect of future profits. The lender is deterred by providence from grasping all the immediate pleasure which is in his power."[12]

Edgeworth explains that Ricardo and Mill indicate that because of the previous aspects, "distance in time is an element in the value of two important agents of production, borrowed capital and trained labour. It is accordingly also an element in the value of products."

The more modern term which is used to relate distance in time as an element in value is "time preference". Usually, the rate of time preference indicates the proportion of perceived value which is diminished as consumption of a given good is placed further and further into the future. Time preference has been used to reflect both a preference for present consumption due to seemingly "non-rational" or impulsive elements in individual decisions, as well as rational elements such as risk and uncertainty. The discussion of rationality in time preference is pursued more fully later in this chapter, for now I will simply assume that pure preference captures all individual preference for current consumption for reasons other than risk and uncertainty. The understanding of what is rational is, in fact, very controversial, and is left open at this point in this chapter.

Pure Time Preference

Rawls (1971) assumes that in choosing a just principle

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[12] Ibid., p. 593.

of savings, persons in the original position exhibit no pure time preference. He agrees with Sidgewick that:

> "rationality implies an impartial concern for all parts of our life. The mere difference of location in time, of somethings being earlier or later, is not in itself a rational ground for having more or less regard for it."[13]

He does qualify this somewhat, by considering the role of relative certainty or probability of occurrence, and also by recognizing changing individual capacities for the enjoyment of specific goods. For Rawls, the different positions of persons in time should not affect our treatment of them. However, it is emphasized that, whereas for utilitarian ethics like those of Sidgewick, the argument against pure time preference can be made on the basis of the grounds of individual rationality, and the aggregation of individual utilities, the argument on the basis of justice as fairness is of a different sort. The views converge, but for different reasons.

Individual Sources for Time Preference

Bohm-Bawerk (1959 edition) begins his chapter entitled "On the Motivation of Present Economic Actions by Future Wants" with the work of Bentham who he claims probably

> "...first introduced the exceedingly difficult question in economic sciences as to what kind of psychical process induces us to make present economic provisions for future wants or future joys and sorrows."[14]

He states that Bentham's general value theory was based

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[13] Rawls (1971), section 45, p. 293.

[14] Bohm-Bawerk (1959), V. 111, p. 137.

on hedonistic principles, and to each pleasure there corresponds a "dimension of value" whose extent is influenced by seven causative factors. Bohm-Bawerk notes that four of these are relevant to the discussion at hand, the intensity, and duration of the pleasure, the probability of its occurrence, and the temporal remoteness of its occurrence. Bohm-Bawerk claims that Bentham offers no proofs for the above, the only evidence being the statement itself, and appeal to the fact that the force of interest causes a decline in the value of sums of money, which he refers to as a "general source and therefore representative of enjoyment".[15] Money declines in present value as the source of its possession becomes more remote. This, he states, does not constitute a psychological defense of Bentham's presumably factual assertions regarding temporal remoteness. He notes that Jevons[16] while generally accepting Bentham's approach, inserted an intermediate result, that it is the present feeling about the future occurrence which affects present economic decisions. He notes that Sax[17] and Bentano[18] also follow the above approach of Jevons against which Bohm-Bawerk argues.

He argues against the Jevons approach, by considering a trip to Italy. He notes that he might plan for such a trip considering "personal experience or from travellers' tales heard or read", imagine his pleasure from the trip and estimate its intensity so high that it is worth $500 to him. However, the action of imagining or anticipating may only be valued at a few dollars, and is perhaps comparable to that

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[15] Quotation of Bentham by Bohm-Bawerk (1959), p. 137.

[16] Jevons, Political Economy, 2nd ed., p. 37.

[17] Grundlegung, pp. 178, ff. 314.

[18] Versuch einer Theorie der Bedurfnisse, p. 9 ff., 30 ff., 35 ff.

which one might get from reading a good story about travel. He claims that

> "No constant or regular relationship can be established between a "main pleasure" and a "pleasure of anticipation" for this relation varies greatly as to person, motive, and circumstance. With dreamy, imaginative men, for instance, who are apt to be strongly excited by their own imaginings, the pleasure of anticipation may be relatively strong; with hard-headed, unimpassioned men, on the other hand, they will be disproportionately weak."[19]

It should be noted that the above ideas seems to be based on his observations and reflection alone, and are not the results of empirical testing or quantitative analysis, despite the use of words like "disproportionately". Bohm-Bawerk wishes to make two key points in his discussion:

> "first, that the intensity of the imagined future main pleasure and that of the actually experienced pleasure are two different phenomena; second, that in the vast majority of cases, the intensity of pleasure of anticipation is less than the main pleasure not by a few percent, but infinitely."[20]

He claims that Jevons confused these two, in concluding that "economic actions are motivated by 'present feelings' which trail the intensity of future pleasures and sorrows by a few percent in accordance with their temporal remoteness..."[21] Bohm-Bawerk states that it is our foresight which protects us against the experience of our future pleasures and pains, and not by merely reducing them by a few

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[19] Bohm-Bawerk (1959), V. III, p. 138.

[20] Bohm-Bawerk (1959) V. III, p. 138.

[21] Bohm-Bawerk (1959) V. III, p. 139.

percent. Bohm-Bawerk states that the rating by the intellect is what causes us to choose among possible future goods, and we rely on sober judgement for that, but it is the momentary feelings of pleasure which lead those judgements astray. He states,

> "If any doubt should remain, which I think unlikely, it may be dispersed by our consideration of the well-known fact that enthusiastic dreamers, who experience very lively present emotions when considering future events, by no means provide most efficiently for their future needs. On the contrary this is done by coldly calculating persons whose sober and reasoned evaluation of future situations is little or not at all influenced by accompanying emotional excitement."[22]

Bohm-Bawerk states that he wishes to pursue explanations consistent with several "facts", which, he claims "...seem to be reliably certain according to the unanimous or at least overwhelming agreement of psychologists observing human life." They are the following:

> "1) Consideration of future feelings of pleasure or threatening pain somehow leads to present valuations and motivations. 2) The corresponding value or power of motivation stands in some functional relationship to the intensity of the future pleasure or pain. ... 3) Furthermore, we can somehow form an opinion on the degree of intensity of a future pleasure or pain. ... 4) ...a more or less lively conception of future situations connected with pleasure and pain usually gives rise to feelings already in the present. ..."[23]

It would seem that "utility discounting" which is usually pursued in intertemporal analysis is a poor analogue

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[22] Bohm-Bawerk (1959) V.III, p. 139.

[23] Bohm-Bawerk (1959) V.III, p. 140.

for the human processes which Bohm-Bawerk is discussing. While Bohm-Bawerk seemed to be displeased with the then current statements of psychologists on the subject of the motivation of present actions by future wants, he was reluctant to criticize them, because he considered himself a layman in that field, and did not really wish to produce a new treatise in psychology himself. Still his comments are enlightening and thought provoking, and clearly are relevant to this thesis.

Some Implications of Excessive Discounting of Future Needs

It might be reasonable to suggest for example, that should a significant portion of the population inadequately plan for their future wants, according to someone's test of rationality, then that rationality might justify a system of social security being adopted. In parallel, if a generation of individuals does not adequately provide for the requirements of future generations, certain parallel social institutions may be justified. This idea suggests that the standard economic approach to the problem of the future, existence of forward markets, or contingent markets, is inadequate in that there are motivational problems, or the interest that members of society should have in the future or that they believe they should have in the future simply is not there, or is not strong enough, according to some rational test. Perhaps this is an alternative approach to, or an explanation of incomplete markets; at any rate, it may well be an argument for state intervention, depending on the value system, or ethical code of the society. There are several elements here. First, does the behaviour of individuals fall short of their own ideals, based on values, or ethical codes, etc., and second, are their ideals, values, or ethical codes the correct ones? There is also a third question, and that is, do individuals know which actions to perform to get to

their ideals, a question which may or may not have real meaning, depending on the values, or ethical code in question, as some ethical systems de-emphasize, or ignore actual consequences, and hold that it is only intentions that are relevant.[24]

A Note on the Relations of Cognitions, Emotions and Behaviours

On the subject of approaches to Bohm-Bawerk's problem of the motivation of present actions by future wants, recent research in psychology may offer some insight. A recent summary of some results on the relationship between cognitions, feeling, emotions and actions is offered by J.E. LeDoux (1984), who in "Cognition and Emotion" states,

> "Most cognitive scientists would surely agree that an adequate theory of mind, when it arises, will have to incorporate feeling, effect, emotion, or some such concept as a central concept (see Meisser, 1963; Simon, 1967; Miller and Johnson-Laird, 1976; Zajonc, 1980). Just how feelings, effect, or emotion should be plugged into or at least related to cognitive models in other than trivial ways, however, has remained rather mysterious."[25]

LeDoux notes that

"Indirect interactions between cognitive and

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[24] Perhaps another question is the issue of whether individuals can, through their own individual actions, accomplish their own social goals. For example, suppose it was the majority view that this generation should reserve the gas in a certain geographical reserve for a future generation to develop. An individual or even a group of individuals could hardly be expected to buy and hold the reserve, and in a free market that may be necessary in the absense of concensus.

[25] LeDoux, J.E. "Cognition and Emotion, Processing Functions and Brain Systems", in Handbook of Cognitive Neuroscience, (New York, Prenum Press), 1984, p. 357.

> affective processing systems are a key feature of human emotion..."

and

> "Certain anatomical facts are consistent with the view that direct connections between the cognitive and affective processing systems are limited."

He cites empirical evidence in support of those statements, and concludes as follows:

> "One implication of these observations is that as humans, our ability to know ourselves consciously is limited by the patterns of anatomical connectivity between the cognitive and affective processing systems and by our cognitive skill in constructing interpretations of affective processing on the basis of limited data from our own behaviour and autonomic reactions and from our physical and social environment. Unless the human brain someday evolves in such a way that direct neural interactions between the cognitive and affective processing systems supersede indirect interactions, firsthand knowledge of the motivational conditions that underlie much of adaptive behaviour will remain inaccessible to the conscious, feeling person."[26]

In the light of such limitations, it may be difficult to respond to the queries of Bohm-Bawerk. The two systems do not seem to be independent, yet the level of direct connection is limited, and indirect interaction seems to dominate. Given the above, the resolution of the problem of wherein lies the motivation for present actions and behaviours seems unlikely.

The fact that the systems are different, however, is relevant to the problem at hand. One may go to extensive length in describing a cognitive model of how an optimal decision should be made in a certain decision context, and

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[26] LeDoux (1984), p. 366.

despite that, find that an individual chooses an alternative action or behaviour due to the influence of emotion, feeling or affect. And individuals' abilities to "know themselves" in this way may be limited. Individuals often plan to behave in certain ways based on often elaborate cognitive models but when the time arises, behave in rather different ways, perhaps responding to more immediate feelings and emotions. This could create potentially serious problems for the use of preference and choice theory of neoclassical economics and its presumed ties or links to social optimality in resource use.

Some Notes on Individual Rationality and Intertemporal Choice

Lea et al. (1988) state the following:

> "Almost all economic theory, and almost every empirical economic investigation, seems to be fundamentally based on the idea that human behaviour is rational, in the sense that it can be understood by asking how a well-informed individual would act to secure his or her best advantage. By contrast, almost every approach to psychology implies that something other than rationality determines behaviour. For learning theorists, it is schedules of reinforcement; for Freudians, unconscious motivations; for developmentalists, the individual's stage of cognitive development; for social psychologists, the current social context and the way the individual represents it; even cognitive psychologists argue that the individual's particular information processing machinery will constrain his or her performance."[27]

The authors state the above as a prelude to a discussion of three topics related to this thesis, riskless choice, choice under uncertainty, and intertemporal choice. They

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[27] Lea et al. (1988), p. 103.

conclude that

> "...the rationality assumption is at best unproven, generally unhelpful, and sometimes clearly false."[28]

They note other areas where such failures occur as well, such as

> "...the tendency to commit further resources to a failed course of action (see Staw 1976), or the kind of situation studied by Teger (1980) in which short-term "rational" behaviour leads people into long-term disasters..."[29]

Such things as this are of interest to the researcher, because the optimality of the market is conditional on the optimization/behavioral assumptions made about the actors.

Lea et al., however, do not believe that just because it can be shown that certain assumptions are violated, the economic rationality paradigm need be discarded. They offer three types of arguments. The first is based on work like that of Friedman (1953) which suggests that the important issue is not the validity of assumptions, but rather the accuracy of predictions. The authors feel that the usual analogy to the assumptions of physics (i.e., that gas molecules are smooth, etc.) fails in important respects, and they suggest the explanation would, perhaps, be better accepted if economists record for forecasting could parallel the physicists' record (for example for the behaviour of gasses). They state:

> "...false assumptions are trickly tools. Constant effort is required to make sure that their implications are kept out of the range where

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[28] Lea et al. (1988), p. 127.

[29] Lea et al. (1988), p. 127.

falsehood matters (cf. Stewart 1979, chapter 6). By itself, then, this pragmatic defense of rationality would seem to be insufficient."[30]

The second argument turns on the issue of what behaviour is deemed to be rational. They note that Rochlin (1980) emphasizes that the economic paradigm will continue to evolve to cover more and more types of behaviours which seem to be consistent, and therefore rational. One example they site of this is the evolution of the subjective expected utility theory from the expected value principle. Determining what is rational behaviour is a type of question which keeps evolving as the assumption of what constitutes rational behaviour evolves. Rochlin (1980) suggests that psychologists should rather focus on the diverse things which people pursue, and spend less time fighting the maximization hypothesis. Lea et al. (1988) would seem to be of the opinion that rationality and maximization are equivalent. They refer to Rochlin's (1980) view that "any consistent behaviour can be described as maximizing something.[31]

The authors focus on approximate maximization as an explanation for some behaviours which depart from strict rationality. They suggest that the costs (lost benefits) from not pursuing strict rationality are low, or the maximum is relatively insensitive to departures from strict rationality.

Their conclusion is that the rationality assumption cannot easily be shown to be indefensible, and the focus on that question, "is economic behaviour rational?", merely leads us to other questions about human behaviour, such as what are the ends of human behaviour?

This in itself has implications for the use of economic models for policy evaluation. For example, if the ends of

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[30] Lea et al. (1988), p. 128.

[31] Lea et al. (1988), p. 130.

human behaviour are not represented properly in the utility structures posited, then even if the rationality assumption is ever approximately satisfied, the policy prescriptions may be totally wrong.

One of the subjects covered by the authors is of particular interest to this thesis, that of intertemporal choice. Lea et al. (1988) claim,

> "Conventional economic demand theory says nothing about intertemporal choice...Koopmans (1960) pointed out that to give any coherent account of most intertemporal choices, we need to make an assumption in addition to the conventional axioms of demand theory. In effect we need to add a new axiom, the axiom of time preference proper. This axiom asserts that if two outcomes differ only in the time of delivery (certainly of delivery therefore also being equated), the sooner outcome is preferred."[32]

Many critical economic choices are of this sort, savings, investment, consumption all have intertemporal dimensions which affect the economy. Four influential factors which the authors cite are:

> 1. the probability of receiving the commodity bundle chosen; 2. the interest rates available; 3.the likely movements of prices of the commodities concerned; 4. time preference proper.

These types of economic activities or behaviours are most commonly studied in "the so-called delay of gratification" experiment. The authors state the following results:

> "...young children are less likely to delay gratification than older children" (Mischel and Metzner 1962).
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> "...psychotics are less likely to do so than are

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[32] Lea et al. (1988), p. 123.

normal controls" (Shybut 1968).

> "...normal adults certainly do not delay gratification to a rational extent" (Turchi 1980).

and conclude

> "The entire delay of gratification literature, in fact, suggests a far greater preference for immediacy than any economic theory could justify."[33]

The authors also cite the work of Friedman (1963) (based on large-scale panel data and econometric estimates), which identified subjective discount rates of about 30% where inflation and interest rates were single-digit numbers. Again, the authors conclude:

> "Qualitatively, these data...support the conclusion that there is more preference for immediacy than rationality predicts."[34]

Although all of the available research seems to point in the same direction, the amount of the psychology literature which can directly be applied to economic decision questions is limited (i.e., failure to delay gratification may not be economically irrational), and the results on purely economic choice problems come from a small number of studies.

Still the potential implications can be very serious if personal discount rates are excessive. For the representative mine owner, a 30% discount rate would encourage a much more rapid drawdown and sales rate than market optimality would prescribe. The future costs of environmental pollution also discounted at 30% could be negligible today. This is

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[33] Lea et al. (1988), pp. 124-127.

[34] Lea et al. (1988), p. 127.

certainly an area where further research is clearly called for in the context of the equitable way of consuming finite resources over time.

Modern Time Preference

Robert Lind in his introduction to Discounting for Time and Risk in Energy Policy, a collection of papers by prominent expert economists on discount rates, states that as far as work on the social discount rate goes,

> "...there is no agreement on how this rate should be determined, nor on what the correct rate should be."[35]

Lind points out the idea that the choice of a social discount rate will often reflect political determination for this reason. Groups which will be favoured by a high rate in a particular case, will push for it. But this can create problems even within specific groups. For example, environmentalists may find that for a water resource problem a high discount rate is preferred because it will slow development, whereas for a long term pollution problem, a low discount rate may be more favourable.

There are several components which may be combined to form the discount rate. One reflects the social cost of capital, and another reflects a risk adjustment for a specific project, others reflect adjustments for various time preference measures.

Lind states, that in the 50's and 60's at one extreme there were economists who claimed that the social discount rate should equal the market rate of interest, focusing on the theoretical model for a competitive economy, and at the other extreme were economists who claimed that it should

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[35] Lind (1982), p. 3.

equal the consumption rate of interest. The consumption rate of interest is the rate at which consumers are willing to trade consumption in this period for consumption in the future. Others thought some combination of rates would be best. Lind refers to a polling of experts at a Resources for the Future conference in 1966, where the suggested optimum rates ranged from two percent to twenty percent. Today there still seems to be a quite wide divergence of opinions.

There are a number of questions of intergenerational equity which are raised in the context of finite resource economics. Lind describes the following cases,

> "We have finite supplies of fossil fuels and at some point we will have to switch to alternative sources of energy to support future generations. If we are to have new sources of energy in place for future generations, we must begin to do the necessary research and development. If we do not, future generations may have a markedly reduced standard of living because past generations depleted the resource base without providing a substitute. However, research and development on technologies that will not be used for many years may not appear justified economically, given that the benefits that accrue many years in the future have a low present value. Proponents of such research and development question the wisdom of postponing or failing to undertake such research on the basis of benefit-cost calculations, which appear to them to assign too little weight to the welfare of future generations.
>
> We are considering energy options that may impose catastrophic environmental costs in the distant future. A striking case in point is nuclear power and the problem of nuclear waste disposal. Suppose that we could put the waste in containers that would safely last two thousand years but then might release the waste into the environment raising the possibility of large-scale contamination. In this case, the potential costs to future generations would begin thousands, not just hundreds, of years in the future. Discounting those costs at any positive rate would make them appear minuscule.
>
> There are many who share the concern that it is not appropriate to choose a nuclear option on the basis of a benefit-cost calculation that places a very low

> weight on possible catastrophic consequences in the future. They have a similar concern about a policy of not pushing ahead on the research and development that will provide future generations with a safe, economical, and environmentally sound energy option. They question the efficacy of an evaluation procedure that appears, from their perspective, to disregard the interests of future generations and lead to the adoption of unwise policies."[36]

There are clear connections between rates of current energy, usage, economic growth, demand for finite resources on the one hand, and pollution, other environmental hazards and more risky energy and production alternatives which are encouraged on the other. We should not consider natural gas depletion without considering the long term as well as short term effects, that it will have on the economy, and the overall quality of life for this generation, and all future generations.

Lind focuses on two questions, specifically relating to the subject of the thesis. The first has to do with the discounting of future benefits and costs, and he suggests that if one is egalitarian among generations, we should perhaps accept a benefit-cost framework, but use a zero discount rate. The second focuses on the philosophical foundations of benefit-cost analysis, choosing programs which maximize some sum of discounted utilities. He notes, as we did in Chapter two, that the utilitarian approach is considered by many to fail badly with respect to fairness among generations. He asks if the criteria can be improved, or constraints added to salvage the framework. Rawls (1971) notes that the failing in the criteria requires the replacement of the criteria.

There were two major papers in Lind (1982) which are particularly relevant to the thesis, Dasgupta (1982), and Sen

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[36] Lind (1982), p. 11.

(1982).

The Dasgupta paper will be reviewed, because he presents and clarifies a number of concepts which have often been confused with each other, for example, the rate of pure time preference and the consumption rate of interest. Dasgupta presents a model with an infinite horizon, with constant population size, and identically treated individuals. Consumption at time t is divided equally among all people living at the time. Consumption is normalized, and aggregated at time t, and $\{C_t\}$ represents an infinite consumption sequence $(C_0, C_1, \ldots, C_t, \ldots)$. C_t is an element of the set F of feasible consumption sequences. The objective function is $W(\{C_t\})$, which is the planners social welfare function.

He defines a sequence $\{C_t\}$, an element of F, as efficient if there is no other sequence $\{C'_t\}$ such that $\{C'_t\} >= \{C_t\}$ for all time, with $\{C'_t\} > \{C_t\}$ for at least one time period. Now it is assumed that W is increasing in each of its arguments; that is, that W is Paretian.[37] "Because of this", he claims, "we know that the optimum consumption sequence is efficient." (He does note that what he offers is not the usual definition of a Paretian welfare function).

The "consumption rate of interest", denoted by P_t, is the "rate at which it is found just desirable to substitute consumption at some period t for that in the next period t + 1." The factors which lie at the basis for this are several. An extra bit of consumption at t may be more valuable than an extra bit at t + 1, because one might have more total consumption at t + 1 in the first place. Because of this Dasgupta says, we may wish to have P growing proportionately to time, or even more than proportionately. He focuses on the rates between adjacent time periods only,

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[37] Meaning Paretian efficient.

stating "...it may not seem reasonable to have P_t depend significantly on consumption rates at times far away from t."[38]

A second factor relates to the idea of "the rate of pure time preference" or the "rate of impatience" which has to do with individuals undervaluing consumption at time t + 1, as compared with time t. In our previous discussions of this topic, we saw a fair amount of opinion which implied that such an approach reflected a defect in planning on the part of individuals. Dasgupta, however, states that a rationale for this would be that "one may wish to take into account the possibility of extinction." These are the rationales offered for P > 1, or positive consumption discounting. He states,

> "The rate P_t is a pure number per unit of time. In traditional terminology, it is the marginal rate of indifferent substitution between consumption at time t and consumption at time t + 1 less unity."[39]

Thus far we have encountered

- the consumption rate of interest
- the rate of pure time preference
- the rate of impatience
- the marginal rate of indifferent substitution

No wonder this area is a bit bewildering to the layman, and there is more to come.

Intertemporal optima are analogous to those of single period analysis with several goods, or the usual two period models presented in basic texts. The social rate of return on investment, r, is the slope of a tangent to AB at point D, given a W we wish to maximize, on the picture below.

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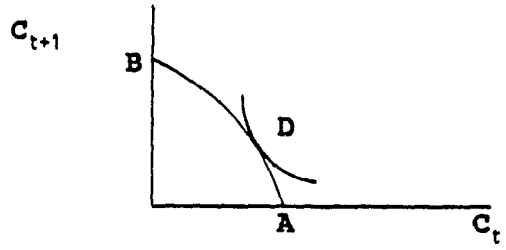
[38] Dasgupta (1982), p. 276.

[39] Dasgupta (1982), p. 276.

AN INTERTEMPORAL OPTIMUM

$$W(\bar{C}_0, \ldots \bar{C}_{t1}, \bar{C}_t, \bar{C}_{t+1}, \bar{C}_{t+2} \ldots) = \text{a constant}$$



The social rate of return on investment relates the rate at which it is technologically possible to exchange consumption at time t for consumption at time t + 1. $\frac{C_{t+1} - Ct}{C_t}$ is a rate of return for witholding consumption today for consumption tomorrow. Given the above, we can not do better than set P = r, at D, where the marginal rate of indifferent substitution is equal to the marginal rate of transformation. The above P = r is a necessary and sufficient condition for social optimality.

Dasgupta next presents a continuous time formulation,

$$* \qquad W = \int_0^{\infty} e^{-\delta t} U(C_t)\, dt$$

with

$$\delta \geq 0,\ U'(C) > 0,\ U''(C) < 0,\ \lim_{C \to 0} U'(C) = \infty \text{ and } \lim_{C \to \infty} U'(C) = 0$$

similar to the usual discrete time utilitarian formulation

$$W(\{C_t\}) = \sum_{t=0}^{\infty} U(C_t)/(1 + \delta)^t \ , \ \delta > 0.$$

He states,

> "I have qualified the term 'utilitarian' advisedly. There are several distinct moral frameworks that can be appealed to, to justify equation (7) [* above], of which classical utilitarianism is one. Since I do not wish to appeal to classical utilitarianism, it will be appropriate to refer to U(·) as the

felicity function."[40]

δ is defined as the felicity discount rate.

There are many other authors as well, who have focused on the use of the market mechanism to solve intergenerational and intertemporal problems, and an overview of their results will be offered later in this chapter, as it represents the standard neoclassical approach to these problems. However, there are dissenting opinions.

Some Notes on the Use of Growth Models in Economic Resource Allocation

The economics profession does not uniformly condone the use of market mechanisms for resource allocation, or the use of growth models in providing evidence of "fair" treatment of different generations. One of the most outspoken critics of growth orientations, and the ethical implications of the acceptance of those models is Esra Mishan. Mishan (1977) examined five growth models which produce different generational time paths for resource use. These models were selected by Mishan because they are as a group, representative of the bulk of the economic research directed toward the problem of intergenerational equity, and a brief review of some of his results will help to elucidate his, and many other economist's views of this class of models.

The first model is that of Ramsey (1928). This model is an extension of the basic neoclassical market model, where the labour force is constant over time, and consumer goods, capital goods and labour are homogeneous aggregates. Analogously to the standard neoclassical paradigm, we are given tastes, factors of production, and initial endowments,

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[40] Dasgupta (1982), p. 279 $u_t(.)$ refers to $u(c_t)$ in * above, however is interpreted in a wider way than the classical utilitarian approach.

as well as several constraints which are that the returns to capital and the utility of consumption increase at a decreasing rate. The maximand is aggregate utility. [41]

In the Ramsey model, a time path of savings generates a time path of capital and consumption, and therefore of utility. Mishan states that Ramsey expresses a moral judgement when Ramsey claims that discounting the utility of future generations is "unimaginative and unethical". Hence, the intertemporal capital stock which maximizes utility is described as that which results from the equality of the percentage rate of decline in marginal utility and the percentage rate of return on capital; a ceiling on the path of aggregate utility is established by requiring that the returns to capital or the marginal utility of consumption eventually go to zero. The optimal consumption path is one that grows at a diminishing rate until a highest possible level is achieved where it remains through the rest of time.

It appears, that in the Ramsey model, early generations are willing to give up consumption so that later generations can gain more, and this aggregate utility is maximized. This is due to the influence of the "no discounting" assumption.

The next model which Mishan (1977) discusses is that of Strotz (1955). In this model, there is one individual (Crusoe) per generation, who has at his disposal a non-deteriorating consumption goods stock. The individual must decide how to distribute this stock over time such that at any later point in time he is equally satisfied with all the previous plans which he had made. In this example though, it is as if Crusoe is a different person at each point in time, although he has the same utility function. Still, even with identical utility functions, each

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[41] Mishan, E.J., "Economic Criteria for Intergenerational Comparisons", Futures, October 1977). Ramsey, F., "A Mathematical Theory of Saving", The Economic Journal, 38 (1928). pp. 543-559.

generation-individual could prefer a different intergenerational consumption path. The question is which criterion should be used to choose among the various time paths? The choice of consumption path, given the generation-individual's utility weights, is that which maximizes utility for him, still given that the utility of consumption increases at a decreasing rate whenever it takes place.

Strotz claims that a sufficient condition for all individuals to choose the same consumption path is that they all use an exponential weighing device, which applies a common rate of discount to the utility of all future generation-individuals.[42] The cutoff rate of consumption for each individual is determined by the point at which the percentage decline in marginal utility is equal to r.

Mishan notes that for r>0, the time path of consumption declines asymptotically; in the case where r=0, the time path of consumption is constant, and the marginal utility of consumption is constant across generation-individuals. It seems that whereas Strotz is concerned about consistency in plans, given that current generation individuals cannot change past decisions, Mishan is concerned with the ethical content involved in the selection of any consistent or non-consistent criterion which might have been agreed upon at a meeting of all generation-individuals in time zero. The Mishan criticism seems to have its basis in the contractarian tradition which seems to have peaked with Rawls. It is not clear that different generation individuals could overcome problems in interpersonal comparison which plague intragenerational comparisons of equity. However, the full discussion of this criticism of Mishan should wait until all of the models he discusses have been presented.

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[42] Strotz, R.H. "Myopia and Inconsistency in Dynamic Utility Maximization", Review of Economic Studies, 41 (1974) pp. 165-180.

The Dasgupta and Heal (1974) model is the next which Mishan analyzes and refers to as essentially a more elaborate and flexible version of the Ramsey model. Besides capital and labour, their model includes natural resource stocks, and as this usage is of prime concern in this paper, we will spend more time in the discussion of this model.[43]

Dasgupta and Heal utilize a production function model, whereby the intertemporal consumption path depends on the rate of discount, the elasticity of marginal utility with respect to consumption, and the elasticity of substitution in a constant elasticity of substitution production function. Mishan notes the above, yet prefers to use the simpler Cobb Douglas function, probably with little real loss in explanatory power; the difference is that in the latter model, the elasticity of substitution is constrained to be equal to one. Mishan states that the consumption time path will depend on the magnitude of the influence, (with respect to output) of capital inputs relative to natural resource inputs (a1 relative to a2).

If coefficient a1 exceeds a2, then it is possible to compensate for any pattern of usage of natural resources by appropriately increasing or decreasing the rate of accumulation of capital, so that output and consumption never fall to zero. We note also that labour is held constant throughout time. Here again, utility over time is maximized, and the general function (equation) which has the property that the percentage change in marginal utility divided by the percentage change in consumption is equal to a constant. This constant is called the elasticity of the marginal utility of consumption (1 + v). Utility increases with consumption, but at a decreasing rate, and is discounted at

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[43] Dasgupta P., and G. Heal, "The Optimal Depletion of Exhaustible Resources", Review of Economic Studies, 41 (1974). pp. 3-28.

rate r. Mishan notes:

> "...for any given positive rate of discount r, the optimal consumption path is one that (eventually) declines at a decreasing rate, though asymptotically. For high enough rates of discount, the optimal path declines continuously; for other positive discount rates the corresponding optimal time paths grow at first to a peak before declining. As for the magnitude of v, the higher it is, the longer the time taken to reach the point of highest per capita consumption before declining."[44]

Again in this model for the case of a zero discount rate, a single unit of consumption is worth the same through time. When v is infinite, Dasgupta and Heal obtain a constant level of consumption through time. With lower levels of v and r=0, the time path of consumption grows along with the continuous growth of the capital stock.

With a positive discount rate, and v < r, the higher the percentage loss in marginal utility for a percentage change in consumption, the longer the time it would take to get to maximum consumption per capita - the early losses are valued more highly than otherwise.

The fourth model is that of Solow, a neoclassical growth model with a maximim objective function, which differs from the others most radically from an ethical point of view in the following way (as well as in that he explicitly incorporates technological progress). The key item in the Solow paper is really the use of the Rawlsian approach which is reviewed in chapters one and two, and also later in this chapter.

The fifth and last of the models considered by Mishan is that of Page. This model requires that individuals weigh the utilities of all generations, past and future using the same

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[44] Mishan (1977), p. 387.

discount factor. These utilities are in the individual's own utility function, and it is presumed that there is just one "average person" in each generation, which results in utility maximization associated with equal consumption over time. This is interesting, but epistemologically impossible, the knowledge requirements are too great, and the model is not pursued here.[45]

Some Historical Concepts Relating to Time Preference

There are a number of circumstances, events and ideas which we have observed throughout history, which tend to influence time preference one way or the other and which at the same time reflect the values of a society. One of these is death duties, which have been well known from Roman times. The effect of these duties is to encourage the taxpayer to bring consumption closer to the present, and normally to reduce accumulation of wealth by individuals depending on love of children versus state. The value of this depends on one's view regarding who benefits from the dead person's industriousness. If one loves the state this can be a positive motivation for accumulation. Certain types of goods have been exempted from these duties, for example, land or family estates were frequently exempted, presumably to assist in the perpetuation of dynasties.

One of the oldest concepts relating to the rate of time preference is that of usury. In Jewish law, a loan was considered an act of charity. It was intertemporal, but paid back without interest. This tends to imply a zero discount rate. This was later embodied in Catholic Church doctrine and elsewhere. The earliest examples of this loan involved seed. With individual crop failures, seed was loaned by one farmer

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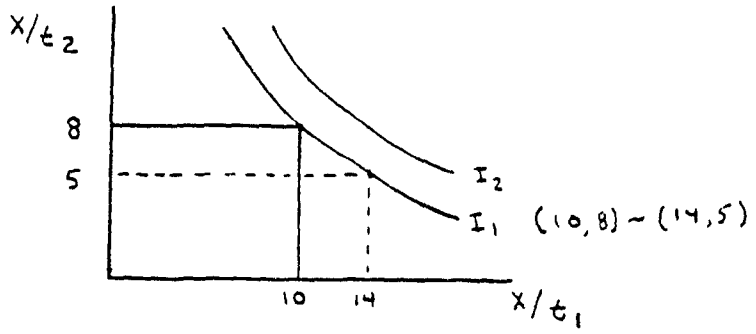
[45] See Koopmans(1965, 1967) for some notes on ethics and optimal growth models.)

and replaced after the following harvest. Here we see an example in which present consumption is viewed as equal to future consumption. Some individuals did try to get around the usury laws by becoming partners with those to whom money or seed was loaned, as it was not against Jewish law to share profits with a partner or repay a loan to a partner. This tends to lend credence to the view that not all individuals were in accord with the preference of religious leaders for a zero discount rate, or else they did not wish to consider all loans charitable acts. Still we realize that even today loans are sometimes made with zero interest rates, as charitable acts or social investments (an example would be interest-free student loans), and it would be an error to consider such a loan to be indicative of a general community endorsement of a zero rate of time preference.

It would appear that one could argue that high real interest rates are indicative of high rates of time preference. This may or may not be so because the time preference rate relates to only one item which influences the price of loans while the availability of good projects is also influential. Those with a preference for accumulation will tend to reduce current consumption and invest via the best means available, as they individually judge the alternative investment projects. This creates a supply of current funds. Those with an overwhelming propensity to consume today will borrow funds and face the possibility of reduced future consumption in order to repay the current consumption.

The discussion of modern preference theory thus far sounds quite myopic. Suppose an individual perceives that by reducing this year's consumption by twenty percent, he can increase his consumption by ten percent per year for the next twenty years. This individual may prefer today's consumption of a good to next year's yet, some sequence of increased

future consumption can tempt him to reduce today's consumption. In our modern analysis, we evaluate the location of indifference curves in intertemporal consumption space.



The above individual is indifferent between ten units of X today and eight units of X tomorrow (t2). How will he actually (perhaps physically) feel tomorrow about eight units of X? Would he still be on I1? Probably not. This is the element that was referred to as the "irrational" element in the section which preceded this. This brings us to a consideration of the relationships between individual savings, conservation, and intergenerational equity.

INTERGENERATIONAL EQUITY, JUSTICE BETWEEN GENERATIONS

The Approach of Rawls

In approaching the problem of justice between generations, Rawls offers the following caution:

> "There is no need to stress the difficulties that this problem raises. It subjects any ethical theory to severe if not impossible tests."[46]

Still, it is a problem which must be faced, and in the context of Rawls theory, it begins with a consideration of the level at which the "social minimum" should be set, which is

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[46] Rawls (1971), p. 284.

in turn connected to the question of "how far the present generation is bound to respect the claims of its successors"[47] If a "just savings principle" can be established, the level of the "social minimum" would be determined.

As an example, Rawls states the following,

> "Suppose for simplicity that the minimum is adjusted by transfers paid for by proportional expenditure (or income) taxes. In this case raising the minimum entails increasing the proportion by which consumption (or income) is taxed. Presumably as this fraction becomes larger there comes a point beyond which one of two things happens. Either the appropriate savings cannot be made or the greater taxes interfere so much with economic efficiency that the prospects of the least advantaged in the present generation are no longer improved, but begin to decline. In either event the correct minimum has been reached. The difference principle has been satisfied and no further increase is called for."[48]

In discussing the problem of finding a just savings principle, Rawls notes the work of several economists working in the area of growth theory, Sen (1961), Tobin (1966), Solow (1970), Ramsey (1928), Koopmans (1965), and Chakravorty (1969). He concludes, however, that in his opinion,

> "...I believe that it is not possible at present anyway, to define precise limits on what the rate of saving should be."[49]

He comments on some problems with classical utilitarianism, stating that from the "point of view" that his moral theory offers, the usual applications of the

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[47] Ibid., p. 284.

[48] Rawls (1971), p. 285-286.

[49] Rawls (1971), p. 286.

classical principle lead to errors in justice between generations. As an example, he describes a scenario where population size is a variable, marginal productivity of capital is high, and the relevant time horizon is long. Maximizing total utility leads to very high levels of capital accumulation in early periods, with early generations making great sacrifices for later generations. Thus, the utilitarian approach would allow early generations to suffer for later generations.

This approach is contrasted with the approach of contract doctrine. In the original position,

> "The parties do not know to which generation they belong or, what comes to the same thing, the stage of civilization of their society. They have no way of telling whether it is poor or relatively wealthy, largely agricultural or already industrialized, and so on. The veil of ignorance is complete in these respects. Thus the persons in the original position are to ask themselves how much they would be willing to save at each stage of advance on the assumption that all other generations are to save at the same rates. That is, they are to consider their willingness to save at any given phase of civilization with the understanding that the rates they propose are to regulate the whole span of accumulation. In effect, then, they must choose a just savings principle that assigns an appropriate rate of accumulation to each level of advance. Presumably, this rate changes depending on the state of society."[50]

Thus, there is no one, no single savings rate which all generations must meet, say ten percent per year, but rather it is some function of the stage of civilization, or possibly the level of income, or wealth of society. The rate of savings is decided by choice behind the veil of ignorance, and covers all rates for all time, just rates being elected

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[50] Rawls (1971), p.287.

on the basis of comparisons of states along entire alternative spans of accumulation.

To make this more concrete, Rawls states

> "When people are poor and savings is difficult, a lower rate of saving should be required; whereas in a wealthier society greater savings may reasonably be expected since the real burden is less. Eventually once just institutions are firmly established, the net accumulation required falls to zero. At this point, a society meets its duty of justice by maintaining just institutions and preserving their material base. Of course, the just savings principle applies to what a society is to save as a matter of justice.. If its citizens wish to save for various grand projects, that is another matter."[51]

There are several items to note here. First, Rawls does not state how the level of the burden is to be judged. Utilitarian psychology might be useful here. Second, the level of accumulation at which just institutions can be maintained is not specified. Third, Rawls seems to differentiate between saving for grand projects and saving for accumulation for the achievement of just institutions, or the raising of the material well being of society. In either case the latter would seem to suggest "directed savings" or the accumulation of certain kinds of capital, and seems to imply a much more specific understanding of the future than is ever likely to be possible. General statements regarding savings levels and capital accumulation seem to be more reasonable.

Rawls does state, that the capital which is accumulated,

> "... is not only factories and machines, and so on, but also the knowledge and culture, as well as the techniques and skills, that make possible just

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[51] Rawls (1971), pp. 287-288.

institutions and the fair value of liberty."[52]

This wider definition captures the idea of "human capital" used in economics, but goes beyond that conception and into culture and values. This seems to point to valuations being even more subjective and therefore less likely to be agreed upon. However, Rawls implies that these things will be known, and not problematic, because

> "It is characteristic of the contract doctrine to define a just state of society at which the entire course of accumulation aims. This feature derives from the fact that an ideal conception of a just basic structure is embedded in the principles chosen in the original position."[53]

Rawls states

> "The just savings principle can be regarded as an understanding between generations to carry their fair share of the burden of realizing and preserving a just society. The end of the saving process is set up in advance, although only the general outlines can be discerned."[54]

Rawls states that it is the agreement on the principles of justice for institutions that tells us what to strive for.

> "The savings principle represents an interpretation, arrived at in the original position, of the previously accepted natural duty to uphold and to further just institutions. In this case the ethical problem is that of agreeing on a path over time which treats all generations justly during the whole course of a society's history. What seems fair to persons in the original position defines justice in

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[52] Rawls (1971), p. 288.

[53] Rawls (1971), p. 288.

[54] Rawls (1971), p. 289.

this instance as in others."[55]

Rawls also emphasizes that his final stage to which society progresses need not be one of great wealth, which interestingly, is the sole end to which the utilitarian criteria directs us. He states,

> "It is a mistake to believe that a just and good society must wait upon a high material standard of life. What men want is meaningful work in free association with others, these associations regulating their relations to one another within a framework of just basic institutions. To achieve this state of things great wealth is not necessary. In fact beyond some point it is more likely to be a positive hinderance, a meaningless distraction at best, if not a temptation to indulgence and emptiness."[56]

Arrow on the Utilitarian and Rawlsian Approaches

Arrow states the utilitarian position with respect to allocative justice in the distribution of wealth between generations, and each generation's obligations to the following as:

> "The traditional economic problem has been the general art of investment in productive land, machine, and buildings which produce goods in the future; more recently we have become especially concerned with preservation of undisturbed environments and natural resources. The most straight forward utilitarian answer is that the utilities of future generations enter equally with those of the present. But since the present generation is a very small part of the total number of individuals over a horizon easily measurable in thousands of years, the policy conclusion would be that virtually everything should be saved and very

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[55] Rawls (1971), p. 289.

[56] Rawls (1971), p. 290.

little consumed, a conclusion which seems offensive to common sense."[57]

I don't really see the offense to common sense, especially as regards the state of the natural environment, or the use of finite resources which may be essential to life - the ozone layer, etc. If forest lands and recreation areas of value to humans can be used (consumed) in such a way that they can be used by other generations to follow - there's little problem. But if they are used, such that they are lost to all following generations, then we may be doing them a bad turn.

Arrow continues the representation of the usual utilitarian approach in the following:

> "The most usual formulation has been to assert a criterion of maximizing a sum of discounted (italics) utilities, in which the utilities of future generations are given successively smaller weights. The implications of such policies seem to be more in accordance with common sense and practice, but the foundations of such a criterion seem arbitrary."[58]

Arrow notes that Rawls' approach of using the initial position to find a just rate of savings has two problems,

> "(1) Why should they agree on a fraction rather than some more complicated rule, for example, an increasing fraction as wealth increases? (2) More serious, it would appear that the maximin rule would lead to zero as the agreed on savings rate; for the first generation would lose under any positive savings rate, whereas the welfare of all future generations would increase."[59]

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[57] Arrow (1973), p. 260.

[58] Arrow (1973), p. 260.

[59] Arrow (1973), p. 261.

This is exacerbated by the likely effects of technological progress, and Arrow notes that the lot of the first generation can only be improved by negative savings.[60]

Rawls, however, uses a different type of motivation here, which Arrow quotes as follows:

> "The parties are regarded as representing family lines, say, with ties of sentiment between successive generations."[61]

Arrow notes that this is a radical departure from Rawls earlier egoistic assumptions and notes that the intergenerational ties suggested amount to a discounting of future utilities as the generational ties reach further out into the future. Similar structures have been applied in some societies as measures of other-regardedness, "kinship ties".

Arrow also proposes that Rawls approach to the intergenerational problem is essential, but compromising,

> "Although my guess is that any justification for provision for the future will run somewhat along these lines, it cannot be said that the solution fully escapes all difficulties. (1) It introduces an element of altruism into the original position; if we introduce family sentiments, why not others

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[60] Arrow notes, "To be precise, the above argument is valid only in the absence of population growth. If population is growing, then zero savings would mean less capital per person and therefore a falling income per capita. Hence, a maximin rule in the absence of technological progress would call for positive savings; it can easily be shown that the rule would be that the rate of savings equals the rate of population growth multiplied by the capital-output ratio." [Arrow (1973), p. 261]

[61] Rawls (1971), p. 292, in Arrow (1973), p. 261.

(nation, tribal)? And why not elements of envy? (2) One might like a theory of justice in which the role of the family was derived rather than primitive. In a reexamination of social institutions why should the family remain above scrutiny, its role being locked into the original assumptions? (3) Anyway the family argument for savings has an implication that should be displayed and might be questioned. Presumably the burden of savings should fall only on those with children and perhaps in proportion to the number of children. Since education and public construction are essentially forms of savings, taxes to support them should fall only on those with children. In the original position, this is just the sort of contract that would be arrived at if the concern for the future were based solely on family ties."[62]

However, children are not only consumers and consumption goods. They are also the actors in the plays the elders enjoy, and are responsible for technological progress which may make the standards of living for both parents and non-parents superior. There are probably a number of non-family sentiment reasons to be interested in the provision for the next generation.

In a critical note on the possibility of justice in his review of Rawls (1971), Arrow identifies a number of interesting points. First he considers the possibility of a universalizable concept of justice. He notes the serious problem that having limited information creates, even if one can forget who one is for the purposes of the original position. This he suggests causes the possibility of application of the theory to be exceedingly unlikely. He notes that Rawls was aware of this, and notes that Rawls argued the benefits of diversity in life experiences to society - a kind of natural complementarity is possible and the social nature of man, it is said, springs from this. But Arrow sees a positive value to conflict, in this arena

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[62] Arrow (1973), pp. 261-262.

characterized by participants with limited information,

> "...many sociologists would hold that... conflict unresolved by appeal to commonly agreed principles may have a positive value; it is the means by which information about others is conveyed. In its own sphere, this is the role assigned to competition by economists; if everyone attempted to act justly at every moment in his economic life, it might be difficult even to find out what the true interests of anyone were."[63]

As for the economic analogy, I note that while independent assertiveness is essential to competition, fair and equitable rules are also necessary, and selfishness and total absence of other-regardedness are not essential.[64] Such concerns are possible, under two situations (1) one guesses as to what the other prefers (2) one acknowledges what the other tells us about his preferences. While individual's needs may not be totally known to us, neither are they completely unknown. Further, there is also the issue of whether what others believe to be best for them is actually best for them. Arrow's conclusion may be a trifle strong in this regard.

> "To the extent that individuals are really individual, each an autonomous end in himself, to that extent they must be somewhat mysterious and inaccessible to each other. There cannot be any rule that is completely acceptable to all. There must, or so it now seems to me, be the possibility of unadjudicable conflict, which may show itself logically as paradoxes in the process of social decision-making."[65]

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[63] Arrow (1973), p. 262-263.

[64] These ideas and others relating to competition are analyzed in depth, in Armstrong (1982), Competition and Monopoly.

[65] Arrow (1973), p. 263.

Obligations to Future Generations

In their introduction to Obligations to Future Generations, a collection of symposium papers, Sikora and Barry (1978) emphasize that the development of nuclear destructive capability encourages the questioning of our obligations to future generations. We have moved beyond a point where we once thought that mankind has an unlimited future, and the practical reality of making sacrifices today, to ensure the quality of life, and even just the survival of future generations is much more important than ever before. If we don't think we have any obligations to future generations, we may be more likely to hit the nuclear button than if we do.

They also raise an issue very relevant to this thesis,

> "Large population increases are also a threat to mankind's survival. Paradoxically, increasing the world's population may decrease the number of people who exist in the future because the more people there are, the more potentially lethal pollution there will be, the more the danger of conflict over limited resources there is likely to be, etc., so that the more people there are the greater the threat to the existence of future generations will be. The question then of whether or not it is wrong to prevent the existence of future generations is not an idle academic issue, but bears directly on very real contemporary problems."

Few would disagree that our destructive capability has increased dramatically over the years, but the issue of conflict over scarce resources is debatable, and here economics and the natural sciences may offer some factual information to the philosophical debate. The question which is pursued in a first group of papers is

> "...whether and to what degree it can be morally incumbent on us to make sacrifices to bring happy people into the world or avoid preventing them from

being brought into the world."[66]

Schwartz (1978, Warren (1978) and Naverson (1978) answer in the negative, Bennett (1978) and Scott (1978) are in the middle, and Sikora (1978) is on the positive side. The Williams (1978), Kovka (1978) and Barry (1978) papers emphasize the question of what, if anything, we owe future generations.

Protecting Future Generations

R.E. Goodin (1985) in Protecting the Vulnerable, devotes special attention to the problem of future generations. He gives examples from Parfit (1983, 1984) and Smart (1973) involving the discounting of the interests of future generations, and even those who are distant from us on the basis of kinship ties. Goodin states,

> "Discounting the claims of our descendants, of course,, flies in the face of any theory of intergenerational justice. Alas, theories of intergenerational justice have until recently gone undeveloped. Before Rawls (1971), virtually no modern philosopher had devoted any sustained attention to the problem. Ever since then, it has been discussed very largely in connection with the issue of overpopulation."[67]

Goodin sees a primary problem in the way the question has been posed, in asking what we owe future generations. This he says turns into a question about the possibility of purely potential people having claims in terms of rights against us. On this issue he states

"As far as I am concerned, this foundational

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[66] Sikora and Barry (1978), p. viii.

[67] Goodin (1985), p. 169.

> question has been conclusively answered by Feinberg's (1980, 159-84) penetrating essay on "The Rights of Animals and Unborn Generations". Feinberg's argument is twofold. First he demonstrates that 'the sorts of beings who can have rights are precisely those who have (or can have) interests' (Feinberg 1980, 167). Then he goes to show that, 'whoever these [future] human beings may turn out to be, and whatever they might reasonably be expected to be like, they will have interests that we can affect, for better or for worse, right now. That much we can and do know about them. The identity of the owners of these interests is now necessarily obscure, but the fact of their interest-ownership is crystal clear, and that is all that is necessary to certify the coherence of present talk about their rights' (Feinberg 1980, 181)."[68]

Goodin claims that the question of what future generations claims are or what our duties are, and how they can be justified are questions which have received scant philosophical attention. He is critical of Rawls (1971, section 44) contractualist approach, which he says is capable of several interpretations, none of which succeeds. He claims,

> "Rawls, himself prefers to imagine that everyone in the 'original position' is drawn from a single generation; the veil of ignorance merely prevents people from knowing their generations place, early or late, in the history of its society."[69]

This is not pursued by Goodin at this point, but rather he goes on to the two interpretations, the Kantian, and then the Humean version of the theory. He states

> "For the Kantian interpretation of theory, that [the above] may be enough. Each generation would prefer

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[68] Goodin (1985), pp. 169-170.

[69] Goodin (1985), p. 171, on Rawls (1971), sections 24, 44.

> that its predecessors had saved; universalizing that rule, in Kantian fashion, would therefore require that each generation should itself similarly save for future ones. On the Humean version of the theory, however, this argument is of no consequence. Each generation will reason as follows: surely we wish that our predecessors had saved for us; but since we are all members of the same generation, making rules only for ourselves, we must simply take what they have done as given; and however much or little they have saved, we contemporaries will be better off now if we ourselves save nothing."[70]

The Humean version of this theory, as described by Goodin, turns on the mutual disinterestedness of individuals to the pleasures or pains of their contemporaries. This would spell the end for intergenerational justice, save a claim that there is benevolence within households, or that individuals are inclined to be generous with their immediate successors. Goodin notes problems with this, especially "sleeper effects", which hinge on generational distance weakening individual ties of benevolence.

> "...it cannot stop us from doing something now that will inflict damage, however certain and severe on the fifth generation to come."[71]

Goodin notes that it would have been better for Rawls to select the Kantian approach alone (which he notes poses a two pronged attack showing that all meta-ethics leads to the same conclusion), and let all people past, present, and future find the just arrangement in the one which commands "universal hypothetical assent". Goodin notes that Rawls considers the possibility of interpreting his theory in the way in which representatives of all generations are present,

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[70] Goodin (1985), p. 171.

[71] Goodin (1985), p. 171.

however he rejects it on the ground (which Goodin also rejects) that it would "stretch the fantasy too far".[72] Goodin refers to the work of Barry (1977) for what he considers to be the real philosophical problem with the fantasy stated as follows:

> "How are we to conceptualize people who would have been born if one course of action were chosen, but not if others were pursued instead? Rawls allows us only two options. One is to imagine an "original position" that is a convocation of all possible people, present and future. But then we would have to face the prospect that some of the people who join us in our deliberations in the original position might in consequence of those deliberations, never be born. That smacks uncomfortably of making deals with ghosts."[73]

He continues with a quote from Barry (1977, p. 282):

> "Not to be born after you have already attended a meeting of representatives takes on too much of the aspect of dying extremely prematurely."

He rejects a final possibility, of choosing only people who will be sure to be actual people to attend the convocation, as logically incoherent,and concludes that the Rawlsian approach to intergenerational justice is "untenable in any form".[74]

Goodin (1985) also reviews the work of Sumner (1883), and Laslett (1970), in whose scheme "we discharge our debts to our parents through the aid we render to our children."[75]

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[72] Rawls (1971), section 24.

[73] Goodin (1985), p. 172.

[74] Goodin (1985), p. 173.

[75] p. 173

"...Future generations are, in this way, seen as just another instance of that familiar jurisprudential phenomenon, the third-party beneficiary." Also, another version of this type of argument based on trusteeship in Baier (1980) is considered, as are relations based on vulnerability in Barry (1977) and Goodin (1985, p. 177-178).

Other Philosophical Approaches to Intergerational Justice

There are other alternative philosophical approaches to intergenerational justice. Richards (1983), for example, argues in favour of the use of contractarian theory in providing foundations for intergenerational justice, interpreted, he states, in terms of the equal opportunity criterion proposed by Barry (1978) and Page (1983). Richards notes that the Humean circumstances of justice which form the basis for Rawls work, do not really apply well to the international or intergenerational contexts. The circumstances that would make Rawl's analysis applicable are:

> "(1) rough equality in the powers and capabilities of persons, (2) "confirmed generosity" (Hume) such that human nature is neither so vulpine as to make larger social cooperation impossible nor as benevolent as to take no reasonable steps to advance self- interest, and (3) moderate scarcity, such that goods are neither so scarce that social cooperation is pointless nor so abundant that it is unnecessary."[76]

Richards discusses justice as a virtue, in terms of moral sentiment as follows:

> "The principles of justice are those ethical principles that adjudicate the conflicting claims

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[76] Richards (1983), p. 132

> on scarce goods of persons so described in circumstances so defined. If human nature were different or moderate scarcity became superfluous abundance the virtue of justice, like Marx's state, might fade away. Put roughly, within these circumstances the principles of justice, whatever they are, secure a balance of reciprocal advantage to persons who regulate their conduct accordingly. Ex hypothesi, everyone (being roughly equal) stands to gain from justice in the defined circumstances."[77]

It seems that the existence of virtue is contingent upon agents of certain characteristics and potential, and circumstances of certain types. Should one or both change, the virtue of certain types of behaviour would be lost, and "morally right behaviour" in pursuit of virtue would be a different behaviour.

This virtue is achieved in a moral posture based on reciprocal advantage, a situation which is almost impossible to achieve in intergenerational situations and very difficult in international contexts. For the reason that the "radical non-reciprocity associated with international or intergenerational justice", makes ambiguous the idea of equality needed for Humean constructs, Richards claims, that though not "inapposite" to the concept of justice, actual reciprocity is an insufficient basis on which to ground intergenerational justice.[78]

In discussing his basic approach to ethical debate, Richards states,

> "Arguments of justice are, I take it, forms of moral argument especially concerned with the distribution of goods and evils among the conflicting claims of persons on them. Qua moral, these arguments define forms of practical reasoning that persons would find

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[77] Richards (1983), p. 132.

[78] Ibid., p. 132.

> reasonable whether they are on the giving or receiving end. Moral reasoning thus conceptually incorporates some significant constraint of reciprocity - what some philosophers would call universalizing ability and others, role reversibility."[79]

This is clearly not a summary statement on moral discourse, or the rules of the game; for example, such reciprocity is hardly essential to divine command types of systems of moral thinking - but it is consistent with the contractarian approach to moral dilemmas. The latter approach is Kantian, treating persons as equals, and engaging in this type of reciprocity, which is quite different from the reciprocal advantage idea of the Humean approach. He states,

> "...in moral argument we appeal to forms of practical reasoning whereby we inquire whether putative conduct is one [sic] persons (italics) would reciprocally accept whether on the giving or receiving end. In Kantian terms, moral argument invokes our capacity to think critically about our lives and to take personal responsibility for them as beings capable of freedom and reason; we identify others as persons by their having the like capacity; and in reasoning morally and acting accordingly, we treat others in terms of principles we and they would reasonably accept, thus expressing respect for their human dignity."

This type of equality, he claims is basic to moral argument, as well as to the development of the concept of justice.

Thus, Richards firmly settles himself into the contractarian camp, and presents Rawls' theory as the basic analytical model of "Contractarian Theory".

One item of note in Richards' description of Kant and Rawls, is the emphasis he places on the division of goods -

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[79] Richards (1983), p. 132.

general versus distributive goods. He defines "general goods" as "those things or conditions that are typically the objects of rational choices or desires or the generalized means to a variety of particular desires. It is natural to classify forms of liberty as general goods... similarly it is natural to define opportunity, property and wealth as basis distributive goods."[80] Rights and liberties are generalized means, opportunity, etc. are specific means.

Such a partition on goods makes me think that there is presumably a partition between lifestyles based on distributive goods, and lifestyles based on self-actualization. The latter is presumed independent of the specific goods desired, e.g., a nuclear power economy or a solar power economy - distributive goods and self-actualization are independent. If one takes the view that they are not independent, then the lexicographical ordering on the latter goods for self actualization (liberties) may be appropriate to the distribution goods, or some classes of them, as well.

Richards claims,

> "Clearly, this form of analysis, and the underlying Kantian perspective it expresses, can be limited only arbitrarily to the nation state or to one generation."[81]

Apparently, Richards takes the position that the existence of national boundaries is arbitrary, as is the exclusion of the problem of the presently non-existent future generation. He says of Rawls,

"Rawls himself applies the analysis to the

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[80] Ibid., p. 134.

[81] Richards (1983), p. 136.

international sphere, but does so in terms of his present entry interpretation of the contractors (the contractors are only persons living now) so that concern for future generations depends completely on the psychological assumption of one's interest in one's own offspring. His failure to consider international distributive justice is quite ad hoc and ill defended."[82]

In telling us how he sees the application of the contractarian framework to the intergenerational context, Richards suggests,

"... we should remind ourselves of the underlying idea the framework is intended to explicate, namely, to treat persons in the way one would reasonably like to be treated."[83]

Regarding those persons not presently existing he states

"insofar as the actions of one generation directly affect the interests of later generations (for example the depletion of the resource base), there is a relation governable by moral reciprocity."[84]

He later claims that,

"these intuitive moral judgements cannot... be adequately expressed by Rawls' present entry interpretation of the contract, or by variant reformulations of this interpretation, for the present entry interpretation rests on the morally fortuitous fact of one's actual generation. From the point of view of Kantian ethics, which is Rawls' point of view, one's actual generation is as morally arbitrary as one's race, gender, religion,

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82 Richards (1983), p. 136.

83 Richards (1983), p. 136.

84 Richards (1983), p. 136.

particular tastes, or anything else properly screened out by the veil of ignorance."[85]

Richards is critical of Rawl's adoption of the altruistic interest in children, where rational self interest alone is the basic force in the Rawls framework. He cites the many different reasons why people have children, and the problem of population selection as problematic areas for the Rawls structure. Richards suggests the development of hypothetical contract involving all generations, as the natural Kantian solution.

Richards noted that Rawls wants

> "...the intuitive appeal of present entry to enable his readers to enter the contract, and uses an ad hoc device of virtual representation ... to encompass the full class of persons that his Kantian assumptions want him to include."[86]

The idea of virtual representation is very appealing and connects the more abstract moral theory to the readers intuitive decision processes. Richards states his opinion that

> "There is no reason why present entry cannot be retained as a useful methodological tool to bridge the gap between the readers' intuitive moral reflections and the demands of abstract moral theory. But there is no good reason why present entry should be supposed to define the foundations of the contract, for - once present entry enables one to enter into the spirit of contractarian reasoning - one can dispense with it if it fails, as it does, to express the most fundamental ethical idea of treating all persons - whoever, whenever -

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[85] Richards (1983), p. 137.

[86] Richards (1983), p. 139.

as one would oneself like to be treated."[87]

Richards key points are (1) that in contrast to Brian Barry, Richards does not think the analysis of intergenerational justice in terms of a hypothetical contract among all generations that ever exist is "question-bagging" He feels that on an individual level the same moral imagination that is used for currently existing persons would be (in principle) called for. (2) Richards' next point is the fact that future generations are potential persons doesn't alter the ethical analysis of our relations to them.[88] (3) He thinks that it is possible, on a moral basis, decide whether or not to have children, and continue the human race. In some cases, he suggests that it could be morally right to cease having children, preserving only human culture (as records) for whatever rational race may evolve at some later point in history. (Perhaps if all children were to be so radically altered as to revert to lower animal forms). (4) In response to the Parfit "identity" thesis, Richards claims that the moral problem context is just altered to be a contract among whatever collective classes may exist. He states

> "That our choice of a certain policy may lead to one class of persons existing as opposed to another does not disable us from raising and answering the question of how, whoever exists, persons will fare under different policies."

And then he claims,

"the identify of the persons under one policy or

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[87] Richards (1983), p. 139.

[88] Derek Parfit's comments on when a life is not worth living and its problems for this analysis are relevant here - Parfit (1983), p. 168

> another is irrelevant. Whether the policy in question involves energy, population, or eugenics, a reasonable interpretation of moral reciprocity does not require that we think in terms of a particular person, but rather in terms of the more general category - persons who will exist later - so that we can assess how, if we were in that category, we would reasonably want to be treated."[89]

Richards supports this contention by suggesting that the veil of ignorance covers as well, biological identity. The strength of this defence is not clear to me. He has not, I believe, countered Barry's problem with representation, and his formulation seems to rely implicitly on the relatively homogenous nature of the psychological makeup of the individual decision maker, while ignoring altogether the possibility of individuals having a quite different psychological makeup in the future.

He emphasizes how one would like to be treated in a very specific sense - how the reader would like to be treated. If one is given the choice of being living or dead, one would presumably choose life, and therefore, a maximin strategy would always call for the highest population growth possible. I do not really think that Richards has provided secure foundations for the contractarian approach to intergenerational justice.

He does, however, make some interesting points on the matters of risk, and negligence regarding future generations. Rawls bypasses the problem of probabilistic assessment (discussed somewhat in Chapter Two of this thesis) by using the maximin decision criterion, an essentially non-probabilistic criterion, or one at the extreme limit of probabilistic evaluation from a utilitarian point of view. Richards claims, that

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[89] Richards (1983), p. 141.

"Ethical issues of energy policy subdivide into two categories: current forms of energy use or disposal that may harm future generations in serious ways, and resource base depletion."[90]

Richards emphasizes the asymmetry between generations in benefits and costs regarding energy policy, and refers to this as a kind of moral asymmetry. He argues for far lower probabilities (risks) being accepted in the intergenerational case than in the intragenerational case for this reason (for energy use and disposal cases). For depletion cases, he states

"a maximizing argument in the original position would tend toward some form of equality principle defined in suitably neutral terms consistent with allowing each generation to define the meaning of its own cultural life."[91]

He emphasizes the (Barry and Page) principle of equal opportunity, providing a "neutral standard of intergenerational justice."

He states that

"the relevant moral concept of inter-generational opportunity is culture-technology dependent: a certain resource (oil, for example) becomes a human good only concurrent with a certain technological development."[92]

Each generation should

"... leave the aggregate resource base as good as they found it, relative to the state of culture and technology, and the use thus made of resources for realizing general human goods. Accordingly, the

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[90] Richards (1983), p. 142.

[91] Richards (1983), p. 143.

[92] Richards (1983), p. 145.

> depletion of even a non-renewable resource will not be ruled out if, concurrent with that depletion, a technology has been developed that will meet the depletion and make available to later generations, consistent with obligations of not imposing irreparable harms, a technology that can secure from depleted resources at least as much (for example, energy) as would have been secured from the original resource. Relative to the state of culture-technology thus developed, the intergenerational requirement of equal opportunity will not have been violated."[93]

Richards leaves the population decision aside in dealing with the depletion problem, because he later uses lack of population control by an earlier generation, as a factor which could adversely affect a later generation's equality of opportunity. Population-depletion-culture-technology decisions would seem to me to all have to be a part necessarily of the all-generations decisions behind the veil of ignorance. Richards closes with some notes on the perennial question "Why be Moral?", a discussion which was provoked by questions of intergenerational justice.

Principles of Justice Versus Utilitarian Principles

Steiner (1983) contrasts principles of justice with utilitarian principles. The latter describe moral obligation in terms of some good other than what is maximally produced, whereas the former he states,

> "are not subject to the test of instrumental efficacy, and hence, whatever personal inviolability they afford is not thereby subject to revocation under changing empirical conditions for increasing the production of what is desirable."[94]

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[93] Richards (1983), p. 145.

[94] Steiner (1983), p. 152.

This is consistent with Frankena's partition of major types of moral theories. Steiner also notes that it is much harder to show that some action or behaviour is good in itself rather than merely to show that it promotes some other good, although he notes that the justification of the utilitarian good in the end, is beset by at least equal difficulties.

Steiner (1983) has two main goals, first,, to suggest why the rights of future generations are not moral rights, and second, why enforced conservation lacks justification in principles of justice.

Steiner refers to tests of a proposed right to see if it is a demand of justice, or a moral right. The first he says,

> "...is to ascertain that the proposed right possesses the analytic or formal characteristics of rights in general."[95]

He mentions that what these characteristics are is subject to dispute, but he still states that in his opinion, that "future persons have a moral right to conservation by present persons" is not such a right. He claims that this is so because

> "a future person is unable to demand or waive fulfilment of those obligations by a present person."[96]

Since that ability, Steiner contends, is essential to rights, and is a logical impossibility in this case, then, that proposal is not a moral right. He states,

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[95] Steiner (1983), p. 154.

[96] Steiner (1983) p. 155.

> "Future persons' necessary (italics) lack of any contemporaneity with present persons implies the logical impossibility of their authorizing some present persons to exercise such powers. Hence, any such exercise by present persons cannot be regarded as the exercise of powers implied by future persons rights."[97]

Steiner makes the point that there is really no way to know what they would want us to do vis-a-vis conservation, so it can't be enforced as a right. Future living standards may be very high and on moral grounds they may wish that their predecessors had not practised conservation at all, but had allowed themselves higher living standards. He states

> "... it is precisely because future persons are necessarily incapable of present choice - precisely because their choices about present acts logically must be objects of prejudgment - that they cannot be said to have rights against present persons."[98]

This moves the discussion to the question of what the correct tests of moral rights are, and leaves considerable doubt in my mind whether we are led to ignore issues of rights of future persons altogether on this basis.

Steiner, in suggesting a possible defense for the enforcement of conservation, appeals to a utilitarian framework. He notes that in his opinion, such enforcement is acceptable if it can be shown that there is a greater amount of social good produced, or balance of net good, with conservation, as compared to a situation without it. His is a particular version of utilitarianism, as he says that the social good is solely associated with individuals - the gains accrue to future persons, the costs must be borne by present

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[97] Steiner (1983), p. 156.

[98] Steiner (1983), p. 156.

persons.

He notes that there are, associated with conservation, intragenerational effects as well because it is,

> "more heavily encumbering those persons whose production and consumption activities more directly impinge on the conservable environment."[99]

He claims that there are explicitly different property rights, with and without conservation, and states,

> "... it seems reasonably clear that no presumed net gain (if anything) can be invariably secured from the intra-generationally redistributive effects of enforced conservation. Net gains in social utility may be attainable through intra-generational redistributions, but there is no reason to suppose that enforced conservation must be one of those gain-yielding redistributions."[100]

Steiner claims that

> "... if there is a utility-enhancing distribution to be secured through conservation, it will be profitable for those who would gain from this distribution to offer sufficient compensation to those who would lose from it to induce the latter voluntarily (italics) to consume."[101]

This, however assumes that those who would gain have the ability to compensate those who would lose, and though the gain in social utility may be had, sufficient initial financial endowment may not be available to the requisite individuals to achieve this.

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[99] Steiner (1983), p. 157.

[100] Steiner (1983), p. 157.

[101] Steiner (1983), p. 157.

Steiner's basic premise for evaluating conservation is based on the argument, that for resources to be common property mutual consent about the resources is necessary, since future persons are not here to consent or dissent, then resources can only have property rights held by present persons, or past persons who have elected to pass them to present persons. Future persons can have no claims on present persons, hence also present persons have no obligation per se to future generations.

Steiner suggests that since the enforcement of conservation is likely to be independent of the procreation decision, and in the absence of enforcement, conservation would be lower although adequate for the immediately following several generations, the enforcement is likely to affect the overall durability of society rather than just the number of future persons. He does not, however, deal with the question of the value of "species-durability" or extending the number of generations, or whether there may be some obligation to procreate. He wishes only to emphasize that it is a way to think of future persons as "already out there", and that the obligation of conservation is a utilitarian one and not a just one. Also, he states that the utility accrues to society and not to "actual persons",

> "It does not accrue to actual persons because, in the absence of any prospects of their sustainability, they would not have been brought into existence - at least, not by rational persons."[102]

Most of Steiner's criticism of the validity of claims in the pursuit of conservation are based on his "legalistic" approach to rights, and their formal nature, which relies on a defined realm of personal choice - actual, at a point in

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[102] Steiner (1983), p. 159.

time, and not merely potential or future. Rights to resources, or the uses to which they are put, produce derivative rights and obligations for the rest of society, but the individual's title remains intact. Thus, one must trace rights through all antecedent stages to find an original right, which is a property right. The question of an existing right being only as valid as the original right - and there have been may different approaches to that problem as well - raises issues of actual states' claims of territorial sovereignty as well. The Steiner first-come, first served proposal is inadequate because it requires the unanimity of all members of the group (which for Steiner can only be those alive at the time), and "does not (italics) guarantee all putatively obligated persons a chance to acquire such rights."[103] He describes the problem with this allocation procedure in the following:

> "Since all property rights are rights to natural resources or to their physical derivatives, the pedigrees of the universal obligations corresponding to them imply universal consent to initial resource acquisitions. All those said to be obligated - that is, all existing persons - are presumed on this principle to have consented. Yet not only is this presumption false; it could not possibly be true." "...because no existing persons existed when most of these initial acquisitions took place."[104]

Steiner proposes two alternatives to resolve this dilemma - first, relax the principle of property rights being based on everyone's initial consent which he claims would imply that the distribution of property is not a matter of justice and moral rights, or second, agree that property rights may not be passed down in antecedent fashion.

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[103] Steiner (1983), p. 163.

[104] Steiner (1983), p. 163.

Existing persons can veto existing property rights arrangements which were in effect before he was "eligible" to take on an obligation himself. His conclusions are two: first, moral rights presuming periodic unanimity, must be conceived as a tendency rather than an absolute and permanent title; second, the first conclusion is not based on agreements or consent between present and future peoples - or based on obligations between the two.

It seems that Steiner may be able to exploit overlapping generations to make more definite the transfers of title, and obligations. His interpretation of contractarian theory stands in marked contrast to that of Richards, but is similar in its emphasis on existing people to the "present entry" version of Rawls theory.

The Identity Problem

Parfit (1983) examines the "identity problem" for energy policy. This has to do with the difficulty that under different policy choices, different individuals will end up living, and so it is less a choice for policy of harming one given population to a greater or lesser extent but rather of causing one set of individuals rather than another to come into being. If we accept the above, then popular claims about harms to future generations of particular individuals may be ill-founded in theory, but may be a useful fiction. However there is a further question to be asked, and that is, would the same number of people exist under alternative policies? For moral thinking, Parfit claims, different people choices are problematic, but different numbers pose even more puzzling choices.

Parfit states two principles as follows:

> "[A] It is bad if those who live are worse off than those who might have lived. We must claim that this

is bad even though it will be worse for no one."[105]

This produces an interesting wrinkle for the use of the Pareto principle by economists too, however, economists normally ignore the population-affecting aspects of their policy prescriptions.

The second principle is this,

> [B] If the same number of lives would be lived either way, it would be bad if people are worse off than people might have been."[106]

Parfit presents the following diagram to help distinguish between the different types of choices.

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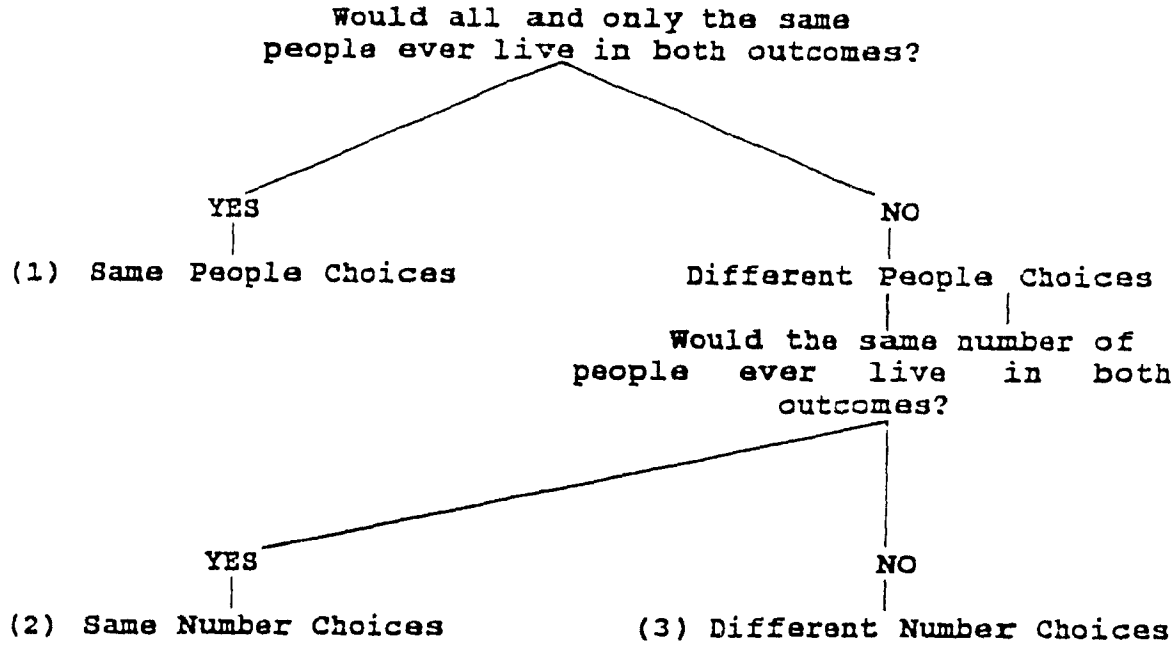
[105] Parfit (1983), p. 175.

[106] Parfit (1983), p. 175.

Effects of Choice Between Two Outcomes[107]



Parfit claims that most of our moral thinking concerns type one choices, most of our moral choices do not cause different people to exist. His point is, that where they do cause different people to exist, our decision does not make anyone worse off. Here the suggested principle focuses on the making of better or worse people.

MacLean cites a number of actual and potential problems for Parfit's (1983) paper, and moves on to arguments about "making the world better" - he says this is something we owe to our ancestors.

> "They sweated, slaved, and sacrificed to give us a better life, but it was not for us alone that they toiled. It was to create a world to which we have rights in usufruct - to use and enjoy - but which

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[107] Parfit (1983).

> we are bound by heritage to improve and pass on, like family treasures. This view seems to capture well the common intuition that we are custodians or trustees of the environment. It captures also Burke's famous claim, "Society is indeed a contract ... a partnership between not only those who are living, but between those who are living, those who are dead, and those who are to be born."[108]

MacLean prefaces his article by stating his beliefs that we are bound by a relative moral requirement to try to create the best world possible. The requirement is relative, because we must do so while respecting the rights of others, and allowing others to pursue other, more personal goals. He claims that philosophical arguments alone can tell us nothing about energy policy,, but rather require empirical data in order to be useful in making policy. His position is that,

> "moral and political principles need not be limited to those that constrain our actions by protecting rights and imposing duties; they should also express certain values and ideals, whose public acknowledgement is essential to our pursuit of good and meaningful lives."[109]

MacLean supports Parfit's person-affecting arguments, noting that they were developed to solve problems of justice, rights, equality, and respect in "normal" situations, and fail in many intergenerational contexts - "especially where our concerns are large-scale policy decisions like energy policies and their effects on remote generations."[110] He is

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[108] MacLean (1983), p. 187. The quotation is from Burke, Reflections on the Revolution in France (London: Dent, 1910), pp. 93-94.

[109] MacLean (1983), p. 81.

[110] MacLean (1983), p. 181.

sceptical about Parfit's arguments, and states,

> "Those who insist that moral principles must be person-affecting principles might be drawn by the identity problem to conclude that we have no moral obligations to future generations."

He notes Parfit's promotion of our common intuition that we do need to care about future generations and Parfit's proposal of a new principle of beneficence which would not be subject to the paradoxes of specific future individuals. MacLean notes the twin problems of environmental circumstance (states of the environment we can leave for future generations) and the procreative decisions we make. The solutions to these problems do not appear to be independent to me. He notes that we may, as Parfit suggests have a larger or smaller population by conscious decision, but it will in the various cases, be different populations. MacLean makes the analogy to two couples deciding whether to have two or three children. The first couple already has two children, the second has none. The second couple considers the timing of the births, for example, given their choices for either two or three children, then, they are likely to have different children. The third child for the second couple doesn't add any burden to the other two, or reduce their parental attention, at the decision point, because two children would have been different children. For the first couple, the third is added "after the fact" of the first two, and is a rather different third child choice, from that of the second couple. MacLean summarizes with the following:

> "Our decisions and actions, therefore, cast the fate of future generations in four ways. The consequences they affect are:

> C1. the number of future generations; C2. the number of people within a future generation; C3. the identities of the people within a future generation; and C4. the environment of future generations."[111]

MacLean notes that we typically focus on one or the other of these consequences when considering particular problems, for example C1 is relevant for deciding to use thermonuclear war and C4 for resource depletion, but he notes that Parfit's argument asks whether such isolation of consequences is sensible. Usually, MacLean argues, policies which affect one of the consequences really affect the others as well. He notes, however, keeping all types of consequences in mind, "we can easily find ourselves in a morass of paradoxes and dilemmas."[112]

MacLean's position is that "plausible" theories of rights or justice depend on person-affecting principles. There can be no question of the rights of potential persons, or of injuries done to a potential person. He states,

> "If we think only of rights or justice, then we conclude only that whether or not we fail to preserve human life has no moral importance."[113]

However, this doesn't lead to scepticism regarding what he feels is moral responsibility toward future generations. Regarding the identity problem, he states

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[111] MacLean (1983), p. 183.

[112] MacLean (1983), p. 184.

[113] MacLean (1983), p.184.

"It leads directly to scepticism only for those who are convinced that intergenerational morality must be a matter of justice or rights."[114]

He feels that we can still choose, on a moral basis, between possible future worlds even if there will be different individuals. We can judge which would be a better world to live in - which would produce better or worse people. Such choices can be made on the basis of a principle of beneficence.

Freedom to Contract and Equity

Equity in process is a concept which has received considerable attention lately because of Robert Nozick's Anarchy, State and Utopia.[115] Here, an equitable process is viewed as one which minimally interferes with or constrains one's freedom to contract,[116] no specific distributions need be compared.

EQUITY AND EQUALITY

Weale (1978) contrasts procedural equality and substantive equality. "Procedural" equality or "formal" equality, he states, can be

"...expressed in the following double barrelled principle;

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[114] MacLean (1983), p. 185.

[115] Robert Nozick, Anarchy, State, and Utopia, (New York, 1974).

[116] Some of the problems of rights between generations were discussed earlier in this chapter.

(a) Good reason has to be shown for treating one person or group of persons differently from any other person or groups of persons. In the absence of such a reason all person or groups of persons should be treated similarly.
(b) Like cases are to be treated as like, and unlike cases as unlike."[117]

This approach focuses on the procedures we follow in going about making decisions, but does not really say much about the outcome of those decisions. Weale emphasizes the reliance on "good reason" for approaching cases in similar or different ways. Reasons have taken many different forms. Frankena (1962) in writing on social justice refers to the classical solutions of Plato, and Aristotle and many of their followers, where equal allotments among men in the current use of the word "equal" did not mean the same thing. He states,

> "Justice simply is the approportionment of what is to be approportioned in accordance with the amount or degree in which the recipients possess some required feature - personal ability, dessert, merit, rank, or wealth."[118]

Thus it would appear that the notion of equality with respect to various reference groups identified on the basis of good reason, can prescribe very unequal outcomes, and a variety of treatments according to the numbers of reference

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[117] Weale (1978), p. 11.

[118] Frankena (1962), p. 11.

groups. This brings to the forefront the issue of whether procedural equality can be discriminated in a useful way from substantive equality. If the good reasons for different treatment relate to the distributions of outcomes from the process, then the two equalities are really focusing on a single element, final distribution. If two cases have similar properties, and it is concluded, do deserve similar rewards, for example on substantive grounds, than the correct procedural system, or the system which promotes procedural equality is the one which best, most consistently, or with minimum error produces the desired rewards.

Weale states that

> "The procedural requirement of consistency is identical with the principle of equity."[119]

This seems to be the case, because Weale focuses on equity as a principle which is used to judge distributions of goods etc., under a given principle.[120] However, equity can also be used to argue for the use of different principles. He does, however, allude to the latter possibility[121] and states that although the equity principle is very open, it does not in itself supply the "good reasons" for identifying the different reference groups which would receive different treatment. But equity is what allows us to ask the questions which demand the "good reasons."

Weale (1978) claims that

> "Equity cannot be used to question political institutions or traditions as such..."

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[119] Weale (1978), p. 22.

[120] Weale (1978), p. 26.

[121] Ibid, pp. 27-8.

however, if institutions and traditions should be allowed to exist because they produce desirable social outcomes, and if equity can be used to identify flaws in institutions, then at least indirectly, the institutions and traditions are attacked. My point is that while equity arguments can be used within institutions to resolve claims, they can be used as well in the choice of institutions, or in the structuring of institutions.

EQUITY AND LAW

We can ask about the equity of a process, i.e., have all the appropriate stages been followed? as well as ask, is the law equitable? In the pre-modern British legal system, courts of equity were courts of higher appeal, when the normal application of law was deemed inappropriate, either because the prescriptions were deemed unfair or the circumstances were inappropriate to common law. Though now the common law and equity systems have merged, the idea of equity, equity maxims, and appeal to equity in argument are still influential and widely used.[122]

David Walker in The Oxford Companion to Law defines equity as follows:

> "The basic meaning of equity is evenness, fairness, justice, and the word is used as a synonym for natural justice. In a secondary meaning the term is used as contrasted with strict rules of law, 'aequitas' as against 'strictum jus' or 'rigor juris'; in this sense equity is the application to particular circumstances of the standard of what seems naturally just and right, as contrasted with

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[122] Walker (1980), pp. 624-626.

> the application to those circumstances of a rule of law, which may not provide for such circumstances or provide what seems unreasonable or unfair. A court or tribunal is a court of equity as well as of law in so far as it may do what is right in accordance with reason and justice. The opposition between equity and law is frequently minimized by rules of law laying down flexible standards and conferring discretionary powers, but in some cases the conflict between what is fair and just and what is lawful may arise. This distinction, sometimes opposition, between law and equity was recognized in Roman law where the action of the praetors in granting remedies in situations for which the 'jus civile' provided no remedy was well recognized."[123]

Equity in the above sense more closely captures the common use of equity, and it is this wider sense which is emphasized in this thesis. The concept of equity questions the structure, operations, and outcomes of institutions, as well as attending to the issue of whether the institutions' prescribed steps were followed in dealing with each case or individual involved.

SOME NOTES ON THE ECONOMIC APPROACH TO INTERGENERATIONAL COMPARISONS

I have already referred to the work of E.J. Mishan in "Economic Criteria for Intergenerational Comparisons", where he reviews and critically evaluates five major economic models that produce generational time paths.[124] As we already know,

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[123] Walker (1980), pp. 624-625.

[124] E.J. Mishan, "Economic Criteria for Intergenerational Comparisons", Futures, October 1977, pp. 383-403.

Mishan is rather critical of the approach economists take to inter-generational problems. He states:

> "...cursory attention to their procedure reveals that the economist has really nothing of substance to contribute to the debate on the "ideal" intergenerational time path. In effect, the models are "cooked up" so as to give the imprimatur of science to what is, after all, no more than a popular ethical judgement."[125]

First, Mishan notes that for the economist interested in a welfare related problem, the basic data are the preferences of the individuals in the economy. They may be either stated by him, or revealed by market behaviour, but they are assumed to satisfy certain assumptions relating to logical consistency and stability. Mishan challenges the common presumption that with respect to major decisions (foreign trade, economic growth, fiscal and monetary policies etc.) each individual really does know his own interest best. For small choices, buying carrots or peas, Mishan agrees the assumption may be reasonable:

> "But it is suspect for larger and more complex choices such as the allocation of the individual's time over the week or year, or the allocation of his income between broad categories of goods entailed by his adopted style of life.[126]

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[125] Ibid., p. 383.

[126] Ibid., p. 384.

As quoted earlier, Mishan (1977)[127] suggests that the revelation of an individual's claims can be the expression of that individual's problems to the psychotherapist. Revealed preferences should, perhaps, not be taken as attitudes sacred in part to social decisions. As the welfare conclusions of the economist are possibly contingent on a seriously erroneous understanding of what is best for a group of individuals, the resultant criterion must also be seriously suspect.

Further, Mishan notes that the welfare of a group is seen only as the aggregate welfare of the individuals in either money or utility terms, which he considers to be (both) limiting cases of the social welfare function. Mishan refers to the latter as "that grandiose but ineffectual excrescence on the body of welfare economics."[128]

He states that economists tend to like models which result in more equal distributions and tend to construct models to achieve these ends. Mishan concludes this after undertaking a review of developments in welfare analysis from Pigou through to the early 1970's.[129] He notes that Pigou assumed that utility functions were identical, and if the criteria for welfare maximization was to maximize aggregate utility, then one would equate the M.U. of income for all individuals by equalizing income. Mishan wonders what Pigou would have thought if he assumed that individuals could have different utility functions and different potential capacities for enjoying income. Mishan asks, if incomes were equal and it was shown that utility (for income) functions differed,

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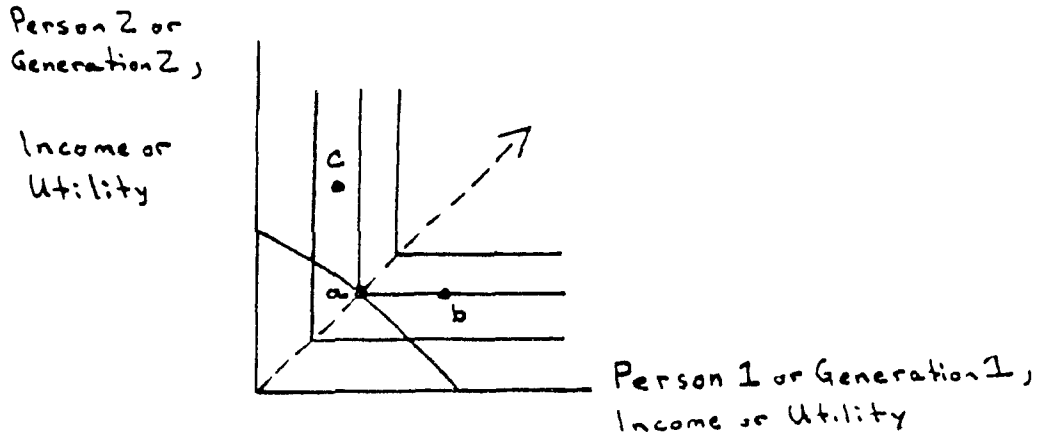
[127] Ibid., p. 384.

[128] Ibid., p. 385.

[129] Ibid., pp. 389-393.

would Pigou have pushed for income inequality to maximize utility. He implies that would not be likely.

Mishan describes the Maximin criterion adopted by Solow in a graph similar to the following:

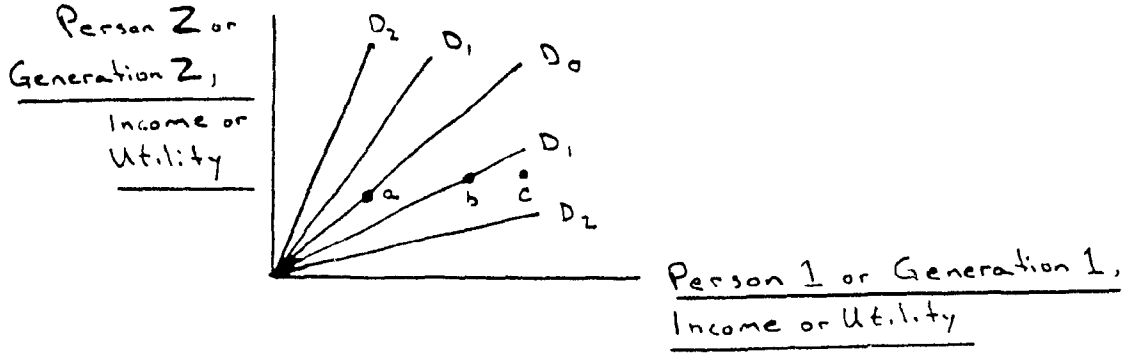


The axes measure per capita cardinal utility for generations one and two in an intergenerational context or persons 1 and 2 in the intragenerational context. He notes that this criterion is "imported" from outside economics by Solow.

Point b, which returns more to person 1, but the same as a for person 2, is rated as equal to a, because the minimum consumption is the only criterion. Similarly, point c represents a far higher level of utility for 2 than a, and only very slightly lower utility for 1, yet is strictly inferior from the maximin point of view.[130]

Mishan describes an even more extreme approach, where the criterion is income equality, where absolute income level is irrelevant. This is pictured as below,

[130] The maximin criterion and the Rawls' decision behind the veil of ignorance are not identical as discussed earlier in this chapter, yet are often treated as being such.



where the axes refer to levels of (income or) utility. D_0 identifies the highest level of the criterion, perfect equality, D_1, D_2, identify lower levels of the criterion. By this criterion, although C which has higher utility for both than b, and b has higher utility for both than a, a is preferred to b, which is preferred to c because the criterion is based on equality in distribution alone. This is an interesting example, because it is generally accepted[131] that Pareto improvements are non-controversial, i.e., an improvement that makes one person better off without making anyone else worse off is a good things. This example shows a case where Pareto improvements can produce inferior (lower utility) outcomes.

Mishan notes that the departure Rawls encourages from an equal per capita consumption path is not because such a distribution is unjust. Earlier generations are asked to make large enough sacrifices in consumption, to accumulate sufficient capital to secure the foundations for justice. These sacrifices are agreed to behind the veil of ignorance. Once the foundations are secure, however, the equal per capita consumption path is sought.[132]

The next point that Mishan makes is that one's view of the world colours one's perception of a just distribution.

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131 See for example Musgrove, R.A. et al (1987), p. 75.

132 Ibid., p. 396.

Mishan states:

> "The appeal of an equal division among all members of a community of the fruits of their collective efforts rests ultimately on a philosophical view, perhaps on interpretation of the world, or in the last resort, a factual judgement - that the material success of a person depends predominantly or entirely on factors outside his control. These are, primarily, his endowments of ability and character, the family that rears him, the social environment in which he grows, the people he happens to meet, and the events that overtake him.[133]

This appears to be a rather deterministic view, and the view implies that being strongly influenced by external factors, one has little control over one's destiny. In a society made up of slothful and industrious individuals, all aware of their inability to change their nature, I could imagine unequal as well as equal distribution as being promoted by different groups. Similar statements were considered in the earlier section on ideology.

Mishan states that a contrary view sees those factors noted above as relatively minor influences. Also, personal differences in income are the result of personal decisions about the efforts and sacrifices to be made in one's life. He claims that those individuals would tend to support the dictum: "to each according to his work".[134] Mishan goes on to state that although differences in world view such as the

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[133] Ibid., p. 396.

[134] Ibid., p. 396.

two described are relevant to problems of intragenerational problems, such considerations are not relevant in intergenerational problems. He states:

> "For whatever is our view of the fundamental factors explaining differences in existing incomes, we are likely to agree that an equal per capita real consumption for all generations is an eminently fair arrangement. ...For making the minor assumption (which can always be modified) that the average effort of each generation is about the same, the reasonable supposition that the distribution of relevant characteristics is much the same for one generation as another impels us to the view that no generation deserves as of right to enjoy a higher standard than any other."[135]

One can, however, envisage a system in which a skewed distribution of income, being passed from generation to generation in families, sequentially produces more and more highly skewed distributions as time goes on, and this could happen, quite aside from differences in individual characteristics. If one accepts that an intragenerational distribution may be skewed, but feels that the welloffness of the lowest ten percent of the population should be a factor in judging the justness of a distribution, then equality in average per capita income over time is not the correct criterion.

Mishan claims:

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[135] Ibid., p. 397.

> "Irrespective, therefore, of the way each generation chooses to distribute its own outputs among its members, and irrespective also of the way we think any generation ought to distribute its output among them, we can agree on each generation's right to a natural resource and capital endowment, that with the same average effort will produce for it the same per capita real consumption as that of any other generation. In sum, the ethical appeal of equality of per capita consumption over generational time is independent of a belief in the justice of an equal division of the product in any existing society, and is far more compelling.[136]

Mishan seems to assume that growth potential for an economy intertemporally is independent of the distribution of income. We note, however, differences in incentive rewards (reflected in differences in income within a generation) may encourage growth and output [for some generations], while lack of such rewards (reflected in equal consumption) may stifle it. The ethical decision with respect to intragenerational distribution would most certainly influence the consumption path, based on average per capita consumption throughout time. The intergenerational decision really cannot be made independently of the intragenerational decision because the latter affects the per capita output and consumption of individual generations and most likely affects the capital and natural resource endowment of following generations as well.

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[136] Ibid., p. 397.

Growth and Equity

At this point, it is useful to consider some of the elements of the relationship between growth and equity. Are growth and equity goals mutually reinforcing, independent, or conflicting? For the moment, we may put aside index number problems in relating increases in income to increases in utility, and use income at the individual and national levels as a proxy for well-offness. National income is taken as the simple sum of individual incomes.

In the case in which one is interested in growth, reflected in the growth of national income, equity is relevant to the extent that it helps to promote growth. If equality in income distribution promotes growth, then it is encouraged, if inequality in distribution promotes growth, then it is similarly encouraged.

It has been hypothesized that individuals with higher incomes tend to save a proportionately larger portion of their incomes, than those with lower incomes.[137] If one then associates a higher savings rate with faster capital accumulation and more capital with more rapid growth in real income, then an unequal distribution of income may be preferred in the interests of growth. If those with proportionately higher incomes do not proportionately save more, then there would be no preference, from the based-on-growth arguments for income inequality. If, perhaps for reasons of security, all individuals wish to save an identical absolute level of income, then those in upper income levels save proportionately less, and equality in income distribution may be preferred to encourage growth in national income. The income-savings-investment linkage referred to is by no means universally accepted, as the distribution

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[137] See Keynes (1920), The Economic Consequences of the Peace

theories reflected in macroeconomic models in the literature are many and diverse. Still such a linkage is implicit in various forms in most of the models. The following table may represent the likely effect distribution policy may have on growth, given the assumptions accepted for savings rates for individuals at different income levels.

TABLE 1

Effect of Distribution Policies on Growth Goals

		Savings Propensities Across Income Levels			
		Equal	Increasing with Income Level	Decreasing with Income Level	Constant Absolute Level
Policy for Income Distribution	Equal	Growth Unaffected	Growth Restricted	Growth Encouraged	Growth Encouraged
	Unequal	Growth Unaffected	Growth Encouraged	Growth Restricted	Growth Restricted

In equity, we may be concerned with the income level of the lowest ten percent of the population. If savings propensities more than proportionately increase with income, and this strongly encourages growth, then we may best encourage equity between generations by permitting and encouraging unequal distributions of income at a point of time. Thus, there may be a conflict for this criterion, as the intratemporal policy could favour immediate redistribution of income, while the intertemporal policy does not. We might expect participants in the economy, (especially the lowest ten percent in income) to feel differently about this conflict, depending on whether the significant growth effects are felt over a short period of years or within a

generation, as opposed to being felt only over generations. This would be the case if savings by the rich of a generation produced sufficient growth to encourage intragenerational equality. Thus, the time frame for the analysis of equity and the influences of other factors on equity may be very important.

Implicitly, in the previous discussion, equality in distribution is a causal factor in growth. There are feedback effects in most models, and the growth process tends to effect the intertemporal changes in income distribution. In the previous discussion, equity reflected in income equality at a point in time may or may not be in conflict with growth as a goal, depending on the behaviourial assumptions one makes about individual savings activities. Growth as an instrumental variable itself may or may not adversely affect equality in distribution depending on the macroeconomic growth and distribution model selected. There are definitely competing schools of thought on what the "correct" macroeconomic model is for a capitalist system, and for other economic systems. An elaboration of these models and their implications for equity would be a book, or several books, and is beyond the scope of this paper.[138]

Equity and the Choice of an Economic System

A key point which we again encounter is that equity issues, in the main, are not independent of economic analysis. Different economic models reflect different assumptions for the organization of economic life. They embody differing assumptions for individual behaviour and interactive processes. Putting aside the issue of which

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[138] See, for example, Martin Bronfenbrenner, Income Distribution Theory, Ch. 16 (Chicago: Adeline Atherton Inc., 1971).

model best represents an existing system, the various models describe alternative systems; they offer choices for the organization of economic activity. There are considerations regarding equity within given systems, as well as in the comparison of alternative systems. Certain systems may be deemed more equitable than others, not necessarily because of the way income is distributed at a point in time, or over time, but because of the nature of participation in the process which is allowed.

Equity and the Goals of Economic Policy

Arrow (1978) notes that some of the goals of economic policy are:

> "...drawn from outside the economic sphere: national security and power, the achievement of a broad range of social goals (such as the aesthetic improvement of urban life, social communication, health, and internal order and personal security), or the better development of individuals and of the modes of social interaction."[139]

These would be considered exogenous goals to the normal functioning of the market system. As Arrow says, the usual endogenous goals which economists focus on

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[139] Arrow (1978), p. 17.

"...all or virtually all can be reduced in one way or another to three: economic stability, allocative efficiency, and distributive equity."[140]

Now as far as economic goals go, it does seem that economists would naturally be drawn to efficiency in the use of resources. Stability may be argued for, on grounds of efficiency, in maximizing the efficient use of resources, but it is not at all clear that equity need be considered endogenous.

Economic stability and allocative efficiency do not seem to interfere with utilitarian ethics, Rawls theory, or intuitionism, but distributive equity cannot be described in the absence of a statement of considerable moral content. The use of Nozick's notion of equity in process, where anything agreed to by two parties should be allowed, and whatever resulting distribution arises is acceptable, has dramatically different implications from the maximization of utility with the assumption of identical utility functions. Equity seems to me to be more exogenous than endogenous to economic models.

Growth, Arrow claims,

"is not an elementary goal; it is derived from the goals of efficiency and equity as applied to choices over time. Specifically, just as we are concerned with possible conflicts between efficiency and equity in resource allocation at a moment in time, so we are also concerned with possible conflicts between efficiency and equity in allocating

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[140] Arrow (1978), p. ??.

resources among individuals at different points in time."[141]

The above is cited by Arrow as the "values" problem of optimal growth policies, as opposed to the descriptive problems of finding the specific effects different policies can have on the economy from the point of view of efficiency and equity. The approach of economists has been to treat such tradeoffs in the context of preferences, judgements on efficiency, and equity are presumed to be reflected in preferences on the allocations of resources.

Arrow emphasizes that not all allocations are feasible, and feasibility is defined by existing technologies, resource availability, and a variety of institutions such as private property, and the free sale of labour services. Thus, social institutions put constraints on economic possibilities which constrain economic possibilities beyond the limits of technology and resource availability. Taxation, and other relatively freely permitted government interventions are mild compared with the force of existing institutions. Arrow notes that, for example, a socialist economy with a different set of institutional constraints might be capable of achieving a wider set or greater range of allocations. And this is an important point regarding our discussion of equity. Equity as we have seen it used generally implies a wider scope for analysis than most economists admit. Equity questions the structure and value of the institution as well as allocations by and within those institutions.

Arrow states,

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[141] Arrow (1978), p. 2.

> "Even in a static world, equity is an elusive concept. There is no need to enlarge on the rival concepts that have always held the field. The differences among the utilitarian viewpoint, Rawls' principle of benefiting the worst off, and Nozicks view that any distribution arrived at by free contracting is just, sufficiently illustrate the variety of views."[142]

Arrow uses a concept of equity, in a form which he admits is deliberately simple to consider income distribution choices, promoting income equality and illustrating a few points regarding equity-efficiency tradeoffs, but thereby dramatically changing the scope of equity. The question of "how equal income distribution should be" is a part of equity, but only a part. The above cited references do not focus only on income distributions per se, although they do tend to take different perspectives with respect to income distribution, then go beyond to consider the equity and social justice of the institutions themselves. In fact, the primary thrust of Rawls work is on the structuring of just institutions.

Arrow notes that from the point of view of economic theory, efficiency and equity may not be seen as purely conflicting, the relevant inverse theorems for the market using a competitive price system can be shown to identify the optimal lump sum transfers which would "efficiently" produce any desired distribution of income.

Arrow makes the point, however, that this would only result if such a redistribution did not affect agents subsequent behaviour in the market, which would impair

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[142] Arrow (1978), p. 3.

efficiency if the productivity of resources, especially labour were impaired. He also notes that whereas capital or property can be redistributed, labour skills cannot, therefore taxes on labour income are the only alternative. Such taxes could well cause individuals to reduce their offerings of services which in turn would reduce efficiency. Here then we encounter a likely place for an efficiency-equity tradeoff to arise. Arrow also notes that the market system leads to efficiency in the case of perfect competition, but competition is far from perfect. He then cites a possible program which could encourage both equity and efficiency simultaneously, and another which would exacerbate the conflict between the two.

With regard to the intertemporal problem, Arrow initially chooses to ignore intragenerational equity issues by assuming that all individuals are alike (and the same age). He notes that in the intertemporal context, resources can be redistributed from the present to the future, and the act of

> "Refraining from consumption of exhaustible resources can be thought of as a special case of investment."[143]

Arrow notes that the well known condition for efficiency in this context is that all investments yield the same rate of return in any given period, and

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[143] Arrow (1978), p. 5.

"...among the efficient allocations, there is a distinction between the concept of growth and the concept of equity. If for the moment, we assume that growth basically results from capital accumulation, then the greater the capital accumulation, the faster the rate of growth. [Within some limits which Arrow notes] ...But indefinitely high growth is not necessarily good. Quite apart from problems of exhaustible resources, there is no particular reason why the present generation should sacrifice large amounts of consumption indefinitely to achieve higher rates of growth and higher rates of consumption for its successors. Justice requires a balance between competing values of the current and future generations."[144]

Arrow notes that whereas intratemporal reallocation is often viewed as incentive reducing and as having the effect of reducing total product, at the same time intergenerational transfers are viewed as having positive rates of return. And this, he states, is a powerful argument for such transfers regardless of one's ethics. This argument is not immediately clear from the perspective of equity, or of a maximin decision criterion approach. The mere fact that there is a positive rate of return is fairly unimportant on its own without some intergenerational comparison of well-offness. Arrow alludes to this argument, and suggests that the required rate of return should be higher, the higher is the rate of growth. A second qualifier, Arrow notes, is that there is

[144] Arrow (1978), p. 5.

"...an intrinsic tendency to discounting the future. No individual living today can really regard individuals living in the future as being equivalent to himself. Indeed if benefits for all future generations were counted equally, the value of the present would dwindle into insignificance."[145]

Arrow notes that his argument suggests that present consumption should be reduced to subsistence levels. He suggests an "Investment Criterion" based on the following:

"Thus a rough consensus is that a future investment ought to be made if and only if the productivity of the investment is at least as great as the sum of two countervailing effects, the pure futurity or discount effect, and an allowance for the greater income of future generations."[146]

Further, Arrow states, that most economists are in agreement that the Investment Criterion should be governing public investment, however he says that actual public investments are often not made on this basis. It is unlikely that they ever would be.

Arrow also notes that from a social rather than individual perspective, individuals should save and invest less than the investment criterion requires. If future

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[145] Arrow (1978), p. 5.

[146] Arrow (1978), p.6. We note that the above productivity of the investment could be quantified or measured objectively to a point.

income is discounted at a higher individual rate, more savings and investments would be made than if discounted at a lower (social rate), perhaps zero. Also concern for one's immediate descendants tends to encourage a lower rate as well. With this effect, the actual market may lead to a more just outcome than the theoretical market model which suggests underinvestment as a possibility.[147]

Perhaps the primary thrust of the Arrow paper is to consider the important role which human capital formation plays in our economy, and why it should be encouraged. He states that among efficiency losses due to capital market imperfections, human capital formation is a big loser. He emphasizes the negative effect taxation can have on output, and suggests that government intervention to encourage education especially for the poor, while a drain on the economy, raises the earning potential of the poor in later life, and has the positive intergenerational effect of reducing future inequalities in income as well as raising the general level of future income. He mentions that there is probably a very high rate of return associated with the education of the poor with repayment dependent on future income. However, he does also mention the previously discussed argument that a skewed distribution of income with some individuals at far above average savings rates further encourages growth. He states, however, that there is likely to be a net positive effect, for the combination of these two factors. Arrow's preference for equality is also shown by a favouring of wealth taxes and in the end he concludes:

> "I take very seriously the moral obligation to achieve equity in income, now and in the future.

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[147] Arrow (1978), p. 6.

> This obligation does have to be properly balanced against the requirements of efficient allocation at a given moment of time and over time. No simplistic solution is possible, but recognizing the intrinsic imperfections of competition in a capitalist system affords opportunities to reconcile the two aims."[148]

In the end, equity in income is described as a moral obligation, and I think that is very much the thrust of most of Arrow's equity arguments. The equity goal seems to be exogenous to the capitalist system, rather like national security, or order, etc. Further, although Arrow focuses on equity in income, he implicitly encourages equality in opportunity, and a fair start.

PSYCHOLOGY AND INTERTEMPORAL DECISIONS

Expectancy Value Theory

The common approach of social psychologists to intertemporal choice problems, relies on expectancy value theory. There appear to be many expectancy theories[149] in the psychology literature, however, for our purposes here, it will be sufficient to outline briefly the general structures of those theories. One of the most well known of these theories is that of Vroom (1960, 1962, 1964) and I will focus primarily on this one.

There are several basic ideas to the theory. A "valence" represents a "feeling about specific outcomes". These feelings are anticipated feelings of satisfaction associated with the achievement of specific goals or outcomes. These items present a representation of future

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[148] Arrow (1978), p. 10.

[149] Miner (1980) p. 134.

wants, that is relevant to this thesis. The goals are personal, and, in contrast to the approach of moral theories, are not necessarily coincident with what a person should have as a goal. Outcomes, or events which will be associated with the anticipated feelings, can of course, have negative as well as positive values associated with them. In many ways, expectancy value theory is also related to research in decision analysis using the expected utility approach, with utilities as an analogue of a valence. Miner (1980) describes the relationship between instrumentality and valences of outcomes as follows:

> "As a basis for establishing the valence of a specific outcome, Vroom sets forth the following proposition:
>
> The valence of an outcome to a person is a monotonically increasing function of the algebraic sum of the products of the valences of all other outcomes and his conceptions of its instrumentality for the attainment of these other outcomes.
>
> Thus the size of the valence of an outcome is dependent on the extent to which it is viewed as a means to various other outcomes and the valences of the other outcomes".[150]

The ties to utility theory seem fairly extensive, as individuals are assumed to maximize "force" or positive values. Extensions to this particular work, and variations on the general theory of the area reviewed by Minor (1980) include Galbraith and Cummings (1967), Porter and Lawler (1968), Graen (1969) and Georgopoulos, Mahoney and Jones (1957).

Among the major criticisms raised regarding the theory by Minor (1980), are (1) the postulation of man as a hedonistic satisfaction maximizing being is untenable; (2)

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[150] Minor (1980), p. 136.

it is doubted that humans can cognitively handle the calculations required; (3) people differ in both time perspective and the proclivity for search (p. 148); and (4) individuals do act out of unconscious motives; "impulsive behaviour, the repetition compulsions of neurotic individuals, and the like" (p. 149).

Values, Psychological and Sociological Approaches

Some researchers in dealing with decisions looked to values directly in trying to explain behaviours. Strumpel (1972) states:

> "Values are affective states long before the resultant behaviour; they are relatively stable personality attributes, they are generalized concepts and effective in several spheres of action."[151]

In motivating the use of the concept value rather than attitude, Strumpel quotes Milton Rokeach in the following passage:

> "While attitude and value are both widely assumed to be determinants of social behaviour, value is a determinant of attitude as well as of behaviour. If we further assume that a person possesses considerably fewer values than attitudes, then the value concept provides us with a more economical, analytical tool for describing and explaining similarities and differences between persons, groups, nations, and cultures."[152]

The basic structure of the relationships between different kinds of belief statements, values, and value statements used by Rokeach may be represented

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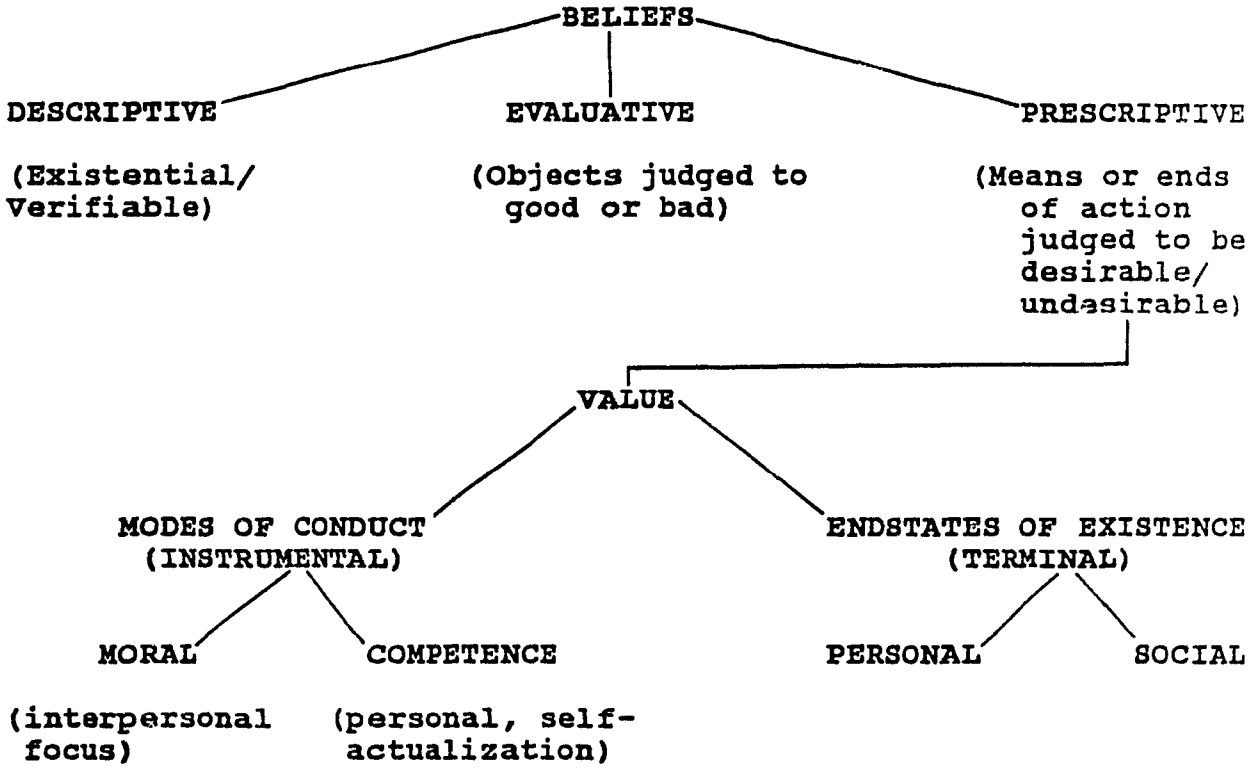
[151] Strumpel (1972), p. 96.

[152] Rokeach, M. (1970).

diagrammatically below.[153]



VALUES
- BASIC - Amenable through rational argument
- NON-BASIC - Not amenable through rational argument

VALUES --> ATTITUDES TOWARD OBJECTS, EVENTS, BEHAVIOURS (MODES OF CONDUCT)

ATTITUDES --> INTERVENING FACTORS --> BEHAVIOURS

Rokeach's approach is interesting, because he puts much emphasis on measurement, which it is hoped will reduce the usual vagueness of the values concept. He states,

"Any conception of the nature of human values, if

[153] Rokeach (1973), pp. 5-12.

> it is to be scientifically fruitful, should satisfy certain criteria. it should be intuitively appealing yet capable of operational definition. It should clearly distinguish the value concept from other concepts with which it might be confused - such concepts as attitude, social norm, and need - and yet it should be systematically related to such concepts. ..."[154]

His approach, if successful, must be considered a valuable and useful avenue of research to pursue. If we accept Robin William's statement below, the range of applicability is enormous.

> "Problems of values appear in all fields of the social sciences, and value elements are potentially important as variables to be analyzed in all major areas of investigation."[155]

While the pervasive use of the term values cannot be denied, it could be argued that in part the pervasiveness can be due to the very vagueness of the concept. The work of Rokeach makes a definite effort to clarify the values concept, in a scientifically operational way. Essentially, a scale construction approach is used to identify values, and then comparative studies are done between groups, and of similar groups over time. Some test results are offered in Rokeach (1973) and Rokeach (1979).

Generally speaking, Rokeach seems to satisfy fairly reasonably his assumptions and conclusions which follow:

> "(1) The total number of values that a person possesses is relatively small; (2) all men everywhere possess the same values to different degrees; (3) values are organized into value systems; (4) the antecedents of human values can

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[154] Rokeach (1973), p. 3.

[155] William (1968), p. 286, quoted in Rokeach (1973), p. 4.

> be traced to culture, society and its institutions, and personality; (5) the consequences of human values will be manifested in virtually all phenomena that social scientists might consider investigating and understanding."[156]

While there are many other researchers working in the area, however Rokeach himself seems to be a central figure in this research area, and this is why I focus on his work.

Not all researchers have been satisfied with the research, however. Handy (1970) reviews Rokeach's (1968) early work, as well as many of the other major theories of value produced by that time of publication. On Rokeach, Handy seems to be most critical of the claimed implications for therapy, education etc., associated with the identification of values, and much less critical of the procedures to establish values and results on values. Most of the problem areas were addressed by Rokeach in subsequent research.

In Understanding Human Values, Rokeach presents results concerning the relationships of individual and social (institutional) values, the enduring nature of values and how they evolve and can be effected by media, self-confrontation techniques etc., and the identification of likely value conflicts, evidenced in politics.

Rokeach's research is broad, but does address the problem of vagueness, by clearly identifying the specific items which are values,[157] and the statements and items which define them. Interestingly, none of the values listed appear to be concerned with intergenerational problems, although "Family Security (Taking care of loved ones)" may be so construed.

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[156] Rokeach (1973), p. 3.

[157] More detail on the values identified and associated scale items and test results could be presented here, but they are really more tangential to the central argument. See Rokeach (1979), p.133.

Equality focuses on equality at a point in time, and other values seem to focus only on the situation of the particular generation. Perhaps one area of research which could be pursued in this area would be a study of future oriented values, or the relationship of values to intergenerational problems. Certainly there are many current problems, such as groundwater pollution, deforestation and so on, which are likely to have intergenerational impacts.

Harf and Trout (1986) focus on values in the study of energy. They state,

> "The problems that arise in resolving the energy issue are a consequence of differences in value preferences that each actor or set of actors brings to the arena. All actors obviously do not share the same values. The field of energy values can be divided into four broad categories."[158]

Now, this seems to be a different approach from Rokeach, because the authors state that the actors have different values. But, this may also be interpreted to mean merely that all actors have the same values, but their relative importance differs, or the rankings of values may differ. The four values Harf and Trout identify are (1) economic, (2) institutional, (3) societal, and (4) non-energy. It is doubtful that any actor has one economic value, but none of the others, etc. It is likely that these different values are promoted or pursued to differing degrees by different actors and groups of actors.[159]

Their work also brings to the forefront the ethical decision regarding the initial choice of the market in

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[158] Harf and Trout (1986), p. 165.

[159] Their work also encourages the recognition that values may be grouped in different ways, a social versus personal breakdown would be a useful category.

settling issues. The economic approach of treating natural gas for example, just as a commodity, ignores the institutional issues such as the power of multinationals in our society, the rights of all present and potential members of society to the mineral wealth of a country, and the security of a society through energy self-sufficiency. The selection of the market alone to determine the use of a finite resource presumes a prior consideration of all these other issues. These values and tradeoffs will be further pursued later in this chapter.

Values, Axiology

The name which is given to the philosophical approach to the study of values is "Axiology". The term value is generally interpreted to be the "goodness" of a thing, and there have been many different philosophical schools which dealt with this term in different ways. Each of the schools, Pragmatists, Kantians, etc., all have different ways of answering the question, "What is intrinsically good?" Usually, however, in the philosophical literature the term "value" seems to have subjective connotations, as opposed to factual or objective connotations. For the purposes of this work, we will accept the premise that individuals subjectively judge the goodness of a thing, and can act based on these judgements.

Collective value, by a community or society, will generate what is referred to as that community's or society's values, or value system. Considered as a part of a hierarchy, values are the most general of a series of terms which include attitudes, beliefs, and opinions. The term values may refer to a collection of the values of the individuals of a society and those will usually evolve over time. The reason why they appear to change slowly would seem to be that in the main, one generation learns "what is good"

from the previous one. Children born in one culture and brought up in a different culture will generally have attitudes and behave in ways which reflect the value of the culture in which they have been brought up. The key point of this argument is to suggest the hypothesis that values are individual, but are frequently shared communally and passed from generation to generation. They appear to be learned.

International Equity

One item which is conspicuously absent from most intergenerational type economic arguments are references to other people outside national borders. It seems odd in this problem context to be very concerned about generations living five hundred years from now, while ignoring the equity issue involving people five hundred miles away. This discussion though an interesting one in the context of comparisons of different social and cultural institutions, and even different economic systems is going beyond the scope of this thesis. The problem of equity in international contexts would in many ways be an equally interesting problem to consider. Some consider the international extensions to be an essential and integral part of the development of the moral theory of justice. Richards (1983) is critical of Rawls (1971) for this reason. "His failure to consider international distributive justice is quite ad hoc and ill defended".[160] Inclusion of international dimensions dramatically alter the typical economic approaches to problems, and I believe would encourage quite different thinking on this subject. The main point, however, is that a lack of concern about the welfare of people now living but in another country does not suggest that we should expect much concern about people not yet born. In the context of

[160] Richards (1983), p. 136.

this study, the international aspects of value are important, and are intrinsically tied to intergenerational considerations. The adoption of a pro-export gas policy in Canada may imply the favoring of this generation of foreigners at the expense of future generations of Canadians

Values, Held Values, Assigned Values, and Equity

Brown (1984) focuses on a key issue in this thesis, the use of market prices, to determine resource allocation. He argues that in certain cases market valuations are inappropriate. He notes that his paper is concerned with preference related concepts of value. He refers to Von Wright (1963) in the following:

> "Preference is used here to mean the setting by an individual of one thing before or above another thing because of a notion of betterness."[161]

He also describes three preferences-related value realms; the conceptual, the relational, and the object realms. Conceptually,

> "...A value is an enduring conception of the preferable which influences choice and action. One can think of this conception of the preferable, as a preference of the first order, which influences all subsequent second order preferences (and therefore choice and action), or as that which underlies all preference."[162]

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[161] Brown (1984), p. 232.

[162] Brown (1984), p. 232.

This structure is very similar to that which was described in the work of Rokeach (1968, 1973). And the value labels which Rokeach used, e.g., loyalty, happiness, and beauty, are described as underlying values, or value proper; and these ideals are called "held values".[163]

> "Held values are the modes of conduct, end- states, or qualities which could possibly be desirable."[164]

He also is consistent with Rokeach in stating that (1) most individuals have many held values, (2) the value system of any individual is the individual's organized set of values, (3) held values can be categorized into instrumental and terminal values with their subdivisions into moral and competence values for the former, and personal and social values for the latter. He also refers to Rescher's (1969) categorization of values on the basis of subscription - personal values, professional values, national values.

In the relational realm, value neither belongs to subject or object per se, but arises through the interaction of subject and object.[165] Brown states,

> "Value in the relational realm is not observable; it is only at the feeling level. However, value in the relational realm often gives rise to an expression of value, which brings us to the object

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[163] Brown refers to Rescher (1969) for this label.

[164] Brown (1984), p. 232.

[165] Brown refers to Scheibe (1970)

realm."[166]

In discussing the object realm, Brown states,

> "...value is the expressed relative importance or worth of an object to an individual or group in a given context. The relative importance or worth results from a preference relationship. It is not a character of the object, but rather the standing of an object relative to other objects. Such value is always relative because we have no absolute value standard, and thus, can only express the importance or worth of an object by implicit or explicit comparison. Value in the object realm will, for lack of a better term, be called 'assigned value'."[167]

We note that Brown emphasizes that the individual does not just "assign" a value to an object, but rather value arises in the relational realm, given one's held values, and results in an object having a particular (relative) worth to an individual. Brown describes the relationship among value in the three realms in a diagram similar to the following:

Preference

HELD VALUES ----------> ASSIGNED VALUES

Relationships

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[166] Brown (1984), p. 233.

[167] Brown (1984), p. 233>.

Brown refers to the possibility of assigning values to held values, or ranking the importance of held values (as thoughts) using held values. The value system, however, is the basis for this assignment. He also emphasizes the contrast between "norms" and held values. He states:

> "Norms or normative ideals, are the principles that are held up by philosophers of all distinctions as the concepts that should be followed. The Ten Commandments are perhaps the best known examples in the Western world. Norms are the held values which, according to the proponents, should influence individual preferences; that is they are the held values to which others are asked to assign great value."[169]

This aspect of values was noted earlier on, in the context of finite resource use. One is concerned that even if we do choose a depletion pattern that people say they want, is it the one they should want? Is it the morally correct one to choose?

Assigned values will be the focus of our attention here, because price in our market oriented system is our measure of value, which determines usage rates of our finite resources. Brown states that assigned values may be general (unspecified), or specific. As an example, Brown notes that

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[168] Brown (1984), p. 234

[169] Brown (1984), p. 234.

a forest may have assigned value in general, as well as value for specific purposes, e.g., educational, food, recreational, and commercial.

Assigned values can be expressed by two modes, actions or words, on ordinal or interval scales, using different measures, e.g., price or time commitments as actions, and opinions of importance or willingness to pay as words. These expression mode-scale-measure dimensions presumably interact. Further, there are source-constituency combinations which may influence assigned values. Brown pictures the following:

		Source	
		Individual	Group
Constituency	Individual	1	3
	Group	2	4

The following were given as examples:

1) Trustee administering a trust for an individual
2) Vote of a senator regarding public policy.
3) Advice of parents to a child
4) Market prices, election results, survey results.

Further, Brown states,

"The value assigned to an object by a person depends on (1) the person's perception of the object and all

other relevant objects, (2) the person's held values and associated preference, and (3) the context of the valuation."

The person's perception is "what he sees and understands about the object". The "held values" are described earlier, but the "context" requires elaboration. Brown explains:

"Several factors determine the context of the valuation, including (1) the internal state of the valuator, (2) the valuator's external situation and expectations for future changes in that situation, (3) the social setting of the valuation, (4) the mode, scale, and measure in which the valuation is expressed, and (5) the constituency of the valuation."[170]

The following are examples and references relating to the above:

(1) physical and emotional state
(2) financial situation, free time, possessions
(3) influence of others' judgements
(4) degree to which valuation is constrained by circumstances, e.g., limits of available choices
5) whose values are being represented

[170] Brown (1984), p. 235

Interestingly, Brown refers to Arrow (1963) where, in Social Choice and Individual Values, the latter states:

> "In general, there will...be a difference between the ordering of social states according to the direct consumption of the individual and the ordering when the individual adds his general standards of equity..."[171]

A return to the work of Arrow will be useful here, because it places the Arrow theorem in the context of this discussion of values. Referring to the above quote, Arrow states,

> "We may refer to the former ordering as reflecting the tastes of the individual and the latter as reflecting his values."[172]

and later,

> "...we must look at the entire system of values, including values about values, in seeking for a truly general theory of social welfare.

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[171] Arrow (1963), p. 18) Arrow notes that this distinction was stressed to him by Milton Friedman.

[172] Ibid, p. 18.

> It is the ordering according to values which takes into account all the desires of the individual, including the highly important socializing desires, and which is primarily relevant for the achievement of a social maximum. The market mechanism, however, only takes into account the ordering according to tastes."[173]

Thus, Arrow, in his work chooses to focus on the wider idea, that of social states, which encompasses the distribution of all goods and services, the amounts of all resources used in all activities, including all government and diplomatic services, and as well any implicit valuation, such as equity, etc. His work extends to cover choice over alternative economic systems as well. This is discussed in "The Decision Process as a Value".[174] While this aspect of Arrow's work is fascinating in itself, it is really the contrast between a values based focus, and an individual tastes based focus which is of primary interest at this point. It is the latter focus that is characteristic of the neoclassical market mechanism approach.

Arrow differentiated between the choices individuals make between systems, based on values, and the choices individuals make in the market, based on tastes. The former is the focus of his work on the voting paradox, and his use of values in that context makes them appear to be the same as "held values" in Brown's terminology. Choices among social states can reflect one's feelings regarding equity and fairness.

In the standard neoclassical market model formulations,

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[173] Arrow, (1963), p. 18.

[174] Arrow (1963), p. 89.

however, values are represented by individual preferences, represented by utility on an individual basis. Each person has consumption preferences, and utility offers a way of ranking those preferences for the individuals. Preferences are presumably independent of the distribution of goods in the economy. Thus, an individual's demand for a finite resource, is presumably independent of the demand that an individual 200 years from now would have for the same finite resource. If supplies are withheld from current consumption for future consumption under a conventional market system, it is only by the action of firms that wish to maximize profits. The fact that future Canadians will have a need for natural gas does not directly affect current demand for natural gas.[175]

In Brown's terminology, the current assigned value may not be representative of the true held values of individuals in the economy regarding future generations. If the government advertises the need for individual conservation for future generations (e.g., turn down the thermostats), and quantity demanded decreases at each price, then we have a direct values based response, and the price that had reflected only assigned values might decline. This seems like a curious result: greater concern for future generations reduces current demand, reduces apparent assigned value (price), and reduces total current use. Also, in industrial applications, assuming overall demand for other goods stays the same, output levels must be maintained, and we should identify increased demand for other energy inputs, raising their prices, and assigned values.

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[175] Indirectly, of course, if one investor is of the opinion that the consumers in the future will pay a price that is higher than the present discounted value of that price then to this extent the investor will purchase gas now for sale in the future.

What are the implications for the Hotelling rule? Other things equal, the reduction in demand caused by a concern for future generations should drop the intertemporal price path, and the intertemporal quantity path, and thereby extending the time of final exhaustion. If the firms are profit maximizers, then, one should expect the terminal time i.e., the time of exhaustion to be moved farther into the future. The effect of the change in assigned value, as a result of the government campaign, is to produce an alternative, and equally optimal depletion pattern. It is, in a sense, an examination of an alternative world with different held values emphasized, or with a slightly different context emphasized, or with perceptions altered.

Such choices cannot be challenged on economic grounds. For example, the assignment of property rights is a choice that may be made by individuals in a democratic society, and accepted as a basic institution by economists. Economists may argue that the choices of certain institutions may have particular impacts on the level of foreign trade, or national income, however, the selection of a non-market rule for the distribution of property, allocations of finite resources, or basic freedoms allowed by social institutions involves choice outside the strictly economic sphere.

If in the interest of future generations of Canadians, the population chooses to set aside specific quantities of finite resources, and protect certain natural environments from the encroachment of industry, because such concerns are highly valued, the economist as economist cannot say that such a thing is wrong. The economist may perform analyses which show the possible loss in income perhaps, associated with such programs, or effects on unemployment, relative to say a pure market solution, but there are no economic bases on which one can condemn such value based decisions.

CHAPTER FOUR

A NATURAL GAS INDUSTRY SIMULATION MODEL

INTRODUCTION

One purpose of this chapter is to describe some of the decisions which the Canadian government has taken regarding the usage rates of a finite resource, natural gas, and to consider the provisions made for the use of this resource by future generations. The key institutions which regulate the use of this resource in Canada are the National Energy Board (NEB) and the Alberta Energy Resources Conservation Board (AERCB).

The NEB and AERCB are charged with (among other things) the protection of the interests of present and future generations of Canadians, and they have elected to use certain non-market rules in fulfilling these charges. Particular emphasis is placed on the role that rules for exports play in the exhaustion of the Canadian natural gas stock, as exports are a critical and central factor in the exhaustion of the stock. In this chapter, the impact that the use of these rules is likely to have is considered especially in contrast to a "more market oriented" approach. The impact on the natural gas supply industry, on depletion patterns, and the possible exhaustion times for natural gas will be the primary focus.

As a tool to help to evaluate these rules, a simulation model of the Canadian natural gas industry will be presented. The model contains national and international demand, domestic exploration, domestic development and production sectors, and pipeline delivery sectors, as well as a decision sector representing the NEB and AERCB. Prices are assumed to be determined in the larger world and North American gas substitutible energy supply markets for the open and restricted exports cases. In the closed border case it is argued that the same political regime which does this,

possibly in the interest of conservation, would also set prices at or near world and North American levels. Thus the model will not contain endogenous price determination. The structure and processes of the model will be discussed in detail, and it is argued that it is fairly representative of the actual industry. Appropriate modifications to parameters are made in order to simulate "more market oriented" solutions for rates of depletion and resource exhaustion. It is argued that contrasting results that follow from different rules and assumptions will offer valid insights regarding the directional influence that non-market rules are likely to have with respect to relevant outcomes.

The National Energy Board and The Alberta Energy Resources Conservation Board

The National Energy Board was created in 1959 by an Act of Parliament that followed, and was much influenced by the 1957 Royal Commission on Energy (Borden Commission) report. Douglas Fraser, one of the five founding members notes,

> "The creation of the NEB was not a sudden flash of inspiration. It was more an adaption to foreseeable needs of a long history of regulatory law. It brought together the regulation of exports of power and natural gas established by an Act of 1907, the importation of gas tacked onto the export legislation in 1954, and the regulation of interprovincial and extra provincial pipe lines enacted in 1949."[1]

The activities of the Board at its inception covered a wide range, and grew even wider in fulfilling its responsibilities as time went on. Some of the key responsibilities which are detailed in Parts II, III, IV and VI of the Act and which are of concern for this thesis are the

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[1] National Energy Board (1984), p. 53.

following:

Under Part II,

- advisory function to government covering all aspects of oil and gas activity from exploration to final disposal within and without Canada.

Under Part III,

- approval of the construction of natural gas pipe lines, studies into the availability of supplies for use in those lines, as well as financial viability, economic feasibility, existence of actual or potential markets, and "any public interest that in the Board's opinion may be affected by the granting or refusing of the application"[2]

Under Part IV,

- The Board is responsible for all tariffs and tolls on pipelines, and they must be just and reasonable.

Under Part VI, sections 81, 82, 83 and 85 are quoted in full below.

"Part VI: Exports and Imports

Gas and Power
81. Except as provided in the regulations, no person shall export any gas or power or import any gas except under the authority of and in accordance with a license issued under this Part.

Issue of Licenses

82. (1) Subject to the regulations, the Board may

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[2] NEB Act, section 44(e) in Statutes of Canada, 1959, Vol. I.

issue licenses, upon such terms and conditions as are prescribed by the regulations, a) for the exportation of power or gas, and b) for the importation of gas. (2) A license issued under this Part may be restricted or limited as to area, quantity or time or as to class or kind of products.

83. Upon an application for a license the Board shall have regard to all considerations that appear to it to be relevant and, without limiting the generality of the foregoing, the Board shall satisfy itself that a) the quantity of gas or power to be exported does not exceed the surplus remaining after due allowance has been made for the reasonably foreseeable requirements for use in Canada having regard to the trends in the disdovery of gas in Canada; and b) the price to be charged by an applicant for gas or power exported by him is just and reasonable in relation to the public interest.

Regulations

85. The Governor in Council may make regulations for carrying into effect the purposes and provisions of this Part and, without restricting the generality of the foregoing, may make regulations respecting: a) the information to be furnished by applicants for licenses and the procedure to be followed in applying for licenses and in issuing licenses; b) the duration of licenses, not exceeding twenty-five years, from a date to be fixed in the license, the quantities that may be exported or imported under licenses and any other terms or conditions to which licenses may be subject; c) units of measurement and measuring instruments or devices to be used in connection with the exportation of gas or power or the importation of gas; d) the inspection of any instruments, devices, plant, equipment, books, records or accounts or any other thing used for or in connection with the exportation of gas or power or the importation of gas; and e) reports or other information to be supplied by persons to whom licenses have been issued and any other matter associated with their use." [3]

In fulfilling those charges, the NEB has at various times elected certain non-market rules for the determination of

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[3] Statutes of Canada, 1959, Vol. I.

quantities placed on the market, and especially the volumes made available for export. On the domestic use side, prices have been fixed from time to time by government order.

On the export side, both prices and maximum quantities have often been fixed by the National Energy Board. Approvals for export facilities likewise must be obtained from the National Energy Board.

It should be noted, however, that the Board has recently moved in the direction of more market-oriented pricing both domestically and internationally. The current conservative government has encouraged this change, however it is quite possible that the election of a less market-oriented government at some future time could reverse this trend and cause a return to a more regulated approach. While the NEB is presumably independent of the Minister of Energy, all decisions are nonetheless subject to the Minister's review.

Geoffrey Edge, an ex-chairman of the National Energy Board notes that since the Act's inception, the government has had the power to revoke any of the NEB decisions. He goes on to say, however,

> "In considering the applications for certificates and licences put before it, the overriding criterion applied by the Board in keeping withthe NEB Act is the public interest. The fact that no recommendations by the Board on such regulatory matters have ever been rejected by the government of the day is one measure of the Board's success in fulfiling its mandate."[4]

Edge also notes that very few challenges on tolls and tariffs, which can be taken to the courts, have ever been upheld. The National Energy Board, along with its rules and procedures seem to have been well accepted, at least in the sense of being relatively unchallenged.

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[4] NEB (1984), p. 2.

The general procedure which the Board followed in 1960, when the first major export permits were issued[5] was as follows. Information on present and future requirements for Canadian markets on a province-by-province basis were estimated by applicants, and by other interested parties including other government agencies, and by National Energy Board staff using all available information. These requirement estimates were then compared with reserves and deliverability data obtained in a similar fashion in order to identify the amount of natural gas which was surplus to Canadian needs. The origin or basis for the first surplus test was not published. In the NEB (March, 1960) Report to the Governor in Council, the Board stated only that:

> "The Board believes thirty years to be an appropriate period for the calculation of the reasonably foreseeable requirements in Canada."[6]

This first test required that thirty years of domestic demand be capable of being met from established reserves plus future reserves that were estimated on the basis of historical finding trends. The rationale for such a test was never clearly identified, but in any event, from this very simple beginning, the tests have evolved significantly over time.

Most of the intervenors in the first hearings were in favour of exports, the Saskatchewan Power Corporation, however, was an exception, and noted the following concerns.

(1) The proven reserves of natural gas in Canada were not

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[5] Westcoast had been exporting small quantities earlier on.

[6] NEB (March, 1960), p. 12-1.

more than adequate to meet 30 years of future domestic requirements;

(2) The National Energy Board must determine what level of proven and probable gas reserves is required before export are justified;
(3) In the light of the limited proven reserves and of the uncertainty concerning estimated requirements and the expected increases in new reserves, the Board should exercise a cautious approach to gas export;
(4) Before exports are allowed, proven reserves should, as a minimum, be equal to 30 years of Canadian requirement. In order to provide incentive for exploration the Board should recommend that the Dominion Government acquire proven reserves within the limit of economic feasibility;
(5) The establishment of a minimum national reserve should involve an independent appraisal by the National Energy Board inasmuch as applicants had an interest in understating Canadian requirements and in over-stating the reserves that were available;
(6) Canadian utilities should have a prior right to use gas licenced for export should other sources of gas available to Canadian utilities prove inadequate. Such a right should apply to any Canadian utility operating in an area traversed by or supplied with gas from a Canadian pipeline.[7]

The brief statement by the Board and the intervention by the Saskatchewan Power Corporation seem to be the only references to the thirty year term, and these offer no specific explanation of why that term was selected or to what extent domestic requirements might be satisfied by proven or

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[7] NEB (March 1960), pp. 11-13, 11-14.

"trend" (probable but unproven) reserves. In the first decision, the "reasonably foreseeable requirements" of Part VI seem to have been emphasized, whereas in later decisions and publications, the Board referred to its responsibilities to protect the interests of present and future Canadians. This may not have been so much a change in the interpretation of that particular section of the Act, as a broadening of the concern of the Board to protect the wider "public interest" which was also mentioned in the Act. In the NEB (1960) Reasons for Decision, the role of the Alberta protection rules and contracted reserves are emphasized in the development of the protection formula. No specific mention seems to be made regarding why reliance on markets for oil alone would be inadequate to "protect" Canadian needs, or why "protection" was specifically required.

Certainly, the rules evolved over time to address particular problems. For example, explicit concern with short term deliverability was incorporated into the protection formula, in response to deliverability shortfalls in the early 1970's. At this time, there was no shortage of reserves, but there was a problem with deliverability. The history of the evolution of the surplus tests for exports used by the National Energy Board since 1960 appears in Appendix 2 at the end of this thesis.

The National Energy Board was greatly helped in the early years by the Alberta Oil and Gas Conservation Board.[8] It is quite possible that the origin of the thirty year test was to be found in the rules of the older Alberta regulatory body. Exporters had to obtain Alberta removal permits, and to satisfy Alberta surplus tests in addition to being granted an export license by the NEB. The Alberta tests, however, were concerned solely with the surplus of Albertan gas supply over

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[8] NEB (1984), p. 57

Albertan gas requirements. Thus, a potential exporter has had to attend hearings and present evidence to both a Federal and Provincial regulatory board and has to satisfy two sets of public interest requirements.

An Evaluation of NEB and AERCB Rules

Based on the discussions presented in the previous chapters, it is reasonable to expect that Canadians might wish to make explicit provision for the future needs of Canadians, and not necessarily to rely only on the market for this protection. A key purpose of this chapter is to present evidence on the likely influence that the use of the export rules would have on depletion patterns, time of final exhaustion, and industry performance. Literature reviews and contact with industry and regulatory body personel indicate that such an analysis has not been published since the inception of the export rules.

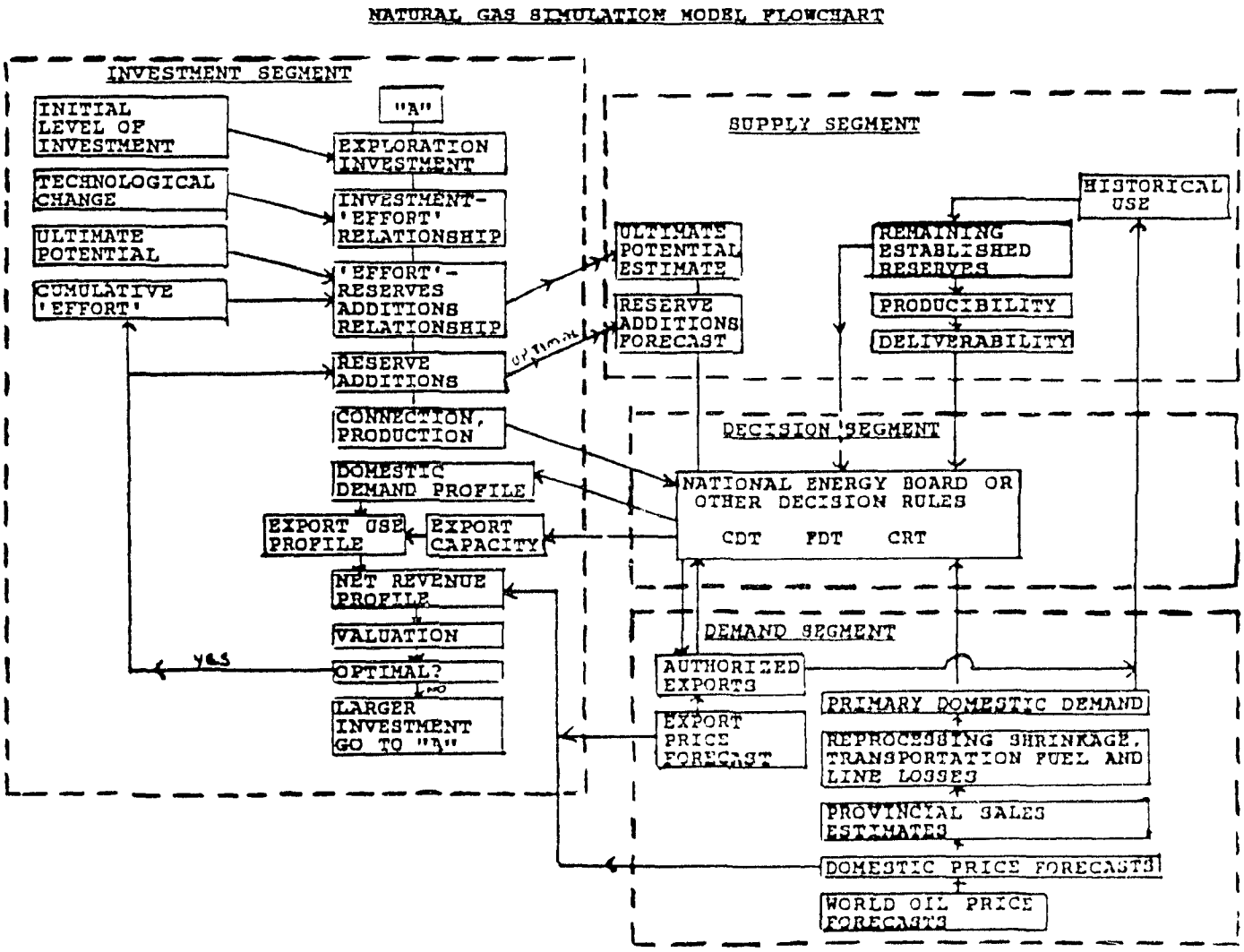
The structure of a simulation program to evaluate the influence of the export rules should be one which reflects, as accurately as possible, the structure and functioning of the natural gas industry. Of course, the model requires compromise, as it must be a simplification of reality, and an abstraction based on reality. Ideally, one would like to capture the central and critical aspects and elements of relevant reality while at the same time constructing a useful and practical analytical tool.

SIMULATION MODEL

The simulation model developed in this thesis has four main segments. The first is the demand segment, which contains information on domestic and export demand for natural gas. The second segment is supply information on ultimate potential, historical use, reserve additions forecasts, deliverability and other variables. The third

segment is the exploration and investment sector. The fourth and last is the NEB decisions segment. The diagram on the following page shows the overall natrual gas simulation model flows.

Diagram One


NATURAL GAS SIMULATION MODEL FLOWCHART
INVESTMENT SEGMENT
"A"
INITIAL LEVEL OF INVESTMENT
TECHNOLOGICAL CHANGE
ULTIMATE POTENTIAL
CUMULATIVE 'EFFORT'
EXPLORATION INVESTMENT
INVESTMENT-'EFFORT' RELATIONSHIP
'EFFORT'-RESERVES ADDITIONS RELATIONSHIP
RESERVE ADDITIONS
CONNECTION, PRODUCTION
DOMESTIC DEMAND PROFILE
EXPORT USE PROFILE
EXPORT CAPACITY
NET REVENUE PROFILE
VALUATION
OPTIMAL?
yes
no
LARGER INVESTMENT GO TO "A"
SUPPLY SEGMENT
ULTIMATE POTENTIAL ESTIMATE
RESERVE ADDITIONS FORECAST
HISTORICAL USE
REMAINING ESTABLISHED RESERVES
PRODUCIBILITY
DELIVERABILITY
DECISION SEGMENT
NATIONAL ENERGY BOARD OR OTHER DECISION RULES
CDT FDT CRT
DEMAND SEGMENT
AUTHORIZED EXPORTS
EXPORT PRICE FORECAST
PRIMARY DOMESTIC DEMAND
REPROCESSING SHRINKAGE, TRANSPORTATION FUEL AND LINE LOSSES
PROVINCIAL SALES ESTIMATES
DOMESTIC PRICE FORECASTS
WORLD OIL PRICE FORECASTS

Demand Segment of the Simulation Model

The National Energy Board, in its policy pronouncements, has repeatedly emphasized the need to determine the demand for natural gas in a total energy system. A great variety of approaches have been used,[9] for example, the Department of Energy, Mines and Resources supported a multi-equation estimating system for all fuels and energy sources, the demand for natural gas being identified simultaneously. Most of these procedures, however, focus on the use of data from historial time periods to identify trends which are then expected to apply in the future.

There are, however, many reasons why one might expect the future to be quite different from the past. Some of these reasons include the maxims and meaning of the rise and relative demise of OPEC's power, dramatic increases in sources of supply of energy resources in both Communist and non-Communist countries, deregulation in oil and gas in Canada's largest importer of natural gas - the United States, substantial regulatory reform in Canada, and a persistent trend in conservation of energy rather than the one-shot conservation effort that was expected as a result of the sharp price increases in the seventies.

For these or other reasons, one might consider an approach which utilizes some results from historical demand estimation, but is more future oriented, with the use of judgmental factors that are not likely to be revealed by either projections or equations based on historial data. One feature which must be captured by the model, is the idea that at various prices in the future, it is likely that natural gas will be "backed out" of certain uses in favor of other inputs. Models based on historical data have distinct

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[9] see Ziemba et al. (1980).

limitations in this regard. To the extent that the technological changes that were evident in the past, can be expected to carry into the future, the historically oriented models may capture the elements fairly well. However, many of the expected technological changes are not reflected in historical trends, and the relative price changes which will encourage the "backing out" of gas in certain uses, and conversely the entry into others is not likely to be captured by simple historical analyses.

For example, in Pindyck (1979), we read of a variety of different elements influencing residential natural gas demand for different countries over the period 1960-1974. This diversity, Pindyck argues, makes the estimates of elasticity etc., obtained on a pooled basis, more likely to provide a good basis for long run estimation, than for the short run. (Elasticity estimates range from -.9 to -1.8 which he claims to be at the high end compared with previous studies). His results are particularly interesting, because the nine countries studied had quite different backgrounds in relative prices, overall energy use per dollar of GNP, consumption per capita of residential energy etc.. By studying the past experiences of the various countries, we might improve our subjective estimates of what the demand for natural gas could be in different situations encompassing the myriad other variables, including the effects of competing fuels, regulation, and so on. The following table lists some of the key end users for natural gas, which influence overall demand for gas.

The End Users of Natural Gas

The following table (based on ERCB 78-1) will give the reader an overview of the particular demand segments for natural gas.

1) Electric Power

a) electric end-use
   - base load generation
   - peaking generation

b) special purposes
   - coal fired power plants
     · start-up
     · flame stabilization

c) on-site electrical generation for plant self-sufficiency
   - tar sands
   - petrochemicals

2) Non-Electric End Use

a) residential
   - home heating
   - home air conditioning

b) commercial
   - heating and air conditioning of apartment buildings, mobile homes, businesses, etc.

c) industrial
   - on site use for fuel & feedstock inputs, tar sands, heavy oil
   - petrochemicals: ammonia, benzene, ethylene, methonol, other fertilizer products
   - cement, gas or coal fired operations
   - oil refining operations
   - coal preparation operations
   - thermo chemical processes in pulp and paper
   - transportation

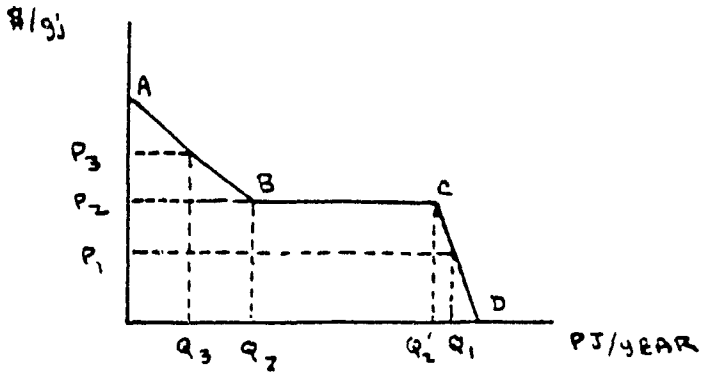
Displacement and "Backstops"

It would be desirable to identify the price levels at which various substitutes for natural gas could come on stream. For example, at some price level for gas, coal would replace gas in most base load power generation. At some other natural gas price, electricity might replace gas in, say, 50% of residential heating. At some price, refined heavy oil could replace gas in 40% of commercial applications.

The following diagram illustrates how a demand curve can reflect natural gas being replaced by other fuels, or alternatively natural gas replacing the other fuels in various

market applications as the price of gas goes up or down. It also incorporates the idea of backstop technologies for natural gas, in a way which is slightly different from the way the term is generally used in the literature.

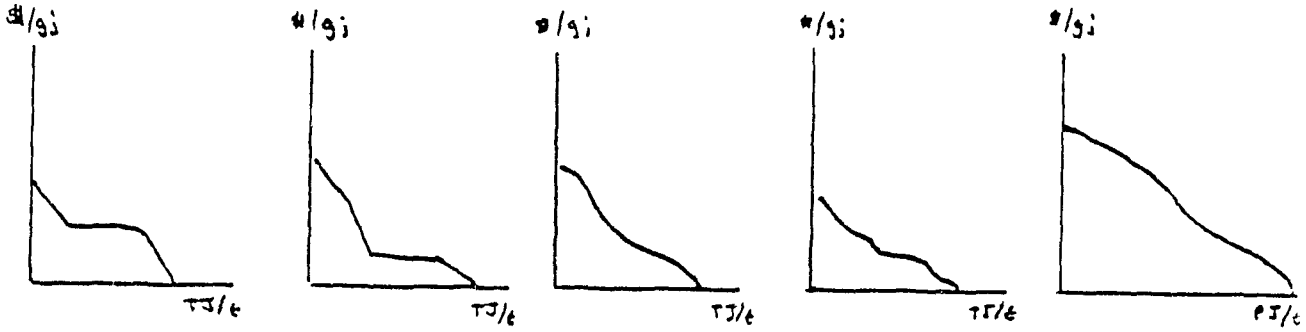
At a particular year, the demand for natural gas may be represented by demand curve ABCD in the figure below:



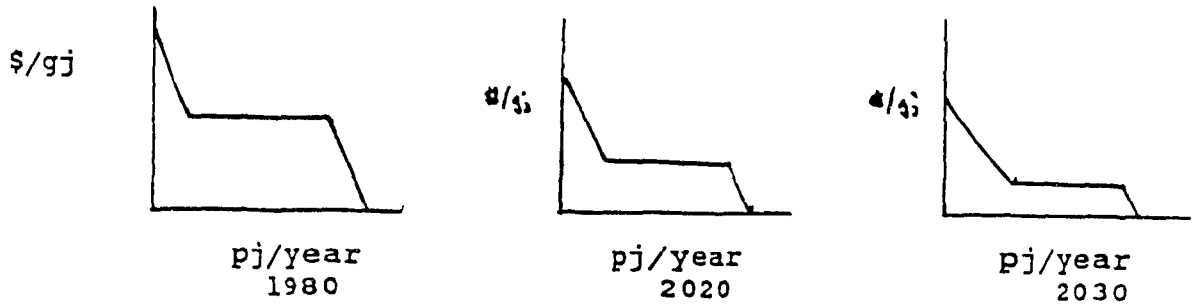
At initial price P_1, Q_1 petajoules of gas would be sold annually. Were prices to rise to the critical value P_2, sales would rapidly drop from Q_2' to Q_2, as gas is replaced in many uses, perhaps by say heavy fuel oil, which is priced below P_2 on an energy efficiency basis. Heavy fuel oil may be seen as a "backstop", or substitute in a major way for natural gas at that price level, and market shares shift rapidly. However, there are still many uses for which natural gas does not have other "backstop" or "substitutes", possibly as petrochemical feedstock, etc., unless price is higher, in the AB region of the demand curve.

The curve presented shows a single "critical price" P_2, at which a dramatic shift in market share occurs. In practice, it is likely that gas would be backed out of a variety of different uses at different prices, and so there would likely be a rising sequence of "initial prices" for different substitutes in different uses as shown below.

This substitution would produce a set of sectoral demand curves for gas that might look somewhat as follows:



Further, as time goes on, other technologies, solar, wind, tidal power, etc., will likely become less expensive, and conversion efficiencies for them will improve. To this extent, the price at which the backstops would enter would be declining over time, so we might observe the following intertemporal pattern, for say residential demand for natural gas.



Conversely, to the extent that conversion efficiencies for gas improve, i.e., 79% heaters to 98% heaters, the backstop price might be higher. We note, however, that we are emphasizing the <u>future</u> orientation of this approach, the introduction of heretofore unused or little used alternative technologies, and of conversion efficiencies not yet achieved. This approach is in a way reminescent of the scenario building of Herman

Kahn, but with perhaps more reliance on analytical modelling.

It is clear, however, that while the focus is on natural gas, we must continue to examine this problem in the total energy context. Gas competes on many fronts with another finite resource, oil, which generally has a higher cost per BTU, and a lower reserve life than gas. On the basis of the theory outlined in the first chapter, one would expect that the price of oil would normally be above the price of gas, and that gas would be generally preferred wherever it could be obtained at a reasonable cost. Historically, however, this has not been the case. Several factors are involved. For example, refinery capacity and technology along with the type of oil found in western Canada produced excessive (and therefore low priced) heating fuel. Refineries had to have high through-puts in order to meet the demand for gasoline and light products and the co-product heating fuels had to be sold for what they could obtain in the market. It is not surprising that studies of natural gas usually include a study of oil, especially heating oils.

World Oil Prices

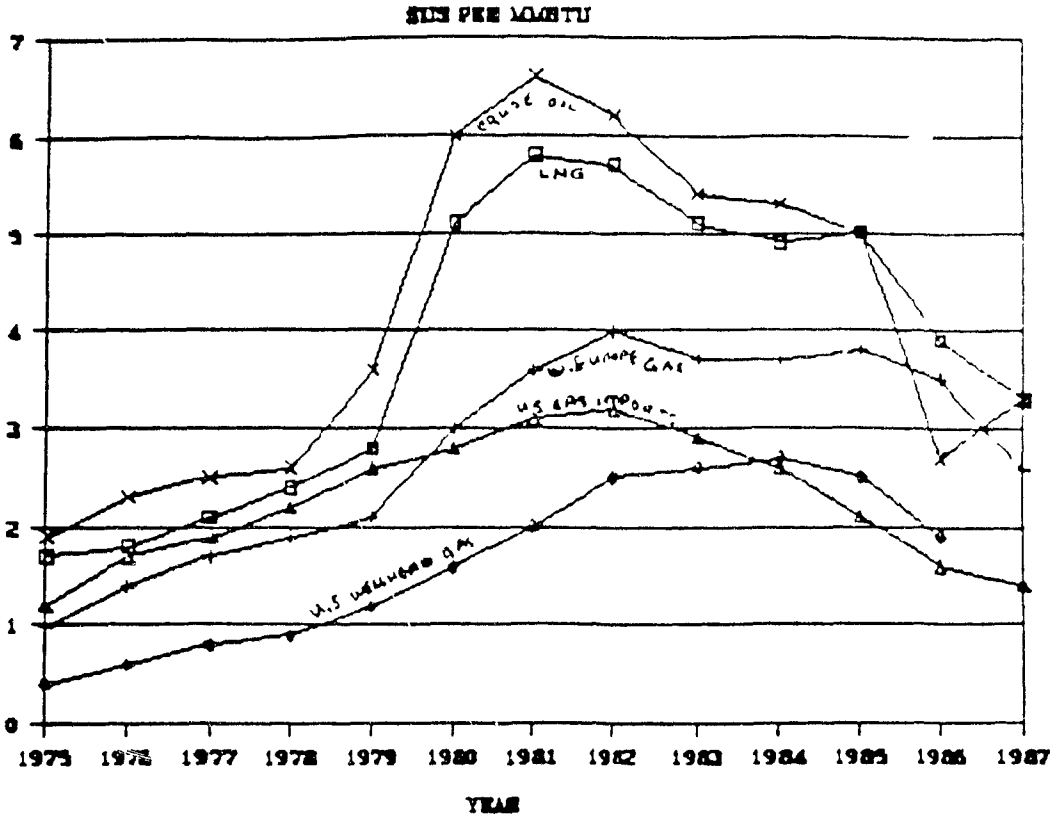
Gas and oil price relationships

As has just been noted, there is a good reason that most of the Canadian natural gas demand studies done by economists, have begun with an analysis of the world price of oil. This is because petroleum products such as fuel oil provide the closest competition for natural gas in most applications. Further, Canada is such a small percentage of world and North American production and consumption, that it is deemed to be "too small" to influence world prices for oil. Thus, Canada is often viewed as a price-taker in the North American oil and gas market. This is more true of oil,

however, than of gas because Canadian production and Canadian regulation have had some influence on North American (especially Canadian) prices for natural gas. In this thesis, the regulations of interest are the rules on exports, and it is reasonable to treat price as an exogenous variable for the analysis in this context. Over the horizon of the analysis, Canadian natural gas is likely to be a relatively small part of world and North American gas substitutible energy supply and the assumption of exogeneity for this study is a reasonable one.

Through the 1970s to 1982, natural gas export prices increased fairly steadily as Canadian governments and the Canadian industries moved to capitalize on the world "oil shocks" of 1973 and 1979. United States import prices from 1975 to 1987 are shown on the following page. From 1975 (and earlier) to the end of 1983, U.S. import prices (of Canadian gas) were consistently higher than average U.S. wellhead prices. This can be explained in two ways. First of all, U.S. price regulations held down the price of "old" gas whereas Canadian exporters (with the help of Canadian governments) were able to take advantage of the U.S. gas shortages - brought on in large measure by gas price controls. From 1984 on, U.S. wellhead prices were at or above (Canadian) import prices at the border, reflecting a more competitive environment in which Canadian gas border prices reflected the fact that Canadian gas imports were generally further from the U.S. burner tips than were the gas supplies within that country.

GAS AND OIL PRICES 1975-1987



GAS AND OIL PRICES 1975 - 1987 US$ PER MMBTU

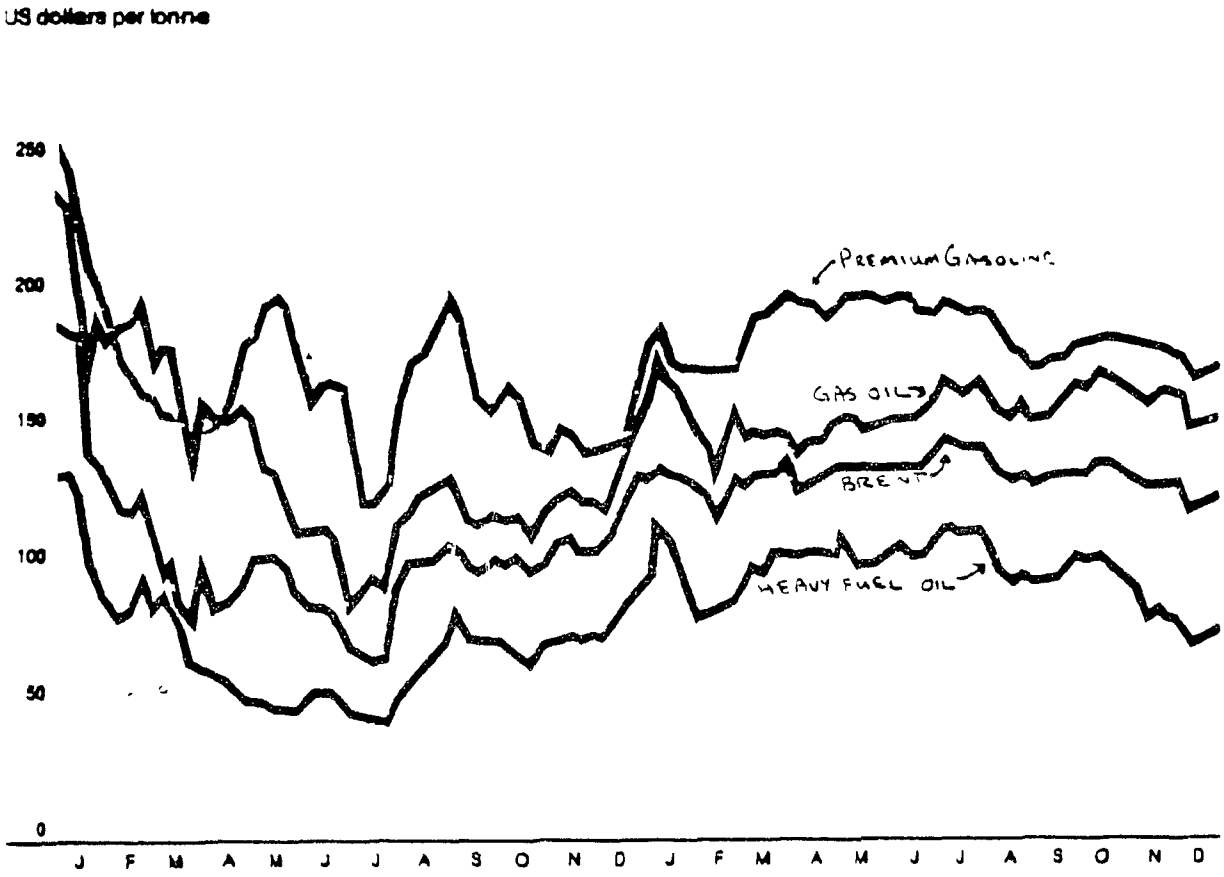
YEAR	LNG	NATURAL GAS			CRUDE OIL
	LNG cif JAPAN	W. EUROPE	U.S.A. (wellhead)	U.S.A. (imports)	cif IEA countries
1975	1.7	1.0	0.4	1.2	1.9
1976	1.8	1.4	0.6	1.7	2.3
1977	2.1	1.7	0.8	1.9	2.5
1978	2.4	1.9	0.9	2.2	2.6
1979	2.8	2.1	1.2	2.6	3.6
1980	5.1	3.0	1.6	2.8	6.0
1981	5.8	3.6	2.0	3.1	6.6
1982	5.7	4.0	2.5	3.2	6.2
1983	5.1	3.7	2.6	2.9	5.4
1984	4.9	3.7	2.7	2.6	5.3
1985	5.0	3.8	2.5	2.1	5.0
1986	3.9	3.5	1.9	1.6	2.7
1987	3.3	2.6		1.4	3.3

Source: BP(1988a p.18)

Evolution of world oil prices

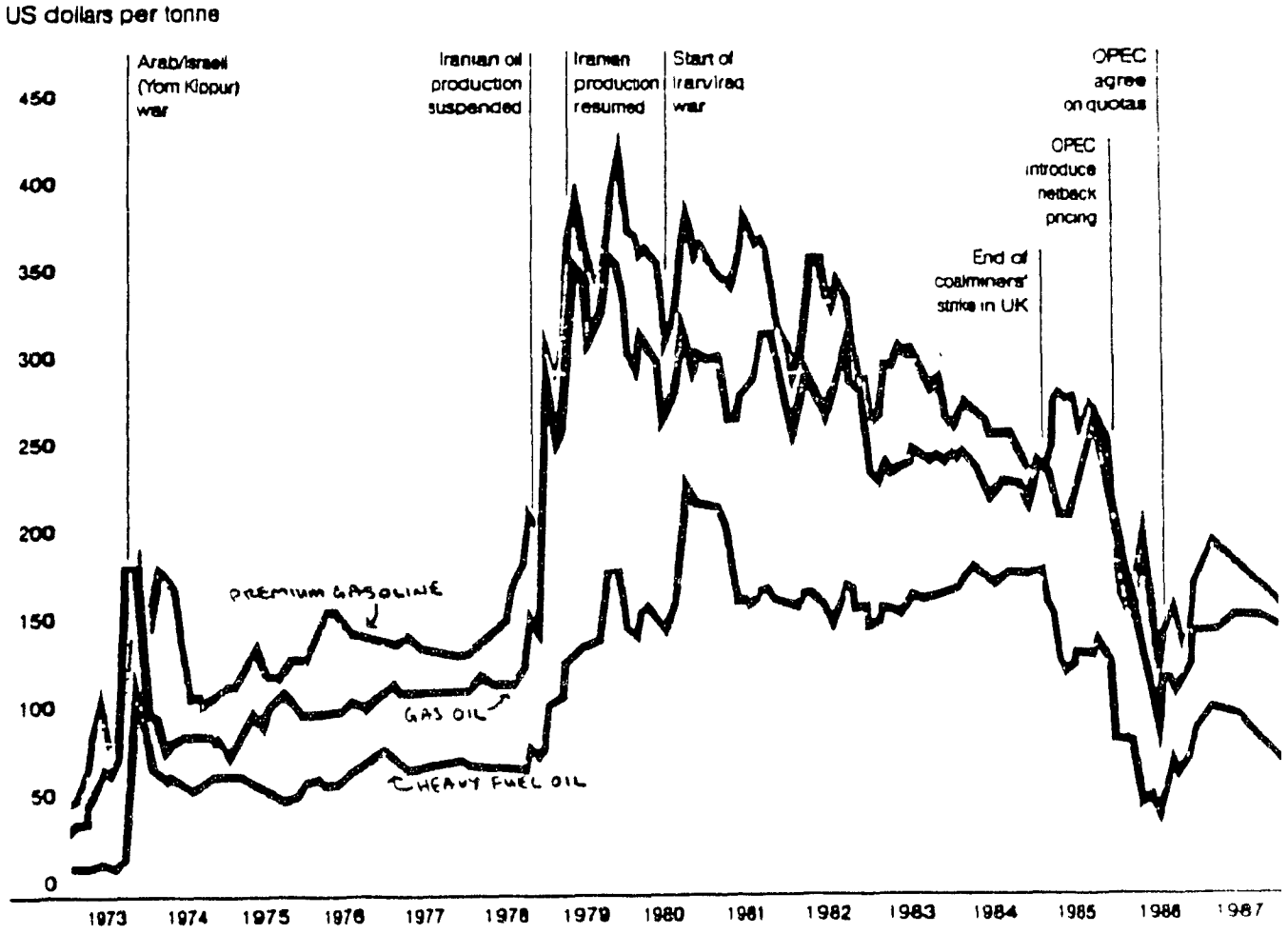
The preceeding graph also suggests that oil prices have been generally higher than gas prices and somewhat more unstable. This oil price instability is even more noticeable in the spot and product markets. There will always be short-term disturbances which affect prices, as indicated in the spot price chart below.

Spot Crude and Product prices 1986-1987



Source: Platts European Marketscan and Crude Oil Marketwire (mean weekly averages) in BP(1988,p.15)

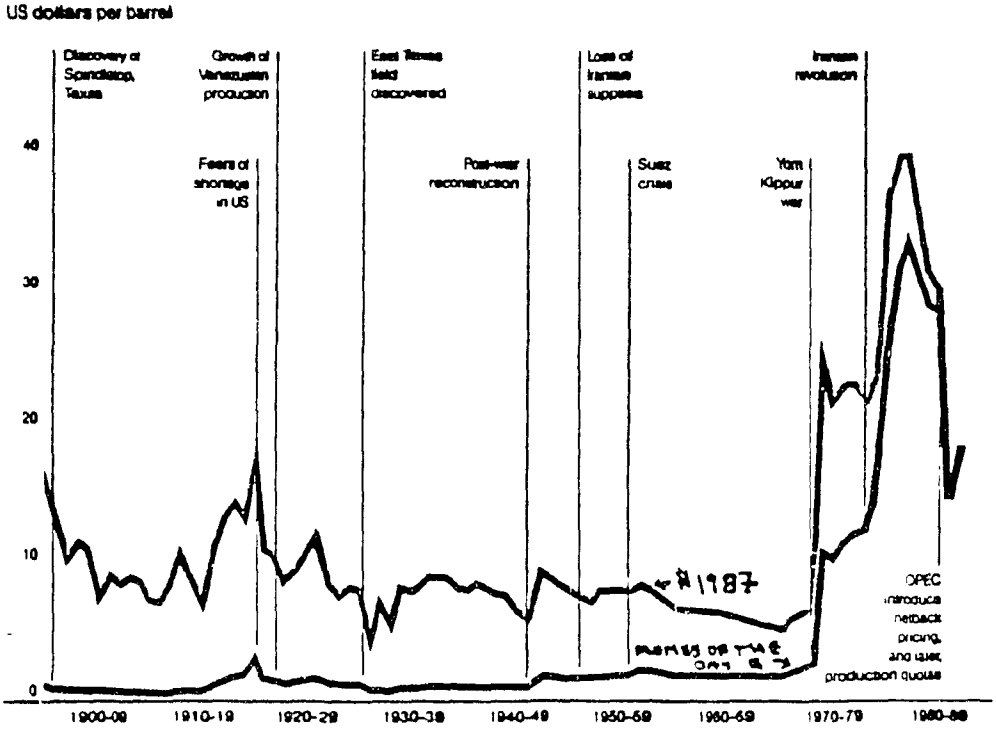
The instability of oil prices can be attributed to such matters as the waxing and waning of O.P.E.C. power and the Iran- Iraq war. The following graph indicates the links that have been made by Platt's Oilgram between political events and price changes.



Source: Platts Oilgram Price Report in BP(1988, p.15)

Even though it is axiomatic to say so, it is worth noting that temporary disturbances aside, the long-term behavior of prices will depend on the underlying world costs of competing fuels and on worldwide demand. Current prices, as low as they are, in the winter of 1988, are still fairly high by comparison with historical prices, as indicated on the chart below. From 1973 onwards, prices have been considerably above their pre-1969 average levels. It is difficult to demonstrate, however, that the post-1973 price increases can be attributed to a long-term supply-demand imbalance - at least not if production (demand) and reserve (supply) are to be taken as proxies for supply and demand.

Crude Oil Prices Since 1900

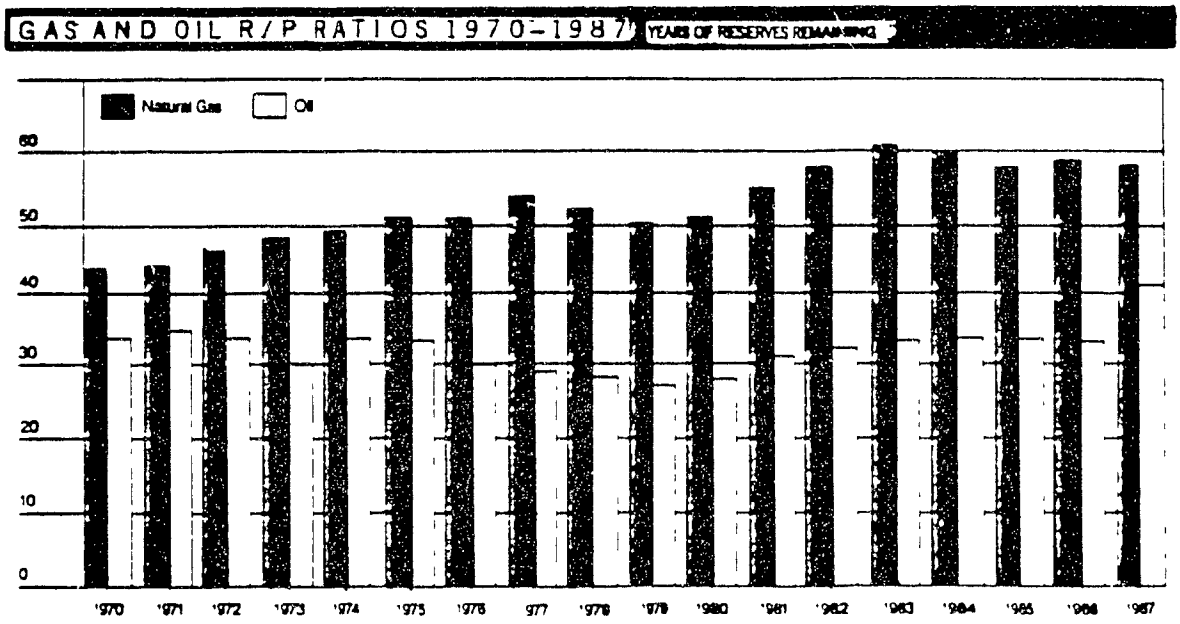


Source:BP(1988b, p.14)

World oil reserves to production rates

The following chart shows that world oil reserves to production ratios have not changed significantly since 1970, with the exception of 1987 when there was a major upward revision in reserves estimates for a few Middle East suppliers. Current world reserves are in excess of forty times current production - a ratio that is considerably higher than it was in 1965..

Natural gas reserves to production ratios are close to sixty years supply, and the chart shows that they have been trending upwards since 1970. The world does not seem on the face of it to be running out of either oil or gas. In view of these high reserves-to-production ratios, one might wonder if it makes sense to continue to try to enlargen the stock of known reserves. Part of the answer to this might come from a consideration of the growth of oil consumption in the LDCs.

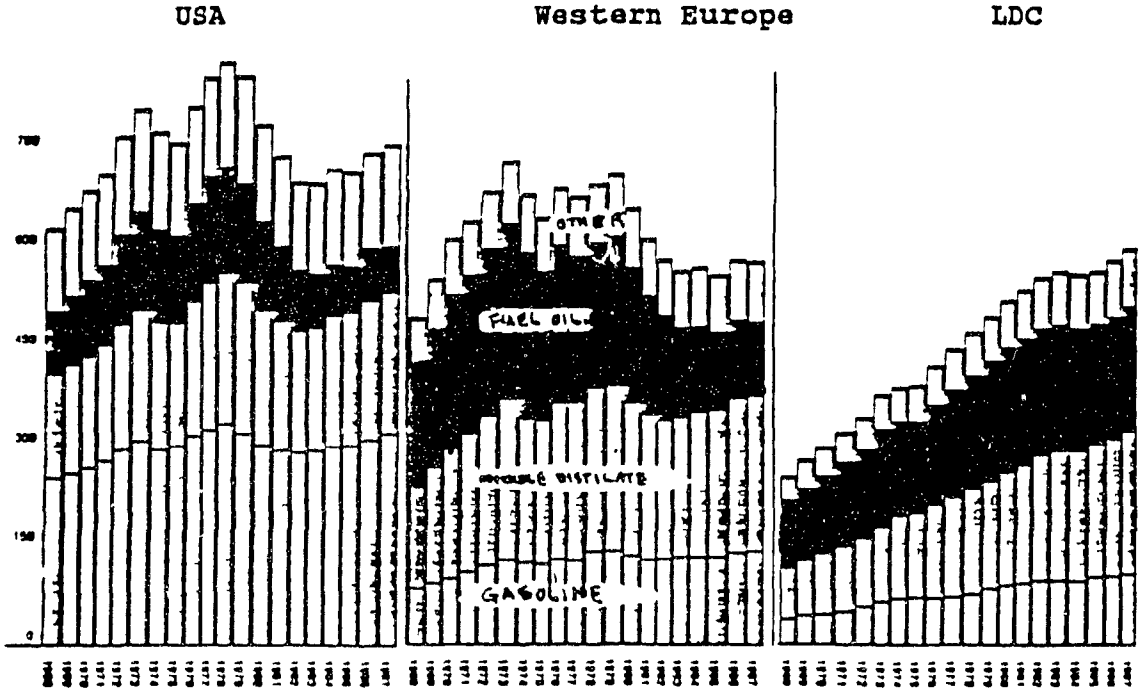


Source: BP(1988a)

Oil consumption growth patterns

The next chart shows the rate of increase in demand for oil in four countries or regions. In the major consuming countries, the United States, Western Europe and Japan, consumption has declined or, at least is considerably below the level reached in the late 1970s. In the LDCs on the other hand the 1973 and 1979 oil shocks show up as no more than a ripple in what would seem to be a relentless rate of growth in consumption - even in the face of the escalation in world oil prices. If consumption per person in the LDCs ever did approach the levels reached in the United States, the world oil reserves might not look so large. Thus, in contemplating forecast reserve requirements, current demand and production are less useful, and judgmental estimates of future requirements are necessary. Attention should perhaps be focussed on a reserves/expected future production ratio.

Regional Consumption by Product Groups



Source: BP(1988b, p.13)

World natural gas reserves and production

Natural gas and oil can be drawn down from reservoirs only at limited rates. There is, however, great variance in these rates, depending on recovery characteristics and the amount of development (number of wells, etc.), but a ratio of 12:1 or 15:1 seems not unreasonable. This suggests that one would like to have reserves equal to about 12 or 15 times current production to support current demand, plus some additional reserves or the promise of sustained reserve additions to provide for future demand. Thus, if demand is flat for ten years, and there are to be no reserve additions, the production industry would need a reserves level actually 22-25 times current demand to support demand for ten years. For natural gas, world demand has been growing at an overall compound average of 3.1% p.a. from 1977 to 1987. That does not seem like much, but for this eleven years the growth in world requirements rose 36% from 1977 to 1987.

Natural Gas Production 1977-1987 (10^3m^3)

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	Change 1987 over 1986	1987 Share of total
North America													
USA	549.3	548.1	563.6	556.2	549.8	509.0	459.6	498.5	469.1	458.0	**466.6**	+ 1.9%	25.0%
Canada	81.7	78.7	84.4	77.6	75.7	74.7	70.3	72.4	77.4	72.2	**76.3**	+ 5.7%	4.1%
Total North America	631.0	626.8	648.0	633.8	625.5	583.7	529.9	570.9	546.5	530.2	**542.9**	+ 2.4%	29.1%
Latin America													
Argentina	7.6	7.9	7.3	8.0	9.4	9.8	10.4	13.6	14.3	19.0	**18.9**	- 0.5%	1.0%
Bolivia	1.8	1.9	2.2	2.4	2.9	2.9	2.8	2.6	2.6	2.9	**2.8**	- 3.4%	0.1%
Chile	3.8	3.6	3.5	2.8	2.4	3.1	3.0	2.9	2.7	4.4	**4.4**	+ 0.0%	0.2%
Mexico	20.8	24.7	26.3	30.6	35.2	36.7	35.3	29.7	27.3	27.3	**27.9**	+ 2.2%	1.5%
Trinidad	1.7	2.1	3.3	2.5	2.5	2.5	3.0	3.5	3.2	3.6	**3.9**	+ 8.3%	0.2%
Venezuela	15.1	14.9	16.5	16.9	16.9	17.2	15.8	17.5	17.4	17.6	**19.4**	+10.2%	1.1%
Others	4.4	4.4	4.9	5.3	5.2	5.7	7.4	8.4	9.1	9.1	**9.1**	+ 0.0%	0.5%
Total Latin America	55.2	59.5	64.0	68.5	73.4	77.9	77.7	78.2	76.7	83.9	**86.4**	+ 3.0%	4.6%
Western Europe													
France	8.0	8.2	8.1	7.9	7.4	7.0	6.2	5.0	5.1	3.9	**3.8**	- 7.7%	0.2%
Italy	13.0	13.9	13.6	11.6	13.0	14.3	12.5	13.1	13.9	16.2	**16.5**	+ 1.9%	0.9%
Netherlands	82.4	75.4	79.6	77.4	76.0	65.5	68.7	69.1	72.4	63.1	**63.4**	+ 0.5%	3.4%
Norway	2.9	15.1	21.8	28.5	28.4	25.7	25.7	27.9	25.6	27.3	**29.7**	+ 8.8%	1.6%
United Kingdom	39.6	37.9	38.4	36.0	35.8	34.3	34.4	37.4	41.7	43.8	**43.7**	- 0.2%	2.3%
West Germany	16.2	17.3	17.3	15.8	16.2	14.2	14.7	15.4	13.7	15.4	**17.8**	+14.3%	1.0%
Others	2.5	2.5	2.7	2.6	2.5	3.0	3.1	3.7	4.8	5.2	**6.3**	+21.2%	0.3%
Total Western Europe	164.6	170.3	181.5	177.8	177.3	164.0	165.3	172.6	177.0	174.9	**180.8**	+ 3.4%	9.7%
Middle East													
Abu Dhabi	3.3	5.1	6.3	5.8	6.1	6.2	6.3	6.5	6.6	7.2	**7.8**	+ 5.6%	0.4%
Iran	21.2	19.7	20.2	8.4	7.3	7.3	11.1	13.7	14.7	15.4	**19.2**	+24.7%	1.0%
Kuwait	8.1	6.3	8.8	7.0	5.4	4.2	4.8	4.9	5.2	4.2	**4.5**	+ 7.1%	0.2%
Saudi Arabia	8.1	9.8	11.8	14.8	25.7	10.7	9.4	13.1	13.7	15.3	**21.2**	+38.6%	1.1%
Others	7.0	7.1	10.9	11.1	9.4	10.4	9.3	11.8	12.6	12.7	**14.3**	+12.8%	0.8%
Total Middle East	45.7	47.8	58.0	47.1	53.9	38.8	40.9	49.8	52.8	54.8	**68.8**	+21.9%	3.5%
Africa													
Algeria	8.8	14.0	28.3	21.7	24.8	27.0	38.1	34.2	37.8	35.5	**42.1**	+18.6%	2.3%
Libya	3.9	5.2	8.9	5.3	4.0	3.4	3.7	4.6	5.3	6.4	**6.7**	+ 4.7%	0.4%
Nigeria	0.6	0.3	1.3	1.1	1.8	1.2	1.5	1.7	1.5	1.2	**1.1**	- 8.3%	0.1%
Others	1.1	1.3	1.8	2.0	2.0	3.1	3.8	4.7	6.4	6.7	**7.3**	+ 9.0%	0.4%
Total Africa	14.4	20.8	36.3	30.1	32.6	34.7	44.9	45.2	51.0	49.8	**57.2**	+14.9%	3.2%
Asia and Australasia													
Japan	2.8	2.7	2.5	2.2	2.1	2.0	2.1	2.1	2.2	2.1	**2.2**	+ 4.8%	0.1%
Indonesia	5.7	11.0	16.0	18.8	19.4	19.9	22.4	29.4	30.7	31.9	**32.9**	+ 3.1%	1.8%
Other South East Asia	9.0	8.8	9.0	9.1	9.4	10.7	12.8	19.4	24.0	27.2	**30.4**	+11.8%	1.6%
Pakistan	6.0	6.0	5.7	7.0	6.9	8.9	9.7	10.2	10.4	11.1	**12.0**	+ 8.1%	0.6%
Other South Asia	5.8	5.8	5.8	6.3	7.4	10.3	11.6	14.2	14.5	15.2	**17.5**	+15.1%	0.9%
Australasia	9.4	10.0	11.0	12.2	13.4	14.2	15.3	15.6	17.2	19.8	**19.7**	+ 0.5%	1.1%
Total Asia and Australasia	38.7	44.3	49.8	55.6	58.6	66.0	73.9	90.9	99.0	107.1	**114.7**	+ 7.1%	6.1%
Total NCW	948.6	969.5	1 037.6	1 012.9	1 021.3	966.1	932.6	1 007.6	1 003.0	1 000.7	**1 048.8**	+ 4.8%	56.2%
Centrally-Planned Economies (CPEs)													
China	12.1	13.9	14.0	13.7	13.0	11.2	12.1	12.2	12.9	13.2	**13.9**	+ 5.2%	0.7%
USSR	350.2	364.4	397.3	427.2	462.7	507.1	542.0	593.7	650.2	693.7	**733.8**	+ 5.8%	39.3%
Others	60.0	61.6	58.5	57.5	60.2	60.8	62.8	66.3	66.7	66.3	**70.0**	+ 5.6%	3.8%
Total CPEs	422.3	439.9	469.8	498.4	535.9	578.9	616.7	672.2	729.8	773.2	**817.7**	+ 5.7%	43.8%
Total World	1 371.9	1 409.4	1 507.4	1 511.3	1 557.2	1 544.0	1 549.3	1 679.8	1 732.8	1 773.9	**1 866.5**	+ 5.2%	100.0%

Note:
* Excluding gas flared or recycled

Source: BP(1988a, p.8)

If there were to be no reserve additions and if the average compound growth rate for gas was maintained, the existing stock of natural gas would last for only 35 years. However, on the one hand, the growth rate is likely to increase as the high growth sectors (including LDCs) of the world become more dominant, but on the other hand, more reserves are virtually certain to be found. As the previous figure comparing oil and gas reserves to production ratios suggests, in seventeen years, our relative supplies of oil and gas really have not dwindled to an appreciable extent, relative to our demands. The following chart shows the differences in reserves to production ratios for different countries and areas of the world. The U.S. R/P ratio for gas is low, 11.5 to 1; however, it has been at that level for many years now, and the American gas producing industry has been complaining about excess capacity and a persistant gas "bubble".

One does not obtain large reserves of gas, generally, without spending considerable sums of money in "proving them up". A company will not attempt to discover more reserves, and prove them up, if it does not expect to be able to put them "on stream" for sales for another twenty years. With R/P ratios in Canada as high as they are, one would be inclined to believe that the discovery and development industry would stop working for a few years. However, producers continue to find more gas and to add to the gas inventory. The cost of drilling a well, compounded at the discount rate for twenty years produces a very high cost per gigajoule. Still, large gas inventories and high costs will have some social value, because consumers may derive some satisfaction from having greater security of supply.

Natural Gas Proven Reserves at End 1987

	Trillion cubic feet	Trillion cubic metres	Share of total	R/P ratio
North America				
USA	186 7	5 3	4 9%	11 5
Canada	98 0	2 3	2 6%	38 8
Total North America	284 7	8 1	7 5%	15 0
Latin America				
Argentina	23 6	0 7	0 6%	35 8
Ecuador	4 0	0 1	0 1%	*
Mexico	78 5	2.2	2 0%	78.3
Trinidad	10 4	0 3	0 3%	75 7
Venezuela	95 0	2 7	2 5%	*
Others	17 1	0 5	0 4%	30.2
Total Latin America	226 6	6.5	5 9%	75 0
Western Europe				
Netherlands	64 1	1 8	1 7%	29 0
Norway	105 9	3 0	2 8%	*
United Kingdom	22.7	0 6	0 6%	14 9
West Germany	6 4	0 2	0 2%	10 4
Others	19 7	0 6	0 5%	21 4
Total Western Europe	218 8	6.2	5 8%	34 7
Middle East				
Abu Dhabi	183 5	5 2	4 8%	*
Bahrain	6 9	0.2	0 2%	45 1
Dubai	6 0	0.2	0 1%	*
Iran	489 4	13 9	12.9%	*
Iraq	26.3	0 7	0 7%	*
Kuwait	36 4	1 0	1 0%	*
Qatar	156 7	4 4	4 1%	*
Saudi Arabia	139 9	4 0	3 7%	*
Others	38 9	1 1	1 0%	*
Total Middle East	1 064 0	30 7	28.5%	*
Africa				
Algeria	105 9	3 0	2 8%	72.0
Egypt	10.2	0 3	0 3%	45 8
Gabon	0 6	†	†	*
Libya	25 7	0 7	0 7%	*
Nigeria	84 0	2 4	2.2%	*
Others	22.2	0 6	0 6%	*
Total Africa	248.6	7 0	6.6%	*

	Trillion cubic feet	Trillion cubic metres	Share of total	R/P ratio
Asia and Australasia				
Japan	1 0	†	†	13 1
Brunei	7 0	0 2	0 2%	22 5
Indonesia	73 0	2 1	1 9%	53 5
Malaysia	52.2	1 5	1 4%	33 7
Other South East Asia	15 1	0 4	0 4%	45 8
Bangladesh	12 7	0 4	0 3%	*
India	17 8	0 5	0 5%	49 2
Pakistan	22.4	0 6	0 6%	53 4
Australia	18 6	0 5	0 5%	35 1
New Zealand	5.2	0 1	0 1%	33 1
Total Asia and Australasia	224 8	6 3	5 9%	58.1
Total NCW	**2 287.5**	**64.8**	**60.2%**	**62.4**
Centrally-Planned Economies (CPEs)				
China	30 7	0 9	0 8%	63.1
USSR	1 450 0	41 1	38 2%	58.6
Others	29.3	0 8	0 8%	12.0
Total CPEs	1 510 0	42.8	39 8%	52.9
Total World	**3 797.5**	**107.6**	**100.0%**	**58.3**
Of which OPEC	1 452.7	41 1	38 3%	*

Notes:

* Over 100 years

† Less than 0 05

Proved reserves of natural gas are generally taken to be those quantities which geological and engineering information indicate with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions.

Reserves/Production (R/P) ratio. If the natural gas reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at the then current level

Source of data. The estimates contained in this table are those published by the Oil and Gas Journal in its "Worldwide Oil" issue of 28th December 1987. United Kingdom reserves data are taken from the Department of Energy's Brown Book, published in April 1988

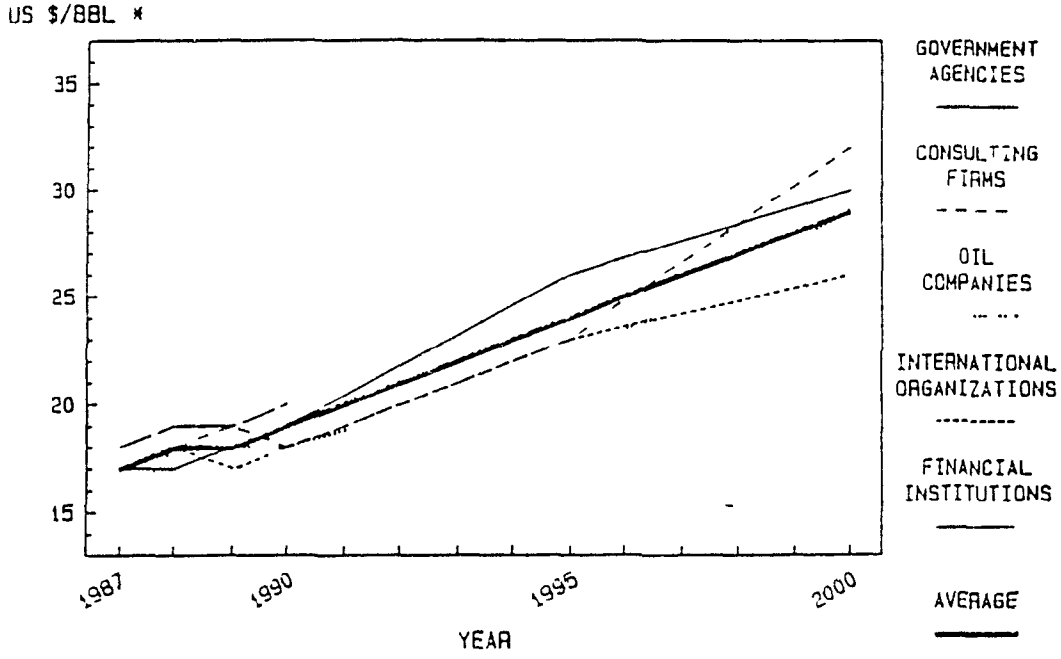
Source: BP(1988, p.4)

A supply security issue

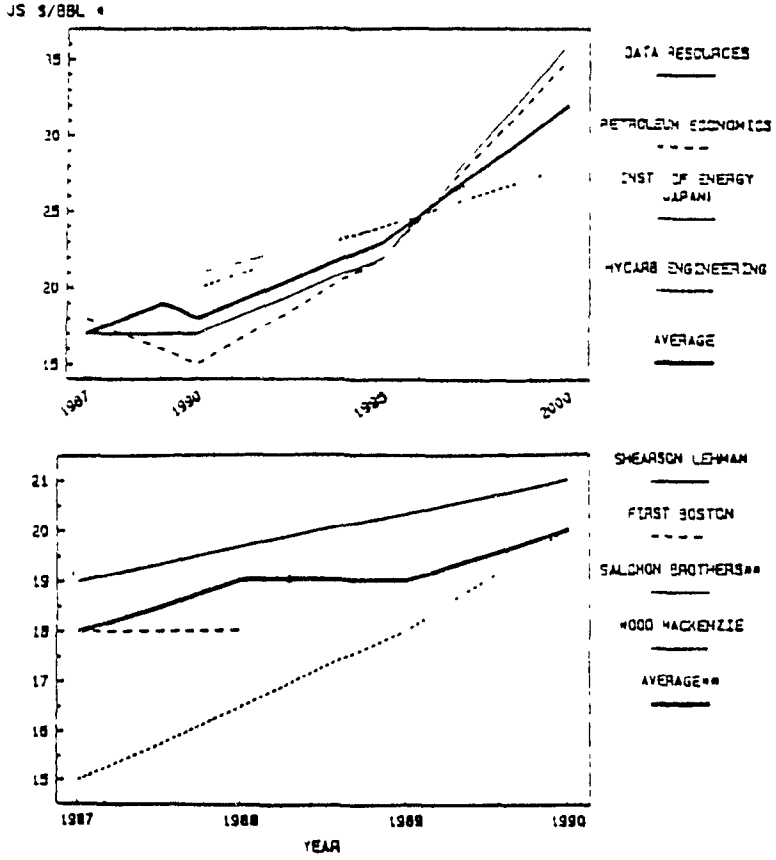
In a free market the amount of security that a buyer could get would depend on how much he or she was willing to pay. In a regulatory environment it might be possible for some buyers to obtain security and make someone else bear the cost. Wanting security and being willing to pay for it are two different things. The interesting thing in Canada is that Eastern utilities want high security, but want the gas producers to pay for it. Through the regulatory and political process they have been able to demand that producers maintain twenty or thirty years of proven reserves before any exports can be allowed. What in effect this does is to make the producing industry hold an inventory at its expense until the Eastern (utilities) customers are ready to buy.

Given the foregoing review, it does not seem that Canada is in any immediate danger of running out of indigenous supplies of oil or gas, especially the latter. World proven reserves have also remained fairly stable despite increases in demand by the LDCs. The increase in prices of oil (and therefore gas) over historical levels, largely due to O.P.E.C., have stimulated what appear to be ongoing trends in more conservation, and trends in increased discoveries and reserves appreciation all over the globe. These latter forces have exerted an influence on O.P.E.C., and have effectively reduced its power as a cartel. It is still influential but differences of opinion about its potential power are one reason for the great divergences among economic forecasts of world oil prices. The following series of graphs show current world oil price forecasts made by several prominent groups. There is a surprising lack of concensus, and this suggests that whatever forecast are used, they should be supplemented by sensitivity analyses.

WORLD CRUDE OIL PRICE PROJECTIONS

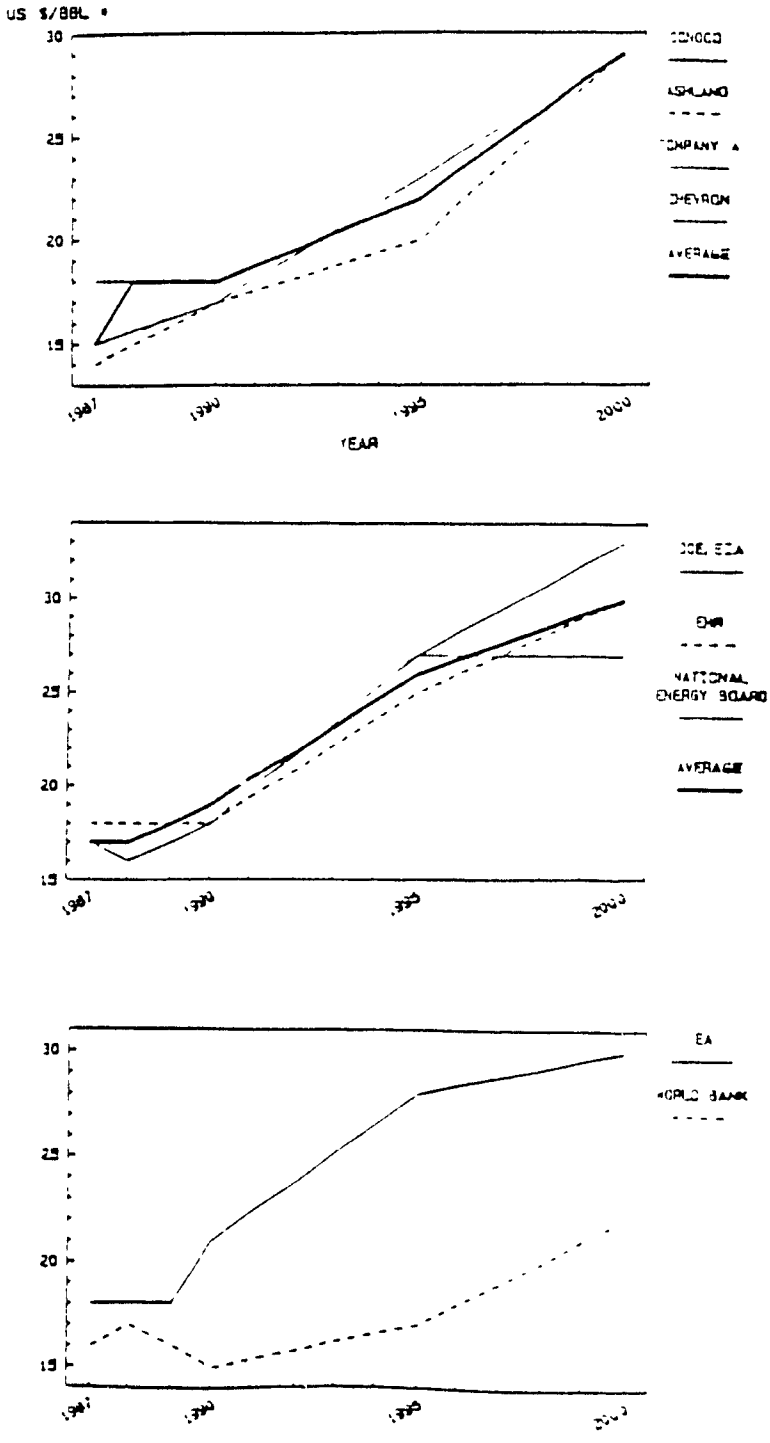


* 1986 DOLLARS



Source: EMR(1987)

WORLD CRUDE OIL PRICE PROJECTIONS



Source: EMR(1987)

Canadian Gas Demand

Natural gas competes with electricity, which is generated by hydro, nuclear, oil turbine, and coal-fired operations, and it competes directly with oil as a heating fuel and feedstock. As a source of heating, gas competes with coal, wood, biomass and solar power. All of these competing sources of energy or fuel stocks affect the demand for natural gas at different prices in Canada. Thus, the demand for natural gas must be considered in relation to other energy and feedstock supplies. It is constraints of this type which influence the current demand by sector discussed on page 325.

Given the current levels of supplies, gas consumers probably take future supply availability for granted. This is to say that because the current levels of reserves are high and are expected to remain so, those consumers who are now contemplating changing their furnaces from, say, oil to gas will not be constrained by the fear that in 15 years time, their local gas utility will suspend their service. More importantly, ample supplies may lead buyers to assume that not only will gas be readily available, they may also conclude that gas will be "reasonably" priced relative to its substitutes.

Representative Values: 'Own' and 'Cross' Price Elasticities of Total Energy and Natural Gas Demand

	Residential		Commercial		Industrial		Total (R+C+I)	
own price elasticities	SR	LR	SR	LR	SR	LR	SR	LR
TOTAL ENERGY	-.10	-.50	-.15	-.40	-.20	-.50	-.17	-.45
NATURAL GAS	-.15	-.90	-.20	-.50	-.30	-1.2	-.25	-.90
cross price elasticities								
NATURAL GAS TO:								
OIL	+.10	+1.0	+.05	+.25	+.25	+.90	+.15	+.80
ELECTRICITY	*	+.25	*	+.15	*	+.20	*	+.15

* - ambiguous: no clear consensus

Source: Datametrics(1988)

Demand elasticity

Some current estimates of short and long-term demand elasticities that have been reported by DataMetrics (1988), are presented above.

As with almost all such forecasts, these are based on historical relationships which means that their applicability to the future depends on underlying factors remaining unchanged. Unfortunately for the art and science of forecasting, a number of influential factors have changed in the last ten years and promise to continue to do so in the coming years. Time and space do not permit an independent forecast of price elasticity in this thesis, and so the "concensus" long-run estimate of total natural gas demand elasticity provided by DataMetrics is a basic input for the elasticity estimate for the post-NEB forecast period demand. In the post-NEB period, world and North American price forecasts will be used in conjunction with an elasticity estimate of -1.00 to produce the point estimate for demand.

Demand forecasts

For the purposes of this exercise I begin with the year 1982, because that is the year of the last major NEB Omnibus Hearing for natural gas exports. There were some thirteen applicants who filed applications for export licences for some 29 projects. A massive amount of evidence was presented regarding world oil price forecasts, Canadian ultimate potential, gas deliverability, domestic and export demand, public interest issues, benefit-cost analyses, etc. The choice of that year also gives the opportunity to compare some of the forecast data by participants and the NEB to the recent historical period, 1982 to 1988.

As can be seen in the following table, the 1982 NEB domestic demand forecast for the Base Case is representative on the high or conservative forecasts made by submittors. The

conservative bias of the NEB is demonstrated by the following graph showing the forecasts made by the NEB in different years.

NATURAL GAS DEMAND - CANADA

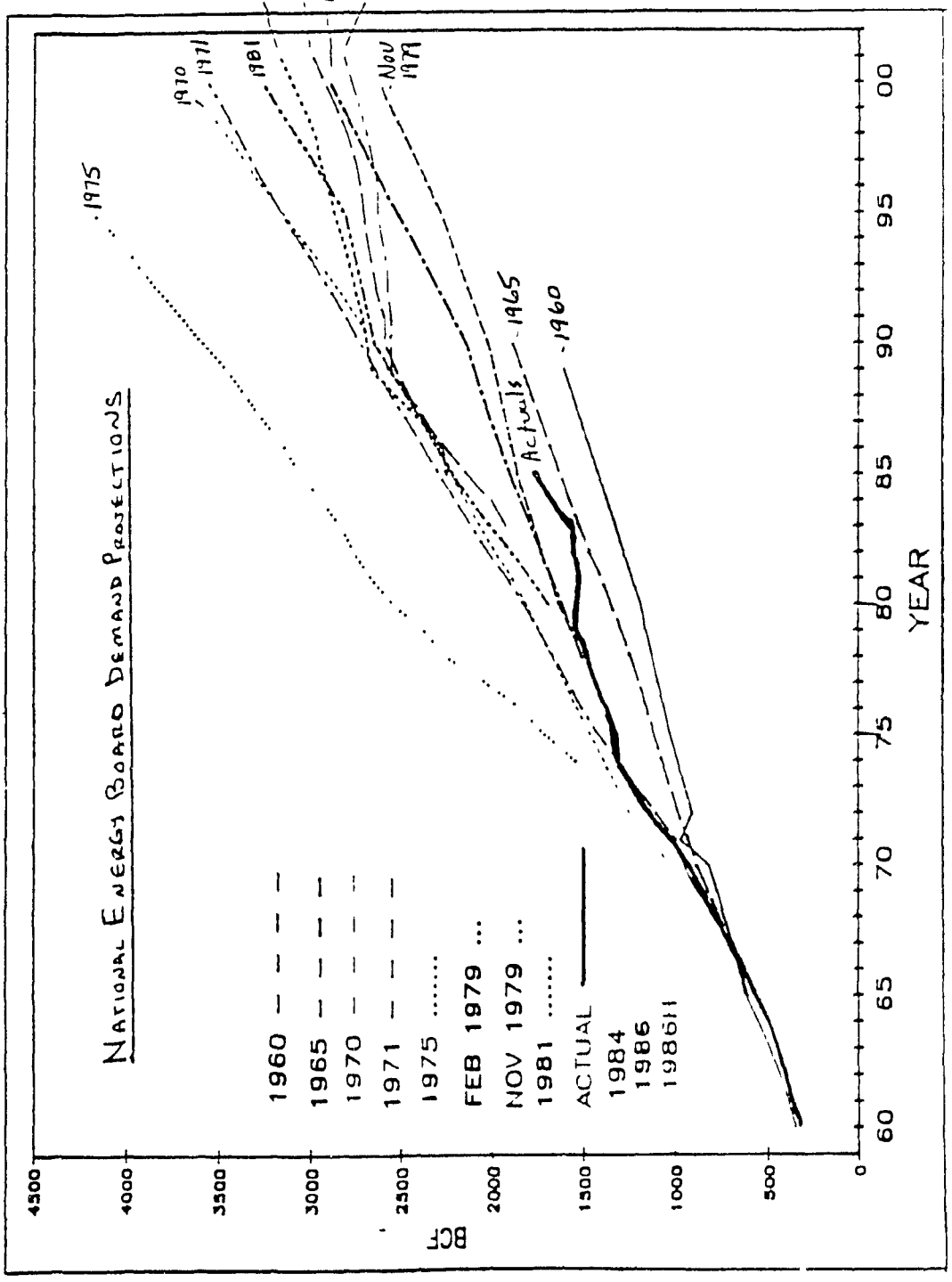
COMPARISON OF PROJECTIONS

(Petajoules)

Submittors[1]	1980	1981	1982	1983	1985	1990	1995	2000
CPA[2]	N/A	N/A	1 821	1 902	2 093	2 446	2 745	2 989
Dome	N/A	N/A	1 864	1 977	2 144	2 466	2 711	2 951
Esso	1 780	1 690	1 845	N/A	2 010	2 275	N/A	2 560
Gulf	1 787	1 708	1 776	N/A	N/A	2 297	N/A	2 773
Norcen	1 754	1 791	1 903	1 916	2 072	2 402	2 633	2 876
NOVA	N/A	N/A	1 833	1 900	2 184	2 552	2 721	2 916
Pan-Alberta	1 781	N/A	N/A	N/A	2 203	2 415	2 659	3 044
Petro-Canada[3]	1 752	1 744	1 871	1 969	2 184	2 566	2 885	3 192
Shell	1 758	1 706	1 752	1 832	2 014	2 423	2 764	3 072
TransCanada[4]	N/A	N/A	N/A	2 051	2 316	2 754	2 935	3 223
High[5]	1 787	1 791	1 871	2 051	2 316	2 754	2 935	3 223
Median	1 769	1 708	1 827	1 916	2 138	2 434	2 733	2 970
Low[5]	1 752	1 690	1 752	1 832	2 010	2 275	2 633	2 560
1981 NEB Projections[6]								
High	1 781	N/A	N/A	N/A	2 630	3 212	3 782	4 566
Middle	1 781	1 873	1 958	2 103	2 323	2 664	2 955	3 410
Low	1 781	N/A	N/A	N/A	2 228	2 436	2 666	3 053
1982 NEB Projections[7]								
Base Case	1 770	1 721	1 716	1 778	2 030	2 441	2 886	3 280
Alternative Case	1 770	1 721	1 716	1 776	1 992	2 363	2 779	3 154

(1) Consolidated, IPAC, and ProGas projections were excluded because they included part, or all of reprocessing fuel and shrinkage demand in their estimates.
(2) CPA's forecast has also been adopted by A&S.
(3) Forecast probably excludes reprocessing fuel and shrinkage.
(4) Year commences November 1st previous to the year indicated.
(5) High and low values shown do not necessarily represent the same submittor for each year shown.
(6) These three projections were prepared in the course of the 1981 Supply and Demand Hearing. The middle case was shown in the June 1981 Report (Table 7-1, page 69).
(7) 1980 and 1981 are actuals.

Source NEB (1982) p 24



SOURCE: ALBERTA AND SOUTHERN GAS CO. LTD

With the exception of the forecasts made in 1960 and 1965, the NEB forecasts of domestic demand have turned out to be on the high side. This should in no way be taken as evidence that the economists at the NEB are bad forecasters. Over that historical time frame, most forecasters in fact overestimated the demand for natural gas. Also, given the Board's position and its responsibilities, it was generally considered that it would be more costly to Canadians to underestimate demand and thereby suffer a shortage than it would be to lean in the other direction; to overestimate demand and thereby encourage a supply surplus.

While the bias of the NEB may be to err on the side of "conservative" forecasting (overestimating future demand and underestimating supply), it may be presumed that potential exporters have some interest, in the context of export tests, to produce (within reason) low estimates of Canadian demand, and high estimates of supply. Such forecasts would improve the probability of export proposals being allowed. Thus, there is scope for some game playing in the hearing process, and the possibility of such behavior on the part of participants may further encourage the NEB to choose forecasts on the high side of demand, and the low side of supply. This type of posturing could be looked at as either an agency or game theoretic type of problem, and will be explored in a separate paper.

Domestic sales and price, export price assumptions

In the first simulation analysis, the NEB provincial sales estimates are combined with the fuel and losses for sales in each province and with reprocessing shrinkage estimates to obtain the estimate of total domestic demand. Domestic prices are assumed to begin at $4.00/GJ in 1982 and increase at five percent per annum. Export prices are assumed

to remain 25% above domestic prices over the forecast period. Sensitivity analyses on these various inputs are discussed in Chapter Five. The price assumption used seems to be clearly out of line with the historical behavior from 1982 to the present, but is representative of typical 1982 thinking on price.

Demand, General Overview for the Simulation Model

Total demand is made of the combined demands from two main sources, domestic demand and export demand. It is assumed that export demand is driven by world gas prices, and that demand for Canadian gas on export markets is unlimited at the export market prices. Actual exports at those prices may be constrained by NEB export rules and by pipeline capacity.

Domestic demand is a function of domestic energy price expectations which are given exogenously. Provincial sales estimates are combined with transportation fuel and line losses and estimated reprocessing shrinkages to yield primary domestic demand. The primary domestic demand is combined with the schedule of currently authorized exports (by the NEB) to create the total primary demand estimate.

Supply Segment of the Simulation Model

Costs of Supply, By-product Difficulties

On the supply side, I am interested in identifying not only the long run supply potential or "Ultimate Potential", and the producibility and deliverability of those reserves to domestic and export markets, but also their costs. There have been a number of studies which have dealt with the issues of gas supply and costs of supply, in different ways.

Here I review some of the recent work on Canadian natural gas costs of supply. Often, for industry level studies, costs are one of the easiest factors for an analyst to obtain, however such is not the case for natural gas. The key difficulty has to do with the fact that oil is often found

with gas, both in the same general locations, and in many cases they are mixed together (associated gas). One industry analyst I spoke with remarked that when people go out to find oil, half the time they find gas.[10] Most of the large oil and gas companies are involved with finding and developing both resources as the following tables indicate.

TOP 25 IN NATURAL GAS RESERVES

Company	1987 Canadian Net Proven Gas Reserves m^3 (millions)	RANK
Shell Canada	[illegible]	[illegible]
Petro-Canada Inc	96 900	2
Mobil Oil Canada Ltd	91 885	3
Dome Petroleum Ltd	85 687	4
Amoco Canada Petroleum Co Ltd	83 915	5
PanCanadian Petroleum Ltd	66 702	6
Texaco Canada Inc	56 000	7
Imperial Oil Ltd	54 200	8
Alberta Energy Co Ltd	46 036	9
ENCOR Energy Inc	41 790	10
Gulf Canada Corp	40 937	11
Canterra Energy Ltd	38 300	12
Chevron Canada Resources	32 387	13
Ocelot Industries Ltd	30 259	14
Norcen Energy Resources Ltd	27 330	15
Home Oil Co Ltd	27 022	16
North Canadian Oils Ltd	24 652	17
BP Canada Inc	22 274	18
Canadian Hunter Exploration Ltd	17 781	19
Westcoast Petroleum Ltd	17 154	20
Westmin Resources Ltd	15 671	21
Poco Petroleums Ltd	15 101	22
Unocal Canada Ltd	14 977	23
Anderson Exploration Ltd	14 414	24
Canadian Occidental Petroleum Ltd	14 292	25

[10] Alex Rankin, Oil Week Magazine.

TOP 25 IN LANDHOLDINGS

Company	1987 Canadian Net Land Holdings (hectares)	RANK
Petro Canada Inc	8 300 000	1
Chevron Canada Resources	6 576 041	2
Shell Canada Ltd	5 431 000	3
Gulf Canada Corp	4 698 000	4
Dome Petroleum Ltd	4 612 000	5
Mobil Oil Canada Ltd	4 105 979	6
Imperial Oil Ltd	3 700 000	7
ParCanadian Petroleum Ltd	3 132 700	8
Texaco Canada Inc	2 143 000	9
Amoco Canada Petroleum Co Ltd	2 008 000	10
ENCOR Energy Inc	1 619 000	11
Alberta Energy Co Ltd	1 310 000	12
Home Oil Co Ltd	1 283 237	13
Norcen Energy Resources Ltd	1 184 515	14
Husky Oil Ltd	1 114 000	15
Canterra Energy Ltd	968 000	16
Unocal Canada Ltd	895 666	18
Canadian Occidental Petroleum Ltd	831 300	19
Suncor Inc	779 000	20
BP Canada Inc	775 809	21
Westar Petroleum Ltd	762 940	22
ICG Resources Ltd	742 000	23
North Canadian Oils Ltd	728 200	24
Oakwood Petroleums Ltd	712 257	25

TOP 25 IN OIL & GAS LIQUIDS RESERVES

Company	1987 Net Proven Cdn Liquids Reserves 000 m³	RANK
Imperial Oil Ltd	236 700	1
Petro Canada Inc	89 000	2
Mobil Oil Canada Ltd	63 238	3
Suncor Inc	61 704	4
Texaco Canada Inc	60 500	5
Shell Canada Ltd	46 100	6
Amoco Canada Petroleum Co Ltd	42 821	7
Dome Petroleum Ltd	40 223	8
Chevron Canada Resources	37 433	9
Gulf Canada Corp	31 164	10
BP Canada Inc	26 812	11
ENCOR Energy Inc	23 953	12
ParCanadian Petroleum Ltd	22 771	13
Canterra Energy Ltd	22 600	14
Alberta Energy Co Ltd	20 817	15
Home Oil Co Ltd	16 772	16
Norcen Energy Resources Ltd	14 487	17
Husky Oil Ltd	13 562	18
Unocal Canada Ltd	12 235	19
Saskatchewan Oil & Gas Corp	8 473	20
Westcoast Petroleum Ltd	8 377	21
Murphy Oil Company Ltd	6 093	22
Canadian Hunter Exploration Ltd	5 924	23
Total Petroleum Canada Ltd	5 657	24
Canadian Occidental Petroleum Ltd	5 384	25

TOP 25 OIL & GAS LIQUIDS PRODUCERS

Company	1987 Gross Cdn Liquids Production m³/d	RANK
Imperial Oil Ltd	38 900	1
Texaco Canada Inc	16 300	2
Mobil Oil Canada Ltd	14 510	3
Petro Canada Inc	14 300	4
Dome Petroleum Ltd	13 801	5
Gulf Canada Corp	13 738	6
Chevron Canada Resources	12 990	7
Amoco Canada Petroleum Co Ltd	11 404	8
Shell Canada Ltd	11 200	9
ParCanadian Petroleum Ltd	10 769	10
Suncor Inc	9 204	11
Husky Oil Ltd	6 633	12
Norcen Energy Resources Ltd	6 015	13
ENCOR Energy Inc	5 919	14
Canadian Occidental Petroleum Ltd	4 963	15
Home Oil Co Ltd	4 627	16
Canterra Energy Ltd	4 044	17
Unocal Canada Ltd	4 016	18
BP Canada Inc	3 695	19
Alberta Energy Co Ltd	2 974	20
Saskatchewan Oil & Gas Corp	2 451	21
Westcoast Petroleum Ltd	1 929	22
Murphy Oil Company Ltd	1 770	23
Oakwood Petroleums Ltd	1 503	24
Total Petroleum Canada Ltd	1 410	25

Common Approaches to Cost Estimation

The primary publicly available data are compiled and reported by the Canadian Petroleum Association, and they generally appear as industry expenditure data for oil and gas combined. Data on geological and geophysical activities, exploration drilling, land purchase and rentals, and development are available from the CPA data file. Some of these data, reported by Pasay (1987), are presented in the following table for Alberta for the years 1970 to 1985.

ALBERTA
NET CASH EXPENDITURES
1970 - 1985
(MILLIONS OF CURRENT DOLLARS)

	EXPLORATION					
YEAR	GEOLOGICAL AND GEOPHYSICAL	DRILLING	LAND PURCHASE AND RENTALS	TOTAL EXPLORATION	DEVELOPMENT	EXPLORATION AND DEVELOPMENT
1970	90.3	83.8	116.6	290.7	327.7	618.4
1971	65.5	80.8	125.9	272.2	376.1	648.3
1972	71.2	102.1	124.4	297.7	333.0	630.7
1973	70.7	131.4	144.3	346.4	350.7	697.1
1974	112.4	146.5	157.3	416.2	455.4	871.6
1975	99.8	149.1	207.9	456.8	562.0	1018.8
1976	145.5	255.5	255.5	657.5	845.6	1503.1
1977	223.4	334.7	679.9	1298.0	861.2	2159.2
1978	358.3	644.5	748.5	1735.3	1129.2	2864.5
1979	349.7	1827.5	1144.7	2521.9	1538.3	4060.2
1980	452.3	1621.6	1176.5	3250.4	2340.7	5591.1
1981	352.2	1543.7	721.3	2617.2	2418.3	5035.5
1982	325.1	1076.3	465.6	1867.0	2408.2	4275.2
1983	372.7	1017.4	565.1	1955.2	1801.4	3756.6
1984	472.3	1128.3	790.2	2392.8	2135.0	4528.8
1985	488.5	1368.3	1021.1	2869.9	2879.9	5749.8

Source: Pasay(1987)

The most common approach to the estimation of the cost of gas is to take the combined oil and gas costs in a year, and allocate a portion of these costs to gas, on the basis of some criterion. Pasay (1987), for example, allocates finding costs (geological and geophysical, drilling, and land purchase and rentals) to annual quantities of oil and gas found on the basis of the proportion of successful exploratory metres drilled.[11] This proportional relationship is taken as a measure of intent, and assumes that operators are "equally good" at finding oil and gas. It does, however, imply considerably more than this. It also implies that beyond the efficiency of search, the probability of finding oil or gas is the same. If, on the other hand, the probability of finding oil is 12.5%, and the probability of finding gas is 37.5%, and if three times the effort is spent on oil compared with gas, this would mean that of 100 wells drilled, it would be deemed that 75 were intended oil wells and 25 intended gas wells. However, 9.375 oil wells (or producing wells) would be found and the same for gas (25 x 37.5 = 9.375). Thus, 50% of the successful exploratory footage would be associated with oil and 50% with gas. The error that is made in this example is shown below:

	Oil	Gas
Actual cost per unit	8.00	2.67
Intent measure cost per unit	5.33	5.33
% error	67%	100%
Type	Underestimate	Overestimate

Thus, it is quite possible for intent type approaches to make serious errors in the assignment of expenditures to oil or gas. Livernois and Ryan (1987) provide a formula for the evaluation of this error, and suggest that such intent type

[11] Pasay (1987), p. 5.

approaches are even more misleading if one focuses on the fact that well completions are a function of marginal product curves and marginal costs, and relax the implicit assumption above that discoveries are a linear function of effort. Well completions will determine the resultant product (oil or gas). Given the fact that the marginal product curves are not similar, and tend to shift over time, the result may be very misleading.

If unit gas costs are based on data which are collected consistently, and in a fairly stable environment, such intent based costs may provide useful benchmarks for trends.

The following table shows the Pasay (1987) results for natural gas.

ALBERTA
PREFERRED CASE NATURAL GAS FINDING COSTS (a)
(LOW CASE)
1970 - 1985
(1985 CONSTANT DOLLARS PER THOUSAND CUBIC FEET)

YEAR	YEARLY	THREE YEAR MOVING AVG.	FIVE YEAR MOVING AVG.	SEVEN YEAR MOVING AVG.
1970	0.52			
1971	0.25			
1972	0.24	0.33		
1973	0.32	0.29		
1974	0.38	0.28	0.32	
1975	0.32	0.31	0.30	
1976	0.24	0.28	0.28	0.30
1977	0.40	0.32	0.32	0.31
1978	0.52	0.38	0.36	0.34
1979	0.57	0.50	0.41	0.39
1980	0.65	0.58	0.47	0.44
1981	0.62	0.62	0.55	0.47
1982	0.51	0.61	0.58	0.49
1983	0.40	0.54	0.58	0.53
1984	0.49	0.47	0.57	0.56
1985	0.97	0.62	0.55	0.58

(a) Based on only fifty percent of land expenditures. Estimated intent * 1.25.

These are her "preferred case", "low case" finding cost results. The "low case" is based on fifty percent of land expenditures being allocated to gas ,which is in turn based on the assumption that fifty percent of total land expenditures are for development activity.[12] Finding costs are the total cost of exploration activity divided by fully appreciated reserves, thus expenditures associated with development activities are to be excluded. The "preferred case" results indicate that exploratory intent for oil is higher by twenty-five percent than the base case analysis which assumes that intent can be directly represented by the ratio of successful oil metres drilled divided by total successful metres drilled. Pasay (1987) states that this percentage is arbitrary.[13]

Reported Oil and Gas Cost Data, Trends in Cost Categories

In order to better understand the structure of costs, which will simplify the review of cost literature results to follow, I present the following data taken from the CPA statistical data bank, which form the primary inputs to most of these analyses. Table 4-7 below and its graph illustrate the major recorded cost components for exploration and development for 1985, 1986 and cumulative from 1947 to 1986.[14]

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[12] It is not perfectly clear which wells and activities are exploratory and which are for development.

[13] Pasay (1987), p. 15.

[14] CPA Statistical Handbook, 1987, Section IV, table 3C.

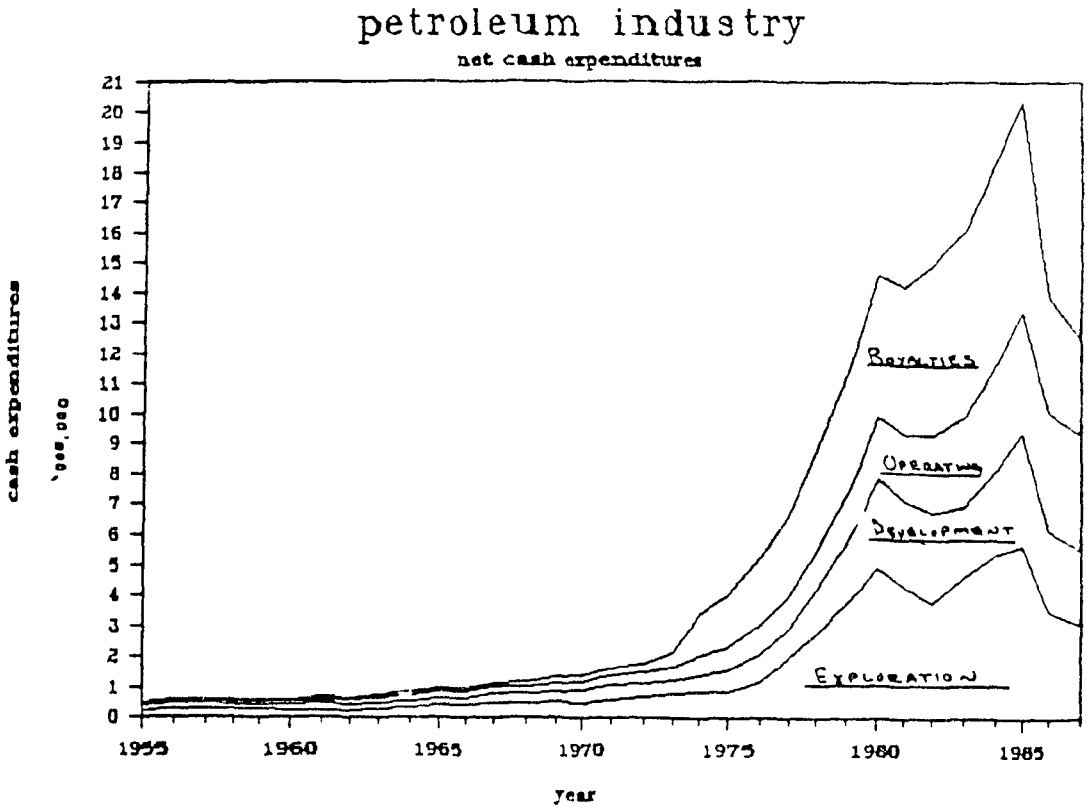
Table 4-7

NET CASH EXPENDITURES OF THE PETROLEUM INDUSTRY

(million dollars)

Alberta	1985	1986	1947-86	
1. EXPLORATION				
a) Geological & geophysical	480.5	448.9	5,446.0	4.13%
b) Drilling	1,368.3	1,021.3	12,832.9	9.72%
c) Land acquisitions & rentals	1,021.1	447.3	11,127.4	8.43%
d) Other	---	---	220.5	0.16%
	2,869.9	1,917.5	29,626.8	22.44%
2. DEVELOPMENT				
a) Drilling	1,296.1	983.1	11,291.8	8.55%
b) Field equipment	902.5	853.0	8,211.2	6.22%
c) Secondary recovery & pressure maintenance	331.0	229.4	1,651.4	1.25%
d) Natural gas plants	263.3	181.0	3,917.0	2.97%
e) Other	87.0	---	1,085.4	8.22%
	2,879.9	2,246.5	26,156.8	19.81%
3. OPERATING				
a) Wells including flow lines & related facilities	2,678.1	2,674.0	17,380.5	13.17%
b) Natural gas plants	602.8	585.6	5,566.6	4.22%
c) Taxes (excluding income tax)	---	---	1,608.1	1.22%
d) Other	---	---	1,372.9	1.04%
	3,280.9	3,259.6	25,928.1	19.64%
4. ROYALTIES	6,005.4	3,284.2	50,298.5	38.10%
TOTAL EXPENDITURES	15,036.1	10,707.8	132,010.2	100.00%
(not included above)	---	---	1,677.5	

The trends in these expenditures are represented in the following graph.



Thus, the cost statistics are collected on an oil-gas aggregate basis, and some method must be used to allocate an annual proportion of these costs to oil and to gas if one wishes to identify separately oil costs and gas costs. Now, although this separation of costs is of interest to this thesis, it is not necessarily so important to companies that sell both the oil and gas that they find, and are interested in cost trends (and revenue) for an oil-gas aggregate. Although some companies do attempt to associate expenditure according to their own internal assignments of wells according to oil and gas intent, and thereby identify their own internal gas and oil costs, none of these types of reports seem to be publicly available.

Drilling Activity, Gas Discoveries

For general industry results, the following tables show

total wells and total metres drilled for oil and gas and total initial volumes in place for raw (unprocessed) gas in Canada from 1947 to 1986.

WELLS AND METRES DRILLED IN WESTERN CANADA

	EXPLORATORY		DEVELOPMENT		TOTAL	
	No.	Metres	No.	Metres	No.	Metres
Cum to 1947	18	300 851	350	1 279 856	2 058	2 140 719
1947	27	125 353	202	60 689	331	286 641
1948	79	209 307	281	340 034	460	548 341
1949	275	352 135	580	669 524	855	1 021 650
1950	311	410 170	859	946 081	1 170	1 356 251
1951	487	652 801	933	1 135 229	1 420	1 788 030
1952	300	1 084 089	1 282	1 571 582	2 182	2 655 671
1953	305	1 157 247	1 334	1 628 611	2 239	2 785 858
1954	928	1 218 705	1 365	1 575 051	2 293	2 791 756
1955	885	1 212 529	2 050	2 663 245	2 935	3 875 774
1956	899	1 342 829	2 383	3 379 146	3 282	4 721 975
1957	1 058	1 518 179	1 942	2 753 686	3 000	4 269 865
1958	849	1 275 048	1 667	2 502 804	2 516	3 777 852
1959	939	1 397 939	1 629	2 476 581	2 568	3 874 520
1960	818	1 335 657	1 718	2 854 036	2 536	4 189 693
1961	769	1 302 665	1 743	2 888 582	2 512	4 191 247
1962	869	1 397 234	1 640	2 563 288	2 509	3 980 522
1963	1 011	1 579 454	1 850	2 751 838	2 861	4 331 300
1964	1 293	1 833 748	2 007	2 910 220	3 300	4 743 988
1965	1 470	2 078 430	2 163	2 894 937	3 633	4 973 387
1966	1 447	2 050 160	1 605	2 143 615	3 052	4 193 775
1967	1 341	1 913 449	1 537	2 359 486	2 878	3 872 935
1968	1 495	2 257 325	1 500	2 886 373	2 995	4 143 698
1969	1 624	2 149 223	1 553	1 886 851	3 177	4 036 074
1970	1 414	1 884 488	1 522	1 610 239	2 936	3 494 727
1971	1 445	1 881 534	1 489	1 579 190	2 934	3 460 724
1972	1 649	2 176 651	1 936	1 968 887	3 585	4 145 538
1973	2 128	2 403 485	2 271	2 465 742	4 397	4 869 227
1974	1 548	1 971 398	2 319	2 237 618	3 867	4 208 914
1975	1 565	1 715 655	2 467	2 315 283	4 032	4 030 938
1976	2 389	2 301 411	3 104	3 021 340	5 493	5 322 751
1977	2 739	2 803 393	3 237	3 238 430	5 976	6 041 823
1978	3 065	3 529 485	3 913	3 751 819	6 978	7 281 214
1979	2 901	4 111 259	4 554	4 463 970	7 455	8 575 229
1980	3 744	5 234 229	5 188	5 138 500	8 932	0 372 729
1981	3 274	4 257 585	3 897	3 810 523	6 971	8 068 108
1982	2 238	3 161 328	4 093	3 963 678	6 331	7 124 706
1983	1 973	2 804 679	4 877	5 153 549	6 850	7 958 428
1984	2 963	3 977 174	6 517	6 567 178	9 380	10 544 352
1985	3 236	4 611 984	8 794	8 596 464	12 030	13 208 128
1986	1 365	2 836 782	3 710	4 347 112	5 685	7 183 894
	52 113	82 392 228	38 681	112 010 966	60 814	94 403 392

Source: CPA(1987)

RAW NATURAL GAS
INITIAL VOLUME IN-PLACE IN CANADA BY YEAR OF DISCOVERY
AT 1986-12-31

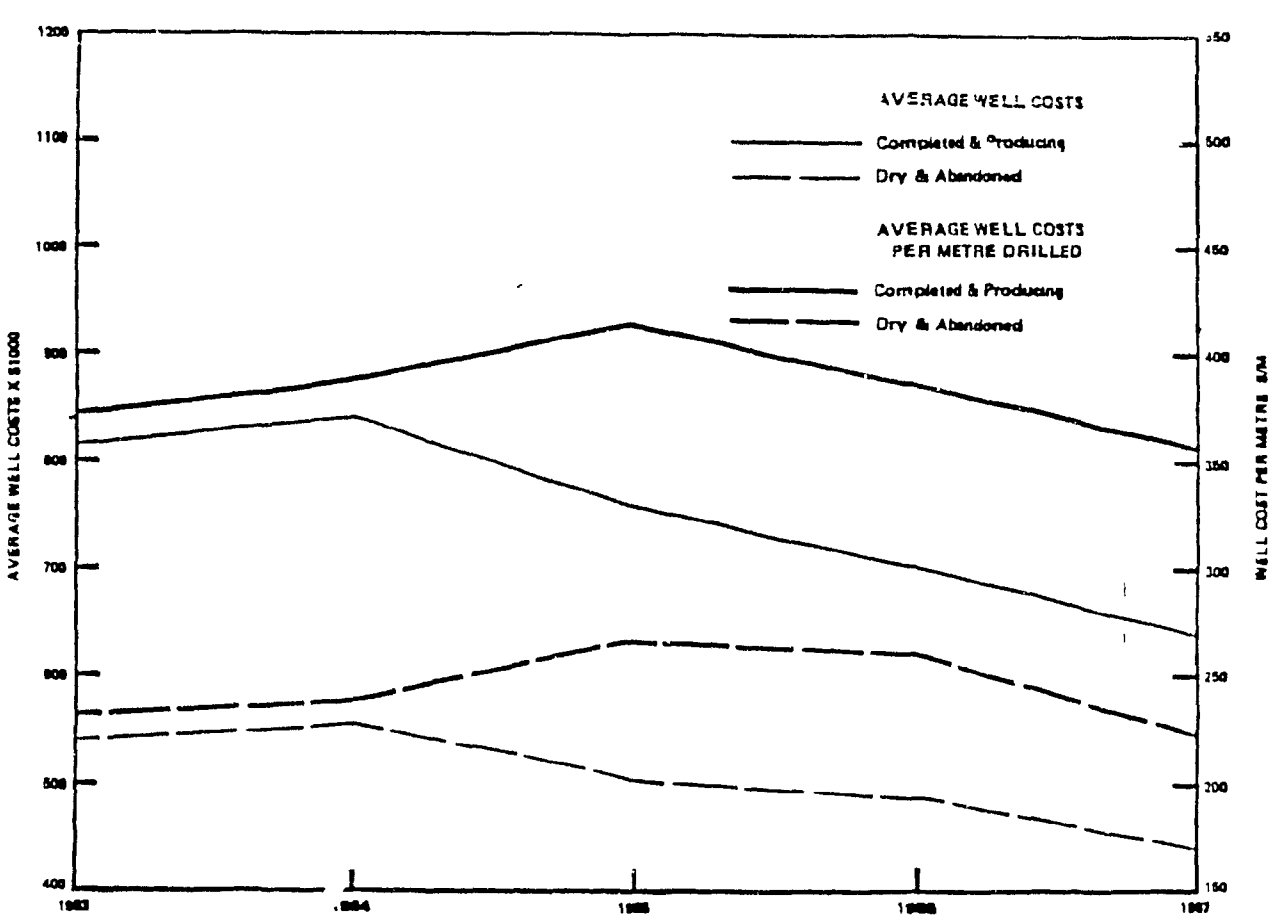
Million Cubic Metres at 101.325 kPa and 15°C

YEAR OF DISCOVERY	PROVINCES											
	MACK. TERR.	PAC. DELTA BEAU. SEA	ARCTIC ISLES	BC	ALTA	SASK.	MAN.	ONT.	OTHER EAST CAN.	E. COAST OFFSHORE	TOTAL CANADA
PRE 1947	6034	0	C	0	734153	388	0	31270	902	0	772949
1947	C	0	0	0	33692	1	0	2100	0	0	35793
1948	C	0	0	0	60067	0	0	233	0	0	60300
1949	C	0	C	0	65749	0	0	1140	0	0	66889
1950	C	0	0	0	23023	0	0	1315	0	0	24338
1951	C	0	C	761	111127	7195	0	582	0	0	119665
1952	C	0	0	10268	147962	665	0	2385	0	0	161300
1953	C	0	C	9115	211338	67840	0	13	0	0	288306
1954	C	0	0	27497	240218	27434	0	535	0	0	295684
1955	162	0	0	22810	124420	7028	0	75	45	0	154540
1956	C	0	0	14476	136559	4706	0	215	8	0	155956
1957	C	0	0	144067	217589	6615	0	0	0	0	370071
1958	C	0	0	45505	110303	2693	0	2601	0	0	181102
1959	C	0	C	18586	249752	19	0	3506	0	0	271853
1960	869	0	0	24250	106530	1071	0	15	0	0	132735
1961	2476	0	0	18895	274664	0	0	650	0	0	296685
1962	C	0	C	59027	99323	594	0	2616	0	0	161560
1963	C	0	C	14561	124639	5483	0	290	0	0	144973
1964	375	0	0	9671	51825	0	0	6489	0	0	68360
1965	410	0	0	31708	108016	1758	0	2482	0	0	144402
1966	15213	0	0	17086	36180	11	0	52	0	0	68540
1967	C	0	C	14438	129556	396	0	885	0	0	145275
1968	C	0	0	5298	65917	305	0	3141	0	0	74661
1969	C	0	162500	8267	112574	4054	0	690	0	0	288085
1970	C	0	0	3926	49463	0	0	5267	0	0	58656
1971	C	113400	23000	9484	54097	305	0	2758	0	0	203218
1972	C	56020	133700	11258	115195	1461	0	5691	0	0	323725
1973	C	32160	28000	21844	92575	147	0	1948	0	0	176674
1974	C	6540	C	15053	110010	419	0	5151	0	0	135573
1975	C	32900	0	30886	80185	0	0	3206	0	0	148177
1976	C	26200	42100	16773	152624	0	0	2436	0	0	234733
1977	25010	0	0	13337	144799	0	0	2909	0	0	286095
1978	C	500	14900	33671	139506	1727	0	2011	0	0	194713
1979	C	0	73000	17024	151298	96	0	6120	0	0	247536
1980	C	46000	14600	18816	103294	29442	0	6020	0	0	216172
1981	C	0	38400	7513	100918	0	0	1570	0	0	148401
1982	C	4830	0	10834	61742	0	0	74	0	0	77500
1983	C	0	C	4310	52800	0	0	55	0	0	57365
1984	C	40100	C	2496	49942	0	0	51	0	0	92589
1985	C	0	20900	2972	39460	8779	0	94	0	0	72205
1986	500	0	C	1987	14407	248	0	0	0	0	17142
TOTALS	51091	367250	1531100	720630	5331287	180918	0	106419	947	0	7891642

Source: CPA(1987)

Drilling Costs and Influential Factors

The average costs of wells from 1983 to 1987 are presented on the following graph, along with the average cost of wells per metre drilled as reported in the 1987 Petroleum Services Association of Canada (PSAC) well cost study. There are clear downward trends in average well costs from 1984, onward, and from 1985 onward, on a per metre basis. The reason is probably related to a small change in the average depth of well.



Source: PSAC(1987)

These aggregate results can be misleading, because there are clear differences in the costs of wells in different areas of Western Canada. The following two tables illustrate the differences in representative well drilling costs in the twelve different areas of Alberta identified by the PSAC.

ANNUAL AVERAGE WELL COST
(x $1000)

	1982		1983		1984		1985		1986		1987	
AREA	D&A	C&P	D&A	C&P	D&A	C&P	D&A	C&P	D&A	C&P	D&A	C&P
1.	3261	4125	3261	4125	3478	4328	3317	4260	3310	3927	2787	3500
2.	290	552	619	910	595	848	592	836	556	782	382	643
3.	172	339	172	339	176	347	169	351	152	329	117	246
4.	134	323	112	254	117	273	109	264	103	259	111	215
5.	384	715	337	634	334	648	339	642	306	591	253	504
6.	269	461	269	461	258	441	197	226	188	213	144	171
7.	469	765	469	765	441	761	389	789	445	713	434	675
8.	611	945	625	935	644	933	296	506	271	478	503	784
9.			62	124	77	162	79	166	71	151	97	192
10.			128	290	131	314	159	321	144	298	133	157
11.			218	442	241	471	218	404	193	391	137	279
12.			143	359	133	294	143	276	132	275	115	249

ANNUAL AVERAGE COSTS PER METER
$/m

	1982		1983		1984		1985		1986		1987	
	D&A	C&P	D&A	C&P	D&A	C&P	D&A	C&P	D&A	C&P	D&A	C&P
1.	715	910	715	909	767	966	738	954	735	883	664	835
2.	224	413	273	402	315	460	312	472	295	441	183	308
3.	140	274	139	274	142	281	136	283	122	266	117	248
4.	124	299	127	286	133	321	127	311	120	309	178	280
5.	173	322	167	315	163	320	169	318	152	293	141	278
6.	240	412	240	411	230	394	606	695	578	655	359	425
7.	250	467	249	407	233	404	262	420	358	380	278	431
8.	288	462	299	496	310	455	262	457	239	427	319	506
9.			62	181	113	238	116	243	104	221	101	203
10.			110	249	113	268	137	273	123	253	133	259
11.			122	247	135	263	141	266	107	218	104	210
12.			146	292	136	298	144	279	133	278	115	247

D&A: Dry and Abandoned
C&P: Completed and Producing

Source: PSAC(1987)

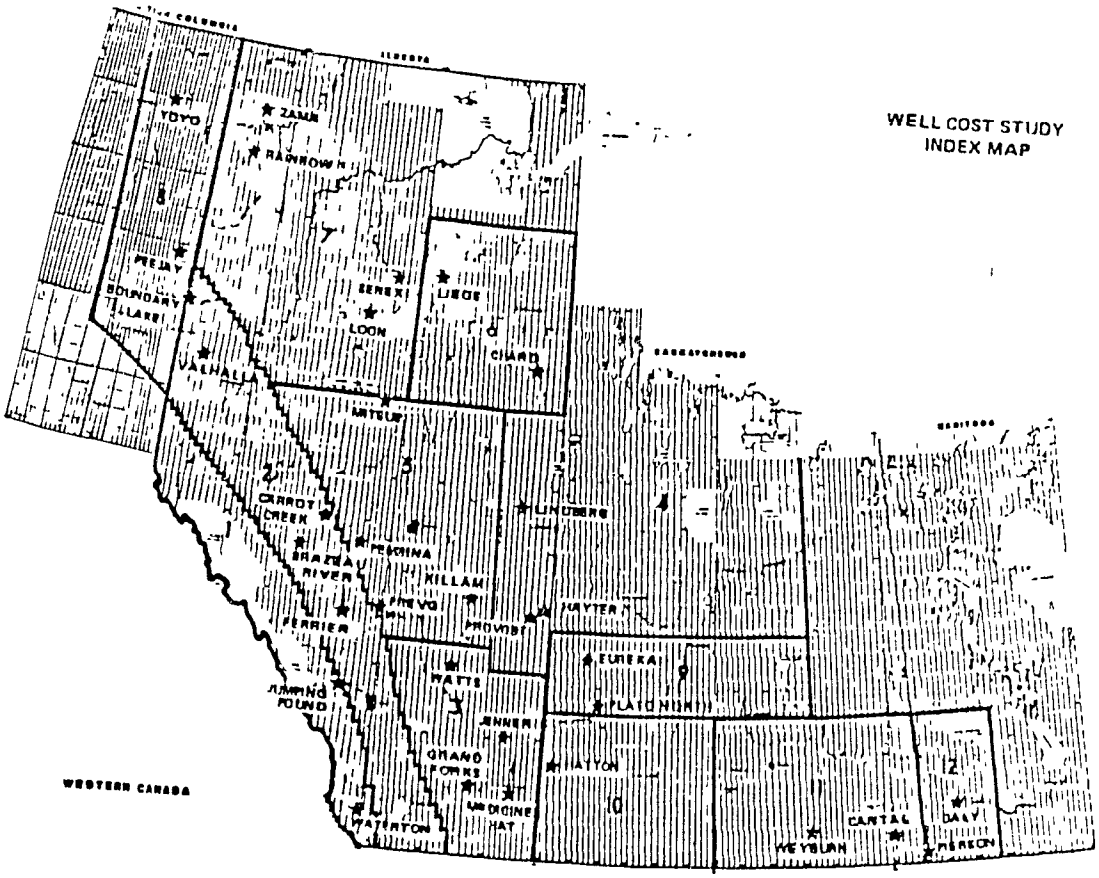
Perhaps the more interesting thing to note is that the cost per well, and the cost per metre drilled is steadily declining from 1983. Unfortunately, similar data for the pre-1982 period are not available for comparison.

Data qualification

Some of the factors which bear directly on drilling costs and which have a very significant impact on the total cost of a given project are:

1. The type and size of company or operation.
2. Company policies regarding certain drilling functions or practices.
3. Economic environment including factor prices.
4. Whether the well is development or exploration.
5. Location of well relative to services, supplies, and highways.
6. Specific programs - hole sizes, casing sizes, types of equipment, mud programs, and the like.
7. Evaluation programs and techniques - number of tests, number and type of logs, cores.
8. Whether drilling for gas or oil.
9. Whether target product is sweet or sour.
10. Seasons - winter versus summer.
11. Surface conditions - muskeg, agricultural, mountains, and others.

We note that most of these variables can and do occur even within the limits of a field or so called typical area. Therefore, "costing" is difficult especially if one attempts to go beyond totals and simple averages.


WELL COST STUDY
INDEX MAP
YOYO
ZAMA
RAINBOW
PEACE
BOUNDARY
LAKE
VALHALLA
LOON
SENEX
LIEGE
CHARD
WATSON
CARROT CREEK
BRAZEAU RIVER
PEMBINA
KILLAM
FERRIER
PROVOST
HAYTER
EUREKA
PLATO MINE
WATTS
JUMPING POUND
JENNER
GRAND FORKS
MEDICINE HAT
HATTON
WATERTON
CARTAL
PEACE
WESTERN CANADA

COST SUMMARY BY AREA

Area	Type	Depth (Metres)	Days	Drilled & Abandoned Cost $	Drilled & Abandoned Cost/ Metre $	Completed & Producing Cost $	Completed & Producing Cost/ Metre $
1							
Jumping Pound, Alberta	Gas	3,520	90	1,898,897	540	2,393,342	680
Waterton, Alberta	Gas	4,660	140	3,673,700	788	4,606,770	989
2							
Valhalla, Alberta	Oil	1,985	21	353,536	178	593,252	299
Ferrier, Alberta	Oil	2,150	17	550 490	256	794,802	370
Brazeau R., Alberta	Oil	2,490	15	367,984	148	728,922	293
Carrot Creek, Alberta	Oil	1,694	12	253,917	150	455,507	269
3							
Medicine Hat, Alberta	Oil	876	4	98,418	119	221,698	268
Grand Forks, Alberta	Oil	950	5	113,652	120	234,943	247
Jenner, Alberta	Oil	917	3	106,325	116	233,997	255
Watts, Alberta	Oil	1,324	7	149,130	113	292,015	221
4							
Provost, Alberta	Oil	876	4	109,255	125	203,607	232
Hayter, Alberta	Oil	862	4	104,968	122	205,761	239
Lindberg, Alberta	Oil	656	3	93,530	143	269,455	411
Killam, Alberta	Oil	975	5	118,826	122	234,403	240
5							
Prevo, Alberta	Oil	1,948	10	251,625	129	470,594	242
Pembina, Alberta	Oil	1,850	11	257,004	139	527,131	285
Mitsue, Alberta	Oil	1,665	13	250,542	156	512,567	308
6							
Chard, Alberta	Gas	388	2	106,179	274	132,715	342
Liege, Alberta	Gas	410	3	181,658	443	207,914	507
7							
Joon, Alberta	Oil	1,515	14	345,794	228	664,498	439
Senex, Alberta	Oil	1,330	14	423,513	318	550,247	414
Rainbow, Alberta	Oil	1,860	18	511,121	275	789,445	424
Zama, Alberta	Oil	1,558	13	454,102	291	695,811	447
8							
YoYo, B.C.	Gas	1,812	42	948,927	524	1,374,710	759
Peejay, B.C.	Oil	1,210	9	279,329	231	483,945	400
Boundary Lake, B.C.	Oil	1,380	12	280,610	203	494,635	358
9							
Plato N., Sask.	Oil	764	5	85,927	113	176,384	231
Eureka, Sask.	Oil	1,188	6	106,820	90	206,968	174
10							
Hatton, Sask.	Gas	604	5	80,315	133	156,687	259
11							
Weyburn, Sask.	Oil	1,479	9	151,946	103	307,227	208
Cantal, Sask.	Oil	1,180	6	122,399	104	250,036	212
12							
Pierson, Man.	Oil	1,067	6	120,144	113	255,052	239
Daly, Man.	Oil	950	6	110,280	116	242,002	255

A Tentative Cost of Gas Estimate, Above and Below Ground Costs

As a general ballpark estimate, one might accept an initial cost per metre drilled of $375 for completed and producing (C+P) wells and $225 for drilled and abandoned (D+A) wells for an average of $325. If the average depth is taken as 1,200 metres, an average cost per well will be about (1987 $C) 390,000. According to data presented by Mansell et al. (1988), we may find about forty million cubic metres of gas per 1,000 metres drilled; or 48 million cubic metres per 1,200 metres drilled. Forty-eight million cubic metres of natural gas is equal to about 1.824 PJ or 1,824,000 GJ. Now, the levilized cost of those 1.824 PJ is equal to the present value of the expenditure ($390,000) divided by the present value of the gas 1.824, delivered at (1/12)(1.824) = .152PJ per year for twelve years. If the well head price of gas could be forecast for the twelve years, a levelized revenue could also be computed. Thus a comparison can be made which results in an estimate of levelized rent potential per foot drilled. It must be emphasized that these costs relate to only a part of the costs of supply, however.

Using Brown's (1988 Appendix D) formula, with a cost of capital of 16% and a drawdown rate of 8%, the above ground cost[15] is equal to P_B (1 + i/d) or (390,000/1,824,000) X (1 + 16/8) = $.64/GJ. Although this seems low, it must be remembered that gas plant costs, royalties, and a number of other categories of cost are left out of this analysis. Also, the data used focuses on the oil-gas aggregate and only gas results are needed here. Still, these costs as finding costs alone seem quite low, about $.214/gj in current dollars, for below ground costs.[16] Using an initial cost of reserves of ($1982) .294/gj, and the NEB's connection and production

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[15] P_A is the above ground cost or price, P_B is the below ground cost or price of reserves.

[16] See Ziff (1988), for a recent estimate of replacement costs based on book value.

ratios,[17] results in a levelized cost of ($1982) $1.40/GJ. This levelized cost seems quite high, on the other hand, compared with average industry costs of supply. Clearly, the NEB (1988) connection and production rules imply much higher above ground costs.

One recent approach to the problem of finding the costs of supply for oil and gas separately is that of Livernois and Ryan (1988). Livernois describes the production (cost) structure of previous studies as special cases of his general model. Anderson (1986), Eglinton and Uffelmann (1983), Slagorsky and Pasay (1985), and Howard and Merklein (1973) treat oil and gas as a composite commodity, which is one way to deal with the joint production problem aspects of the problem, but does not allow one to estimate separate costs for oil and gas. Livernois and Ryan (1987) show that the separability assumption required for the use of such models is not invalid for Canadian exploration data, however a priori estimates for intent are likely to be misleading.

The alternative approach is to partition the costs on the basis of output, using some decision criterion, like proportional amount of successful footage drilled. This approach is taken by Uhler (1979), Eglinton and Uffelman (1983), Slagorsky and Pasay (1985), and also Pasay (1986, 1987).

Livernois also mentions the Uhler (1986) approach of estimating supply functions under the polar assumptions of non-joint and joint outputs, and the former notes that the results are sensitive to this assumption, and suggests that the latter's results probably bound the true case.

The Livernois and Ryan (1988) approach is based on the estimation of a translog (multiple input, multiple output) cost function. This, they claim, obviates the need to

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[17] These are discussed in a section which follows, titled 'connection and production rates. The drawdown rate implied by the NEB ratios is considerably lower than 8% p.a.

arbitrarily assign costs to discovered oil and gas. The authors fit a cost function of the following form:

$$C = C(W_1, W_2, W_3, Y_1, Y_2, Z)$$

to the data from 1955 to 1983 using the following equations, the first on costs,

$$\ln C = a + \sum_{i=1}^{3} a_{i0}\ln W_i + 1/2 \sum_{i=1}^{3}\sum_{j=1}^{3} a_{ij}\ln W_i \ln W_j$$

$$+ \sum_{i=1}^{2} b_{i0}\ln Y_i + g_0 \ln Z + \sum_{i=1}^{2} g_i \ln Z \ln W_i$$

the second on the shares of two of the three expenditure groups,

$$S_j = a_{j0} + \sum_{i=1}^{3} a_{ij}\ln W_i + g_j \ln Z \; ; \qquad j=1,2.$$

Livernois and Ryan include the following restrictions:

$$\sum_{i=1}^{3} a_{i0} = 1; \; \sum_{i=1}^{3} a_{ij} = 0; \; i=1,2,3; \; \sum_{i=1}^{3} g_i = 0;$$

to ensure that the cost function is homothetic in outputs (cost per unit is unaffected by the volume of inputs), and linearly homogeneous in input prices (if input prices double, costs double). The time variable Z, captures both the effects of technological change (assumed to be Hicks neutral neither augmenting labour alone, nor capital alone), as well as depletion effects (these allow costs to drift up over time as perhaps less accessible deposits are pursued. Thus, the variable Z can be thought of as a "net technolcgical change" variable.

The inputs are exploratory drilling (total number of metres drilled annually), geographical effort (total number of annual crew months), and land (the total area acquired under lease and license annually). The input prices for the

estimating equations are obtained by dividing total annual expenditures on these items by the input quantities. The output variables, are the 1985 reported values of the sizes of discoveries made in the years 1955 to 1983. This is done because finds usually "appreciate" over time, which is to say, that our knowledge of the volume in the ground (at some probability level) results in higher estimates as time goes on - the initial estimates given accepted techniques of estimation are normally conservative.

Reserves Appreciation Data

There is some question about the accuracy of reserve estimates for recent years, as they may have had less time to "appreciate" than earlier discoveries. This factor would tend to impart an upward bias to the latter years' cost estimates. Livernois and Ryan (1988) state the following in a footnote:

> "One could argue that the discoveries data for more recent years are less accurate than for early years, since there has been less time for reevaluation of the discoveries. However, as Uhler (1979) points out, recent discoveries are relatively small and subject to much smaller adjustments than earlier discoveries. In addition, with so much extra experience, one could argue, the industry has been unable to make more accurate initial estimates of reserves in recent years."[18]

Pasay (1987) for example, dramatically reduces her rates of appreciation for recent finds, because she claims many of the pools are small and were developed rapidly because the downward price pressures created cash flow problems for many producers. This factor, however, does not really reflect an increase in the scarcity of gas reserves per se.

Effects of Rapid Expansion, and Government Regulations

More conclusive, or less speculative reports on rapid

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[18] Livernois and Ryan (1988), pp. 384-5.

industry expansion and reserves would require explicit historical studies of reserves, appreciation rates, and costs. As an alternative, we may consider the comments of Eglington and Uffelman (1983).

> "...the Canadian industry responded extremely quickly to the prospective incentives during the 1970's by very rapidly increasing the rate of drilling. We note that this is rather easy for the Canadian industry because a small proportion (10%) of all U.S. drilling rigs can, by moving to Canada, double the Canadian drilling fleet in a matter of weeks. This, of course, can happen in both directions. Secondly, the rate of the rise in costs, and the corresponding decline in reserves additions per well, give the strong impression that drilling was overextended relative to industry's knowledge of prospects. Many of the poorer (smaller, low quality reserves) prospects which had previously been put aside were dusted off and drilled. In the words of one company executive: it was a case of too much brawn and too little brain. This is one reason why the trend in costs in the late 1970s is probably <u>not</u> a good indicator of the long run path of costs in the future."[19]

I allude to this quotation later in the discussion of costs, but we must consider the fact that the environment in which the firms were operating was subject to change. As well, we must consider what the expectations of the firm might have been, especially with respect to future gas prices. The charts on the following pages show that there were significant federal changes in the accounting rules, royalty programs, etc. related to exploration and company operations, These rules affected the relative values of different types of drilling programs, for different companies. There were similar types of changes at the provincial level as well.

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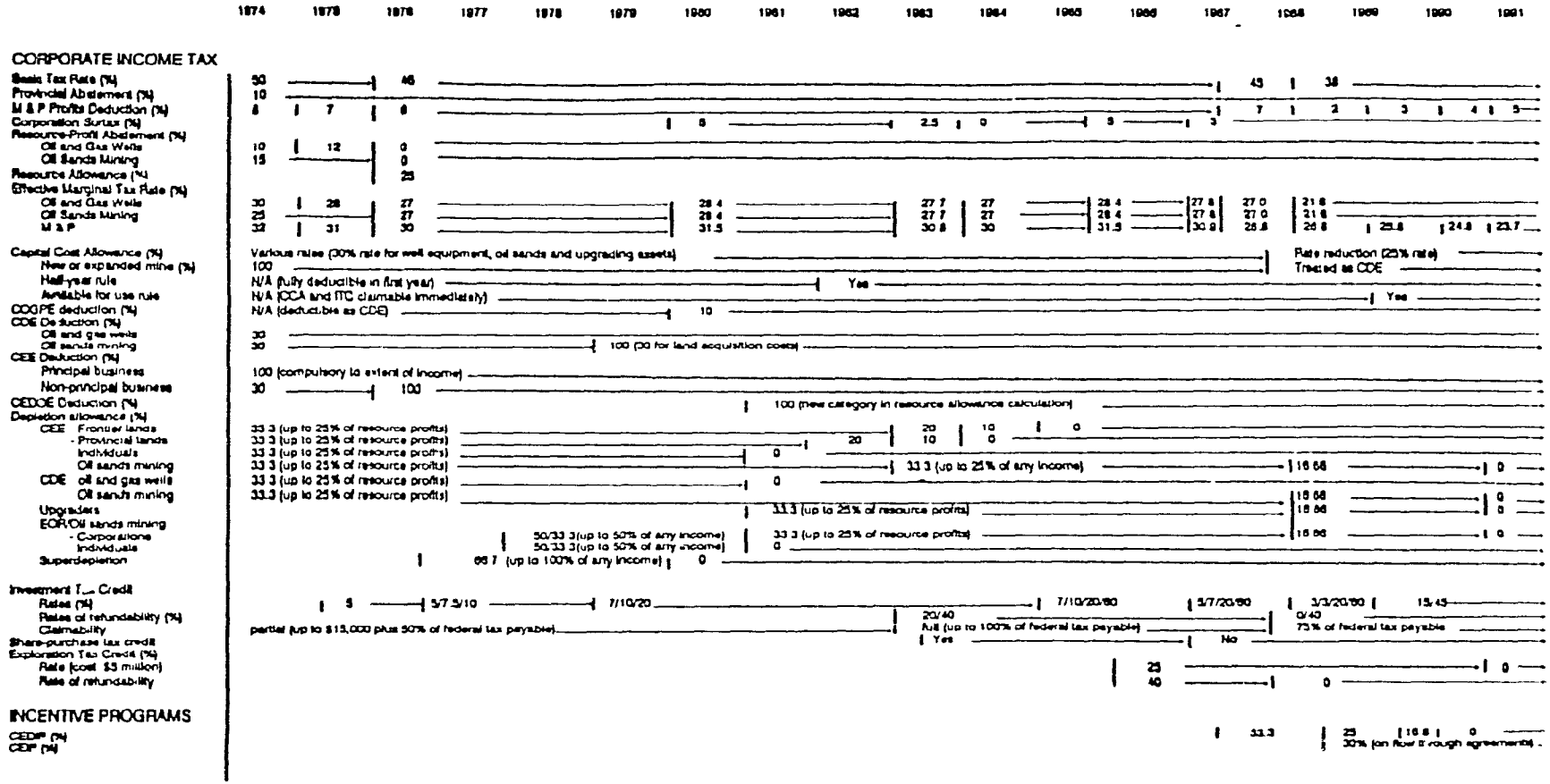
[19] Eglington and Uffelman (1983).

CHRONOLOGY OF FEDERAL FISCAL INSTRUMENTS APPLICABLE TO PETROLEUM: A SUMMARY



CANADA LANDS REGIME

Petro-Canada preferences (%)
Land reversion (%)
Royalties (%)
Three year PIR holiday
Investment royalty credit (%)

DOWNSTREAM TAXES

Sales Tax
- Rate (%)
- Gasoline computation

Excise Taxes (¢/L)
- Gasoline
- Diesel fuel

Fuel Tax Rebate Program
- Gasoline (¢/L)
- Diesel fuel

Excise Tax Refund Program
- Gasoline (¢/L)

NATIONAL ENERGY PROGRAM - FISCAL MEASURES

PGRT
- Basic tax rate (%)
  - General
  - Oil sands mining
- Resource allowance (%)
  - General
  - Oil sands mining
- Effective tax rate (%)
  - General
  - Oil sands mining
- New production
- Income exemption ($)
- EOR capital deductibility
- Corporate tax credit (%)
- CEE and CDE offsets
- Small producer's credit

IORT
- Basic tax rate (%)
- Buncor percentage (%)

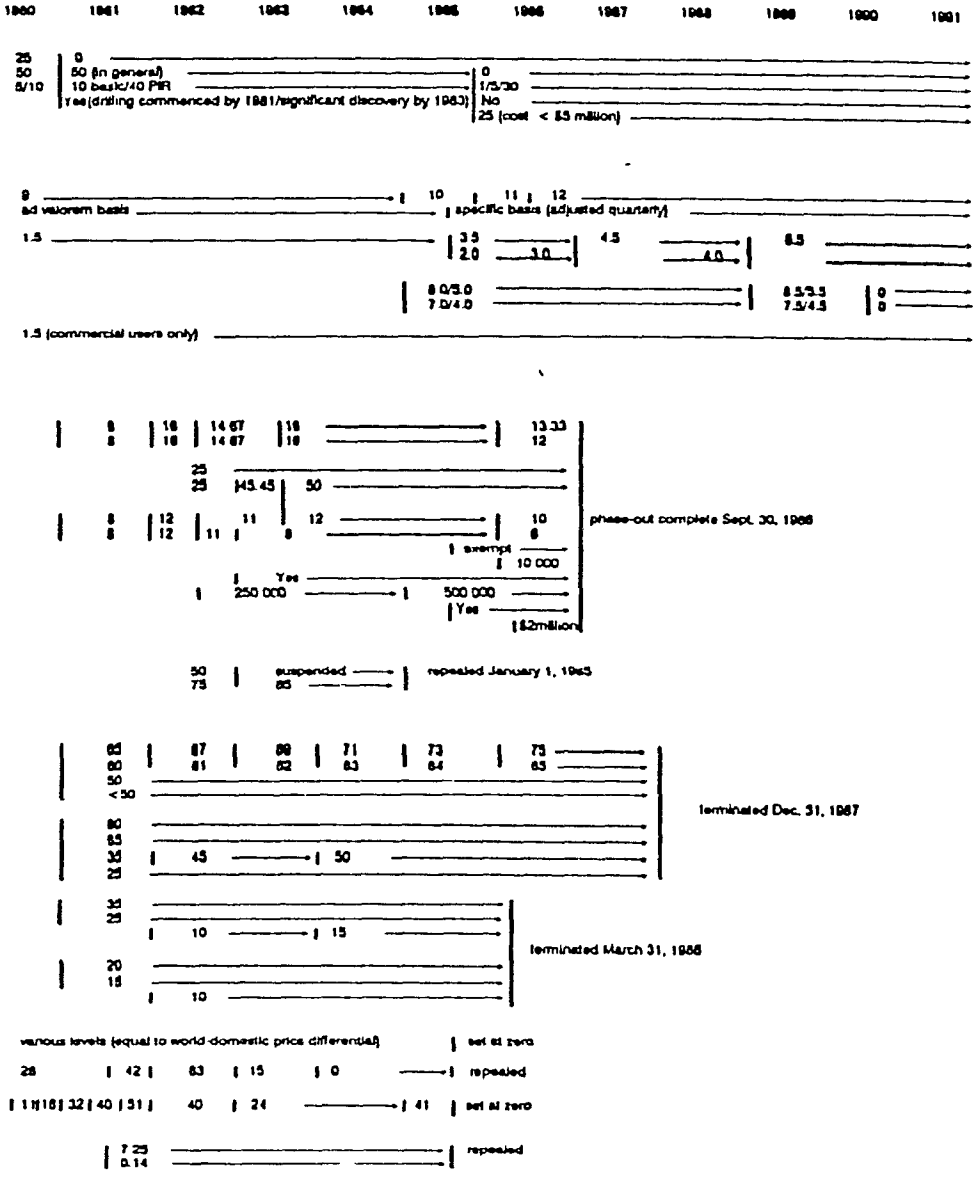
PIP
- COR/CS (%)
  - range 1
  - range 2
  - range 3
  - range 4
- CEE - frontier lands (%)
  - range 1
  - range 2
  - range 3
  - range 4
- CEE - provincial lands (%)
  - range 1
  - range 2
  - range 3
- CDE and EOR Assets
  - range 1
  - range 2
  - range 3

Oil Export Charges

NGGILT (¢/GJ)

PCC ($/m^3)

COSC
- Oil ($/m^3)
- Natural gas ($/GJ)



The influences of various government programs are important because they change the relative (after tax) costs of drilling different types of oil and gas prospects at different depths, in different parts of the country and over time. While it is possible that all of these effects could result merely in random disturbances, it seems more likely that they would impart systematic biases.

The Influence of "the Bubble"

Further, one should also take into account the influence that "the gas bubble" (i.e., the very significant shut in gas deliverability in Western Canada) has had on wellhead prices. While it had been suggested that the natural gas bubble would be a temporary phenomenon, it has in fact persisted for some twelve years. The following table illustrates the effect that only a seven year average lag in delivery would have on the natural gas industry, in terms of levelized unit cost of natural gas.

	Levelized Cost Per Unit $390,000 and 1.824 PJ
NO LAG	$ .64
7 YEAR LAG2	$ 1.80

One recent study which has attempted to account for both geologic and economic factors in looking at supply issues is Uhler (1985) in his book for the Economic Council of Canada, The Potential Supply of Crude Oil and Natural Gas Reserves in the Alberta Basin. Here, models which incorporate profit maximizing behavior on the part of firms are used to attempt to estimate the potential supply of oil and gas separately (at various cost levels), within specific geologic regions (disaggregate analysis) and across specific geologic regions (aggregate analysis). Uhler notes some interesting results for his aggregate analysis, where the problem of targeted

drilling by geological region becomes less difficult to handle. In his models he seems to obtain results[20] which suggest that cumulative discoveries do not have a negative effect on reserves additions, which in turn suggests that there is no clear evidence that diminishing returns in this sense have as yet been identified.

Social Supply Price

A measure which is of interest from the national point of view for economic decision making is social supply price. Social supply prices "represent constant real unit prices sufficient to recover the incremental real resource costs of natural gas production and transportation to market (assumed to be central Canada), including the social opportunity cost of capital." The social supply price captures geological and geophysical activity, exploratory and development drilling, production costs, other recovery costs, gathering, processing, and transmission to central Canadian markets. Profits, taxes, royalties, rents, intergovernmental transfers, etc., are excluded from this calculation - it is a measure of real resource cost.[21]

The social cost of Canadian natural gas is a function of a large number of variables, and the estimates of the quantity of reserves available at given levels of social cost is a significant element in the evaluation of the impact of any Canadian natural gas project. In December 1984, the NEB produced social supply price estimates for successive ten exajoule increments of reserves additions for the Western Canadian Sedimentary Basin (WCSB). The figures represent the levelized cost of supplying these reserves to central

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[20] Uhler (1985), p. 48.

[21] Except that the cost of capital which is a real cost is measured by the discount factor. Profits etc. per se are not counted but the cost of capital is.

Canada. They are the ratios of the present value of all costs (as before, profits, taxes, etc., excluded) divided by the present value of the delivered stream of gas. Thus, there are three sets of prices, depending on whether a 6%, 8% or 10% discount rate is used as a proxy for the social opportunity cost of capital.

When the numbers are converted to 1987 dollars (130.9/117.9 = 1.11 using the GDP deflator) and including transportation charges to central Canada of 25c/GJ at 8% ($1984), [27.76c/GJ at 8% ($1987)], we obtain the table below.

SOCIAL SUPPLY PRICE OF NATURAL GAS

(1987 $/GJ)

Reserves Supply Source	Supply Price 6%	8%	10%	(EJ)
WCSB remaining @ 31 Dec. 1982	.94	.94	.94	81.4
WCSB first	1.94	2.10	2.22	10.0
WCSB second	2.33	2.50	2.66	10.0
WCSB third	2.72	2.94	3.11	10.0
WCSB fourth	3.22	3.50	3.77	10.0
WCSB fifth plus MacKenzie Delta	3.72	4.05	4.44	10.0
Arctic and alternative	5.50	6.00	6.55	very large

To better understand the general methodology of the foregoing (the specific background data and methodology were not available to me), I present the following example.

Relation to previous cost discussion

Suppose in a given year, the following expenditures can be allocated to the discovery of 3.0 EJ of natural gas:

	Millions of Dollars	
Geological and geophysical	250	
Exploration drilling	450	
Land purchase and rentals	100	
	800	
Exploration/finding		800
Development		2,000
Total		2,800

The cost of the reserves (found and developed) "in the ground" so to speak would be 2,800,000,000/3 x 10^9GJ = $.93/GJ. The above ground cost of reserves would have to take into account the production profile associated with the above development (and lifting) costs, which would require that a "levelized cost" be computed. As mentioned previously, this is done by dividing the present value of the costs by the present value of the delivered gas stream. Suppose that the gas stream could be drawn down over a 12 1/2 year life (8% p.a.) as before:

Reserve	.08% Delivered
3,000 PJ	240
2,760 PJ	221
:	:
:	:

Brown (1988) reports the following formula,

$$P_A = (1 + i/a)P_1$$

where i is the discount rate, a is the declining rate of production, and P_1 are the "in-ground" costs (equal to the present value of expenditures divided by the associated

reserves).[22] Thus, for an 8% declining production rate, and an 8% discount rate, the "above ground cost" or "produced cost" of reserves for the example constructed is:

$$P_A = (1 + .08/.08)(.93) \quad = \$1.86/GJ$$

which is a comparable figure to the (2.10 - .28) transportation charge) $1.88 figure associated with the NEB (1984) estimates for reserves additions. The fact that the two numbers are close is merely coincidence.

There is some evidence that the estimate for costs is somewhat high. A recent study by the Ziff Energy Group reports finding and development costs for the period 1984-1986 of $11.20/bbl for oil and gas together. If oil and gas intent and probabilities of success were equal, this would result in a cost of "in-ground" reserves of $.75/MCF or $.7125/GJ (at .95 MCF/GJ). Now the Ziff study measures land cost at market value rather than opportunity cost, so if we reduce the figure by, say 12% to reflect the difference, we have an "in-ground" cost of reserves of about 62.7c//GJ, which may be considered conservative since the probability of finding oil is lower than that for gas, and the relative value of oil relative to gas is higher and therefore influences intent. With an 8% discount rate, this yields an "above ground" cost of about $1.25/GJ. The addition of a NOVA gathering charge would make this figure comparable to the $1.88/GJ figure reported by the NEB for the first 10 EJ of reserves additions.

This scattered collection of data represents about the best information which has been made publicly available on costs. In Chapter Five, it will be essential to treat results as indicative because of the high degree of uncertainty associated with future costs, as well as with other parameters. For this study, the (above ground) costs

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[22] Brown (1988), p. 309.

of finding gas is assumed to start at $1.40/gj ($1982) and increase in ten exajoule increments. Normal producer costs are estimated to be $.50/gj ($1982) at a "normal" level of industry activity of 3,000 pj of output.

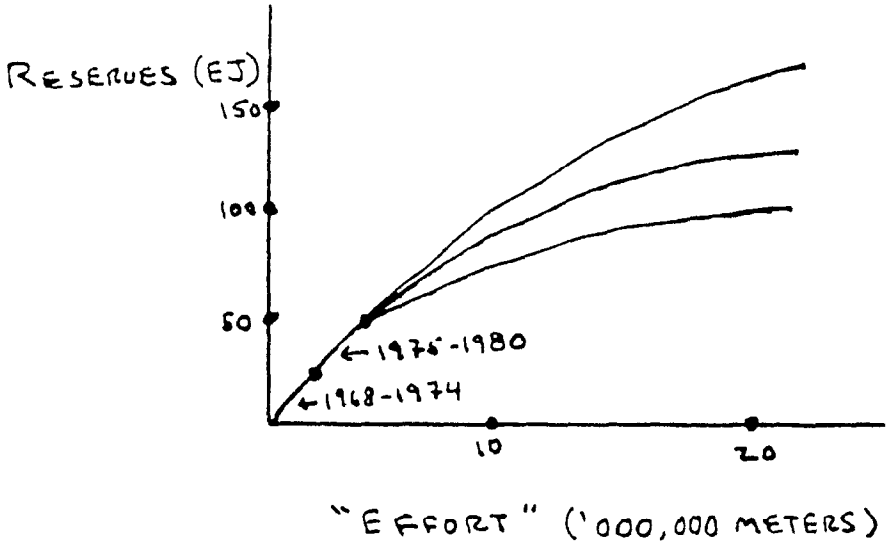
Supply, General Overview for the Simulation Model

Supply data relevant to decision makers are of several types. The first is an estimate of "Ultimate Potential", which is the current "best guess" of the total amount of natural gas that can be found in Canada. Different estimates have been used historically, and certain portions of the ultimate potential are considered "beyond economic reach" at present price levels. This latter estimate of course changes with costs and the level of prices for natural gas in the reserves which are estimated to exist. A certain proportion of the reserve is known with a high level of probability, and such reserves are considered established. The "Remaining Established Reserves" are therefore the reserves which can be included in a future supply forecast with a high degree of probability. They can be drawn down at various rates, but the "maximum producibility" schedule describes the fastest practicable rate of drawdown. The "maximum deliverability" schedule includes pipeline availability and gas plant capacities which together describe the fastest possible rate of use by ultimate consumers. The above estimates of producibility and deliverability are based on the usage rates of "Remaining Established Reserves". There are also estimates of the rate at which established reserves will be increased by forecast discoveries. This is often based on a combination of historical discovery patterns and likely rates of discovery, given that the total quantity of undiscovered gas is presumably getting smaller over time (so long as the ultimate potential is really known). The schedule of future increases to established reserves is called the "Reserve Additions Forecast". Thus, when the producibility and deliverability from this expected pattern

of reserve increases are included with that of currently established reserves, "future producibility" and "future deliverability" schedules may be computed.

Ultimate Potential Estimation

The ultimate potential that is estimated at any one time may not of course be correct. Improved estimates of the ultimate potential are made by observing the relationship between effort in terms of meters of exploratory wells drilled, and reserves discovered over time. There may be several possible trends which will be observed over time, resulting in different estimates of remaining reserves. Ultimate potential estimates may be presented graphically as in the Figure below.



Thus, beginning with present ultimate potential estimates, say 120 EJ, one can observe the effect that a different actual ultimate potential value, say 150 EJ, could have on the behavior of the model, as "learning" occurs and a transition to the appropriate reserves/effort relationship is made within the model. One reason for this type of sensitivity analysis is that the historical data on reserves and effort are consistent with many of the widely varying estimates of ultimate potential available from the literature.

It is assumed initially that there is a single (historically based) relationship between real investment dollars and the level of effort.[23] Technological changes would likely improve investment efficiency and result in higher reserves per dollar of investment. These technological improvements may be captured in the model as well.

Remaining Established Reserves

In the 1982 hearings, there was a high degree of convergence on the estimates of remaining established reserves, which are defined as:

> "Those (oil and gas) reserves recoverable under current technology and present and future anticipated economic conditions, specifically proved by drilling, testing or production, plus that judgment portion of contiguous recoverable reserves that is interpreted to exist from geological, geophysical, or similar information, with reasonable certainty."[24]

The NEB estimate of 80.8 exajoules is representative of the estimates presented at the hearing.

Reserves Additions and Ultimate Potential

The quantity of reserves which can be added over a forecast period is a function of the "ultimate potential" of an area, the amount of drilling required to find those reserves, the cost of bringing them to market, and other economic and geological considerations. Ultimate potential is defined as:

> "An estimate of the initial established reserves which will have become developed in an area by the time all exploratory and development activity has ceased, having regard for the geological prospects

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[23] Effort is a proxy for all exploratory and development activities.

[24] NEB (1986), p. 132.

> of the area and anticipated technology and economic conditions. Ultimate potential includes cumulative production, remaining established reserves and future additions through extensions and revisions to existing pools and the discovery of new pools."[25]

The views of the Board on ultimate potential in 1981 were set out in its supply-demand report as follows:

> "The Board, in previous reports, has emphasized the judgmental nature of estimates of ultimate potential and it continues to believe that ultimate potential cannot be quantified with certainty either mathematically or by the application of geological concepts."[26]

This seems fairly reasonable, however, forecasts must be made, and will continue to be made for planning purposes. Perhaps as discussed earlier in the chapter, there are explanations for the NEB's characteristically low forecasts on reserve additions and ultimate potential in the face of the above-mentioned uncertainty and a bias (no doubt a conscious bias) to be conservative.

The estimates of reserve additions and ultimate potential are related, because the sum of all future reserve additions, plus all past production is equal to ultimate potential. The NEB defines reserves additions as:

> "Incremental changes to established reserves resulting from the discovery of new pools and reserves appreciation."

and reserves appreciation as

> "Incremental change in established reserves

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[25] NEB (1986), p. 137.

[26] NEB (1981), p. 159.

resulting from extensions to existing pools and/or revisions to previous reserves estimates."[27]

When new pools are identified, initial estimates of the contents are made at a certain degree of probability, perhaps 95% confidence. As further drilling is done, over a period of years, the contents of the pool are usually revised upwards to reflect higher estimated contents at that same level of confidence. The difference between the initial estimate of gas, and the final revised estimates of gas are termed reserves appreciation. The underlying resource has not changed but our (knowledge of the) volume of gas in the reserve at a certain level of confidence has improved and usually, though not always, more gas is found in a given field than was first estimated.

Other things equal, the higher the estimate of ultimate potential in a given area, the less drilling it takes to find gas, and the higher the pattern of reserve additions that would be expected over a given forecast period. The issue of resource prevalence aside, the more advanced the technology (seismic, drilling, etc.) the more efficient the finding and extraction process, the lower will be the cost of finding reserves. Thus, for any given market and input cost condition the more efficient the technology, the lower will be the cost of reserves additions, the more reserves there are that are likely to be found and produced in a given forecast period.

Given technology and resource prevalence, the higher the netback price or wellhead price for gas, the higher the rate of reserves additions. This captures the effects of market prices, transportation costs, taxes, royalties, subsidy programs, etc. Also, the higher the cost of supply due to the market being overheated, etc., the lower the rate of reserves additions. The effect of excess demand for the

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[27] NEB (1986), p. 135.

firms' inputs is to reduce the profitability of operations at high levels of outputs, and will cause at least some firms to reduce their drilling programs.

On reserves additions forecasts, the Board states the following:

> "The Board recognizes that the subjective nature of forecasts of reserves additions has led to divergent views due to each submittor's perception of such variables as economic factors, drilling activity, ultimate potential and market conditions."[28]

The divergences of these estimates are presented on the following two charts for reserves additions forecasts and ultimate potential forecasts by submittors and by the National Energy Board.

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[28] NEB (1982), p. 13.

MARKETABLE NATURAL GAS RESERVES ADDITIONS FORECASTS

CONVENTIONAL AREAS

COMPARISON OF ESTIMATES

1982-2000

(Exajoules)

	B.C.	Alta.	Sask.	Southern Territories	Eastern Canada	Canada Total
Amoco						
Base	5.4	41.2	1.4(1)	-	-	48.0
Expanded	8.4	69.3	1.4(1)	-	-	79.1
A&S	-	-	-	-	-	33.6
Consolidated						
Current	-	-	-	-	-	58.9
Improved	-	-	-	-	-	78.1
CPA	5.4	41.2	0.7	0.7	-	48.0
Dome	10.0	52.0	1.0	-	-	63.0
Esso	6.8	49.8	0.4	0.4	-	57.4
Gulf						
Base	6.6	36.3	0.2	-	0.2	43.3
Low	5.4	31.7	0.2	-	0.2	37.5
IPAC	-	-	-	-	-	42.6
NOVA						
Base	8.2	45.6	-	-	-	53.8
Incentive	8.2	56.4	-	-	-	64.6
Norcen	-	-	-	-	-	50.7
Pan-Alberta	-	-	-	-	-	33.6
Petro-Canada	8.6	51.4	1.2(1)	-	-	61.2
Shell	9.3	26.8	-	-	-	36.1(3)
NEB	6.2	37.9	0.4	(2)	-	44.5

Gross heating values applicable to NEB estimate:

B.C.	38.8 MJ/m^3
Alberta	38.8 MJ/m^3
Saskatchewan	36.8 MJ/m^3
S. Territories	36.8 MJ/m^3

(1) For all areas other than Alberta and British Columbia.
(2) Southern Territories included in British Columbia total.
(3) New discoveries only. Appreciation of current established reserves base not included.

ULTIMATE POTENTIAL ESTIMATES OF MARKETABLE NATURAL GAS

CONVENTIONAL AREAS

COMPARISON OF ESTIMATES

(Exajoules)

	B.C.	Alta.	Sask.	Southern Territories	Eastern Canada	Canada Total
Consolidated						
Current	34	147	7(1)	-	-	188
Improved	41	217	7(1)	-	-	265
CPA	41	165	4	2	1	213
Dome	36	174	7	4	1	222
Esso	29	168	3	2	1	203
Gulf	27	171	3	5	2	208
IPAC	-	-	-	-	-	190+
Petro-Canada	49	170	3	2	1	225
Shell	40	157	3	-	1	200
NEB 1981						
Base	21	145	3	-(2)	1	170
Low	19	135	3	-(2)	1	158
High	26	165	3	-(2)	1	195
NEB 1982						
Base	25	154	3	-(2)	1	183

Gross heating values applicable to NEB estimate:

B.C.	38.8 MJ/m^3
Alberta	38.8 MJ/m^3
Saskatchewan	36.8 MJ/m^3
S. Territories	36.8 MJ/m^3

(1) Southern Territories and Eastern Canada included in Saskatchewan.

(2) Southern Territories included in British Columbia total.

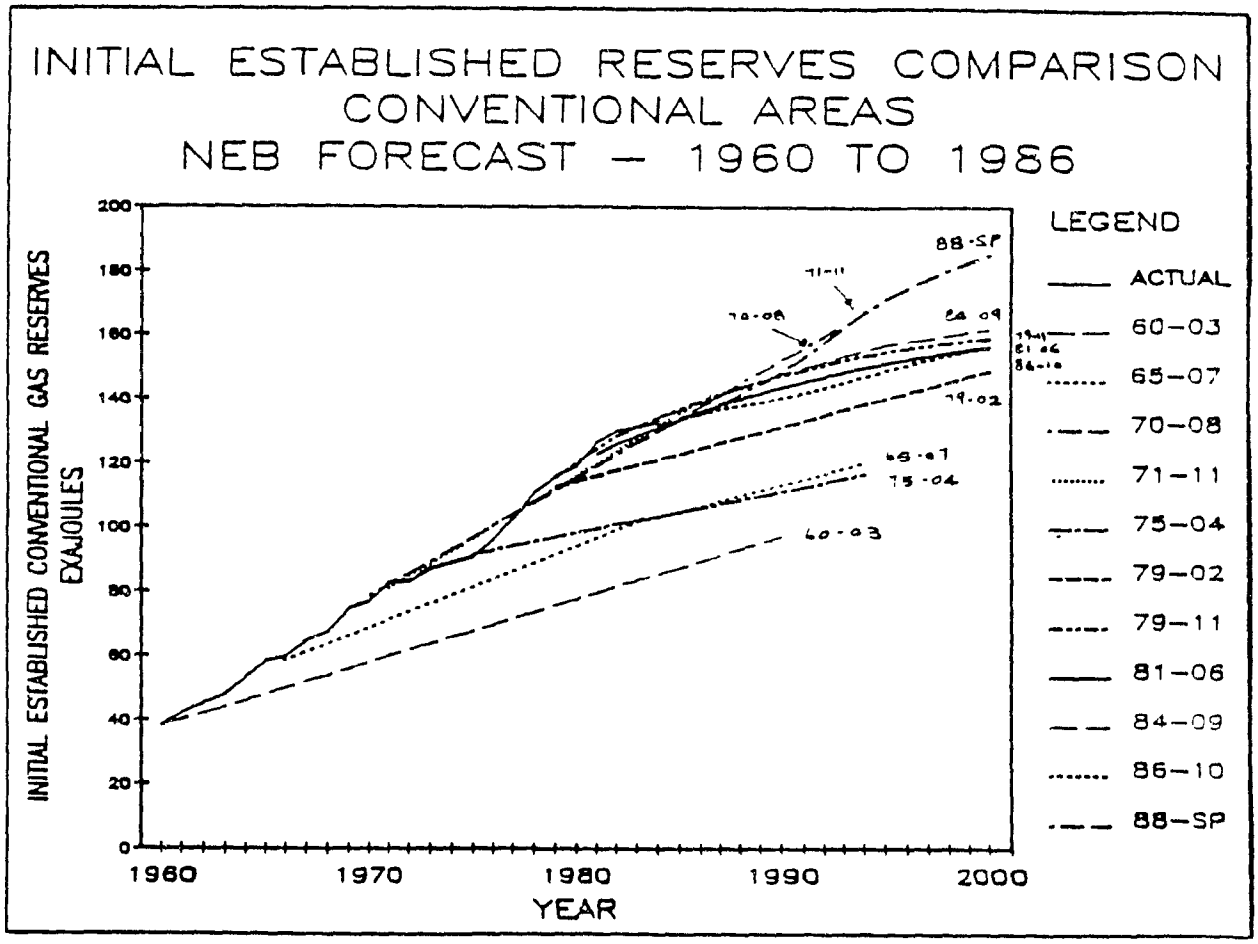
The reserve additions forecast used by the NEB in 1982 was the following:

NEB FORECAST OF MARKETABLE
NATURAL GAS RESERVES ADDITIONS
CONVENTIONAL AREAS
1982-2000
(Exajoules)

Year	British Columbia	Alberta	Saskatchewan	Canada Total
1982	0.33	3.07	0.02	3.42
1983	0.34	2.86	0.02	3.22
1984	0.37	2.94	0.02	3.33
1985	0.47	3.21	0.02	3.70
1986	0.44	2.95	0.02	3.41
1987	0.42	2.70	0.02	3.14
1988	0.40	2.47	0.02	2.89
1989	0.38	2.26	0.02	2.66
1990	0.36	2.07	0.02	2.45
1991	0.34	1.90	0.02	2.26
1992	0.32	1.74	0.02	2.08
1993	0.30	1.59	0.02	1.91
1994	0.29	1.45	0.02	1.76
1995	0.27	1.35	0.02	1.64
1996	0.26	1.25	0.02	1.53
1997	0.24	1.15	0.02	1.41
1998	0.23	1.07	0.02	1.32
1999	0.22	0.98	0.02	1.22
2000	0.21	0.90	0.02	1.13
TOTAL	6.19	37.91	0.38	44.48

"Conservative" NEB Estimates

Historically, except for 1970 and 1971 when estimates were high due to the reserve additions pattern of the 1960s, the National Energy Board has evinced a consistent pattern of supply underestimation. This is shown in the following chart. The heavy black line indicates the actual pattern of initial reserves which result from reserves additions. A similar pattern of sequential underestimates can be shown for ultimate potential as well.



The NEB appears to have been fairly conservative in its estimate of both supply and requirements over the years. Demand seems to be sequentially overestimated, and supply, consistently underestimated. These biases are clearly demonstrated in the two pictures which show the histories of the NEB supply and demand forecasts.[29]

Some of the elements of this type of analysis are discussed in Wildavsky and Tennenbaum (1981), The Politics of Mistrust, Estimating American Oil and Gas Reserves. While the regulatory context in the U.S. was quite different from the situation in Canada, the problem of utilizing technical information supplied by players in a game to structure the rules and outcomes of the game is similar in both countries.

Connection and Production Rates

The connection rate used in the simulation is one used by the Board in its 1979 and 1982 Reasons for Decisions. In percent per year terms this is a sequence equal to 10, 15, 20, 25, 15, 5, 2, 2, 1, 1, 1, 1, 1 over a thirteen year period. The production rate assumed is that also used by the Board and described as the following:

> "The profile is based on an initial rate of 1:7000 and a flat life of eight years with production declining thereafter at 8.22 percent per year."[30]

Thus, the model will contain considerably more realism than those models which assume that for a given expenditure natural gas can be found and sold in the same period. One notable exception is Rowse (1987) who uses a distributed lag

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[29] See the pictures on pages 383 and 344 for the supply and demand estimates.

[30] National Energy Board (January 1983) Reasons for Decisions in the Matter of Phase II - The License Phase and Phase III the Surplus Phase of the Gas Export Omnibus Hearing, 1982.

approach to determine availability of supply in his analyses.

Natural Gas Supply Capability

When the reserves additions outlined are connected as described above, and subsequently produced in accordance with the production rates listed above (with the entire connection and production sequence applied on a year by year basis to each reserve addition), then a maximum productibility curve is generated. This is the maximum rate at which all existing and future reserves can be produced, as if there was unlimited demand. This is referred to as "Total Canada Supply Capability" on the following table.

NEB FORECAST OF NATURAL GAS DELIVERABILITY FROM CONVENTIONAL AREAS

(Petajoules/Year)

	DELIVERABILITY FROM ESTABLISHED RESERVES						SUPPLY FROM RESERVES ADDITIONS				
Year	Total Controlled	S.E. Alberta Uncommitted	Other Alberta Uncommitted	Alberta BER	Alberta Deferred	Total	Alberta	British Columbia	Saskatchewan	Total	TOTAL CANADA SUPPLY CAPABILITY
1981*	61 618	3 190	10 410	1 522	3 978	80 718	37 910	6190	380	44480	
1982	4 580	49	82	2	3	4 716	16	2	0	18	4 734
1983	4 774	98	163	3	3	5 040	55	6	1	62	5 102
1984	4 799	146	245	5	4	5 198	125	14	2	140	5 338
1985	4 551	193	326	6	6	5 082	234	27	3	265	5 347
1986	4 312	238	407	8	6	4 971	367	44	5	416	5 387
1987	4 082	264	462	10	6	4 823	506	63	7	576	5 399
1988	3 722	268	489	11	12	4 502	647	83	8	738	5 240
1989	3 288	253	505	13	27	4 085	784	104	10	897	4 983
1990	2 971	238	515	14	42	3 781	911	124	11	1 046	4 827
1991	2 617	218	513	16	39	3 402	1 027	143	13	1 182	4 584
1992	2 284	192	500	17	35	3 027	1 129	160	14	1 303	4 331
1993	1 981	168	482	18	32	2 680	1 216	176	15	1 407	4 088
1994	1 726	145	453	19	28	2 371	1 287	190	16	1 493	3 864
1995	1 523	125	423	20	46	2 136	1 343	202	16	1 562	3 698
1996	1 336	106	392	21	45	1 900	1 383	212	17	1 612	3 512
1997	1 152	89	363	22	100	1 727	1 409	220	18	1 646	3 373
1998	1 006	75	335	22	97	1 535	1 422	227	18	1 667	3 202
1999	876	62	309	23	95	1 364	1 425	231	18	1 675	3 039
2000	764	50	284	24	112	1 233	1 419	234	19	1 672	2 905
Total	52 346	2 976	7 245	271	738	63 576	16 705	2 464	208	19 377	82 953

Note: Figures may not add due to rounding.

*Remaining Reserves at year end.

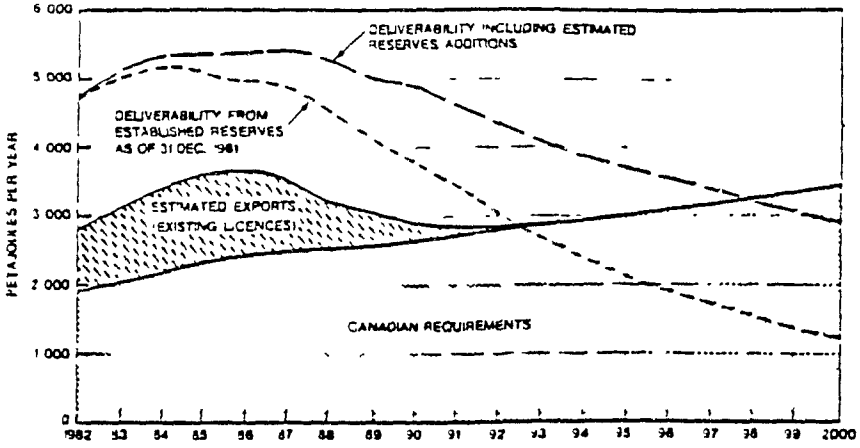
The difference between productibility and deliverability is that deliverability takes into account pipeline

constraints to bring the gas to markets, accounting for connections, and mainline transmissions.

The final element needed to present a first look at the idea of surplus is domestic demand. In the 1982 hearing as in most other omnibus hearings, there was considerable divergence of opinion on demand for natural gas. A comparison of projections was presented by the NEB (1982), and was reproduced on the chart on page 343.

For the purposes of the simulation analysis in this thesis, the NEB base case forecast is adopted. In the simulation, it is assumed that the NEB forecast demand is the demand which actually arises in each year at the accrued prices. The NEB, as previously discussed, tends to err on the high side for demand, and that does create an opportunity for learning and game playing, but this is tangential to the subject of this chapter.

The following graph puts the elements of supply and demand together for a surplus determination exercise by the NEB at one point in time, 1982.



Source: NEB (1982), p. 29.

NEB - Decision Segment, General Notes

Introduction

The NEB and AERCB have used several tests or sets of rules for deciding when natural gas is surplus to Canadian and Albertan needs respectively. The two sets of rules are combined for the purposes of the simulation model, as the AERCB rules can easily be contained in the same decision framework as the NEB rules. The tests and rules will be referred to as NEB rules and tests but it is presumed that the rules and tests also cover the requirements of the AERCB.

This segment of the model is probably the most complicated. It begins with a discussion of labelling conventions for the geographical analysis, then follows a discussion of types of surplus measures, and a general review of various specific types of tests and rules.

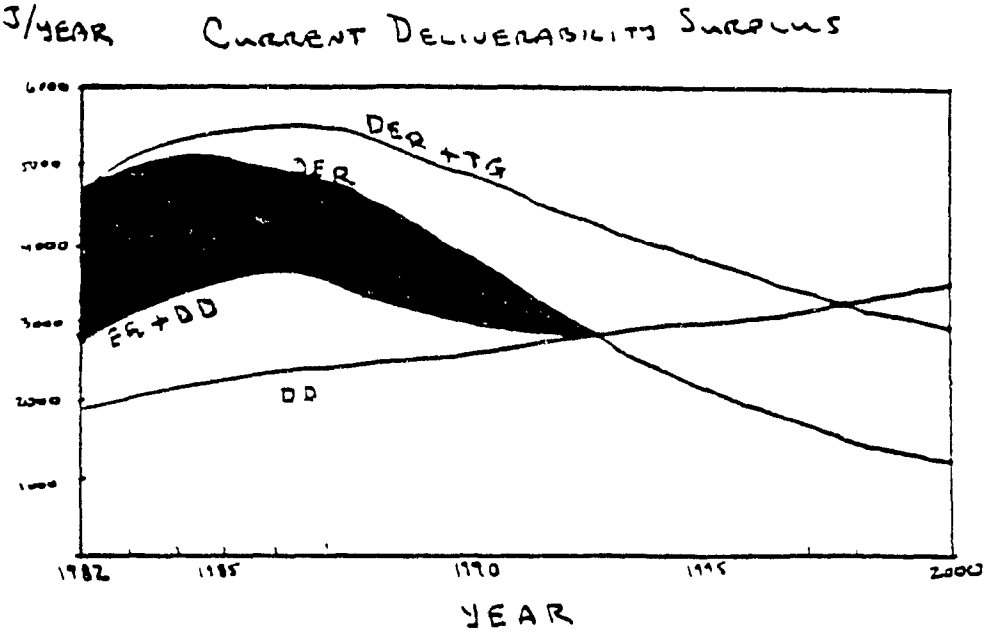
Labelling conventions

In the following graphs in this chapter and the next chapter, I shall adhere to the following labelling conventions:

Canadian Requirements	DD	(domestic demand)
Estimated Exports	EE	
Authorized Exports	AE	
Maximum Producibility	MP	
Deliverability from Established Reserves	DER	
Deliverability for Estimates Reserves Additions	TG	(trend gas)
Proposed Exports	PE	
Volumes	PJ	(petajoules)

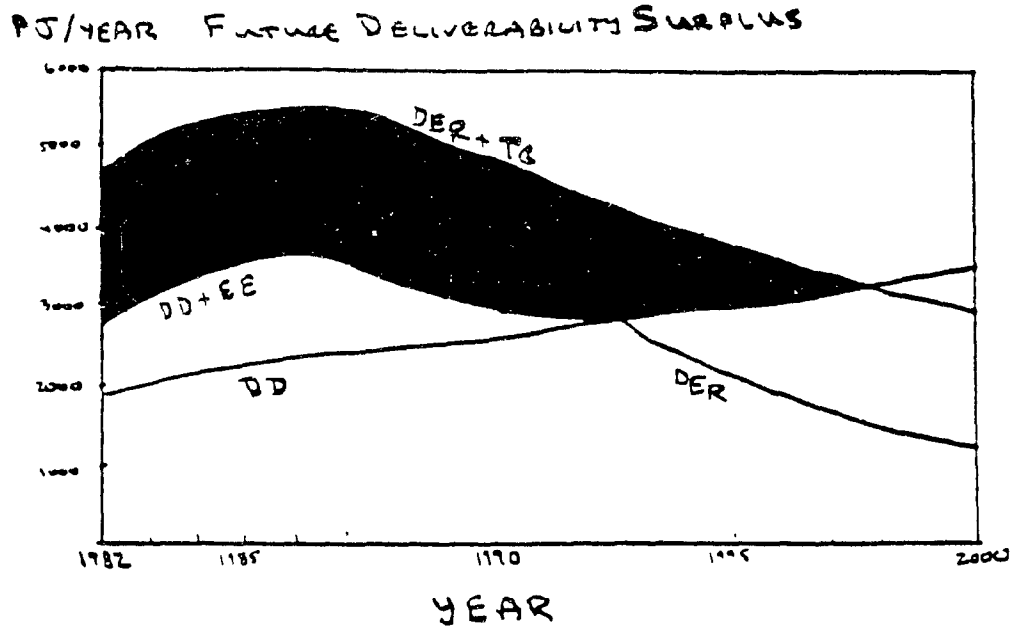
Types of Surplus Measures

Two types of surpluses can be seen directly from the preceeding type of graph, and they are illustrated below. A current deliverability surplus is the difference between deliverability from established reserves (DER) and Canadian requirements (DD) plus estimated export (EE), and is the shaded area in the following graph.



It can be seen that a surplus exists for every year until the "crossover year" 1992.

The second type of surplus, is a future deliverability surplus, based on the difference between the deliverability from established reserves plus trend gas curve (DER + TG) and the Canadian requirements plus established exports curve (DD + EE). This area is shaded in the graph below, and the "crossover" year on this basis is 1997.



The third type of surplus is based on established reserves and is generally not read from the above type of graph. One compares a measure of currently established

reserves with estimated exports plus some multiple of current domestic demand to determine the current reserves surplus. For example, if we wish to have the assurance that current domestic demand at say 2000 PJ can be supplied for twenty years and (40,000 PJs) that all estimated exports (say 10,000 PJs) can be supplied and if currently established reserves are 80,000 PJ, then we can see that there is a current reserves surplus of 30,000 PJ (80,000 PJ - (40,000 PJ + 10,000 PJ).

Non-qualitative Issues

The National Energy Board has taken into consideration more qualitative elements in addition to the pure demand and supply estimator, presented in the previous sections, in coming to export decisions. Our focus here, however, is purely on those more quantitative elements. Judgments regarding the value of developing infrastructure in one part of the country or another, establishing territorial sovereignty, maintaining traditional markets for exports, determining the quality of new markets, and a large number of other more qualitative issues are not pursued here.

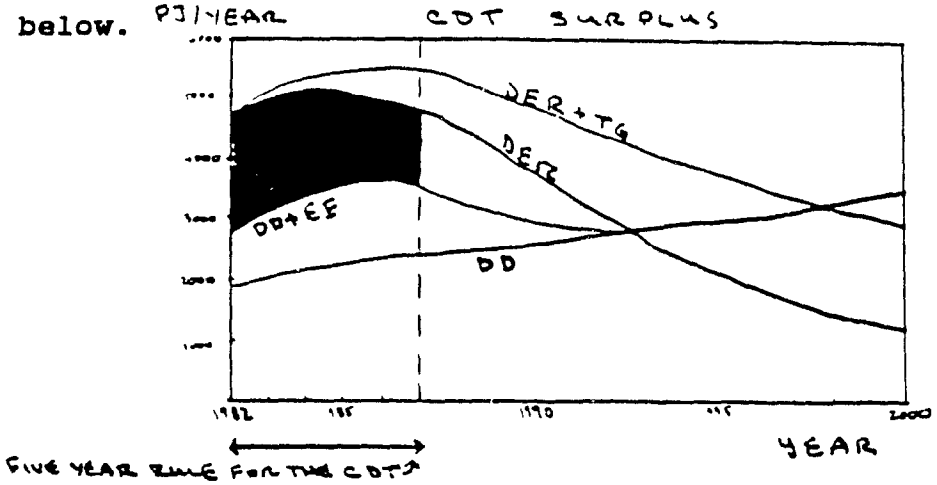
The Tests

The Board has used a variety of tests, based on the previously discussed surplus estimation procedures, since 1959. Appendix Two contains the National Energy Board description of this history, titled "Evaluation of the Board's Natural Gas Surplus Determination Procedures". These procedures have changed over time, but three quantitative "tests" have been of historical importance in these surplus determination procedures. They are a current deliverability test, a future deliverability test, and a current reserves test. Each of these tests is based on the use of a rule.

Current Deliverability Test

The current deliverability test may be based on a "five

year" rule which says that the maximum amount of gas which can be exported is that surplus which exists between the DER line and the DD + EE line between a specified time of an export award and a point of time five years later. Such an exportable surplus is shown on a shaded area in the graph below.

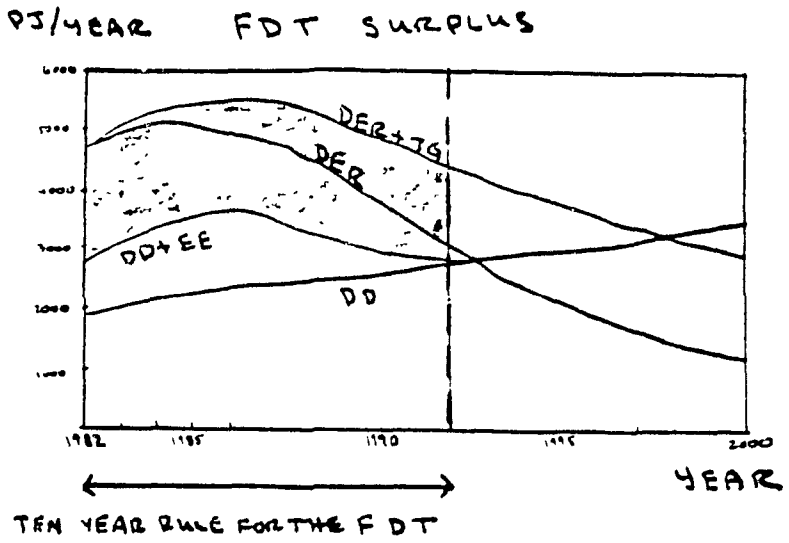


A five year rule for a current deliverability test was used from 1979 until 1986.

Future Deliverability Test

A future deliverability test was used also from 1979 to 1986, and followed in conjunction with a ten year rule. The surplus, under this rule is illustrated on the following

graph.[31]

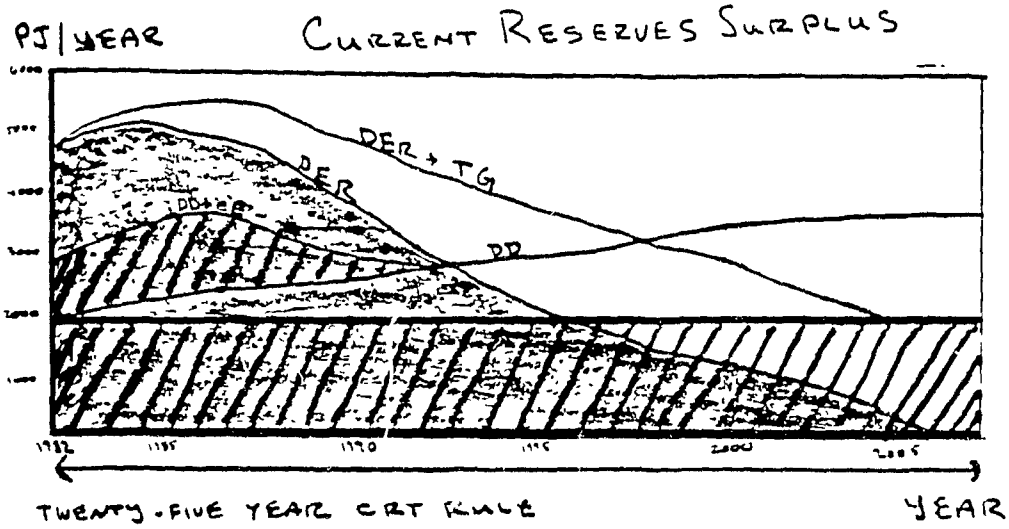


Current Reserves Test

A current reserves test could be represented pictorally as follows. The DER curve would have to be extended to where it crosses the X axis, where deliverability from established reserves drops to zero. One would compare the area under that curve to the area associated with some multiple of domestic requirements in a given year, plus estimated or authorized

[31] Since exports must satisfy the entire procedure, all tests, the largest export that would be allowed, would be the amount which annually would pass all tests.

exports.[32]



For example,, in 1982, the Board used a "25A1" rule for the current resreves test. This means that twenty-five times the current years demand plus estimated exports must be less than established reserves for a surplus to exist under the current deliverability test. On the above graph one would compare the striped area of domestic demand protection plus expected exports to the shaded area of supply from established reserves, under the DER line. A visual comparison suggests that these probability is a surplus under this test as well as under the other two tests.

Other rules have been used for the current reserves test, for example a "25A4" rule was used in 1966. This means that the domestic requirements that must be set aside and not exported are equal to twenty-five times the expected annual demand four years from the time of the test (A4).

The Overall Procedure

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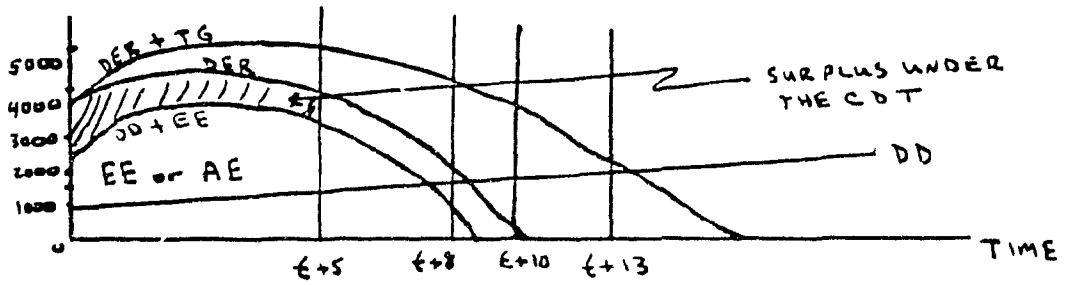
[32] In earlier years, the NEB focused on authorized exports, but in 1982 and thereafter, they focused on estimated exports, an estimate of the amount of authorized exports, which would actually be taken, i.e., on the amount of the authorized exports that the Board thought would actually be exported.

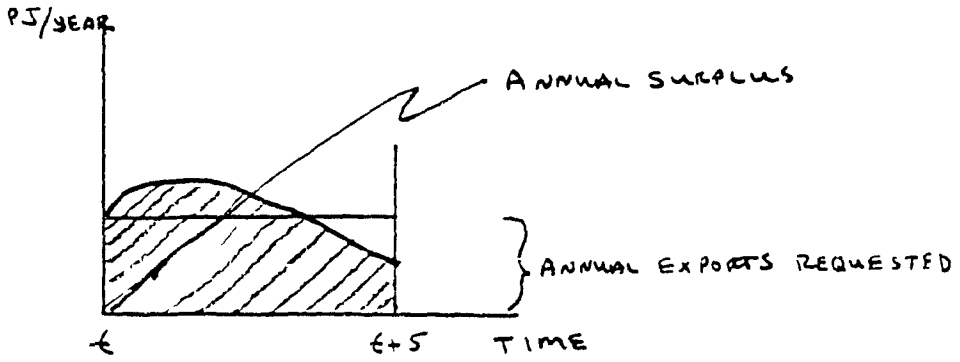
Thus, the overall surplus determination procedure may contain several tests, and each of these tests can be based on different rules. The NEB decision segment of the simulation study is structured so that any test combination with any rules can be studied, or all tests can be deleted, which would characterize a more market oriented exports procedure. The base case analysis in this thesis is based on the use of a current deliverability test (CDT) with a five year rule, a future deliverability test (FDT) with a ten year rule, and a current reserves test (CRT) with a 25A1 rule.

Allocations, Crossovers, and Deliverability "Tracking"

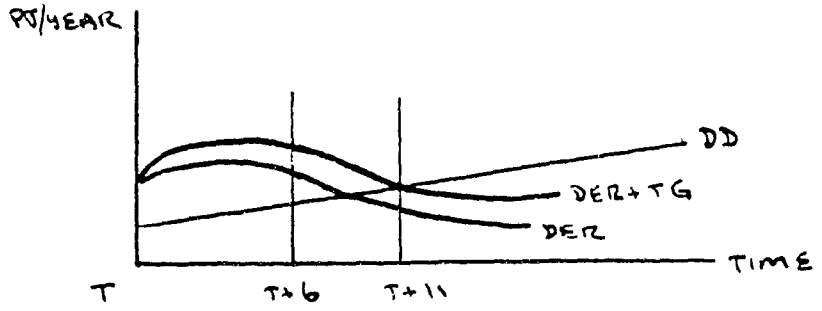
The following series of graphs illustrate the concepts of allocation, crossover, and deliverability tracking. Below, we see a graph which we assume identifies a quantity of gas which we assume is surplus under the current reserves test, and may be surplus under the two deliverability tests.



Now, the exports sought may not agree with the annual volumes available above. This is to say that they may want equal annual volumes. The surplus profile above and an equal annual five year volume are contrasted below.



Because of well producibility characteristics and connection requirements and other problems, it may not be possible for supply to "track" or supply the requirements requested, even though the total exportable surplus equals or exceeds the exports requested. In such a case smaller and smaller export allocations may be tried until an export volume and export profile is found that will "fit under" the deliverability capability of the gas reserves available. In short, a surplus, of say 10 TCF, cannot be delivered in just any annual pattern. It is possible that one pattern of allocation of 10 TCF can pass the CDT and FDT, and another requested pattern of exportation, the same volume could fail one or both tests.



In the above diagram, the effect of an equal annual allocation to exports is illustrated. Deliverability from established reserves (DER) can track the total requirements for five years as the CDT test requires but the new DER

"crossover" is moved up in time from T+8 to T+6. The new DER + TG now has a crossover at T+11, so the FDT is also passed. Had the new DER + TG crossover occurred at say E+9, a new (different in profile or size) allocation would have to be tried until the test is passed.

NEB Decision Segment, More Detailed Notes

Three tests, CDT, FDT, CRT, and deliverability appraisals

The details of the current deliverability test (CDT) and the future deliverability test (FDT) associated with the preceeding pictures are presented in the table below. The current deliverability test is based on deliverability from established reserves only for a period of five years. The future deliverability test is based on deliverability from established reserves (DER) plus deliverability from reserve additions, sometimes called trend gas (TG), and this is for a period of ten years. These periods identify the earliest that a "crossover" between supply and demand could occur if a new export were granted. Thus the area between the total demand plus authorized exports curve, and the DER curve identifies the largest possible volume of exports.

To this point we have been assuming that the DER and DER + TG curves are drawn to be at the maximum practical output, as if demand was unlimited (or limited only by maximum supply). As has been shown, these deliverability curves can be redrawn, however, so that supply can be made to "track" demand. Only those volumes of gas are produced that are required to meet the forecast demand. Surplus deliverability is, as it were, thrown back in the pot to enhance future deliverability. In this way, a number of hypothetical allocation of exports could be made, and a simulation run on the new domestic plus export demand to ensure that this total demand could in fact be satisfied (tracked) by deliverability from established reserves (CDT) and from established plus

"trend" reserves (FDT). It is quite possible that the CDT could be passed and the FDT failed. The deliverability results for 1982 are on the table below:

DELIVERABILITY APPRAISAL
(Petajoules)

	Deliverability			Requirements							
	From Establ. Reserves as of 31 Dec 1981	From Estimated Reserves Additions	Total	Canadian Net Sales	Reprocessing Fuel and Shrinkage	Pipeline Fuel (for Domestic and Export Shipments)	Maritimes Sales and Fuel	Sub Total[1]	Estimated Exports[2]	Total	Gross Deliverability Available for New Exports
1982	4 716	18	4 734	1 598	202	117	-	1 917	887	2 804	1 930
1983	5 040	62	5 102	1 651	209	127	-	1 987	1 142	3 129	1 973
1984	5 198	140	5 338	1 766	273	136	-	2 175	1 267	3 442	1 896
1985	5 082	265	5 347	1 887	281	143	2	2 309	1 290	3 599	1 748
1986	4 971	416	5 387	1 960	287	146	2	2 391	1 226	3 617	1 770
1987	4 823	576	5 399	2 049	279	146	3	2 471	1 035	3 506	1 893
1988	4 502	738	5 240	2 122	250	143	11	2 504	692	3 196	2 044
1989	4 085	897	4 983	2 202	229	113	23	2 551	538	3 089	1 894
1990	3 781	1 046	4 827	2 305	226	116	34	2 633	217	2 850	1 977
1991	3 402	1 182	4 584	2 383	220	136	39	2 700	121	2 821	1 763
1992	3 027	1 303	4 331	2 479	222	139	46	2 794	55	2 849	1 482
1993	2 680	1 407	4 088	2 561	224	134	52	2 877	47	2 924	1 164
1994	2 371	1 493	3 864	2 645	227	148	58	2 962	7	2 969	895
1995	2 136	1 562	3 698	2 732	231	153	65	3 051	6	3 057	641
1996	1 900	1 612	3 512	2 794	229	156	70	3 109	-	3 109	403
1997	1 727	1 646	3 373	2 861	233	160	75	3 179	-	3 179	194
1998	1 535	1 667	3 202	2 935	237	164	80	3 256	-	3 256	-
1999	1 364	1 675	3 039	3 014	240	169	86	3 337	-	3 337	-
2000	1 233	1 672	2 905	3 107	245	173	92	3 433	-	3 433	-

(1) For purposes of the Deliverability Appraisal this sub-total includes domestic net sales, fuel used for domestic and export pipeline transportation and reprocessing fuel and shrinkage) Maritimes requirements are excluded.

(2) Under existing licences.

Note: Figures may not add due to rounding.

Reserves appraisal

Finally, the current reserves test (CRT) as applied by the NEB in 1982 is presented below. From remaining established reserves, a portion of deferred reserves are deducted. These are reserves which are used for reservoir pressure maintenance programs for oil or for any similar reason that would make the gas unavailable during the relevant time frame. Also deducted are a portion of "Beyond Economic Reach" reserves which the NEB defines as:

> "Established reserves, which because of size, location, or composition are not considered economically viable at the present time."[33]

Reprocessing shrinkage accounts for the loss of reserves due to the extraction of liquids, by-products and impurities

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[33] NEB (1982), p. 131.

at the gas plant, and this "shrinkage" must also be deducted in order to arrive at a total available reserve or supply figure. From these reserves are deducted a volume of gas equal to twenty-five times estimated Canadian sales for the next year (including pipeline fuel and losses) as well as currently authorized exports. In 1982 the calculations left a current reserve surplus available for exports of 18.4 exajoules. The overall maximum allowable export would then be the smaller of the three maximum exports allowed under each of the three tests. This description essentially concludes the NEB decision sector of the simulation model which contains the three tests. If the protection period for each test is reduced to one year, then a "no NEB" scenario can be produced. Similarly, if the protection period is made very large, a "no exports" scenario can be produced. The model contains parameters for the periods for the current deliverability, future deliverability, and current reserves tests, and these three parameters can be set to any values one might wish to choose.

RESERVES FORMULA

(Exajoules)

	As of 31 Dec. 1981	
Remaining Established Reserves	80.8	
Less Deferred Reserves[1]	1.3	
Less One-half of Reserves Beyond Economic Reach[2]	0.8	
Less Reprocessing Shrinkage[3]	5.6	
Total Supply		73.1
Canadian Sales[4]	42.2	
Authorized Export Sales[5]	12.5	
Total Requirements		54.7
Reserves Surplus		18.4

(1) The total deferred reserves in Alberta are estimated to be 4.3 EJ, with 3.0 EJ expected to be connected within 25 years.
(2) Beyond economic reach reserves are estimated as 1.5 EJ for Alberta and negligible for British Columbia.
(3) Reprocessing shrinkage is calculated based on testimony that capacity would be available to reprocess all volumes leaving Alberta.
(4) Canadian sales include pipeline fuel and losses but do not include fuel used for exports. They are 25 times 1982 demand of 1.6875 EJ.
(5) Export sales reflect the maximum quantities considered exportable under existing licence conditions and include an allowance of 0.5 EJ for fuel used in Canada to export those quantities.

Hearing dates

The NEB decisions occur at a point in time. If any one NEB hearing really had allocated all of the exportable surplus for present and future time, there would presumably be no more export hearings. However, as forecasts are replaced by experience, exportable surpluses may reemerge, new reports are requested and new hearings are called. If deliverability has been greater than demand in the interval, a "bubble" is created. This "bubble" is treated in the model as a reserve which is fully connected and which can be drawn down at the rate of 1:7300, i.e., over a period of almost twenty years. Thus, the model sequentially "rolls forward" in time from hearing decision year to decision year. The model allows one to choose any year and any number of years to be NEB decision years. The initial model runs assumes that NEB hearings are held every three years.

Export allowances

It is not required by law that the National Energy Board authorize the export of 100 percent of the exportable surplus. In 1982, for example, the National Energy Board approved export licenses and license extensions for a total of 12,230 petajoules. This compares with 14,571 petajoules of potential approvals or surplus. At that particular hearing, only about 84% of the surplus was allocated to exports. (Also noted, is that the 12,230 petajoules authorized for export was about 46% of the total applied for quantities, so the extent of the rationing was quite significant.) The simulation program does contain a feature to allow a variable percentage of surplus to be exported at each hearing date to represent this discretionary factor. The unallocated surplus deliverability between hearing dates is assumed to be connected and can be drawn down in the future at 1:7300.

Exploration-Investment Segment

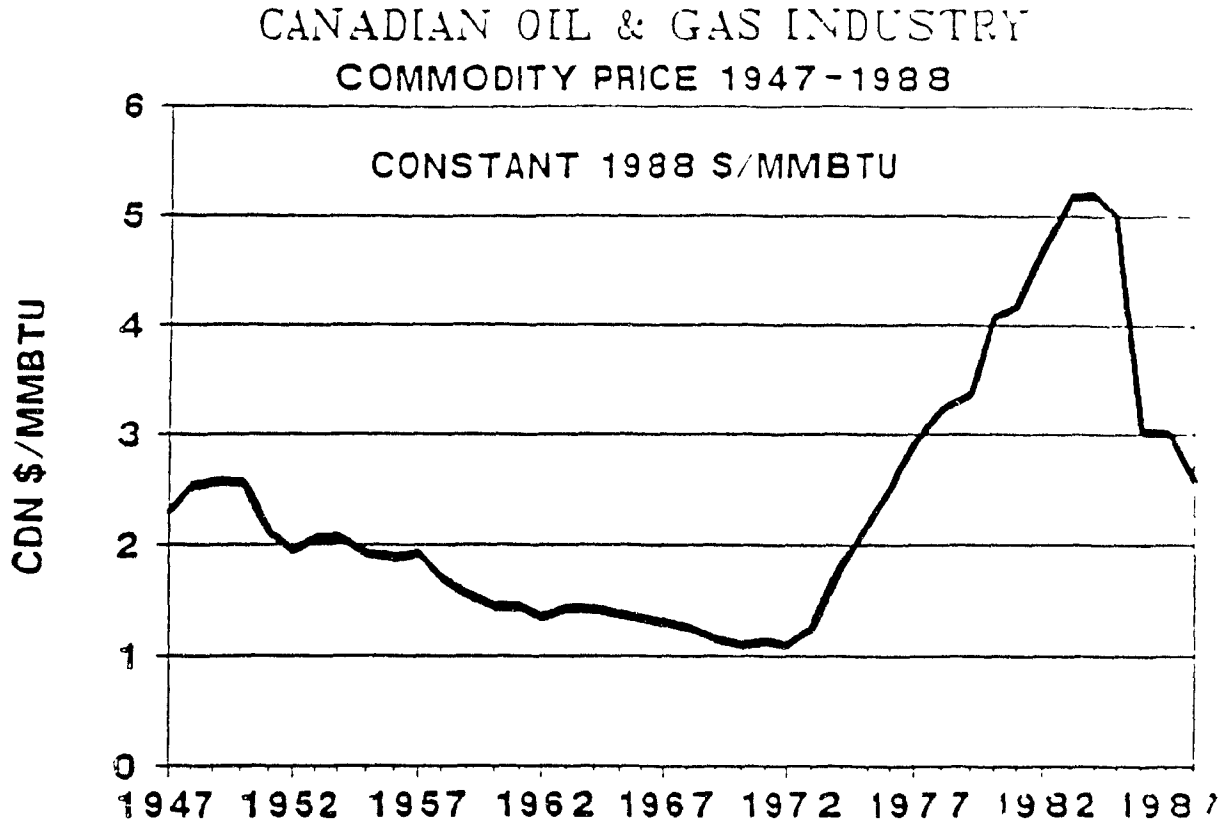
Optimization Criterion

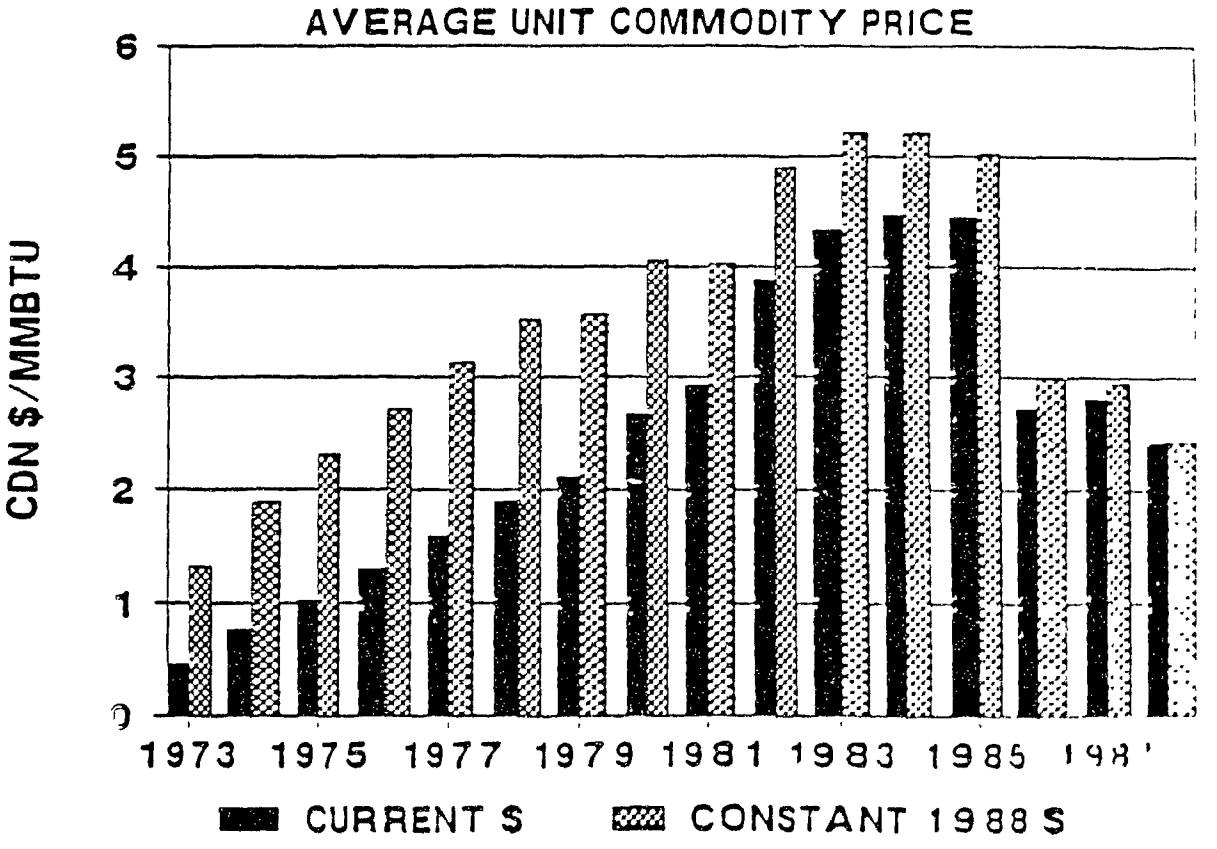
It is assumed that the present value criterion is used by the industry as a whole in the determination of the annual level of investment. From a perusal of articles in the Journal of Petroleum Technology and the Oil and Gas Journal and discussions with industry experts, it appears that this is the criterion most often recommended in evaluating proposals, and most often used by evaluation engineers.

In the following pages, I present some evidence that performance, in increases in reserves, levels of drilling activities, and overall industry activity is related to gas prices, and the returns to producers. It is background information to the discussion of the exploration-investment section of the model.

The influence of price

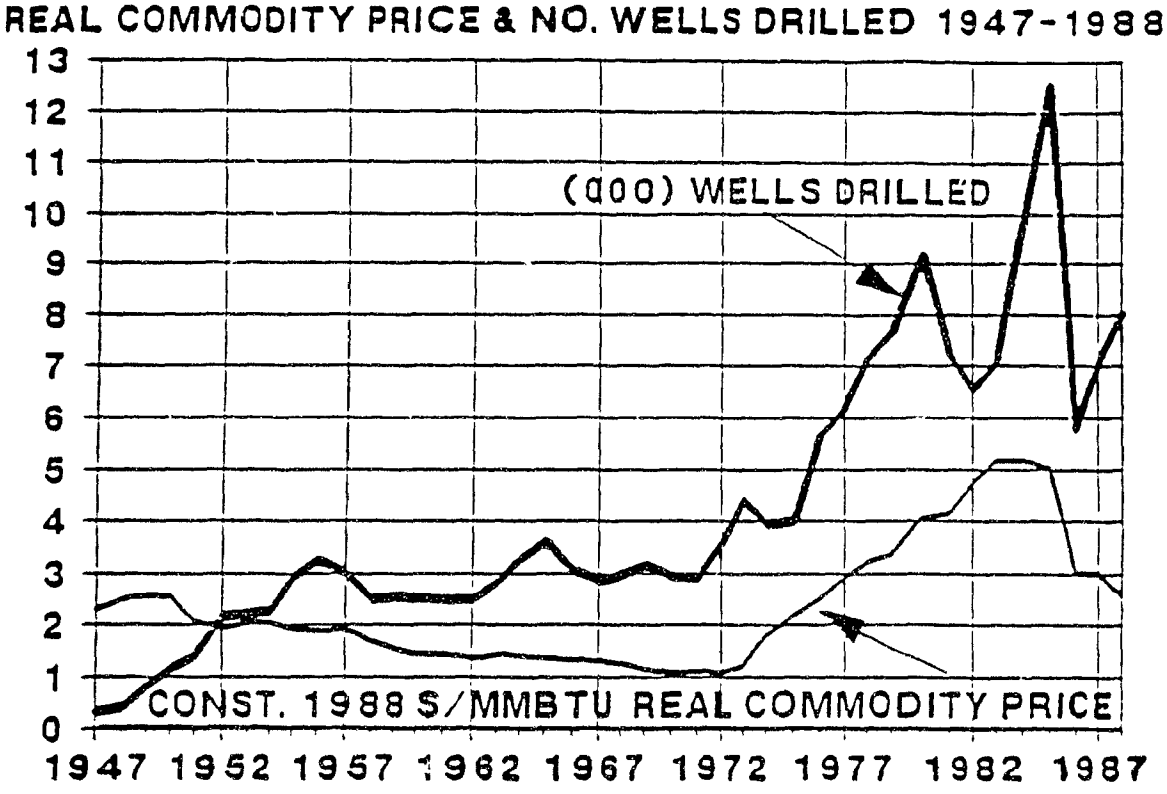
In constant dollars, Canadian oil and gas prices had steadily declined in the twenty-five years from 1947 to 1972. After the OPEC price shocks in 1973, there was a steady upward trend in prices until a peak in 1982, from whence prices have steadily declined. Perhaps it is unfortunate, in hindsight, that the hearings occurred in the year of a turning point, because all of the price forecasts made turned out to be very much in error. The following two charts show the composite price of oil and gas on a BTU equivalent basis.


CANADIAN OIL & GAS INDUSTRY
COMMODITY PRICE 1947-1988
CONSTANT 1988 $/MMBTU
CDN $/MMBTU
6
5
4
3
2
1
0
1947 1952 1957 1962 1967 1972 1977 1982 198


AVERAGE UNIT COMMODITY PRICE
CDN $/MMBTU
6
5
4
3
2
1
0
1973 1975 1977 1979 1981 1983 1985 198
CURRENT $
CONSTANT 1988 $

The price-drilling relationship

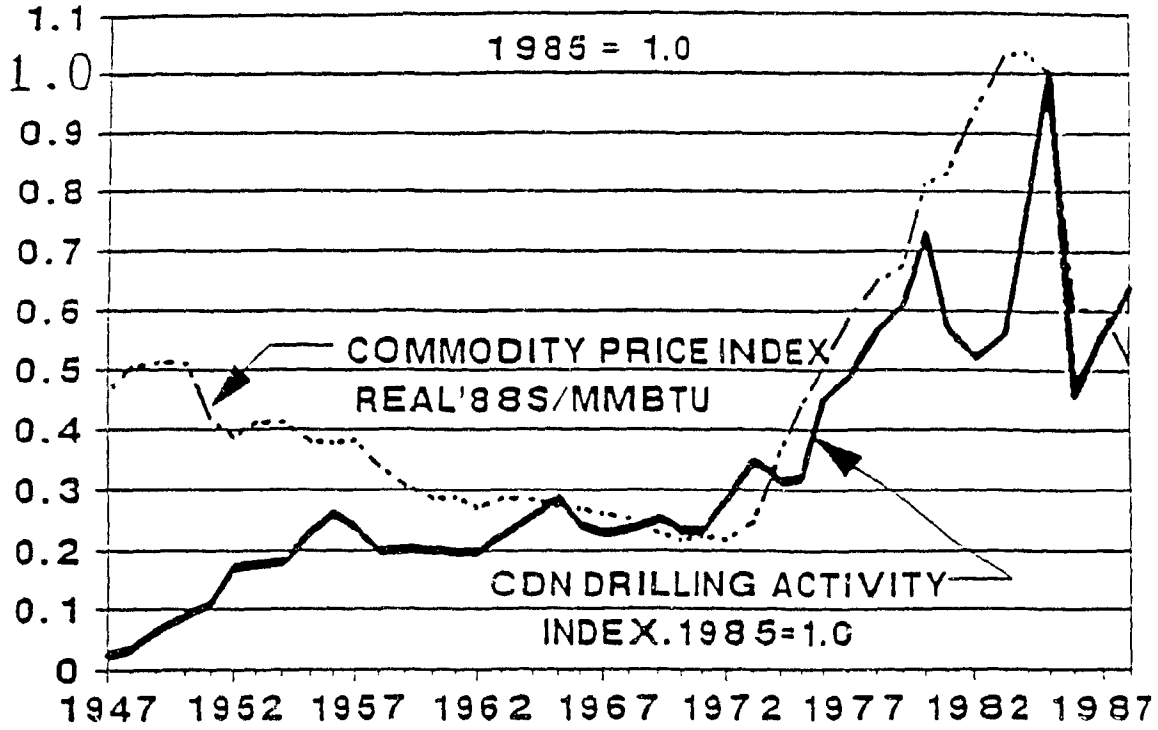
The next graph suggests a relationship between the previous real composite commcdity price and thousands of wells drilled from 1947 to 1987. Prior to 1972, there seems to be a gradual downward trend in price matched by a gradual upward trend in thousands of wells drilled. After 1973 there were increases in wells drilled, matching price increases until 1978, where despite increases in prices, well drilling fell off drastically, until 1982 when there was a resurgence until about 1985 when prices plunged.



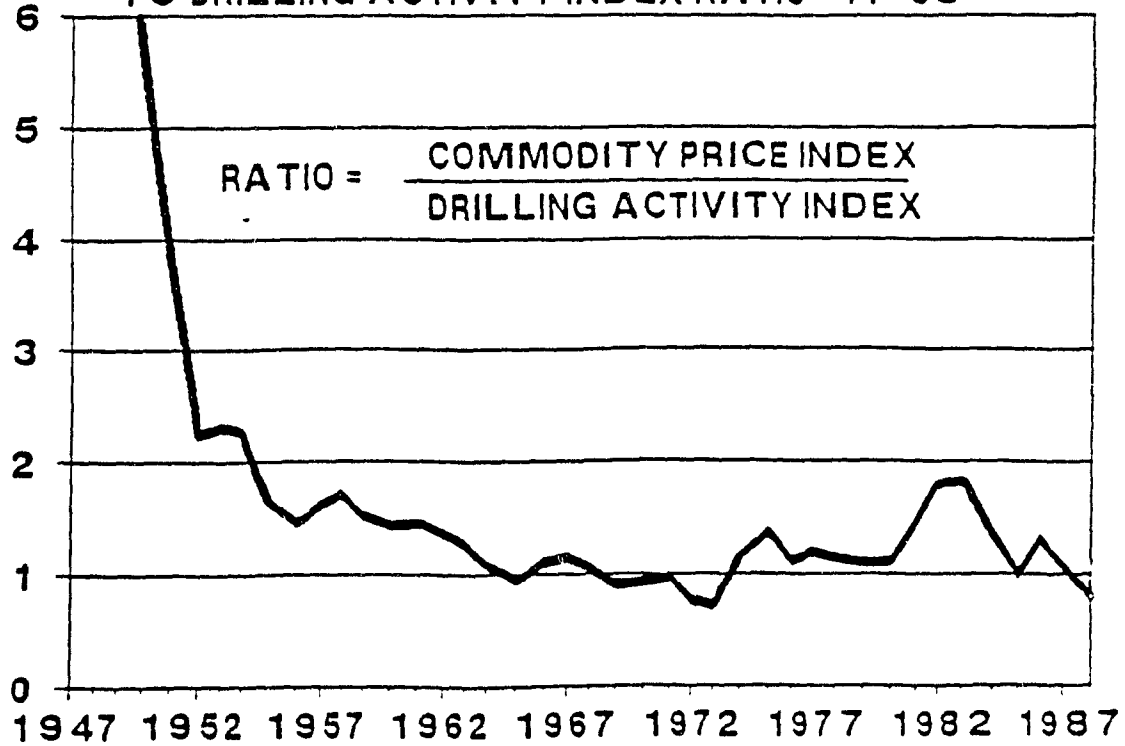
These relationships between the current real composite commodity price and drilling levels is more clearly shown in the following two graphs using indices for the two series. The erratic drilling and price series, appear to have a much closer relationship. Apart from the early years, the ratio of the commodity price index to the drilling activity index indicates somewhat less variation than the price and activity indices, suggesting, not surprisingly, that price really does have an impact on activity and vice versa.

CANADIAN OIL & GAS INDUSTRY

COMMODITY PRICE & DRILLING ACTIVITY INDICIES 1947-1988

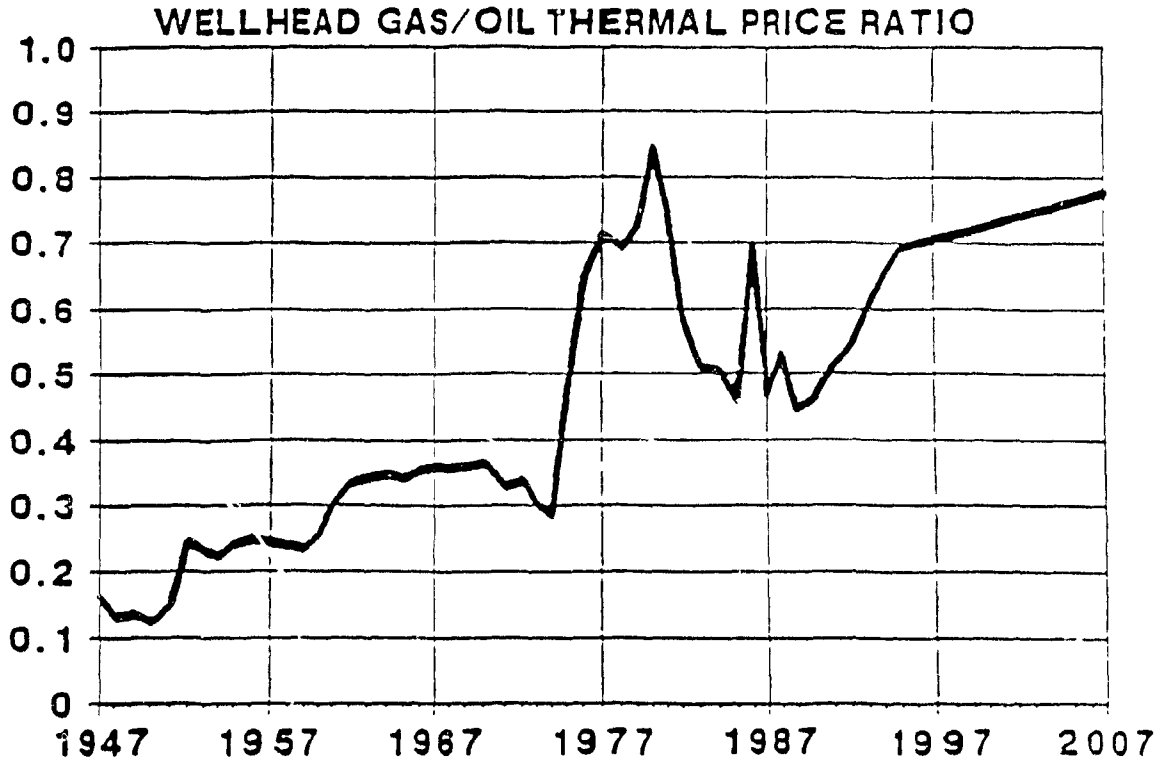


CANADA, OIL & GAS COMMODITY PRICE INDEX TO DRILLING ACTIVITY INDEX RATIO '47-88



Gas-oil thermal price relationship

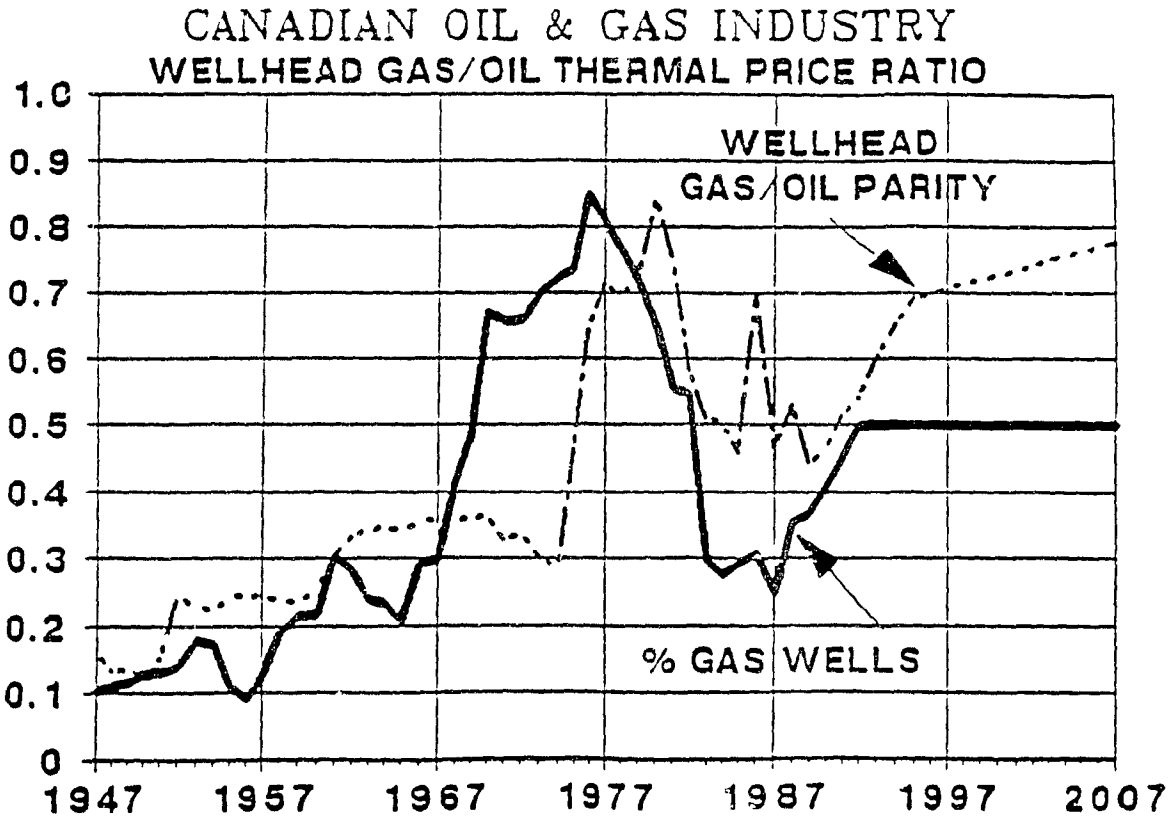
The following chart, provided by Canadian Hunter Exploration, shows the "wellhead gas to oil thermal price ratio" increasing steadily to 1979, then dropping off (with the odd exception of 1986) to about .5 currently. Canadian Hunter forecasts a gradual increase in relative gas prices to 80% on a BTU equivalent basis by 2007. This indicates the lower value placed on gas vis-a-vis oil on a BTV equivalent basis. The graph shows first of all that far from being the "premium" fuel one might expect gas to be (clean, convenient, less pollution), it in fact has generally sold well below the price of oil on a BTU basis. Up to about 1975, there was a modest improvement in the ratio followed by a sharp increase, inspired, no doubt, by the oil shocks of 1973 and 1979. Since 1980, the ratio has declined in a rather erratic way, although as we have seen, Canadian Hunter expects a continuation of an upward drift in the price of gas relative to that of oil.



Drilling and relative prices

The next two charts are also provided by Canadian Hunter - generally acknowledged to be one of the leading gas finders and producers in Western Canada. The first chart below shows the proportion of (successful) gas wells compared to the total of all successful wells drilled for oil or gas. After a fairly steady increase to 1976, it too has dropped off dramatically to 1987, to some extent following the decline in the thermal price ratios of the two commodities - a result that intuitively seems very plausible. With gas in oversupply, and prices low, one would expect gas exploratory intent to drop off, and expect the number of successful gas wells as a percentage of successful oil and gas wells to drop off.

This relationship is shown in the following chart, which illustrates both the percentage of successful gas wells, and the wellhead gas to oil thermal price ratio.



Investment floor and ceiling

The exploration-investment decision is based on an iterative optimization algorithm. A current years' "floor" level of investment is 30% of the previous years optimal investment. The present value of this investment is compared with that of investments increasing in increments of 250 million dollars, to a maximum or ceiling 30% greater than last year's optimal investment.[34] The current optimal investment is that with the maximum present value. The base case discount rate is 20% which is close to the rates currently used in the industry, but it is also a variable in the simulation.

The investment-effort relationship

The exploration evaluation procedure is as follows. An investment means effort, which is measured in thousands of meters drilled, as well as in ancilliary services. Meters drilled in turn yield reserve additions. The additionial reserves may be drawn down according to accepted[35] connection and production schedules which are also variables in the analysis. The proportions of the reserve which may be sold domestically or exported at particular points in the future, are a function of the scenario being run. This is to say that different NEB rules will generate different industry expectations for the timing of exports and domestic sales. The various combinations of export and domestic sales produce revenue streams, and capital and operating costs streams which generate the required present value estimates. Thus, the optimal exploration pattern is produced within the

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[34] The existence of the floor and ceiling constraints are based on empirical abreviations and on a prior consideration which suggests that increased or decreases in investment beyond these levels would be expensive and not very practical.

[35] See NEB (1982).

simulation model. Alternative optimality criterion can be incorporated as well, such as exploration expenditures as a percentage of gross revenue. Thus, the appropriate level of investment can only be evaluated after considering the costs and revenues associated with domestic and export sales.

Transmission costs

The following table shows the estimated costs of transmission from the Alberta border to various export points. From the table one can see that, other things equal, there are clear advantages, to exporting via Kingsgate versus exporting via Niagara.

ESTIMATED COST OF TRANSMISSION(1)
Canadian $/GJ (1981)

	1984	1987	1990	1993
Alberta Border-Kingsgate				
ANG(2)	.07	.07	.07	.07
Foothills(2)	.18	.14	.12	.10
Alberta Border-Monchy				
Foothills(2)	.15	.15	.12	.10
Alberta Border-Emerson, TCPL				
Incremental (3)	.45	.35	.30	.36
Rolled-in (4)	.30	.26	.27	.28
Alberta Border-Niagara Falls, TCPL				
Incremental (3)	2.53	1.97	1.46	1.08
Rolled-in(4)	.92	.81	.84	.87

(1) Cost of transmission has been projected on the assumption that present rate-making procedures will continue.

(2) For ANG and Foothills it was assumed that no new facilities would be required after 1983 and that throughputs would continue at current levels. It was also assumed that Foothills "basket provisions" which provide for accelerated depreciation in the event that Alaska gas does not flow would not be invoked.

(3) Cost of transmission estimated assuming export-related facilities stand alone with 12-year amortization.

(4) Cost of transmission estimated assuming full "roll-in" of export facilities and normal depreciation rates.

Producer netbacks

Other things are not always equal. At the time of the 1982 hearings, Canada and the United States had agreed on a fixed border price that applied to all export points. At the same time the transportation costs within Canada meant that even with a uniform border price, the net backs to the Canadian producers varied with the distance from gas field to the border and with the new or old facilities that would be used.

The following table provided estimates of the expected Alberta border net back from the various export and domestic sales.

ALBERTA BORDER NETBACK FROM EXPORT SALES (Illustrative)
Canadian $/GJ (1981)

Assuming a constant real price for imported oil:

	1984	1987	1990	1993	1999
U.S. Border Price	4.46	4.68	4.90	4.97	4.96
Alberta Border Netback					
-Aden/Cardson	4.46	4.86	4.90	4.97	
-Kingsgate, ANG	4.39	4.61	4.83	4.90	
-Kingsgate, Foothills	4.28	4.54	4.78	4.87	
-Monchy, Foothills	4.31	4.53	4.78	4.87	
-Emerson Inc.(1) TCPL	4.01	4.33	4.60	4.61	
-Emerson Rolled-in(2) TCPL	4.16	4.42	4.63	4.69	
-Niagara Falls Inc. (1) TCPL	1.93	2.71	3.44	3.89	
-Niagara Falls Rolled-in(2) TCPL	3.54	3.87	4.06	4.10	
-Dome(3)	-	2.11	1.96	2.79	4.11
-Dome(4)	-	2.65	2.17	2.59	3.94
-Domestic Sales	2.20	2.56	2.71	2.78	2.72

In the preceeding table, domestic delivery costs, beyond the Alberta border were assumed to be fifty-five cents on average, and export delivery costs were calculated to represent the weighted average distances to export points.

If exports were contemplated that were in excess of existing pipeline capacity then additional capacity would have to be installed. The estimated cost (a levelized charge) for increased capacity is $1.50 per peak petajoule of export capacity.

Finally, I assume a producer cost of fifty cents, with a proportional adjustment factor for production above or below a normal level of output, assumed to be 3000 petajoules. The producer cost includes the cost of developing, lifting, gathering, processing, and connection to mainline transmission facilities.

Summary of Input Data

Some of the basic input and process assumptions are summarized on the following pages.

Assumptions

Initial Remaining Reserves	150 EJ, unlimited supplies at Arctic prices
Forecast Reserve Additions	65 EJ (over 50 years)
Remaining Established Reserves	85 EJ

Domestic Demand Forecast: NEB 1982 to 2007

Year 2007+ is year 2007 demand with a price elasticity of -1.00 applied to the associated price forecast

Domestic Prices	$4.00/GJ (1982$), increasing at 5 per cent per annum (at the Alberta border)
Export Prices	1.25 X Domestic Prices
Domestic Cost for Production & Transportation	$.55 /GJ

Export Cost for Production & Transportation $.40/GJ

Investment - Effort Relationship (in $1982) :

Each 250 million invested results in 1000 meters drilled.

Technological Change Coefficient initially constant at one, which implies a constant $/meter drilled relationship, which can be varied over time.

Effort-Reserves Relationship:

1000 meters drilled yields 850 PJ of reserves and deteriorates with cumulative reserves discovered. (The rate of deterioration is a variable, associated with the size of the ultimate potential).

Initial Cost of Reserves is about 29.4 cents/GJ, a levelized cost of about $1.40/GJ

Connection Rates: NEB 1982 Reasons for Decision

Production Rates: NEB 1982 Reasons for Decision

Export Capital Charge: $1.50/Peak PJ Capacity regardless of export point.

Producer Cost: Maximum Flow Capacity (GJ) x

$$\frac{\text{(Maximum Flow Capacity GJ)}}{3000\ \text{GJ}} \times \$.50/\text{gj}$$

The overall structure of the model was presented in the flowchart labelled diagram one. We begin with some initial ultimate potential estimates, and an associated reserve additions forecast, as well as the current level of known reserves and their producibility and deliverability. Domestic prices are given, which generates expected domestic demand, fuel and losses, reprocessing shrinkage and, finally, primary domestic demand. Export prices are given, along with currently authorized exports. With this current domestic supply, domestic demand, and exports data, the National

Energy Board would be in a position to determine if any natural gas could be deemed "surplus to Canadian needs" and available for further exports.

The preceeding is fairly critical, as it determines from the industry point of view, the percentage of newly discovered and developed gas which can be exported. As exports have generally sold at a premium, and at times a very substantial premium this factor is quite important in determining the present value of the revenue stream associated with a given exploration expenditure. The exploration expenditures will drive the model through time.

Each model run will produce a sequence of industry profits, pipeline capacity, reserves additions, exploration expenditures, exports, depletion rates, and time of terminal exhaustion, among other variables.

Motivation for the Use of a Simulation Approach

The purpose of the simulation model to the thesis must not be lost in its details, assumptions, and number crunching. We set out to examine intergenerational equity and the simulation model must be used to further that goal. The sequence of arguments, and discussions presented in Chapters Two and Three treat the concept of equity, and perhaps offer some insight into the problem of equity in natural resource use. There does not seem be to any hard and fast definition of equity, nor does the discussion of equity lead to the choice of a specific rule to use in approaching equitable use for natural gas. Differences in underlying values, and moral sentiments, tend to make equity a difficult idea to pin down, and even if it is believed that the idea itself is understood, it may well lead to conflicting policy choices on the part of individuals.

Equity may certainly draw on different values and moral sentiments to generate very different attitudes toward behavior, objects, distributions of income, preservation of finite natural resources and the environment, etc. In the

end, the discussion seems to come down on the side of relativism. There may be no single concept of equitable behavior for a pluralistic society. We may be able to identify equity by group, however, this would not solve the problem of finding a single useful national policy criterion based on equity.

What have we done in Canada is to produce a sort of quasi- political solution. A quasi-judicial board was set up, in an attempt to depoliticize the oil and gas problems. A national board would seek best "national solutions", and attempt to overcome regional biases. The NEB was, in fact, sold as a a kind of court of equity. The NEB has in its past hearings faced groups who wanted the border opened, and the gas industry to boom while also facing groups who asked that the borders be closed, and the gas saved for future generations. The NEB has made controversial decisions.

An unpopular NEB decision, however, may reemerge as a political decision, since appeals to Cabinet or the Minister of Energy were contemplated in the Act. However, we note that appeals to Cabinet regarding export licences have never been made. Thus it would appear that the NEB has been fairly successful in settling conflicting claims, unless it can be argued that the opponents are too politically weak to pose a serious political challenge. This may mean simply that the NEB has pursued politically popular or acceptable solutions to the dilemmas that it faced.

One of the key purposes of this chapter was to develop a simulation model which can help to lead to a more informed debate on substantive issues regarding natural gas. How effective are the rules in protecting the interests of present and future Canadians? Do they significantly affect the security of gas supply? Do they have the desired effects on industry activity? Are they in fact influential in affecting intertemporal and intergenerational equity in significant ways?

In the last twenty five years, the National Energy Board

has held lengthy and expensive hearings on exports, rules to define surpluses, and related matters. It has changed its own export rules a number of times. One item which we would wish to examine is what the effect of these different rule changes have had or are likely to have on industry performance and on consumer interests. Thus there are four main comparisons which I would like to make, which are based on simulation model experiments designed to answer the following questions.

(1) How does the performance of the model compare with the historical performance of the industry in general, and how sensitive is it to changes in particular parameters?

(2) How does the model behave if there were no export rules at all?

(3) How does the model behave if the different rules adopted by the NEB, over the last few years, are included in the model?

(4) How does the model behave if the borders are closed to exports and all natural gas is reserved for Canadian use alone?

The results of these runs, along with detailed analyses and criticisms are presented in Chapter Five.

CHAPTER FIVE

NATURAL GAS SIMULATION MODEL RESULTS

INTRODUCTION

Chapter Five presents the results of the simulation experiments outlined in Chapter Four. The experiments may be viewed as being of two classes, experiments on initial model parameters, and experiments on various rules. The rules changes focus on the length of time of protection under the CDT, the FDT, or the CRT; a protection period of zero would indicate that the particular test is not used. Model parameter changes refer to changes in other variables such as domestic prices or the initial size of the ultimate potential estimate for WCSB reserves, within the model. These are later discussed in detail. The first experiments involve the modification of the initial model parameters in the base case which uses the NEB 1982 rules. These are the class one experiments. In the class two experiments, the rules themselves are varied, while keeping the base case initial model parameters constant. These two classes are contrasted below.

EXPERIMENTS

Class One Experiments

- Presentation of the base case using the NEB 1982 rules.
- Comparisons of this model with historical performance for the industry, in different periods.
- Sensitivity of performance measures to changes in initial parameter estimates, with the NEB 1982 rules in force.

Class Two Experiments

- Alternative rules cases - evaluation of the future performance measures based on the long term adoption of

alternatives to the NEB 1982 rules, while keeping the initial model parameters constant.
- Complete removal of all NEB export rules, and evaluation of future performance measures.
- Cessation of all exports,, the closed border scenario, and evaluation of future performance measures.

Thus, the class one experiments focus on sensitivity analyses with respect to model parameters, and the class two experiments focus on sensitivity analyses with respect to the rules.

The performance measures of primary interest are the following: the rate of resource discovery, the time of resource exhaustion, the value of industry profits, the rate of industry investment and the total value of and quantity of exports.

Criticisms and commentary are presented for the results of each class of experiment. As stated in Chapter Four, simulation models abstract from reality, and require compromise in the sense that tradeoffs must be made between the need to capture as many essential features of the real system of interest as possible and the need to reduce the complexity of the real system mindful of time, expense, data and other resource constraints. Essentially, in Chapter Four the focus was on the problem statement and the overall structure of the system and its representation as a model. In Chapter Five, the focus is on the analysis of the model behaviour especially as regards its ability to capture the behaviours of system components, the evaluation of the model for quality and relevant validity, and finally, a consideration of the role the results of the experiments can play in public policy debates. Chapter Six integrates the results of the simulation experiments with the theoretical and conceptual discussions of the previous chapters.

<u>On Model Validation, Base Case Analysis</u>

The base case analysis was done with the following NEB decision rules:

(1) A twenty-five year current reserves test.
(2) A five-year current deliverability test.
(3) A ten-year future deliverability test.

The base case model produced similar results to the NEB 1982 estimates of supply, demand, and surplus variables. In other words the model seemed to replicate the NEB process fairly well. This agreement between the NEB process and the model results is promising. However, since both the NEB assumptions and the model were based on forecasts that turned out to be erroneous, the model results (like the NEB assumptions) cannot be checked against the actual data for later years. The quality or validity of this simulation model cannot be tested on the basis of the accuracy of the models' allocations to exports, or the models' projected exports, because the underlying assumptions were erroneous. If correct assumptions are inserted, then the correspondence to the NEB results are compromised. To some extent, this problem could be approached by the use of learning functions to the time paths of variables of interest, however there are other factors which make this approach alone inadequate as well.

When prices were really high in 1982, the industry was drilling at a very high rate, and as mentioned earlier, with the benefit of hindsight, we can see that the rate of drilling was much in excess of what the then current prospects would justify. The industry was severely "over-heated", and cost consciousness was not much of a concern at the time. Inefficiencies were tolerated, and everybody flew first class. The resulting high costs are reflected in the NEB cost estimates, and in those used in the model. When prices

dropped to current (1987-88) levels, inefficiencies had to be corrected, belts were tightened, and an industry shakeout began. Only the most efficient could survive if prices were to stay low. The problem is that from the point of view of 1982, it would be difficult to forecast how low producer, finding, development, transport, etc. costs could drop as a result of the price-cost squeeze on a per unit basis. A learning function could capture these effects to some extent surely, but the rate of learning, and the possible "true" cost levels would have to be little more than educated guesses.

Thus, validating the initial simulation model on the 1982-88 data is problematic. However, despite the fact that an accurate reproduction of the actual performance of the industry cannot be represented in the model, the model can still be very useful. A critical set of occurrences which could not be foreseen within the model were the post-1982 abandonment of uniform border pricing of export gas sales, and later the complete removal of the current and future deliverability tests as used in 1982. These dramatic institutional shifts were due in large part to political and economic influences and so validation by tracking or reproducing the profile of industry and regulatory performance over time cannot be seen as a reasonable test for the validation of this model. For the purposes of this exercise we merely wish to indicate the likely directional influences the different rules could have on the industry.

As suggested in Chapter Four, there is a positive relationship between real price increases and declines, and exploratory activity levels. The optimization function captures that influence because the present value of exploratory effort is increased when price increases and is reduced for price decreases, ceteris paribus. So also, changes in other variables, the cost of transportation, or the size of the ultimate potential, etc. all have the expected

directional effects on the decision criteria. Thus, the investment function which drives the model seems to react in the correct way to various stimuli. The static analysis reveals that the connection, production, delivery, and decision frameworks all operate as they should, and offer support for the validity of the model. Still, it is clear that this type of component analysis approach to validity, without the opportunity to compare the model directly to a post-initialization data set to gauge performance is rather limited, and constrains the policy value of the model.

For these reasons, the results from the model cannot be claimed to show definitely that a particular change in a policy (e.g., a shortening of the current reserves test) will have a particular absolute effect on the industry or economy. As is shown later in this chapter, the removal of the CRT alone has little effect, when the CDT and FDT are in force. To the extent, however, that the model is internally consistent, and does have a significant level of component validity, its relative assessments of policy changes should be useful.

In the following descriptions of the performance of the model under different rules, the primary variables of interest are annual investment, annual returns to investment, cumulative returns to investment (annual compounding at the discount rate), the annual rate of reserves additions, cumulative reserves discovered and remaining reserves, the year of domestic demand shortfall (if any), and the year of final exhaustion of the stock. In these runs, supply (ultimate potential) is unconstrained at high levels of cost, over the fifty year horizon of the simulation run. At the high levels of cost, there may well be 400-500 EJ of natural gas available. Current estimates by Western Gas Marketing Limited, for example, put the reserves in the Western Canadian Sedimentary Basin (WCSB) alone at over three hundred

exajoules, so with the east coast, arctic, and other possible locations, the remaining reserves of 400 exajoules may be possible. In the following runs, it is assumed that there are about 150 exajoules of remaining reserves in the WCSB. At high levels of cost, reserves are assumed to be available in unlimited supply from the frontier and Arctic regions. The remaining reserves which are the primary focus of our attention, are the WCSB reserves, which with past production of about 50 EJ at 1982, and 150 EJ remaining, suggests an ultimate potential estimate of about 200 EJ.

Class One Experiments

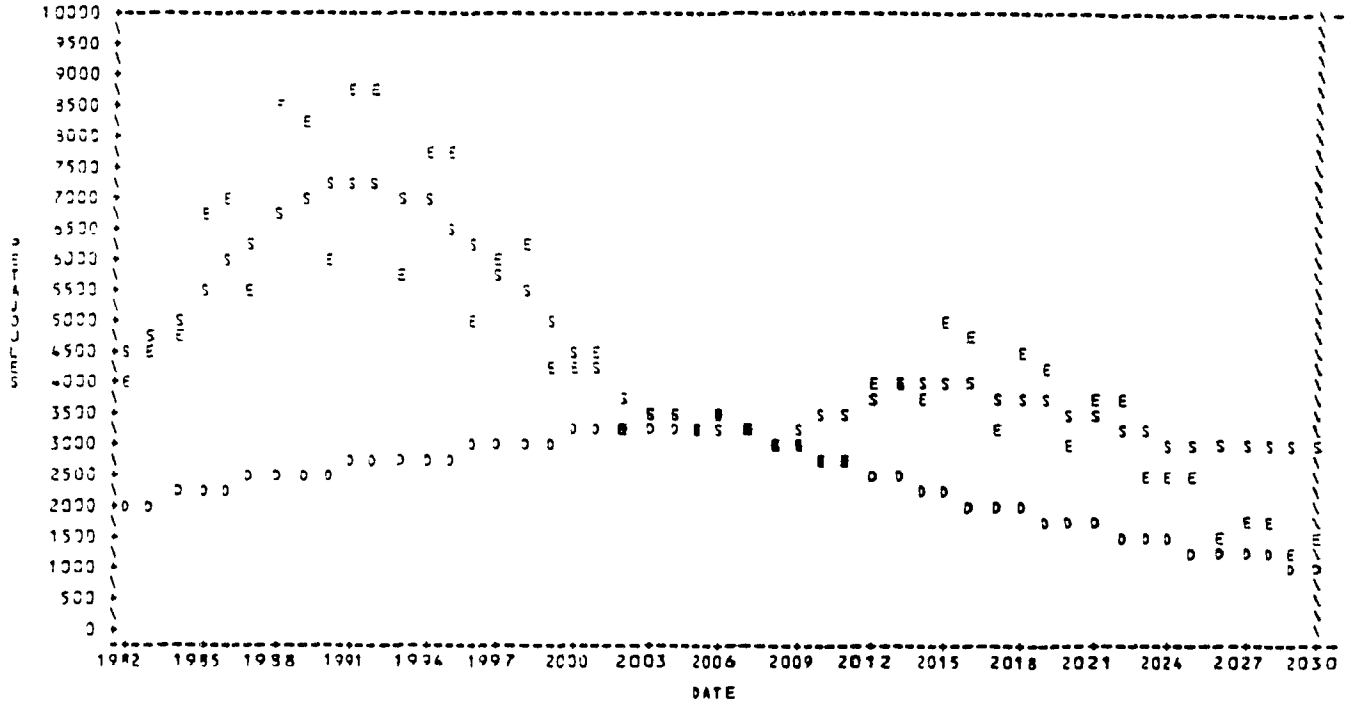
The Base Case - NEB 1982 Rules

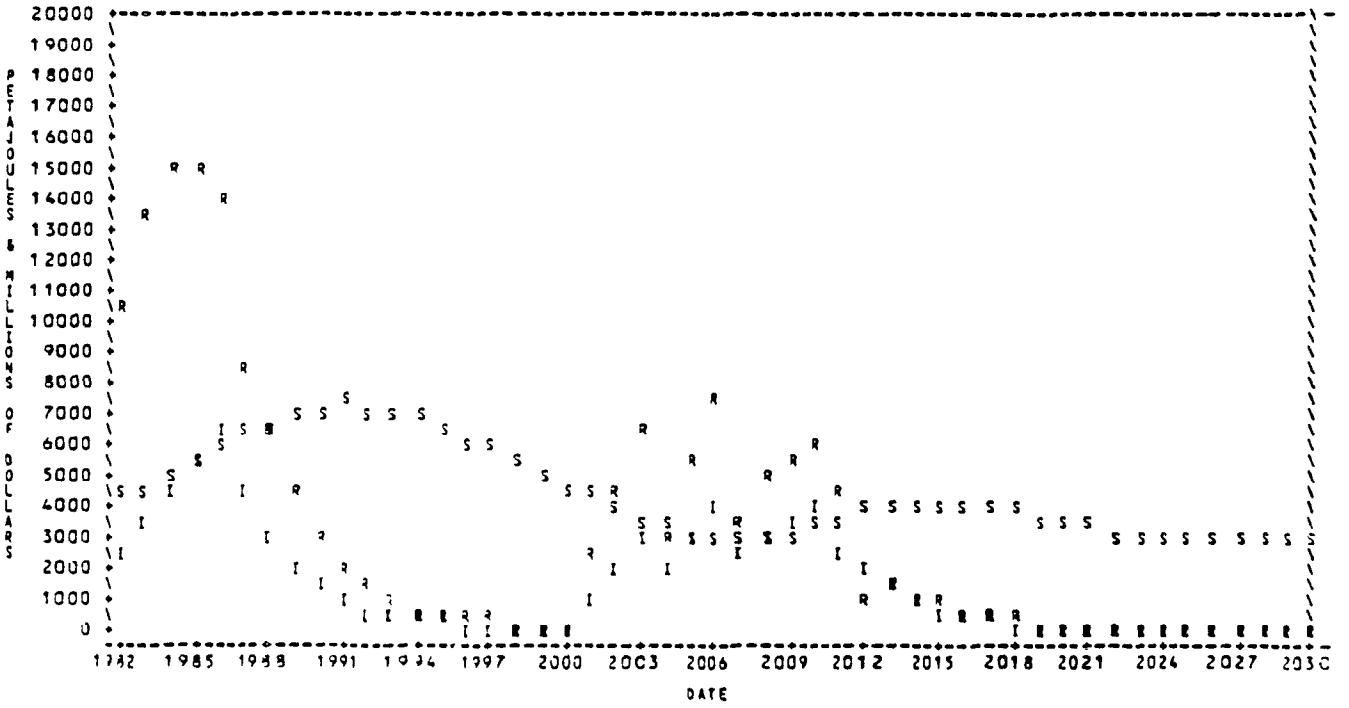
Figures 5-1a and 5-1b on the following page illustrate the pattern of export allocations, deliverability and domestic demand associated with the 1982 NEB rules. Exports that would be authorized by the strict application of the 1982 rules do jump around on Figure 5-1a, but it is possible for that erratic pattern to be "tracked" by deliverability, so the erratic exports would be possible. The deliverability from established reserves line labelled "8" is the maximum "non-tracking" deliverability curve. Thus, the area between the domestic demand curve, labelled "D" and "8" is as large as the annual allowable exports between the "E" curve which is the sum of domestic demand plus authorized exports, and the "D" curve. One item worthy of note is that the decision process over the course of the simulation does result in changing long-term levels of exports, along with the short-term erratic pattern described above.

After an extensive, and high volume growth period for exports, shown as columns (7) and (8) of Table 5-1, exports decline to zero over the twenty years following, until about year thirty when prices have grown to a very high level. Under the NEB rules, the 150 EJ of remaining reserves are used

in forty years time. The rate of growth of known reserves is initially rapid as can be seen in column (4) and on Figure 5-1b. This rate drops to zero, along with industry investment, as exports are reduced to zero. Since at that time additional exports would be allowed under these NEB rules, the anticipated revenue stream is diminished, and investment is discouraged. Investment remains at low levels until reserves are run down sufficiently that more are needed to satisfy domestic demand in the twentieth year. Annually, this makes for an erratic pattern for the investment/revenues relationship, which in reality is usually more stable than it appears in this model. This performance is, however, consistent with the optimization criterion suggested, and does not appear to be unreasonable.

Figures 5-1a, 5-1b
NEB 1982 Rules





LEGEND:

'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ '000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

Table 5-1
NEB 1982 Rules

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2500	6084	10709	10709	139291	4380	1972
1983	3499	14346	13715	24424	125576	4725	2048
1984	4449	23475	15088	39512	110488	5115	2177
1985	5364	32160	15027	54539	95461	5500	2290
1986	6254	39306	13787	68326	81674	5898	2357
1987	4377	45481	8501	76827	73173	6335	2417
1988	3063	52312	6333	83160	66840	6691	2474
1989	2144	59921	4521	87681	62319	6976	2541
1990	1500	68578	3226	90907	59093	7132	2622
1991	1049	78371	1817	92724	57276	7257	2673
1992	734	89726	1368	94092	55908	7230	2711
1993	513	102860	975	95067	54933	7001	2760
1994	359	118029	696	95763	54237	6897	2816
1995	251	135532	496	96259	53741	6524	2864
1996	175	155712	353	96612	53388	6132	2918
1997	122	178956	251	96863	53137	5866	2972
1998	85	205716	178	97041	52959	5403	3026
1999	59	236516	126	97167	52833	4892	3080
2000	41	271951	89	97256	52744	4625	3136
2001	1028	313303	2291	99547	50453	4255	3182
2002	1969	361392	4476	104023	45977	3788	3227
2003	2878	417180	6674	110697	39303	3592	3273
2004	2014	479760	2912	113609	36391	3439	3320
2005	2909	552608	5614	119223	30777	3205	3369
2006	3786	636647	7453	126676	23324	3168	3418
2007	2650	731935	3494	130170	19830	3180	3251
2008	3104	841918	4768	134938	15062	3112	3092
2009	3422	968467	5361	140299	9701	3227	2942
2010	3895	1114081	6225	146524	3476	3404	2800
2011	2726	1281549	4443	150967	-967	3562	2661
2012	1908	1472654	1128	152095	-2095	3797	2535
2013	1335	1693271	1509	153604	-3604	3934	2412
2014	934	1947072	1077	154681	-4681	3958	2296
2015	653	2238999	767	155448	-5448	3960	2185
2016	457	2574754	548	155996	-5996	3919	2079
2017	319	2960902	390	156386	-6386	3835	1979
2018	223	3404982	278	156664	-6664	3802	1883
2019	156	3915686	198	156862	-6862	3682	1792
2020	109	4503001	141	157003	-7003	3538	1708
2021	76	5178418	100	157103	-7103	3403	1627
2022	53	5955152	71	157174	-7174	3171	1550
2023	37	6848399	50	157224	-7224	3142	1476
2024	25	7875634	34	157258	-7258	3056	1407
2025	17	9056961	24	157282	-7282	2943	1341
2026	11	10415490	15	157297	-7297	2909	1277
2027	7	11977802	10	157307	-7307	2911	1217
2028	4	13774463	5	157312	-7312	2911	1161
2029	2	15840625	2	157314	-7314	2932	1106
2030	1	18216688	1	157315	-7315	2998	1055

(1)YEAR
(2)ANNUAL INVESTMENT ('000 000)
(3)CUMULATIVE PRESENT VALUE ('000 000)
(4)ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5)CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6)REMAINING WCSB RESERVES(PETAJOULES)[NEGATIVE FROM FRONTIER]
(7)DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8)DOMESTIC DEMAND

Class One Sensitivity Analyses on Model Parameters

In the following sections, six sensitivity analyses are performed, with variations in key model parameters. They are briefly described below:

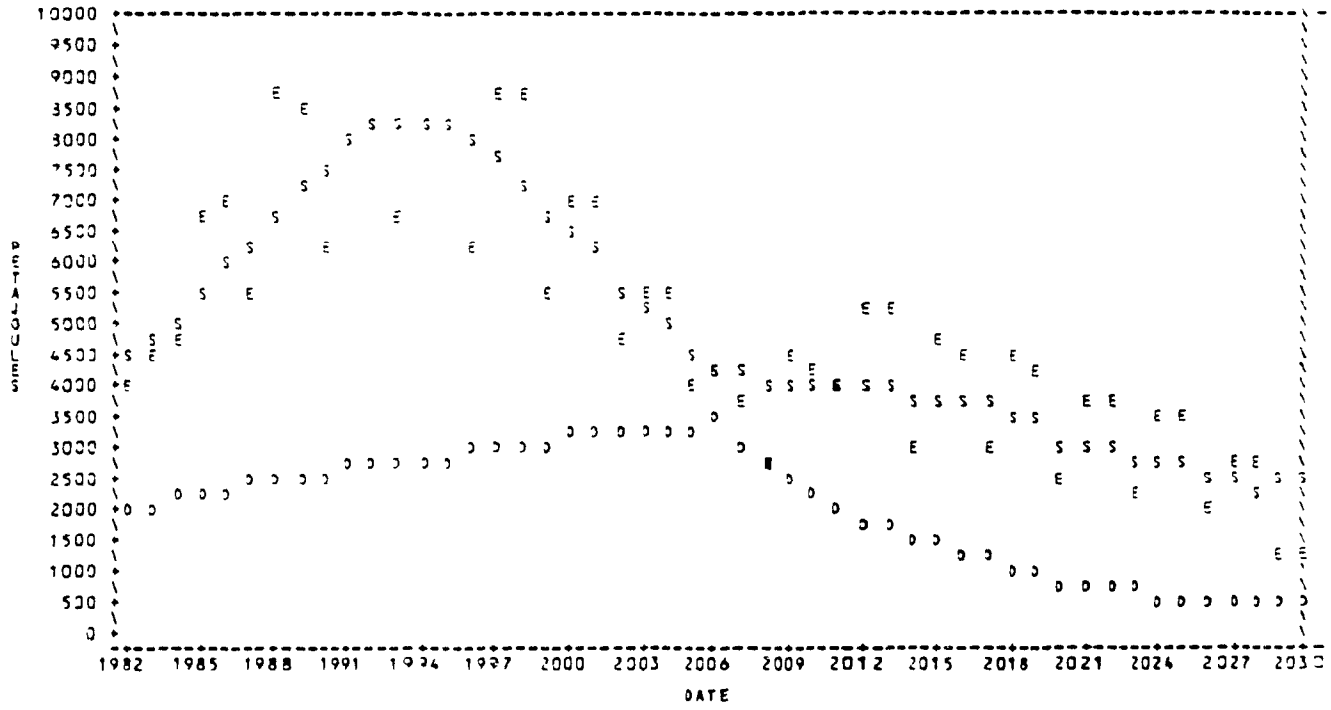
Case	Description
1. Price Increase	The rate of price increase is changed from 5% per annum in the base case to 10% per annum
2. Price Decrease	The rate of price increase is changed from 5% per annum in the base case to 0% per annum.
3. Fewer Hearings	Hearings are held every five years rather than every three years.
4. Investment-Effort Improvement	Here the relationship between investment and metres drilled, a proxy for the overall investment output relationship is improved by one-third, representing technological improvement.
5. Discount Rate Increase	The discount rate is increased to 20% from 15% in the base case.
6. Accelerated Drawdown	The connection rate is increased to 25% per year, full connection in four years, and a flat 8% per year drawdown rate or production rate. The latter implies a reserve life of twelve years, which is much shorter than the base case.

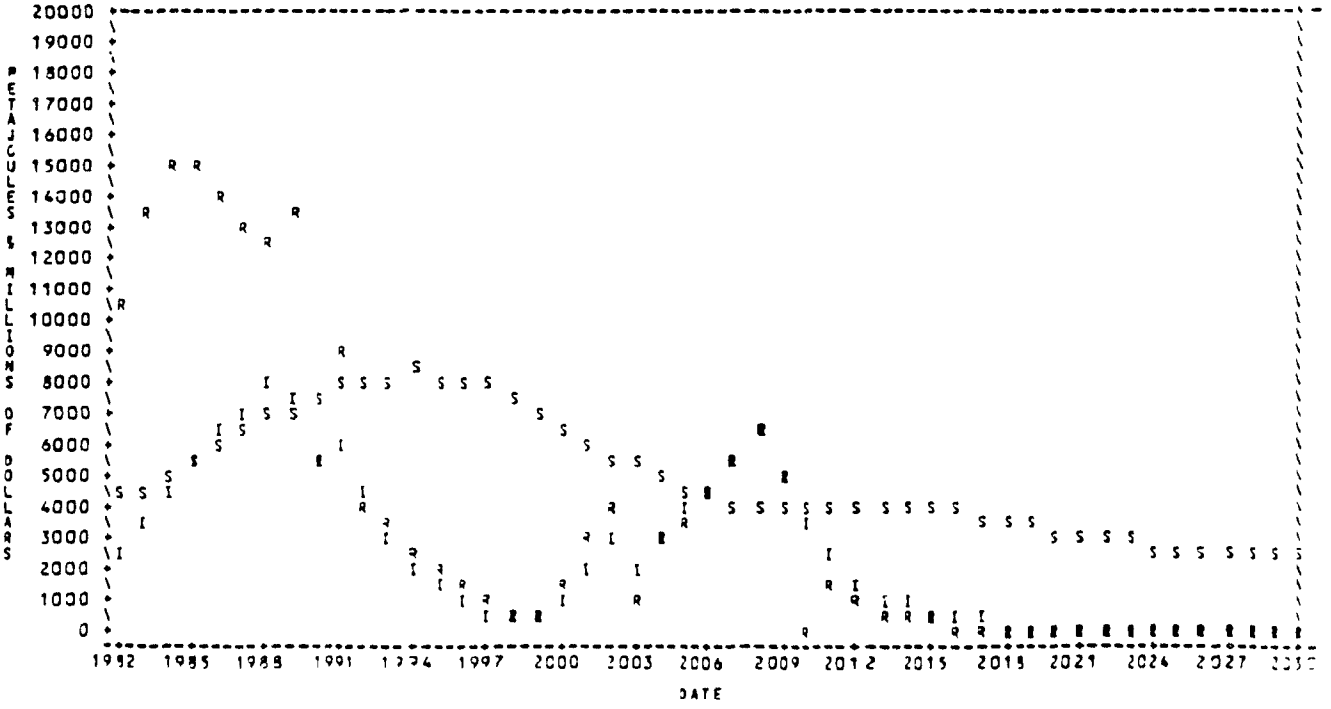
Price Increase Case

(1) A price increase of 10% per annum has the effect of stimulating reserves additions within six years, and has significant effects on deliverability within twelve. The real impact of sustained price increases at that rate does not affect the system until after 1992, in terms of

increased exports. In the post-2007 period, this rate of price increase puts downward pressure on domestic demand, and although exports increase, total domestic demand plus exports is about the same as under the NEB case.

Figures 5-2a, 5-2b
PRICE INCREASE CASE





LEGEND:
'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ '000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

Table 5-2
PRICE INCREASE CASE

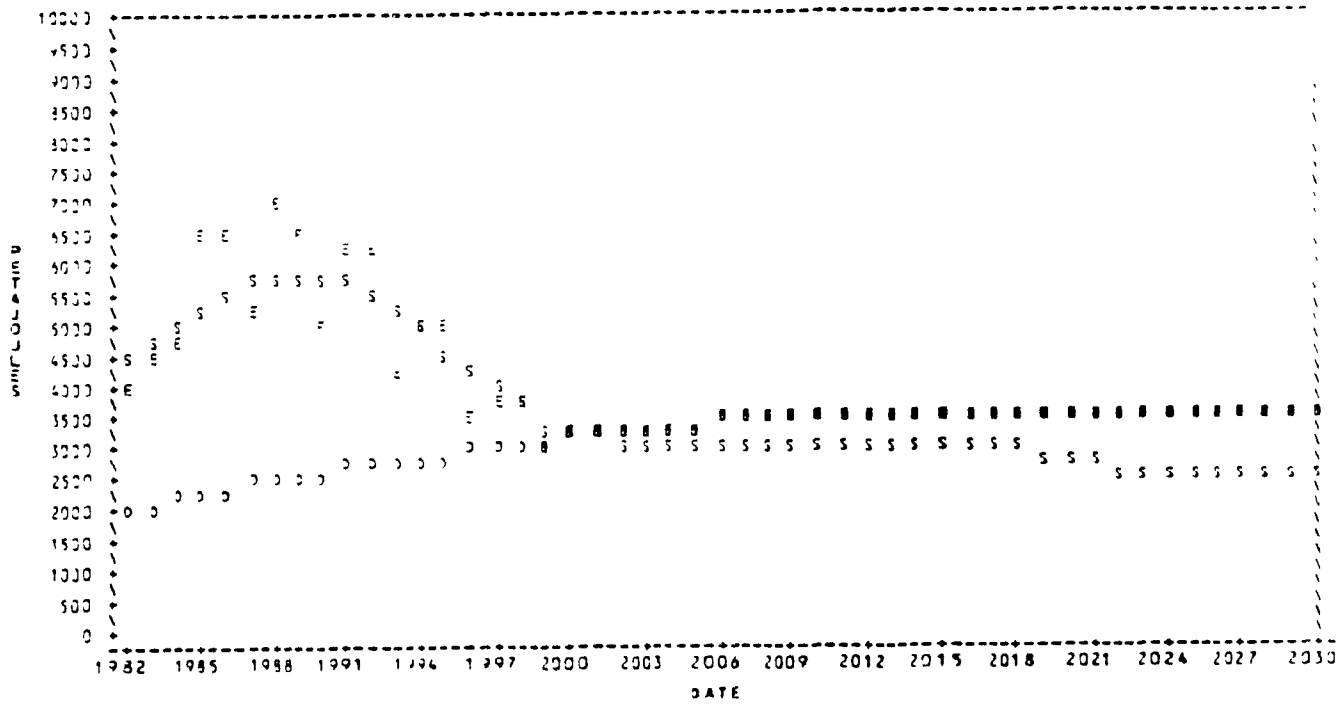
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2500	13794	10709	10709	139291	4380	1972
1983	3499	33357	13715	24424	125576	4725	2048
1984	4449	56675	15088	39512	110488	5115	2177
1985	5364	81675	15027	54539	95461	5500	2290
1986	6254	106435	13787	68326	81674	5898	2357
1987	7127	131726	13147	81473	68527	6359	2417
1988	7988	157969	12711	94184	55816	6788	2474
1989	7591	187775	13341	107525	42475	7216	2541
1990	5313	216084	5744	113269	36731	7581	2622
1991	6219	249699	9096	122365	27635	7989	2673
1992	4353	285870	4098	126463	23537	8236	2711
1993	3047	327970	3477	129940	20060	8242	2760
1994	2132	376441	2481	132421	17579	8366	2816
1995	1492	432288	1771	134192	15808	8157	2864
1996	1044	496626	1264	135456	14544	7889	2918
1997	730	570723	901	136357	13643	7763	2972
1998	510	656019	642	136999	13001	7354	3026
1999	356	754180	457	137456	12544	6849	3080
2000	1249	868222	1637	139093	10907	6595	3136
2001	2124	1000094	2840	141933	8067	6151	3182
2002	2986	1152503	4073	146006	3994	5587	3227
2003	2090	1324835	1180	147186	2814	5328	3273
2004	2962	1524319	2802	149988	12	5009	3320
2005	3823	1754022	3689	153677	-3677	4566	3369
2006	4676	2018519	4602	158279	-8279	4361	3418
2007	5523	2323052	5545	163824	-13824	4207	3088
2008	6366	2673658	6519	170343	-20343	3987	2790
2009	4956	3076551	5176	175519	-25519	4094	2524
2010	3469	3534622	73	175592	-25592	4124	2283
2011	2428	4064126	1319	176911	-26911	4029	2067
2012	1699	4673279	941	177852	-27852	4037	1871
2013	1189	5373939	672	178524	-28524	3984	1694
2014	832	6179790	479	179003	-29003	3832	1535
2015	582	7106590	342	179345	-29345	3842	1393
2016	407	8172449	244	179589	-29589	3766	1264
2017	284	9398207	173	179762	-29762	3627	1148
2018	198	10807854	123	179885	-29885	3557	1045
2019	138	12428966	87	179972	-29972	3389	953
2020	96	14293255	62	180034	-30034	3119	870
2021	67	16437199	44	180078	-30078	3060	795
2022	46	18902720	31	180109	-30109	2925	727
2023	32	21738080	22	180131	-30131	2797	666
2024	22	24998736	15	180146	-30146	2745	610
2025	15	28748512	10	180156	-30156	2639	560
2026	10	33060752	7	180163	-30163	2466	516
2027	6	38019824	4	180167	-30167	2436	476
2028	4	43722752	3	180170	-30170	2362	439
2029	2	50281120	1	180171	-30171	2446	408
2030	1	57823248	0	180171	-30171	2501	379

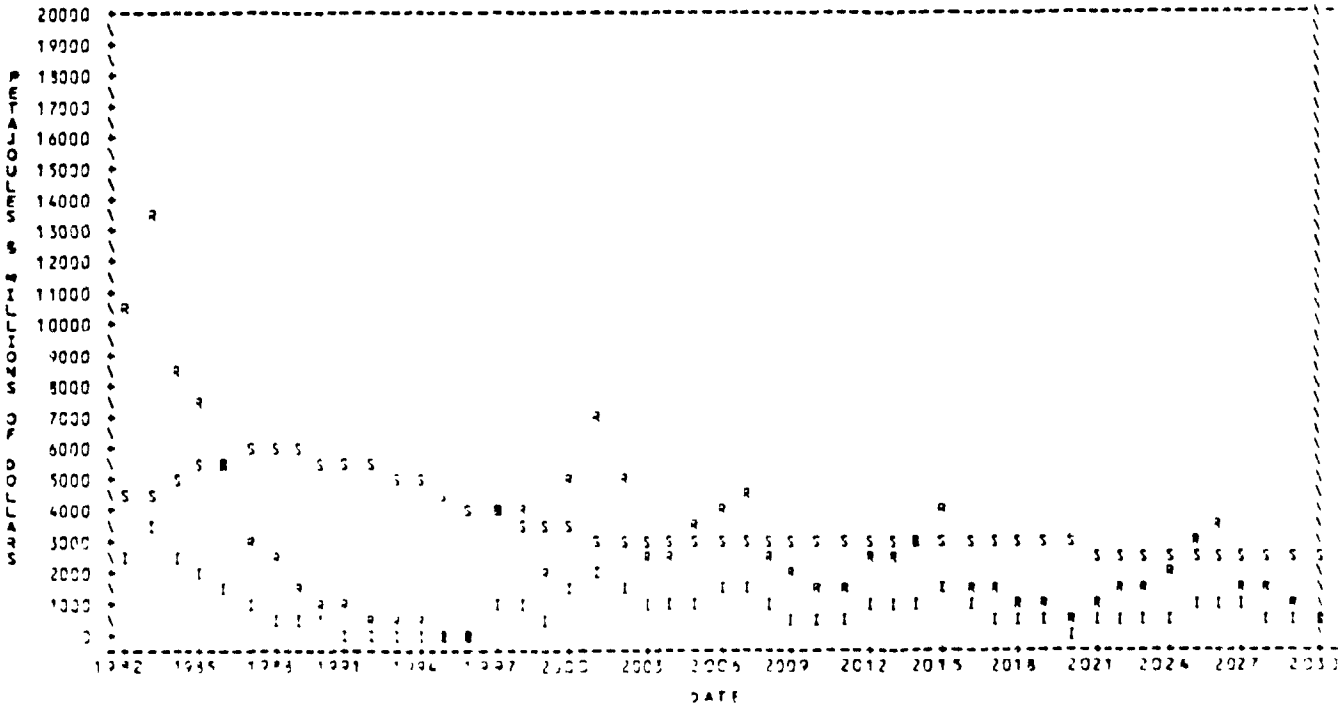
(1)YEAR
(2)ANNUAL INVESTMENT ('000 000)
(3)CUMULATIVE PRESENT VALUE ('000 000)
(4)ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5)CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6)REMAINING WCSB RESERVES(PETAJOULES)[NEGATIVE FROM FRONTIER]
(7)DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8)DOMESTIC DEMAND

Price Decrease Case

(2) The price decrease in this next case can be seen in Figure 5-3a and Table 5-3 to affect investment and reserves additions within two to three years. Supply and exports are severely curtailed, and domestic demand begins to face shortfalls in supply by about 2005. As higher cost reserves are encountered, the ability to exploit them profitably is reduced. Because the use of the NEB rules makes exports difficult in later years, the sole source of profits is from domestic sales. Since this case has a lower rate of price increase than the base case, it is more profitable to postpone investments in exploration as long as possible, in order to bring revenues and costs closer together in time.

Figures 5-3a, 5-3b
PRICE DECREASE CASE





LEGEND:

'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ '000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

Table 5-3
PRICE DECREASE CASE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2500	1846	10709	10709	139291	4380	1972
1983	3499	3906	13715	24424	125576	4725	2048
1984	2449	5196	8721	33145	116855	5082	2177
1985	1964	6472	7652	40797	109203	5375	2290
1986	1374	7581	5461	46258	103742	5607	2357
1987	961	8415	2777	49035	100965	5789	2417
1988	672	9428	2315	51350	98650	5832	2474
1989	470	10603	1652	53002	96998	5827	2541
1990	328	11991	1175	54177	95823	5743	2622
1991	229	13622	837	55014	94986	5656	2673
1992	160	15534	596	55610	94390	5493	2711
1993	111	17765	422	56032	93968	5163	2760
1994	77	20355	298	56330	93670	4936	2816
1995	53	23354	209	56539	93461	4541	2864
1996	37	26816	149	56688	93312	4172	2918
1997	1025	31322	4221	60909	89091	3935	2972
1998	967	36511	4062	64971	85029	3649	3026
1999	676	41990	1832	66803	83197	3350	3080
2000	1473	48626	5149	71952	78048	3286	3136
2001	2031	56317	7242	79194	70806	3196	3182
2002	1421	65160	5168	84362	65638	3038	3227
2003	994	74815	2367	86729	63271	3039	3273
2004	945	86080	2682	89411	60589	3064	3320
2005	1161	99056	3361	92772	57228	2986	3369
2006	1312	114002	3874	96646	53354	2981	3418
2007	1418	131213	4270	100916	49084	3016	3418
2008	992	150743	2268	103184	46816	2999	3418
2009	694	173334	1812	104996	45004	3029	3418
2010	485	199229	1291	106287	43713	3092	3418
2011	589	229233	1600	107887	42113	3086	3418
2012	912	263639	2527	110414	39586	3054	3418
2013	888	303221	2510	112924	37076	3012	3418
2014	1121	348762	3232	116156	33844	2983	3418
2015	1284	401159	3776	119932	30068	2968	3418
2016	898	461082	1745	121677	28323	2959	3418
2017	628	530192	1537	123214	26786	2945	3418
2018	439	609688	1095	124309	25691	2910	3418
2019	307	701122	781	125090	24910	2856	3418
2020	214	806279	555	125645	24355	2776	3418
2021	399	927212	1057	126702	23298	2694	3418
2022	529	1066297	1429	128131	21869	2607	3418
2023	620	1226259	1708	129839	20161	2530	3418
2024	683	1410232	1920	131759	18241	2466	3418
2025	978	1621819	2804	134563	15437	2425	3418
2026	1184	1865170	3463	138026	11974	2404	3418
2027	828	2144762	1736	139762	10238	2402	3418
2028	579	2466387	1321	141083	8917	2411	3418
2029	405	2836290	942	142025	7975	2417	3418
2030	283	3261695	672	142697	7303	2410	3418

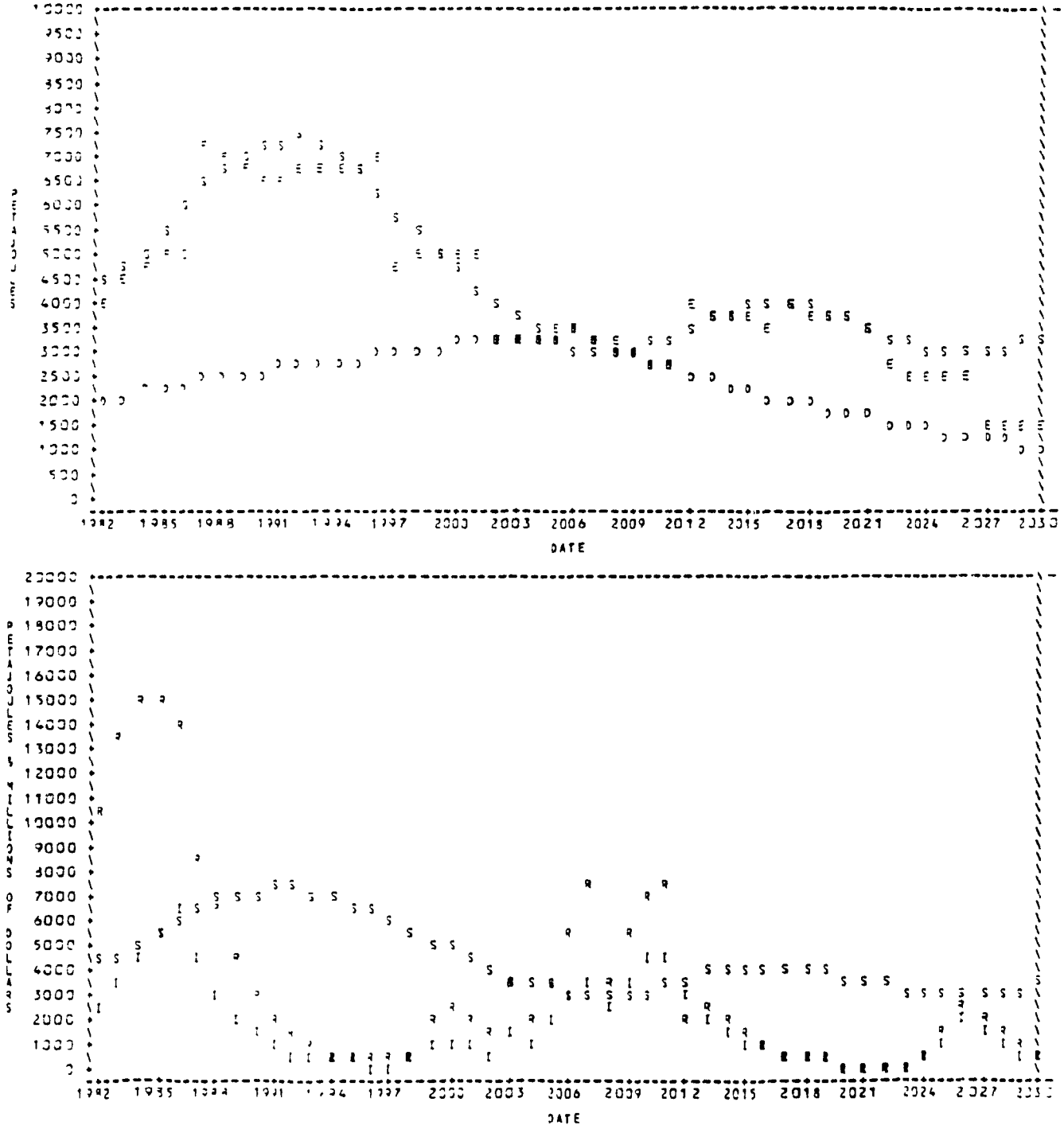
(1)YEAR
(2)ANNUAL INVESTMENT ('000 000)
(3)CUMULATIVE PRESENT VALUE ('000 000)
(4)ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5)CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6)REMAINING WCSB RESERVES(PETAJOULES)[NEGATIVE FROM FRONTIER]
(7)DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8)DOMESTIC DEMAND

"Fewer Hearings" Case

In the base case, it was assumed that there would be hearings every three years, and any surpluses identified under the 1982 NEB rules would be available for export. In this sensitivity analysis case, it is assumed, instead, that hearings will be held every five years. With more infrequent hearings, we might expect some changes in patterns of investment or exports, due to the fact that a longer interval is allowed for exportable surpluses to accumulate. On the other hand, an operator may have to wait an extra two years for his newly discovered gas to go on stream as an export, should a surplus exist.

What we find is that this case is again very close to the base case, in the patterns of investment, reserves additions, and exports, with some slight changes, mostly in the post 1997 period. There is little gain in deliverability and export sales, in the fifty year horizon studied however, and the value of this case is actually lower than the "NEB" case. More investments are made and more reserves are added (171 in the five year case versus 157 in the three year case). The benefits of that alternative pattern are not well reflected during the fifty year period studied.

Figures 5-4a, 5-4b
FEWER HEARINGS CASE



LEGEND:

'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ '000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

Table 5-4
FEWER HEARINGS CASE

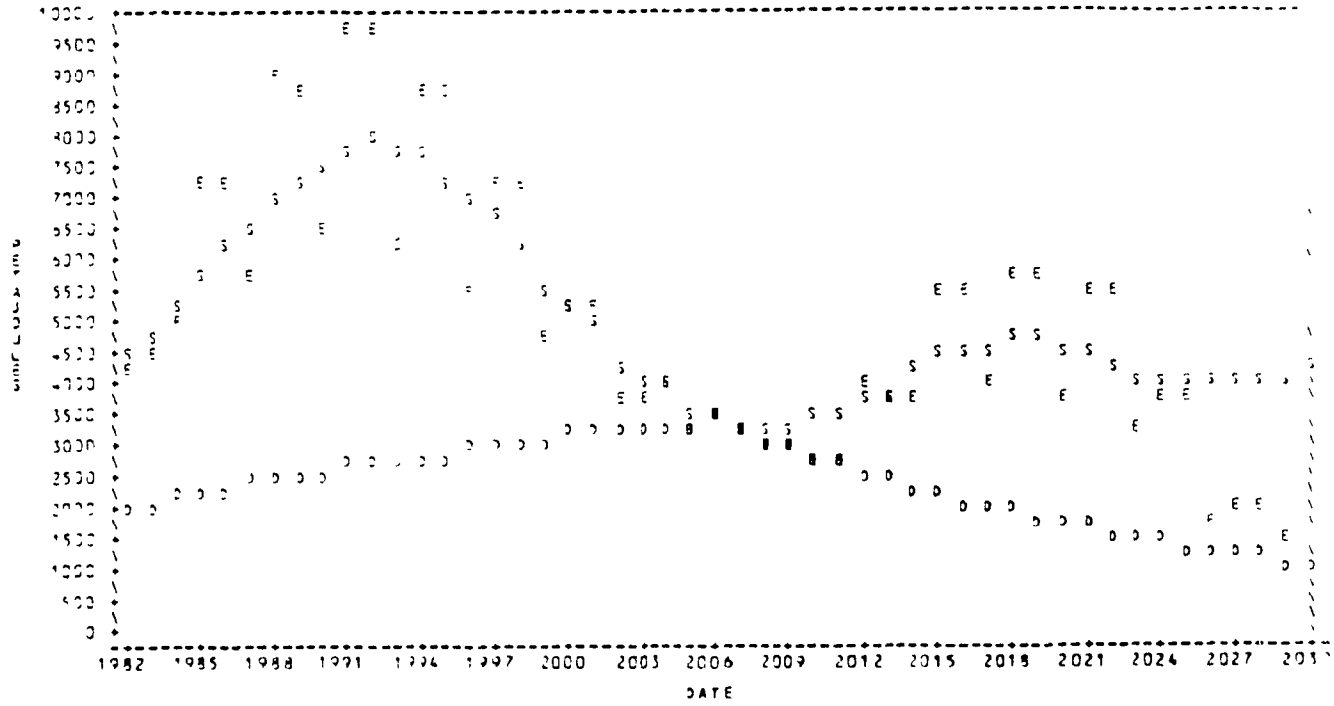
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2500	6084	10709	10709	139291	4380	1972
1983	3499	14346	13715	24424	125576	4725	2048
1984	4449	23475	15088	39512	110488	5111	2177
1985	5364	32160	15027	54539	95461	5507	2290
1986	6254	39306	13787	68326	81674	5955	2357
1987	4377	45481	8501	76827	73173	6482	2417
1988	3063	52312	6333	83160	66840	6765	2474
1989	2144	59921	4521	87681	62319	7048	2541
1990	1500	68578	3226	90907	59093	7243	2622
1991	1049	78371	1817	92724	57276	7335	2673
1992	734	89726	1368	94092	55908	7402	2711
1993	513	102860	975	95067	54933	7236	2760
1994	359	118029	696	95763	54237	7039	2816
1995	251	135532	496	96259	53741	6693	2864
1996	175	155712	353	96612	53388	6300	2918
1997	122	178957	251	96863	53137	5869	2972
1998	335	205936	703	97566	52434	5420	3026
1999	984	237305	2108	99674	50326	5051	3080
2000	1188	273509	2596	102270	47730	4755	3136
2001	831	314987	1852	104122	45878	4369	3182
2002	581	361670	1320	105442	44558	3971	3227
2003	1406	416767	3260	108702	41298	3715	3273
2004	984	479578	1849	110551	39449	3478	3320
2005	1938	552154	3740	114291	35709	3267	3369
2006	2856	635921	5622	119913	30087	3094	3418
2007	3749	732541	7527	127440	22560	3050	3251
2008	2624	842207	3452	130892	19108	3063	3092
2009	3586	968802	5618	136510	13490	3056	2942
2010	4260	1114467	6808	143318	6682	3166	2800
2011	4481	1282070	7305	150623	-623	3357	2664
2012	3136	1472707	2082	152705	-2705	3606	2535
2013	2195	1693157	2481	155186	-5186	3786	2412
2014	1536	1946837	1771	156957	-6957	3858	2296
2015	1075	2238667	1264	158221	-8221	3910	2185
2016	752	2574333	902	159123	-9123	3941	2079
2017	526	2960391	643	159766	-9766	3066	1979
2018	368	3404382	459	160225	-10225	3901	1883
2019	257	3914988	327	160552	-10552	3818	1792
2020	179	4502196	232	160784	-10784	3714	1708
2021	125	5177493	165	160949	-10949	3568	1627
2022	87	5954082	117	161066	-11066	3363	1550
2023	60	6847166	82	161148	-11148	3196	1476
2024	291	7874215	408	161556	-11556	3091	1407
2025	1203	9055351	1724	163280	-13280	3107	1341
2026	1842	10413704	2694	165974	-15974	3043	1277
2027	1289	11974408	1922	167896	-17896	2989	1217
2028	902	13769631	1372	169268	-19268	3030	1161
2029	631	15834422	979	170247	-20247	3141	1106
2030	441	18209120	698	170945	-20945	3266	1055

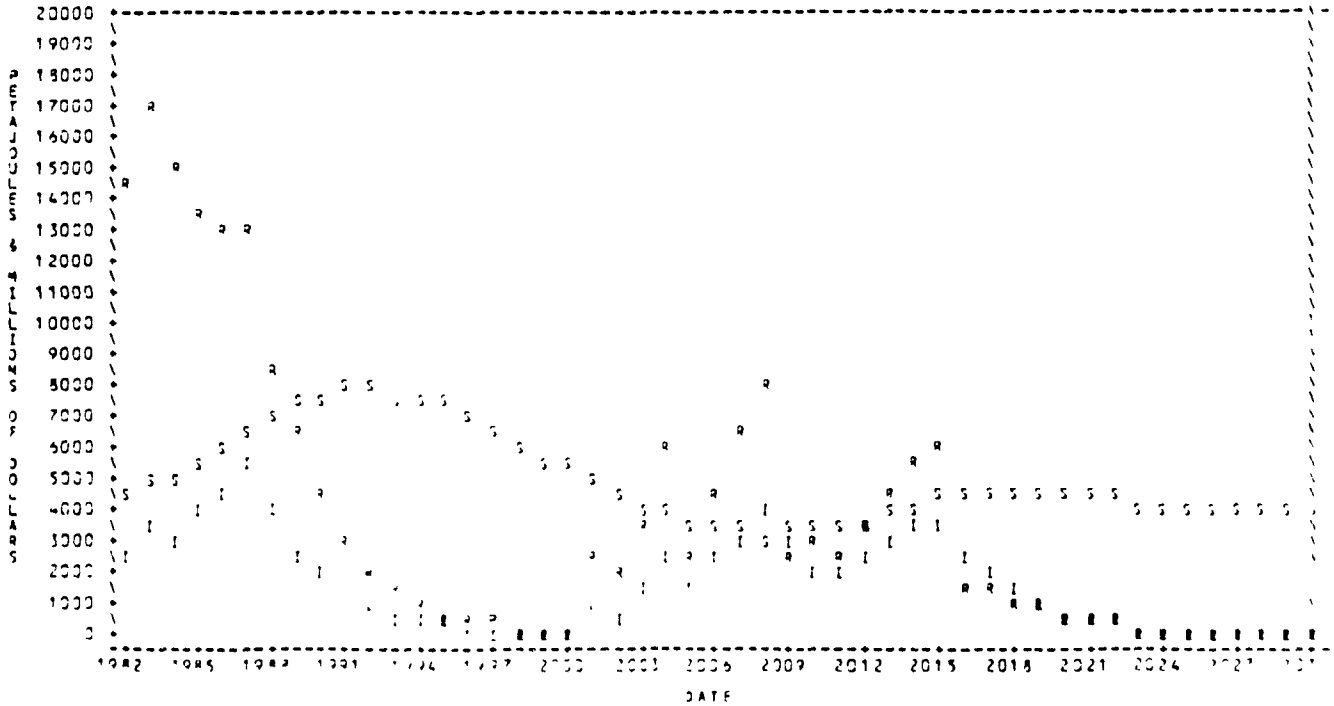
(1) YEAR
(2) ANNUAL INVESTMENT ('000 000)
(3) CUMULATIVE PRESENT VALUE ('000 000)
(4) ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5) CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6) REMAINING WCSB RESERVES (PETAJOULES) [NEGATIVE FROM FRONTIER]
(7) DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8) DOMESTIC DEMAND

"Investment-Effort Improvement" Case

A change in the investment-effort relationship which is an improvement is one which allows a given amount of investment dollars to buy more exploration or drilling, seismic work, etc., and therefore find more gas. This has the effect of reducing the cost of the gas. The effect of this change is as expected, to exhaust the first 150 EJ at an earlier time period, 27 rather than the 30 years in the base case, and ultimately to find 183 EJ rather than 157, as in the base case. As mentioned earlier on, although the WCSB is assumed to contain 150 EJ of reserves additions, additions beyond 150 EJ are available in "unlimited supply" at higher costs than the WCSB reserves. The investment-effort relationship improvement is assumed to affect the viability of the frontier reserves as well as the WCSB reserves, so the costs if both types of reserves declines. The value of the gas sales to the economy is increased by 20%. The effect of a technological change is to increase the availability of low cost reserves, which increases the rates of discovery, and export sales throughout the period. With the exception of the rapid price increase case, this case most rapidly results in the exhaustion of the first 150 EJ of gas reserves.

Figures 5-5a, 5-5b
INVESTMENT-EFFORT IMPROVEMENT CASE





LEGEND:

'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ '000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

Table 5-5
INVESTMENT-EFFORT IMPROVEMENT CASE

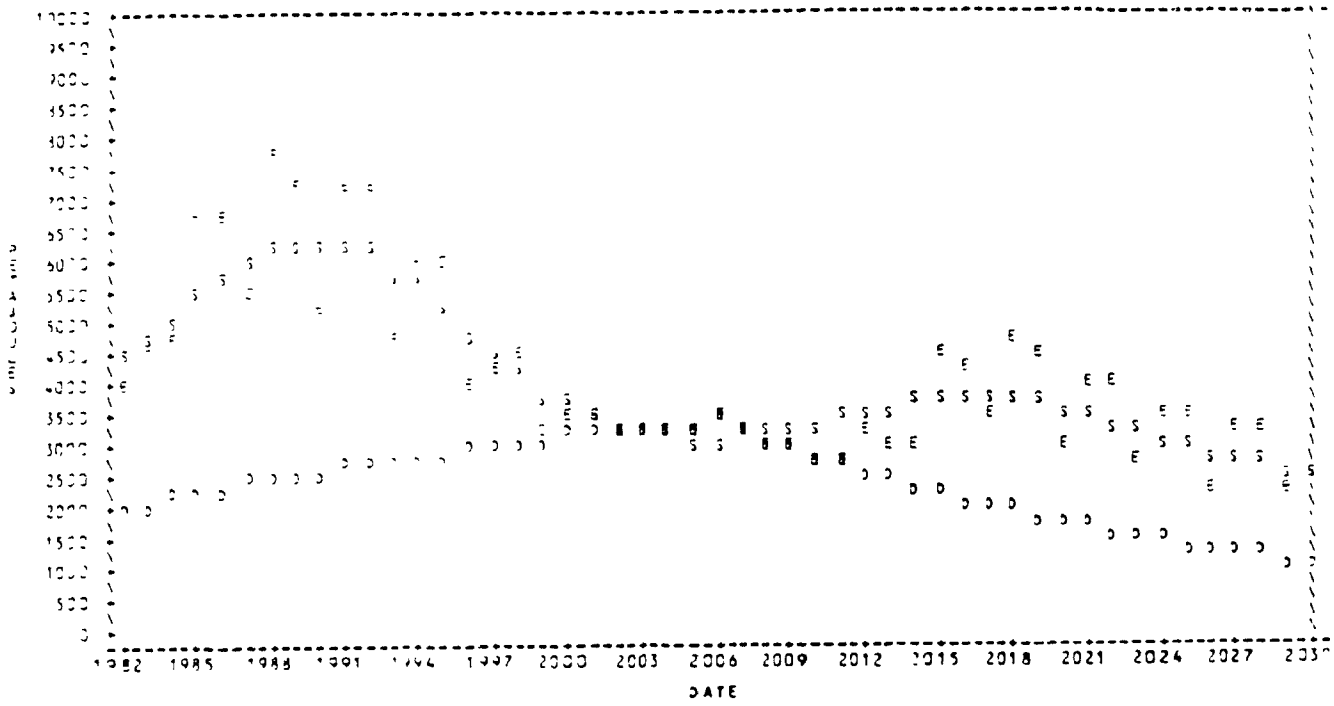
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2500	8980	14279	14279	135721	4399	1972
1983	3499	20400	17160	31439	118561	4782	2048
1984	2949	31862	15021	46460	103540	5233	2177
1985	3814	42202	13394	59854	90146	5694	2290
1986	4669	51955	13002	72856	77144	6148	2357
1987	5518	61296	13181	86037	63963	6620	2417
1988	3862	70531	8365	94402	55598	7013	2474
1989	2703	80981	6333	100735	49265	7358	2541
1990	1892	92824	4522	105257	44743	7611	2622
1991	1324	106385	3227	108484	41516	7849	2673
1992	926	121860	1808	110292	39708	7903	2711
1993	648	139744	1314	111606	38394	7715	2760
1994	453	160394	937	112543	37457	7652	2816
1995	317	184211	669	113212	36788	7287	2864
1996	221	211657	475	113687	36313	6896	2918
1997	154	243266	337	114024	35976	6655	2972
1998	107	279655	239	114263	35737	6169	3026
1999	74	321528	168	114431	35569	5623	3080
2000	51	369706	118	114549	35451	5339	3136
2001	1035	425834	2460	117009	32991	4905	3182
2002	724	489004	1755	118764	31236	4370	3227
2003	1506	563415	3724	122488	27512	4107	3273
2004	2304	649543	5812	128300	21700	3884	3320
2005	1612	747120	2536	130836	19164	3527	3369
2006	2378	860002	4681	135517	14483	3394	3418
2007	3164	990157	6353	141870	8130	3338	3251
2008	3964	1140127	8119	149989	11	3220	3092
2009	2774	1310107	2472	152461	-2461	3298	2942
2010	1941	1506617	2757	155218	-5218	3458	2800
2011	1858	1732645	2692	157910	-7910	3563	2664
2012	2300	1992622	3399	161309	-11309	3749	2535
2013	2859	2291649	4310	165619	-15619	3838	2412
2014	3501	2635598	5383	171002	-21002	4250	2296
2015	3700	3031207	5803	176805	-26805	4378	2185
2016	2589	3484301	1435	178240	-28240	4491	2079
2017	1812	4006165	1478	179718	-29718	4572	1979
2018	1268	4606549	1055	180773	-30773	4680	1883
2019	887	5297154	752	181525	-31525	4636	1792
2020	620	6091461	536	182061	-32061	4552	1708
2021	433	7004984	382	182443	-32443	4512	1627
2022	303	8055591	272	182715	-32715	4336	1550
2023	212	9263825	194	182909	-32909	4124	1476
2024	148	10653318	138	183047	-33047	4068	1407
2025	103	12251251	98	183145	-33145	3944	1341
2026	72	14088888	70	183215	-33215	3876	1277
2027	50	16202165	49	183264	-33264	3922	1217
2028	34	18632432	34	183298	-33298	3959	1161
2029	23	21427248	23	183321	-33321	4027	1106
2030	16	24641296	16	183337	-33337	4158	1055

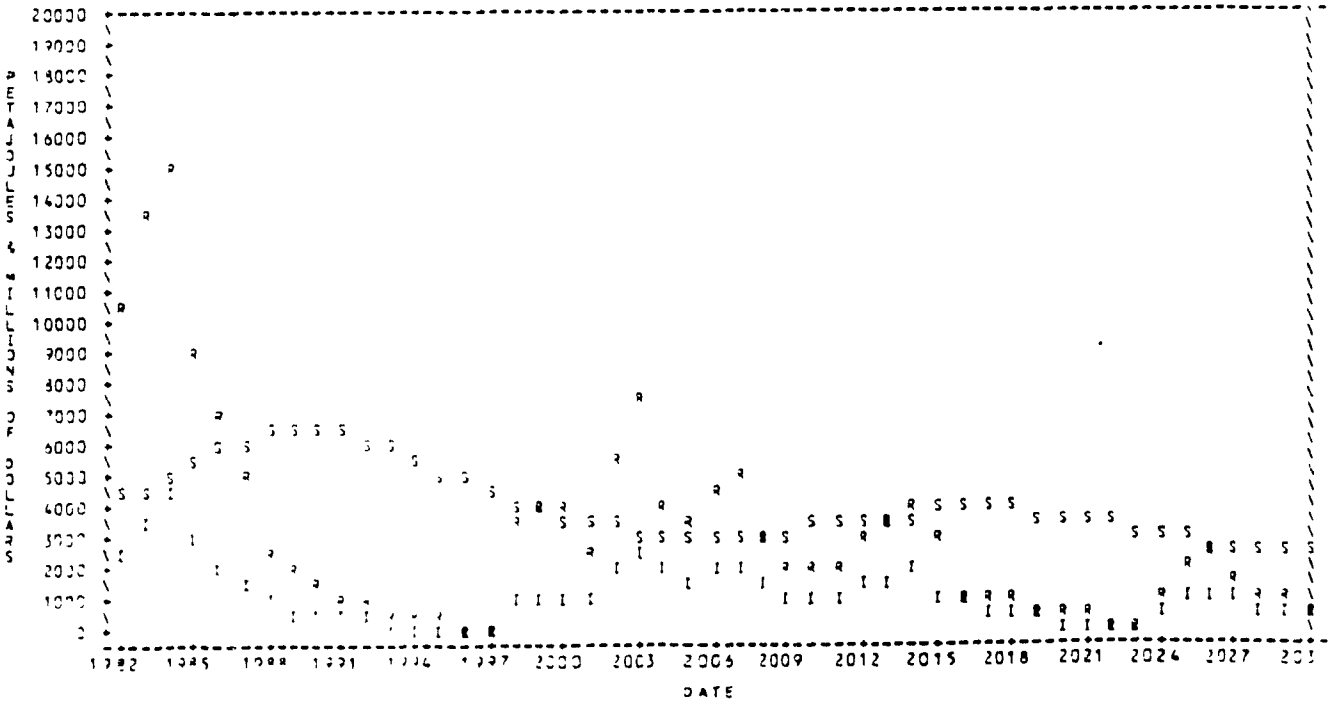
(1)YEAR
(2)ANNUAL INVESTMENT ('000 000)
(3)CUMULATIVE PRESENT VALUE ('000 000)
(4)ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5)CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6)REMAINING WCSB RESERVES(PETAJOULES)[NEGATIVE FROM FRONTIER]
(7)DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8)DOMESTIC DEMAND

"Discount Rate Increase" Case

The effect of the discount rate increase is interesting (no pun intended), because although the rate of drawdown of the stock is slower, due to benefit streams being reduced relative to the discovery costs, the cumulative future value of the sales over the fifty year term is very high. Over the entire period the total discovered reserves are 151 EJ versus 157 for the base case, but the future value of the reserves is more than twice the base case, due to the compounding of early returns at the higher discount rate.

Figures 5-6a, 5-6b
DISCOUNT RATE INCREASE





LEGEND:
'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ '000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

Table 5-6
DISCOUNT RATE INCREASE

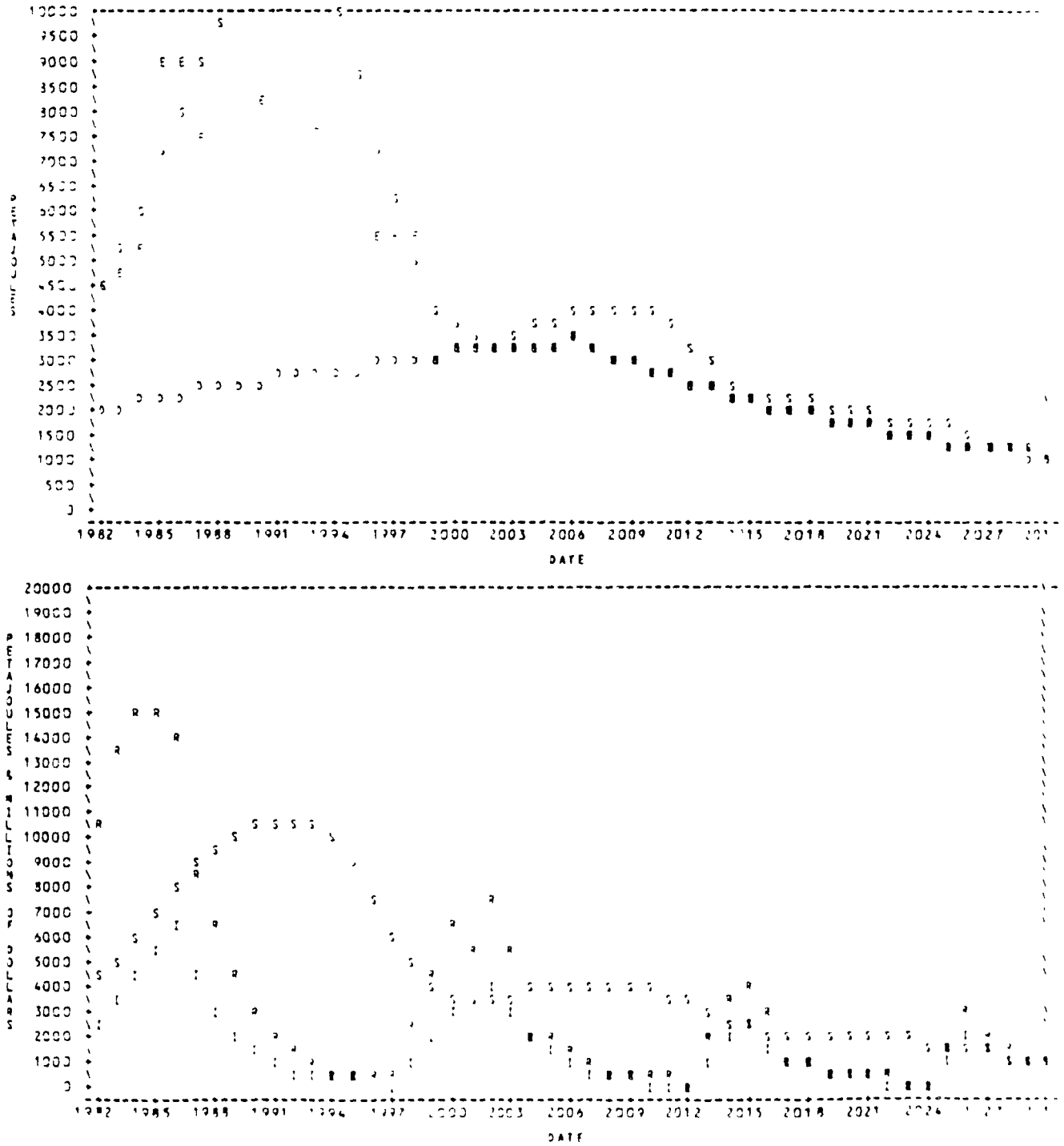
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2500	2740	10709	10709	139291	4380	1972
1983	3499	6201	13715	24424	125576	4725	2048
1984	4449	9455	15088	39512	110488	5115	2177
1985	3114	11752	9182	48694	101306	5469	2290
1986	2179	14319	7217	55911	94089	5788	2357
1987	1525	17116	5152	61063	88937	6095	2417
1988	1067	20078	2552	63615	86385	6251	2474
1989	746	23744	2097	65712	84288	6327	2541
1990	522	28193	1496	67208	82792	6305	2622
1991	365	33579	1067	68275	81725	6276	2673
1992	255	40093	760	69035	80965	6138	2711
1993	178	47958	541	69576	80424	5828	2760
1994	124	57435	384	69960	80040	5641	2816
1995	86	68837	272	70232	79768	5225	2864
1996	60	82542	193	70425	79575	4831	2918
1997	41	99005	134	70559	79441	4560	2972
1998	1028	119330	3454	74013	75987	4181	3026
1999	1219	143841	4178	78191	71809	3802	3080
2000	1103	173233	3856	82047	67953	3666	3136
2001	1022	207896	2278	84325	65675	3493	3182
2002	1965	249859	5360	89685	60315	3251	3227
2003	2625	300291	7304	96989	53011	3189	3273
2004	1837	360260	3910	100899	49101	3155	3320
2005	1535	432438	3703	104602	45398	3052	3369
2006	1824	519093	4488	109090	40910	3083	3418
2007	2026	623168	5085	114175	35825	3147	3251
2008	1418	747697	2838	117013	32987	3144	3092
2009	992	897204	2072	119085	30915	3218	2942
2010	944	1076639	2011	121096	28904	3336	2800
2011	910	1291975	1977	123073	26927	3400	2664
2012	1386	1550405	3072	126145	23855	3487	2535
2013	1470	1860545	3323	129468	20532	3525	2412
2014	1778	2232743	4101	133569	16431	3747	2296
2015	1244	2679398	2926	136495	13505	3833	2185
2016	870	3214919	1106	137601	12399	3840	2079
2017	608	3857811	1116	138717	11283	3822	1979
2018	425	4629312	795	139512	10488	3799	1883
2019	297	5555133	567	140079	9921	3718	1792
2020	207	6666127	403	140482	9518	3604	1708
2021	144	7999324	285	140767	9233	3529	1627
2022	100	9599164	202	140969	9031	3355	1550
2023	69	11518975	142	141111	8889	3151	1476
2024	548	13822758	1155	142266	7734	3052	1407
2025	883	16587308	1899	144165	5835	2892	1341
2026	1118	19904768	2452	146617	3383	2716	1277
2027	782	23884864	1749	148366	1634	2695	1217
2028	547	28661248	1248	149614	386	2661	1161
2029	382	34393088	889	150503	-503	2604	1106
2030	267	41271406	633	151136	-1136	2615	1055

(1)YEAR
(2)ANNUAL INVESTMENT ('000 000)
(3)CUMULATIVE PRESENT VALUE ('000 000)
(4)ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5)CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6)REMAINING WCSB RESERVES(PETAJOULES)[NEGATIVE FROM FRONTIER]
(7)DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8)DOMESTIC DEMAND

"Accelerated Drawdown" Case

This final class one sensitivity analysis case has the most peculiar change in pattern from the base case. The cycles in deliverability and sales are relatively more erratic and more frequent than under the base case, although early investment and discovery patterns are similar (to about 1997). Thereafter, the effects of the more rapid early sales on the value of natural gas are compounded, and the final value is about 50% higher than was the base case. In comparison to the base case, this case results in a larger amount of early export sales, in the years prior to 2010, a lower amount of later export sales following 2010, and a higher overall value for sales over the fifty year horizon. In total 163 EJ of reserves are discovered in this case as compared to 157 EJ of reserves in the base case.

Figures 5-7a, 5-7b
ACCELERATED DRAWDOWN CASE



LEGEND:
'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ '000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

Table 5-7
ACCELERATED DRAWDOWN CASE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2500	10580	10709	10709	139291	4539	1972
1983	3499	24679	13715	24424	125576	5199	2048
1984	4449	40047	15088	39512	110488	6105	2177
1985	5364	54688	15027	54539	95461	7167	2290
1986	6254	67187	13787	68326	81674	8110	2357
1987	4377	78287	8501	76827	73173	8962	2417
1988	3063	90304	6333	83160	66840	9669	2474
1989	2144	103636	4521	87681	62319	10094	2541
1990	1500	118756	3226	90907	59093	10297	2622
1991	1049	135973	1817	92724	57276	10526	2673
1992	734	155860	1368	94092	55908	10483	2711
1993	513	178813	975	95067	54933	10279	2760
1994	359	205289	696	95763	54237	9970	2816
1995	251	235828	496	96259	53741	8756	2864
1996	175	271026	353	96612	53388	7359	2918
1997	122	311557	251	96863	53137	6234	2972
1998	1085	359445	2278	99141	50859	5024	3026
1999	2009	415474	4304	103445	46555	3963	3080
2000	2906	480793	6350	109795	40205	3654	3136
2001	3784	554131	5294	115089	34911	3500	3182
2002	4148	640009	7543	122632	27368	3350	3227
2003	2903	732721	5385	128017	21983	3563	3273
2004	2032	840528	2237	130254	19746	3797	3320
2005	1422	965127	2058	132312	17688	3752	3369
2006	995	1108871	1469	133781	16219	3886	3418
2007	696	1274490	1048	134829	15171	3982	3251
2008	487	1465169	747	135576	14424	3885	3092
2009	340	1684599	532	136108	13892	3907	2942
2010	237	1937050	378	136486	13514	3941	2800
2011	165	2227440	268	136754	13246	3718	2664
2012	115	2561440	191	136945	13055	3358	2535
2013	1080	2946380	1831	138776	11224	2979	2412
2014	2005	3389688	3468	142244	7756	2598	2296
2015	2403	3899800	4240	146484	3516	2253	2185
2016	1682	4482961	3027	149511	489	2138	2079
2017	1177	5154208	1153	150664	-664	2147	1979
2018	823	5926499	1027	151691	-1691	2144	1883
2019	576	6814888	733	152424	-2424	2101	1792
2020	403	7836711	523	152947	-2947	2034	1708
2021	282	9011931	373	153320	-3320	1962	1627
2022	197	10363519	266	153586	-3586	1868	1550
2023	137	11917905	188	153774	-3774	1784	1476
2024	95	13705491	133	153907	-3907	1722	1407
2025	1066	15761756	1528	155435	-5435	1655	1341
2026	1996	18126832	2919	158354	-8354	1534	1277
2027	1397	20844384	2084	160438	-10438	1372	1217
2028	977	23970016	1486	161924	-11924	1246	1161
2029	683	27564800	1059	162983	-12983	1210	1106
2030	478	31699008	756	163739	-13739	1207	1055

(1) YEAR
(2) ANNUAL INVESTMENT ('000 000)
(3) CUMULATIVE PRESENT VALUE ('000 000)
(4) ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5) CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6) REMAINING WCSB RESERVES (PETAJOULES) [NEGATIVE FROM FRONTIER]
(7) DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8) DOMESTIC DEMAND

Class Two Experiments

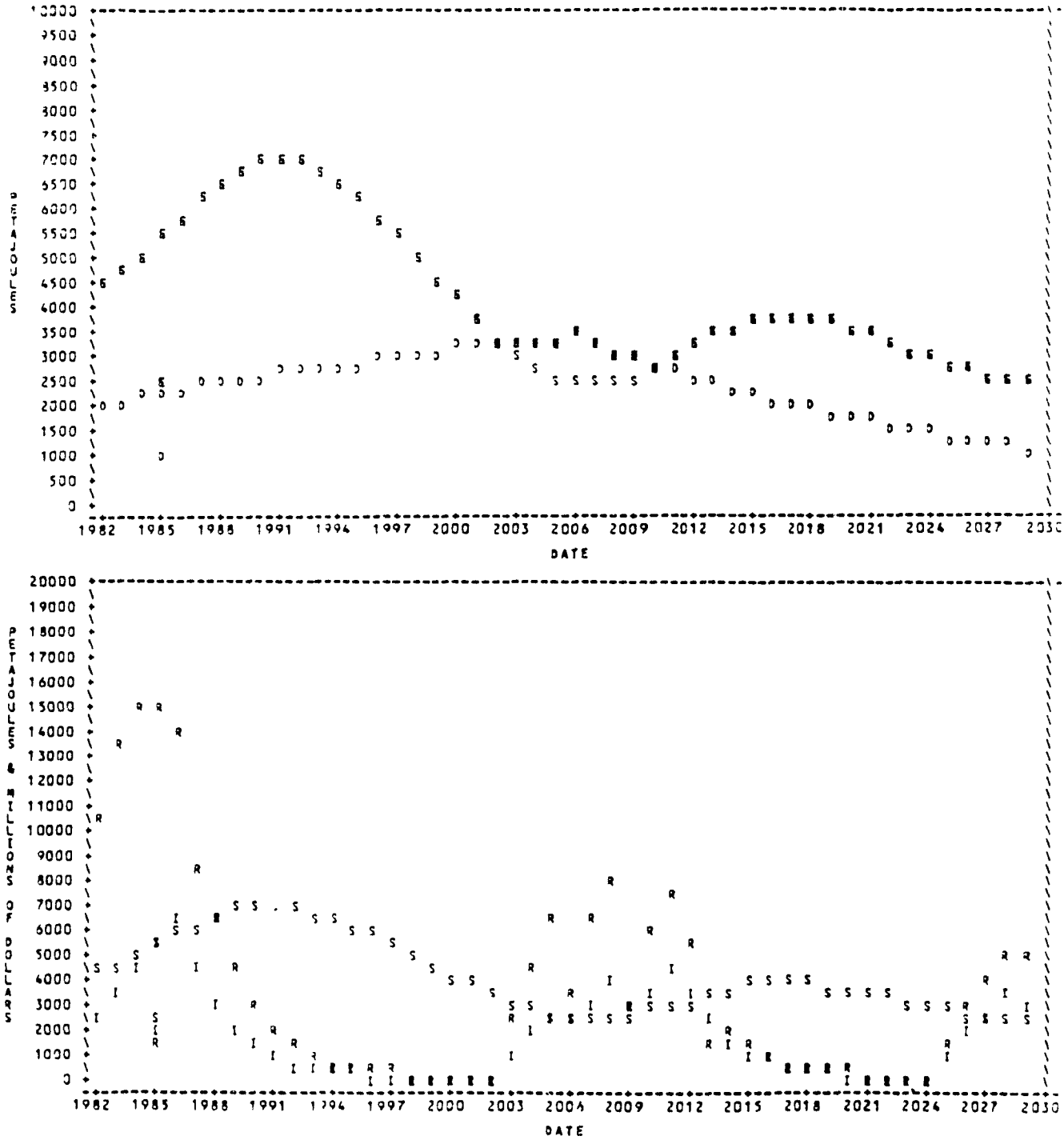
In the class two experiments, five additional cases are studied. These will be referred to in sequence, following the previous six sensitivity analyses. In the seventh case a "no NEB" model is run. This is produced by setting the protection periods for each of the tests, FDT, CDT, CRT to zero. In the eighth case, no exports are allowed, and only domestic sales are permitted. This is referred to as the "no export" case. In cases nine, ten and eleven, the CRT, then CDT, then FDT are respectively deleted, or reduced to a zero protection period.

Class Two Sensitivity Analyses on Rules

The "No NEB" Case

Under the "no NEB" assumption, the rate of growth of exports as might be expected is initially rapid. The constraining elements seem to be the maximum producibility, and the costs of "overheating" the industry, which produce an increase over historic average costs of production, and by the costs of constructing additional export pipeline facilities. In both the base case and the "no NEB" cases, there are rapid buildups in inventories in the short run, but the costs of additional supplies increase rapidly after that initial burst of investment, and the industry must wait for some fifteen years for price increases to justify increased investments in reserves additions. The initial 150 EJ of remaining reserves is exhausted by the year 27 (2008), compared to year 30 (2011) in the base case and over the fifty year horizon. In the absence of the inventory type rules CDT, FDT, CRT, the second wave of investments, reserves additions, and exports are accelerated, and larger than in the previous case.

Figures 5-8a, 5-8b
NO NEB CASE



LEGEND:
'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ '000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

Table 5-8
NO NEB CASE

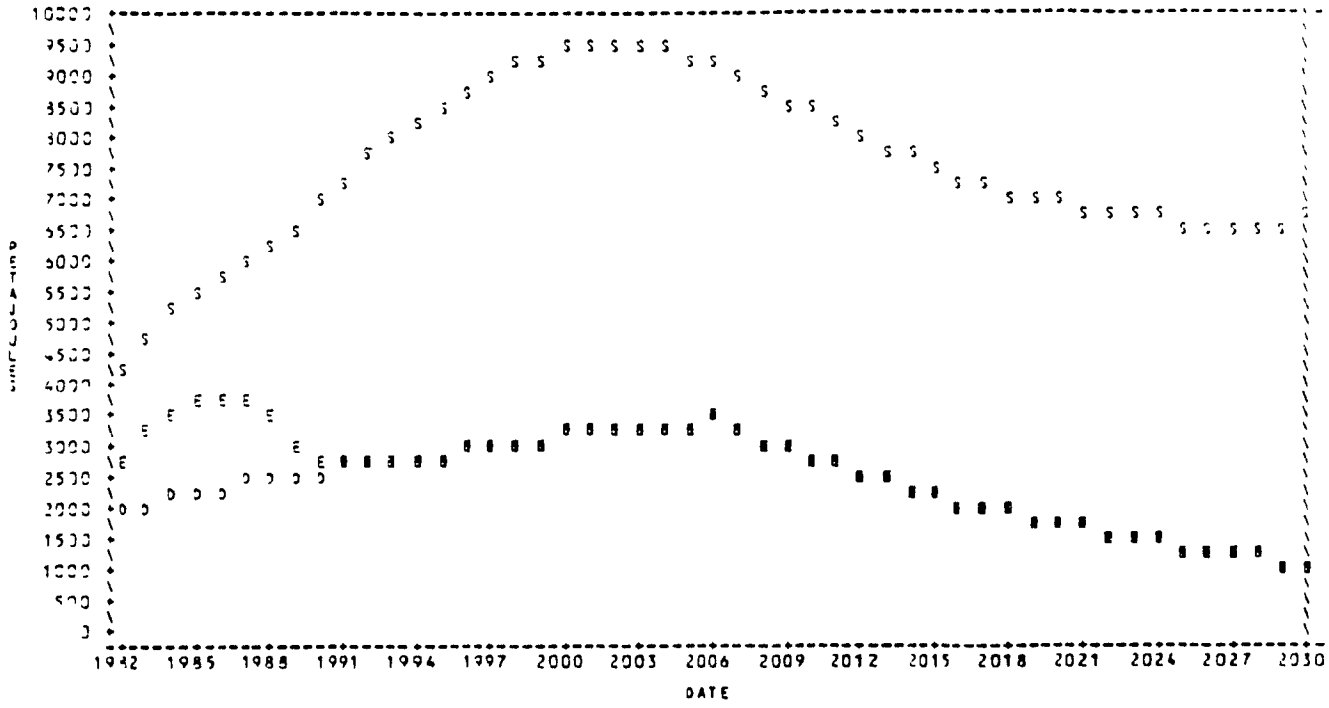
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2500	6084	10709	10709	139291	4380	1972
1983	3499	14346	13715	24424	125576	4696	2048
1984	4449	23475	15088	39512	110488	5049	2177
1985	5364	32192	15027	54539	95461	5402	2290
1986	6254	39343	13787	68326	81674	5800	2357
1987	4377	45524	8501	76827	73173	6234	2417
1988	3063	52363	6333	83160	66840	6515	2474
1989	2144	59982	4521	87681	62319	6800	2541
1990	1500	68650	3226	90907	59093	6953	2622
1991	1049	78456	1817	92724	57276	6967	2673
1992	734	89829	1368	94092	55908	6940	2711
1993	513	102979	975	95067	54933	6709	2760
1994	359	118166	696	95763	54237	6497	2816
1995	251	135689	496	96259	53741	6157	2864
1996	175	155894	353	96612	53388	5796	2918
1997	122	179167	251	96863	53137	5415	2972
1998	85	205960	178	97041	52959	4952	3026
1999	59	236796	126	97167	52833	4515	3080
2000	41	272274	89	97256	52744	4174	3136
2001	28	313086	62	97318	52682	3766	3182
2002	19	360029	43	97361	52639	3369	3227
2003	1013	414655	2349	99710	50290	3052	3273
2004	1959	478054	4633	104343	45657	2783	3320
2005	2621	551382	6323	110666	39334	2585	3369
2006	2334	634175	3506	114172	35828	2453	3418
2007	3133	730391	6291	120463	29537	2432	3251
2008	3943	841322	8075	128538	21462	2488	3092
2009	2760	966972	3202	131740	18260	2592	2942
2010	3681	1112303	5883	137623	12377	2758	2800
2011	4576	1279583	7459	145082	4918	2974	2664
2012	3453	1471997	5741	150823	-823	3198	2535
2013	2417	1691346	1382	152205	-2205	3414	2412
2014	1691	1944727	1950	154155	-4155	3621	2296
2015	1183	2236225	1391	155546	-5546	3760	2185
2016	828	2571513	993	156539	-6539	3804	2079
2017	579	2957137	708	157247	-7247	3809	1979
2018	405	3400633	505	157752	-7752	3771	1883
2019	283	3910670	360	158112	-8112	3686	1792
2020	198	4497229	256	158368	-8368	3582	1708
2021	138	5171776	182	158550	-8550	3457	1627
2022	96	5947508	129	158679	-8679	3296	1550
2023	67	6839607	92	158771	-8771	3116	1476
2024	46	7865523	64	158835	-8835	2948	1407
2025	1032	9045349	1479	160314	-10314	2790	1341
2026	1972	10402201	2884	163198	-13198	2650	1277
2027	2630	11962634	3923	167121	-17121	2553	1217
2028	3340	13757189	5082	172203	-22203	2511	1161
2029	3087	15820991	4791	176994	-26994	2536	1106
2030	2160	18192832	1251	178245	-28245	2593	1055

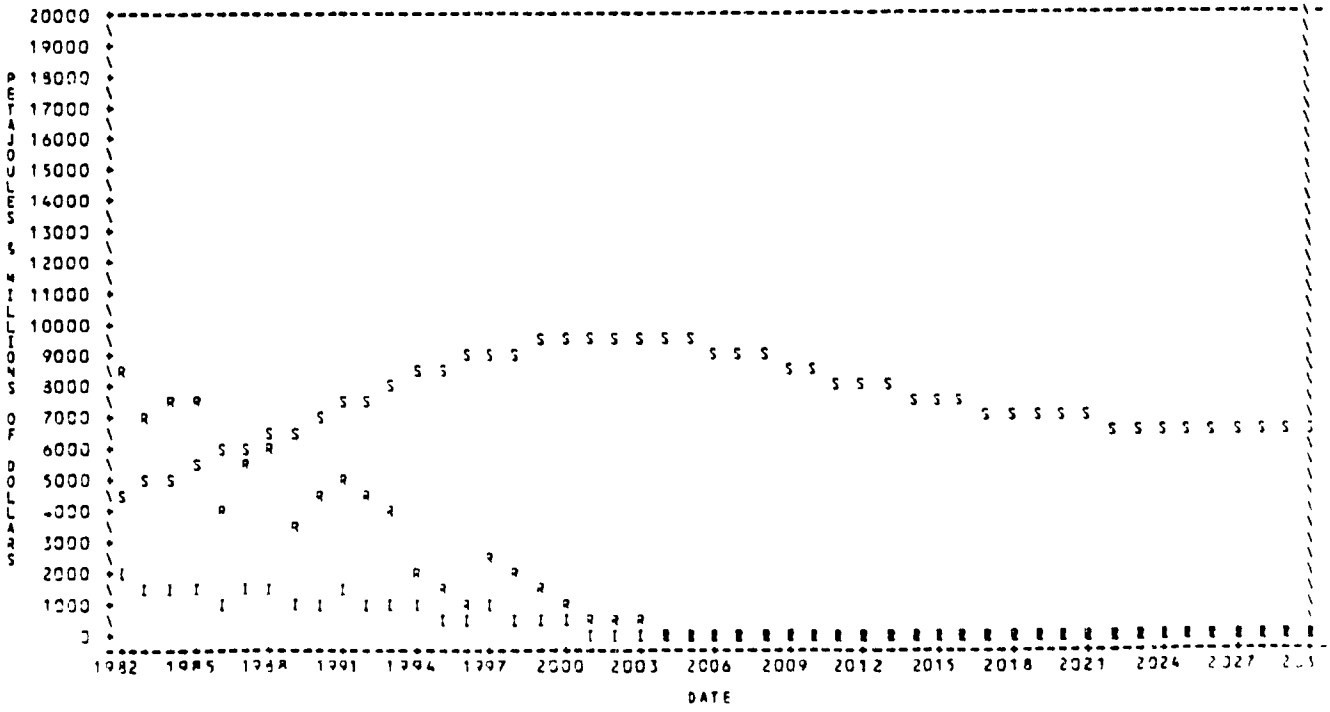
(1) YEAR
(2) ANNUAL INVESTMENT ('000 000)
(3) CUMULATIVE PRESENT VALUE ('000 000)
(4) ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5) CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6) REMAINING WCSB RESERVES (PETAJOULES)
(7) DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8) DOMESTIC DEMAND

The "No Exports" Case

In the case of "no exports", industry investment shuts down for fifteen years, at which time there is a temporary surge in investment, which then dies off for another fifteen years. Only 113 of the initial 150 EJ of initial reserves are used over the entire fifty year horizon. This is a "closed border" example and allows us to compare a no exports strategy with the others. This is not the strongest possible example, as existing export licences are honoured as they stand at 1982, but no <u>new</u> exports are allowed. Clearly those interested in preserving gas for the future would consider this strategy attractive. The "no exports" case can be considered to be simply a case in which the protection periods under the CDT, FDT, or CRT are very long. This case would, therefore be viewed as being near the extreme, of the continuum in which exports are unconstrained (by rules) at one end and prohibited at the other. Before we consider the three cases that simulate the removal of each of these 1982 rules, it might be useful to summarize the two extreme cases (no exports and no rule constraints on exports) and compare them to the base case.

Figures 5-9a, 5-9b
NO EXPORTS CASE





LEGEND:

'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ '000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

Table 5-9
NO EXPORTS CASE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2000	938	8567	8567	141433	4369	1972
1983	1649	1955	7091	15658	134342	4782	2048
1984	1654	3055	7370	23028	126972	5181	2177
1985	1657	4248	7531	30559	119441	5498	2290
1986	1159	5183	4095	34654	115346	5774	2357
1987	1311	6392	5314	39968	110032	6074	2417
1988	1417	7756	5859	45827	104173	6284	2474
1989	991	9226	3414	49241	100759	6588	2541
1990	1193	10958	4277	53518	96482	6928	2622
1991	1335	12933	4882	58400	91600	7282	2673
1992	1184	15170	4416	62816	87184	7701	2711
1993	1078	17690	4101	66917	83083	8022	2760
1994	754	20239	1901	68818	81182	8313	2816
1995	527	23299	1668	70486	79514	8536	2864
1996	368	26809	1188	71674	78326	8769	2918
1997	757	30931	2493	74167	75833	9024	2972
1998	529	35654	1777	75944	74056	9186	3026
1999	370	41014	1268	77212	72788	9339	3080
2000	258	47173	901	78113	71887	9549	3136
2001	180	54247	641	78754	71246	9616	3182
2002	125	62376	454	79208	70792	9605	3227
2003	87	71723	322	79530	70470	9569	3273
2004	60	82471	226	79756	70244	9471	3320
2005	41	94830	157	79913	70087	9332	3369
2006	28	109047	109	80022	69978	9157	3418
2007	19	125392	76	80098	69902	8972	3251
2008	13	144188	52	80150	69850	8778	3092
2009	9	165807	37	80187	69813	8583	2942
2010	6	190671	24	80211	69789	8401	2800
2011	4	219267	16	80227	69773	8216	2664
2012	2	252154	8	80235	69765	8022	2535
2013	1	289976	4	80239	69761	7828	2412
2014	0	333471	0	80239	69761	7638	2296
2015	0	383488	0	80239	69761	7459	2185
2016	0	441006	0	80239	69761	7299	2079
2017	0	507149	0	80239	69761	7167	1979
2018	0	583212	0	80239	69761	7062	1883
2019	0	670682	0	80239	69761	6969	1792
2020	0	771271	0	80239	69761	6879	1708
2021	0	886946	0	80239	69761	6805	1627
2022	0	1019970	0	80239	69761	6735	1550
2023	0	1172945	0	80239	69761	6675	1476
2024	0	1348864	0	80239	69761	6633	1407
2025	0	1551167	0	80239	69761	6603	1341
2026	0	1783810	0	80239	69761	6586	1277
2027	0	2051345	0	80239	69761	6583	1217
2028	0	2359006	0	80239	69761	6591	1161
2029	0	2712815	0	80239	69761	6611	1106
2030	0	3119691	0	80239	69761	6637	1055

(1)YEAR
(2)ANNUAL INVESTMENT ('000 000)
(3)CUMULATIVE PRESENT VALUE ('000 000)
(4)ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5)CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6)REMAINING WCSB RESERVES(PETAJOULES)[NEGATIVE FROM FRONTIER]
(7)DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8)DOMESTIC DEMAND

The following table summarizes some of the key contrasts between the three cases: base, "no NEB" and "no exports".

Case	Year of Discovery of 150 EJ	Reserves Used by Year 50	Reserves Drawn on from Frontier	Cumulative Value of 150 EJ at Year 51
"BASE"	30	157	7	20,974,519
"NO NEB"	31	178	28	20,949,126
"NO EXPORTS"	>50	80	0	3,587,644

There appears to be very little difference in the value of the reinvested profits at year 51, between the base and "no NEB" cases. There is a difference in the pattern of exports, but if the more rapid and earlier exports under "no NEB" are reinvested at 15%, they produce about the same value as the base case stream. This somewhat unexpected result does not reflect the costs of regulation which are far from negligible. One would expect the unconstrained case to have a higher value than the (constrained) NEB or base case, but according to the simulation at least, such is not the case. The explanation, it would seem, is that the future commodities-values achieved by selling gas earlier and investing the proceeds and selling gas later at a higher price are about the same.

Given the nature of the cost of reserves function, it is not profitable to find and export much more reserves than under the base case. Especially, in the early years, the pipeline constraints are expensive to overcome, and producer costs become excessive if the industry gets too heated up. These constraints were effective in the first five years when reserves additions rose. The model does still allow reserves additions to approach annual levels of over 15 exajoules, under both base and "no NEB" cases, far

in excess of anything yet observed in the history of the gas industry. There were no direct constraints on investment funds.

That I perceive this similarity in results as suspect could be due to my view of the results being tainted by recent history; low prices, low reserves additions, the existence of general market oversupply conditions and a gas "bubble". However, if it really was the case that prices were $4.00/gj and growing at 5% p.a. and with oil prices rising in step, the gas industry would be drilling at very high levels. The higher reserves additions, the higher the remaining established reserves, and the greater the deliverability, the less the NEB rules will act as a constraint and the closer would be the NEB and the no NEB scenarios.

In the no exports case, further exploration is not required for twenty years. The rules in the early years when output and sales are highest offer no real constraint. Only when supplies are low do they really effect the system. It is really in the later period, after year 20, that the rules effect allowable exports, and the benefit stream. By then most of the reserves have been found (104 out of 150) and the value of the benefits of the exports that had already been approved is compounding at 15% for both cases for the remaining years. This early exports effect dominates the relatively small effect the differential in allowable exports which the "no NEB" case creates.

Within the model, the financial performance is similar, but domestic demand experiences some shortfalls in year 22 under the "no NEB" case, and only briefly around year 24 under the NEB or base case. These shortfalls must be evaluated, and traded off against the financial results.

The "no exports" model is clearly extreme, the reinvested profits would be valued at three billion dollars in year 51, about one-sixth the value of the other options. However, of the 150 initial remaining established reserves, about 70 remain at year 51, and these exajoules would be an asset, the value of which would have to be taken into account in the no export case.

"No CRT", "No CDT", "No FDT" Cases

These three cases are created by respectively reducing the protection period for each test individually to one year. First the current reserves test is removed, then the current deliverability test alone is removed, and lastly, the future deliverability test alone is removed.

The elimination of the CRT has little effect in the period (years 1 to 26) 1982-2007, thereafter. however, there is a small increase in exports over the NEB case when the effect of reserves additions from 2002 onward began to rebound and allow increases in exports. There is the same pronounced cycle in investment and reserves additions that was noted in the NEB case. This contrasts with the pattern of reserves additions that can be observed in the "no CDT" case, which is somewhat more persistent or extensive, especially in years 12 to 19.

The "no CDT" case is created by including 100% of trend gas expected in future periods due to reserves additions with deliverability from established reserves at any particular point in time. Also, the protection period under the CDT is set to that of the FDT, ten years in this case. This essentially turns the CDT into the FDT, or disables the CDT as a binding test.

In the "no CDT" case, the deliverability from established reserves curve is below that of the base case. This is because the higher volume of exports (over the ten

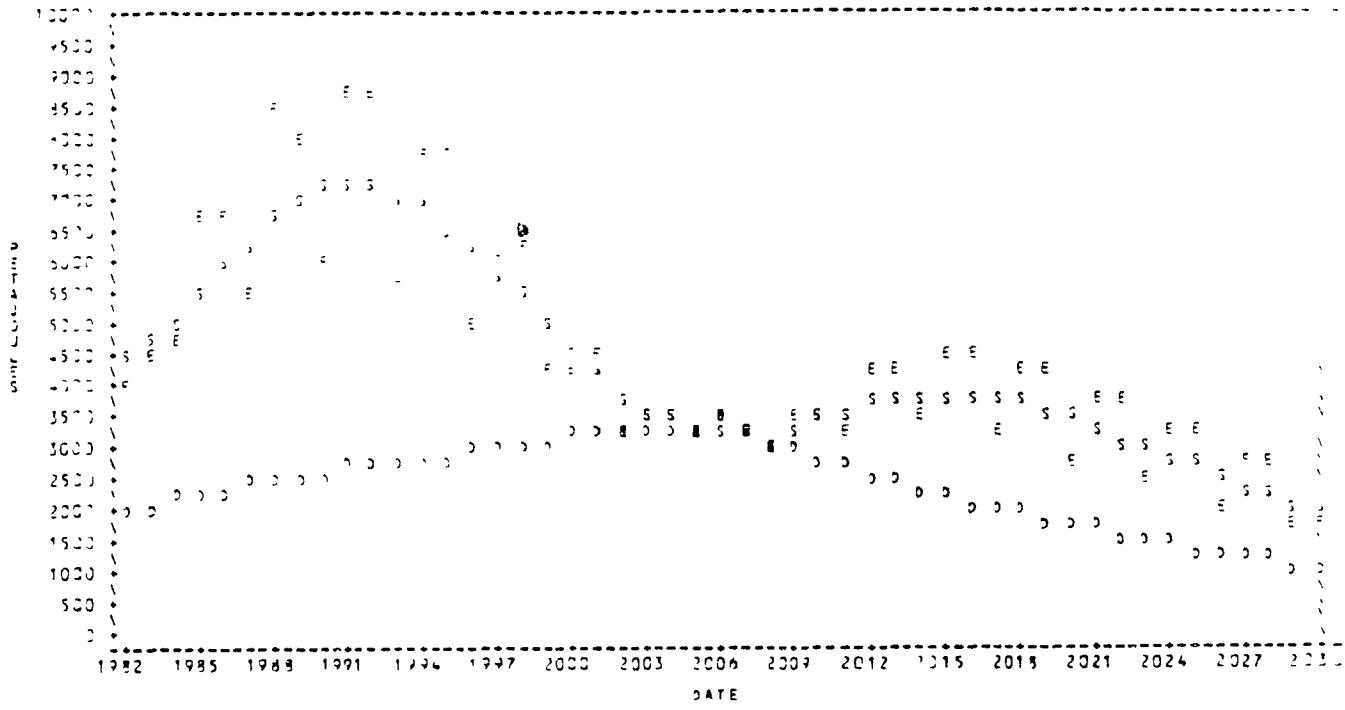
year term which would be allowed with the FDT and CRT in place) rapidly depletes the 1982 established reserves, and the relatively low cost reserves additions. The rapid decline in early exploration noted in the base case does not occur here, because of the possibility of longer term exports which influences the sequential exploration decisions. The certain period for exports increasing from five years to ten years in this way affects the rate of reserves additions and thus deliverability.

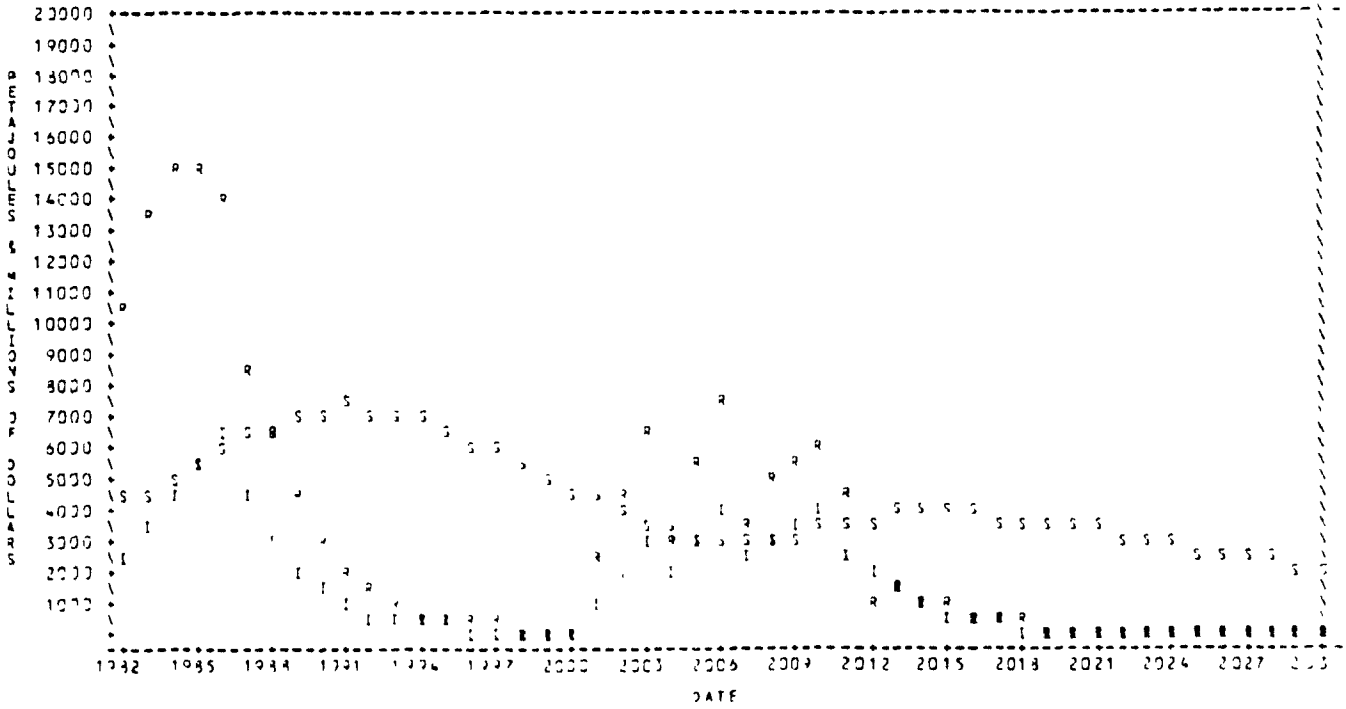
In the first twenty years, the FDT constrains exports fairly severely, and as a result early exports are curtailed relatively to the NEB case. However, the loss of the FDT has the apparent effect of lengthening and smoothing out the cycles of investment and reserves additions, which postpones the later exports under NEB, which begin at about 2007, to about the year 2015. The relatively high early deliverability which is used earlier on, appears to cause the other two tests, CDT, CRT to be binding at the earlier time, 2007, and requires more reserves and deliverability to be built up before the exports would be allowed under these two tests.

The value of these three scenarios is fairly close, within about 1% of each other. The effect of the loss of any <u>one</u> of the tests did not seem to dramatically change the performance of the system.

I also note that under "no CRT", the first 150 EJ are discovered in 29 years, under "no CDT" they are found in 37 years, and under "no FDT" they are found in 38 years. These data reflect the earlier discussions on the changes in the cycles of investment and discovery.

Figures 5-10a, 5-10b
NO CRT CASE





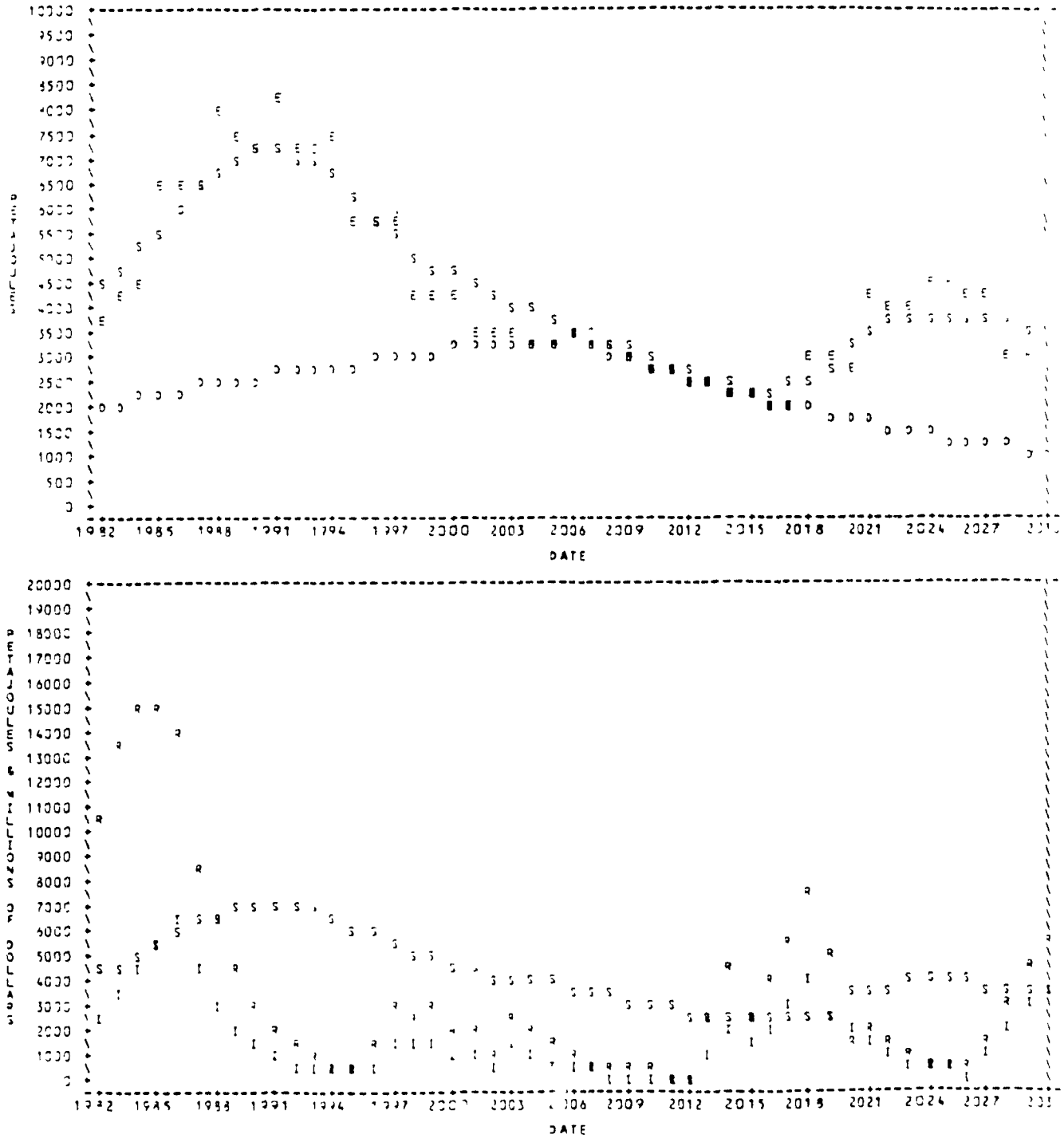
LEGEND:
'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ '000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

Table 5-10
NO CRT CASE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2500	6084	10709	10709	139291	4380	1972
1983	3499	14346	13715	24424	125576	4725	2048
1984	4449	23475	15088	39512	110488	5115	2177
1985	5364	32160	15027	54539	95461	5500	2290
1986	6254	39306	13787	68326	81674	5898	2357
1987	4377	45481	8501	76827	73173	6335	2417
1988	3063	52312	6333	83160	66840	6691	2474
1989	2144	59921	4521	87681	62319	6976	2541
1990	1500	68578	3226	90907	59093	7132	2622
1991	1049	78371	1817	92724	57276	7257	2673
1992	734	89726	1368	94092	55908	7230	2711
1993	513	102860	975	95067	54933	7001	2760
1994	359	118029	696	95763	54237	6897	2816
1995	251	135532	496	96259	53741	6524	2864
1996	175	155712	353	96612	53388	6132	2918
1997	122	178956	251	96863	53137	5866	2972
1998	85	205716	178	97041	52959	5403	3026
1999	59	236516	126	97167	52833	4892	3080
2000	41	271951	89	97256	52744	4625	3136
2001	1028	313303	2291	99547	50453	4255	3182
2002	1969	361392	4476	104023	45977	3788	3227
2003	2878	417180	6674	110697	39303	3592	3273
2004	2014	479760	2912	113609	36391	3439	3320
2005	2909	552608	5614	119223	30777	3205	3369
2006	3786	636647	7453	126676	23324	3168	3418
2007	2650	731935	3494	130170	19830	3180	3251
2008	3104	841918	4768	134938	15062	3112	3092
2009	3422	968467	5361	140299	9701	3227	2942
2010	3895	1114081	6225	146524	3476	3376	2800
2011	2726	1281549	4443	150967	-967	3474	2664
2012	1908	1472654	1128	152095	-2095	3632	2535
2013	1335	1693271	1509	153604	-3604	3769	2412
2014	934	1947072	1077	154681	-4681	3793	2296
2015	653	2238999	767	155448	-5448	3823	2185
2016	457	2574754	548	155996	-5996	3782	2079
2017	319	2960902	390	156386	-6386	3698	1979
2018	223	3404982	278	156664	-6664	3648	1883
2019	156	3915686	198	156862	-6862	3528	1792
2020	109	4503001	141	157003	-7003	3384	1708
2021	76	5178418	100	157103	-7103	3276	1627
2022	53	5955152	71	157174	-7174	3104	1550
2023	37	6848399	50	157224	-7224	2921	1476
2024	25	7875634	34	157258	-7258	2804	1407
2025	17	9056961	24	157282	-7282	2647	1341
2026	11	10415490	15	157297	-7297	2465	1277
2027	7	11977802	10	157307	-7307	2371	1217
2028	4	13774463	5	157312	-7312	2258	1161
2029	2	15840625	2	157314	-7314	2110	1106
2030	1	18216688	1	157315	-7315	2049	1055

(1)YEAR
(2)ANNUAL INVESTMENT ('000 000)
(3)CUMULATIVE PRESENT VALUE ('000 000)
(4)ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5)CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6)REMAINING WCSB RESERVES(PETAJOULES)[NEGATIVE FROM FRONTIER]
(7)DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8)DOMESTIC DEMAND

Figures 5-11a, 5-11b
NO CDT CASE



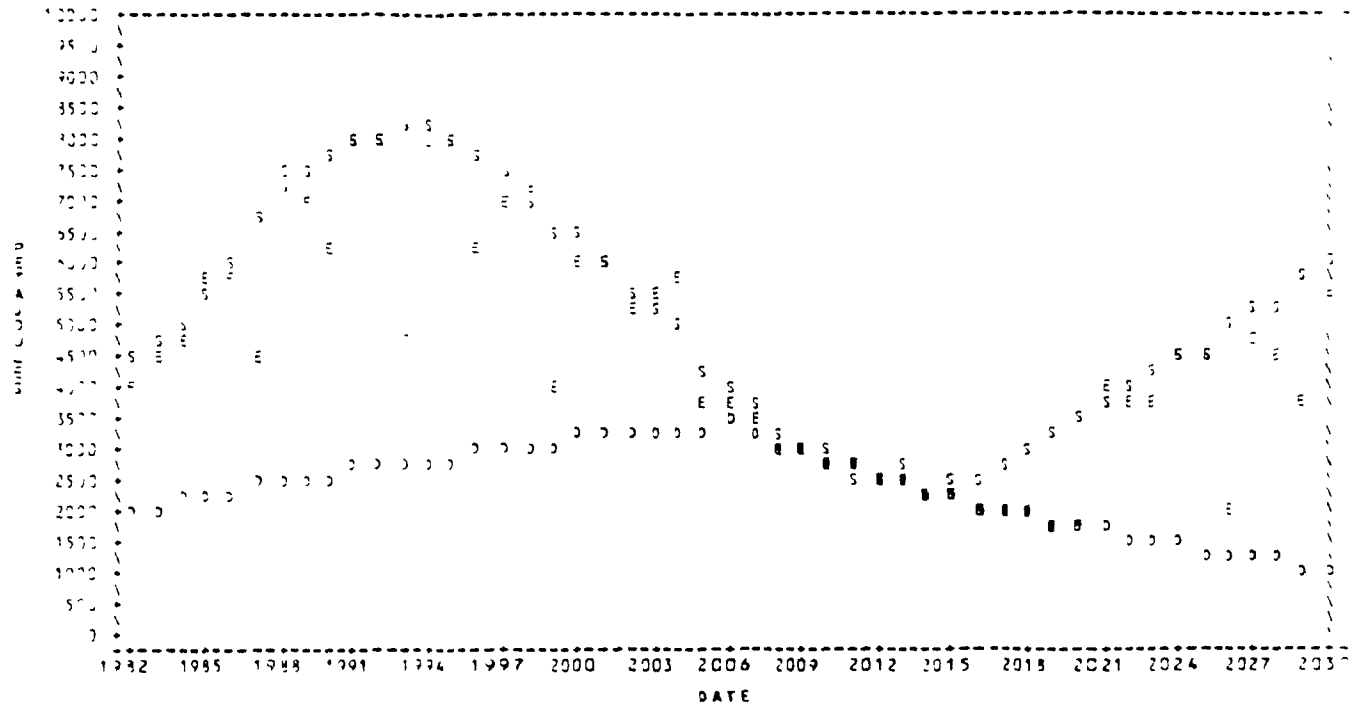
LEGEND:
'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ '000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

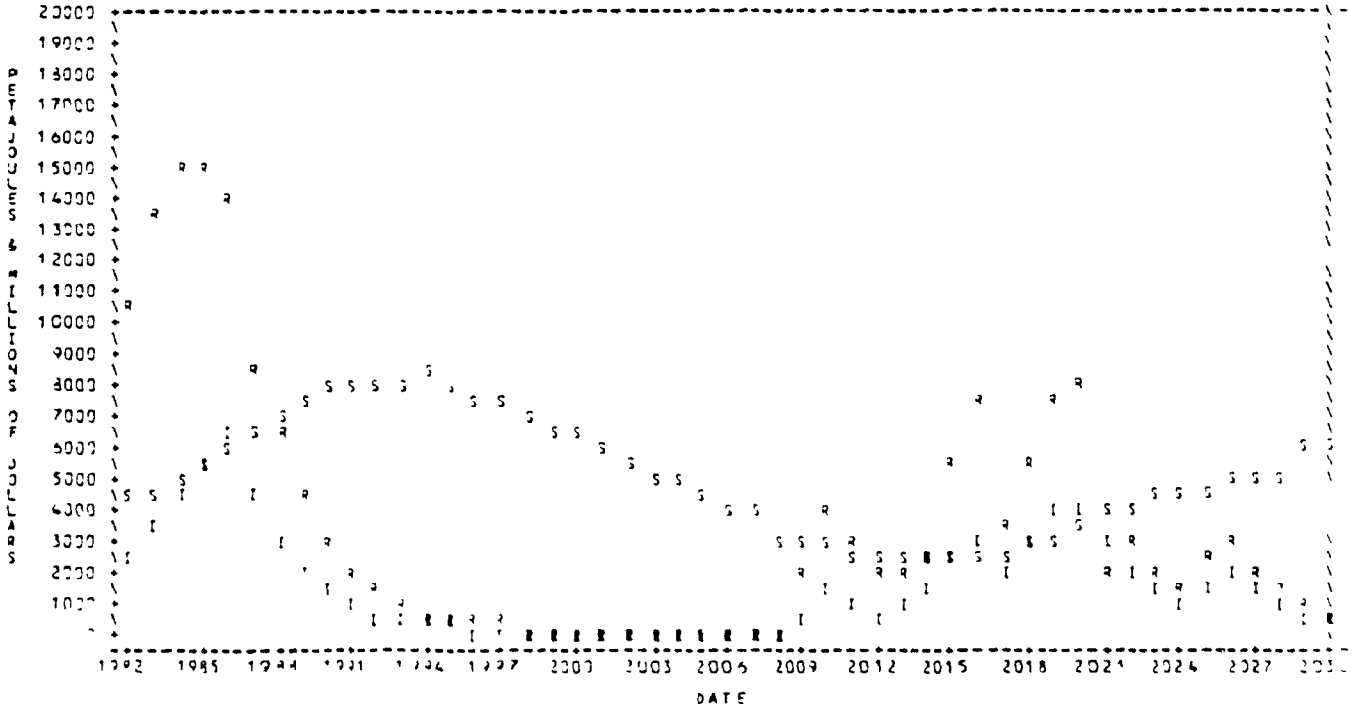
Table 5-11
NO CDT CASE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2500	6084	10709	10709	139291	4380	1972
1983	3499	14346	13715	24424	125576	4748	2048
1984	4449	23475	15088	39512	110488	5164	2177
1985	5364	32162	15027	54539	95461	5577	2290
1986	6254	39307	13787	68326	81674	5975	2357
1987	4377	45483	8501	76827	73173	6412	2417
1988	3063	52314	6333	83160	66840	6693	2474
1989	2144	59926	4521	87681	62319	6978	2541
1990	1500	68585	3226	90907	59093	7134	2622
1991	1049	78379	1817	92724	57276	7148	2673
1992	734	89735	1368	94092	55908	7121	2711
1993	513	102868	975	95067	54933	6892	2760
1994	359	118037	696	95763	54237	6628	2816
1995	251	135539	496	96259	53741	6229	2864
1996	675	156132	1362	97621	52379	5870	2918
1997	1472	180179	3031	100652	49348	5525	2972
1998	1280	207791	2688	103340	46660	5108	3026
1999	1395	239631	2988	106328	43672	4845	3080
2000	976	276077	2132	108460	41540	4670	3136
2001	933	317998	2079	110539	39461	4416	3182
2002	653	365709	976	111515	38485	4227	3227
2003	1457	420983	2702	114217	35783	4072	3273
2004	1019	483087	1927	116144	33856	3912	3320
2005	713	554816	1375	117519	32481	3768	3369
2006	499	637521	981	118500	31500	3621	3418
2007	349	732785	700	119200	30800	3431	3251
2008	244	842416	499	119699	30301	3276	3092
2009	170	968862	354	120053	29947	3159	2942
2010	118	1114226	251	120304	29696	2974	2800
2011	82	1281377	177	120481	29519	2822	2664
2012	57	1473586	125	120606	29394	2706	2535
2013	1039	1695219	2349	122955	27045	2544	2412
2014	1977	1950681	4559	127514	22486	2425	2296
2015	1383	2243593	2413	129927	20073	2359	2185
2016	2218	2580691	3992	133919	16081	2336	2079
2017	3052	2968581	5603	139522	10478	2396	1979
2018	3886	3414878	7276	146798	3202	2530	1883
2019	2720	3927965	5195	151993	-1993	2667	1792
2020	1903	4516200	1352	153345	-3345	3375	1708
2021	1332	5193534	1764	155109	-5109	3582	1627
2022	932	5971583	1259	156368	-6368	3692	1550
2023	652	6866639	898	157266	-7266	3754	1476
2024	456	7896160	640	157906	-7906	3775	1407
2025	319	9080251	457	158363	-8363	3775	1341
2026	223	10442055	325	158688	-8688	3752	1277
2027	1156	12008399	1724	160412	-10412	3711	1217
2028	2059	13809762	3133	163545	-13545	3648	1161
2029	2941	15881401	4564	168109	-18109	3623	1106
2030	3558	18263840	5633	173742	-23742	3671	1055

(1)YEAR
(2)ANNUAL INVESTMENT ('000 000)
(3)CUMULATIVE PRESENT VALUE ('000 000)
(4)ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5)CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6)REMAINING WCSB RESERVES(PETAJOULES)[NEGATIVE FROM FRONTIER]
(7)DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8)DOMESTIC DEMAND

Figures 5-12a, 5-12b
NO FDT CASE





LEGEND:

'D' DOMESTIC DEMAND (PETAJOULES)
'E' DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS (PETAJOULES)
'S' DELIVERABILITY FROM ESTABLISHED RESERVES (PETAJOULES)
'I' ANNUAL INVESTMENT ($ ·000 000)
'R' ANNUAL RESERVES ADDITIONS (PETAJOULES)

Table 5-12
NO FDT CASE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1982	2500	6084	10709	10709	139291	4380	1972
1983	3499	14346	13715	24424	125576	4725	2048
1984	4449	23475	15088	39512	110488	5115	2177
1985	5364	32160	15027	54539	95461	5500	2290
1986	6254	39306	13787	68326	81674	5898	2357
1987	4377	45461	8501	76827	73173	6655	2417
1988	3063	52275	6333	83160	66840	7162	2474
1989	2144	59869	4521	87681	62319	7447	2541
1990	1500	68510	3226	90907	59093	7831	2622
1991	1049	78284	1817	92724	57276	8009	2673
1992	734	89622	1368	94092	55908	7982	2711
1993	513	102735	975	95067	54933	8154	2760
1994	359	117884	696	95763	54237	8257	2816
1995	251	135364	496	96259	53741	7904	2864
1996	175	155517	353	96612	53388	7626	2918
1997	122	178732	251	96863	53137	7383	2972
1998	85	205457	178	97041	52959	6925	3026
1999	59	236217	126	97167	52833	6548	3080
2000	41	271607	89	97256	52744	6471	3136
2001	28	312318	62	97318	52682	6077	3182
2002	19	359146	43	97361	52639	5521	3227
2003	13	413004	30	97391	52609	5218	3273
2004	9	474945	21	97412	52588	4907	3320
2005	6	546180	14	97426	52574	4268	3369
2006	4	628102	9	97435	52565	4032	3418
2007	2	722315	5	97440	52560	3840	3251
2008	1	830660	2	97442	52558	3233	3092
2009	750	955861	1958	99400	50600	3081	2942
2010	1524	1100499	4059	103459	46541	3024	2800
2011	1066	1264406	2896	106355	43645	2574	2664
2012	746	1453260	2067	108422	41578	2568	2535
2013	772	1672009	2182	110604	39396	2640	2412
2014	1540	1923191	2736	113340	36660	2319	2296
2015	2327	2213101	5474	118814	31186	2422	2185
2016	3128	2546973	7506	126320	23680	2578	2079
2017	2189	2929356	3617	129937	20063	2659	1979
2018	3032	3369619	5677	135614	14386	2913	1883
2019	3872	3876163	7395	143009	6991	3245	1792
2020	4210	4458836	8202	151211	-1211	3385	1708
2021	2946	5126086	1959	153170	-3170	3786	1627
2022	2062	5894890	2786	155956	-5956	3993	1550
2023	1443	6779077	1988	157944	-7944	4268	1476
2024	1010	7795919	1419	159363	-9363	4432	1407
2025	1706	8965316	2446	161809	-11809	4483	1341
2026	1944	10310163	2843	164652	-14652	4881	1277
2027	1360	11855260	2028	166680	-16680	5145	1217
2028	951	13632557	1447	168127	-18127	5140	1161
2029	665	15676752	1032	169159	-19159	5852	1106
2030	465	18027776	736	169895	-19895	5882	1055

(1) YEAR
(2) ANNUAL INVESTMENT ('000 000)
(3) CUMULATIVE PRESENT VALUE ('000 000)
(4) ANNUAL RESERVES ADDITIONS (PETAJOULES)
(5) CUMULATIVE RESERVES ADDITIONS (PETAJOULES)
(6) REMAINING WCSB RESERVES (PETAJOULES) [NEGATIVE FROM FRONTIER]
(7) DOMESTIC DEMAND PLUS AUTHORIZED EXPORTS
(8) DOMESTIC DEMAND

Comparisons of Sensitivity Analyses

Case	Year of Discovery of 150 EJ	WCSB Reserves Used by Year 50	Value of 150 EJ at Year 50	Case Description
Base	30	157	18,216,688	"NEB"
1	23	180	66,361,707	P ↑ 10% p.a.
2	>50	143	3,261,695	P ↓ 0% p.a.
3	30	171	18,246,128	Hearings every 5 years
4	27	183	24,667,759	Investment Effort Improvement
5	48	151	49,525,690	Discount Rate=.20
6	36	163	31,712,749	Accelerated Drawdown
7	27	178	18,192,832	"No NEB"
8	>50	80	3,119,691	"No Exports"
9	29	157	18,233,648	"No CRT"
10	36	175	18,263,840	"No CDT"
11	38	170	18,033,427	"No FDT"

The Implications of the Simulation Model Runs

The basic simulation model runs, and the sensitivity analysis offered different types of results. Results on the effect that changes in parameters have on model performance, were produced which allow one to consider if the direction and magnitude of the effects are intuitively what one expects. The results also suggest the likely effect that various types of rules would have on the

performance of the industry. In the latter case, it is only likely directional influences that can be strongly convincing because of the previously stated problems with establishing model validity. This chapter will now continue with a consideration of these results and the overall modelling effort in the context of the discussions of equity in Chapters Two and Three.

Review of Class One and Class Two of Sensitivity Analyses

The effects of the changes in rules were mostly as expected on a priori grounds. Some of the results are summarized in the preceeding table. Price increases accelerate, and price decreases slow the rate of depletion. Technological improvement accelerates the rate of drawdown, and increases the investment value of natural gas, as does an increase in the rates of connection and production. Interestingly, the removal of any one test does not significantly affect the performance of the system as regards the value of the gas sold, but does change the quantity of remaining reserves available at year 50, a tradeoff which would have to be evaluated by the relevant decision-makers. I note, again, that the removal of all three tests, in the "no NEB" case, also did produce results similar to the base or NEB case.

Results and Equity

In Chapters Two and Three I discussed a variety of approaches to the concept of equity, and equity in finite resource use which have appeared in the literatures of several fields. One of the results of that review was that the market solution to the problem of finite resource use, traced through the literature in Chapter One, is only one of several or even of many ethically acceptable solutions. The market does present one solution to the problem, but the

acceptability of the solution is clearly subject to debate. In Chapter Two we emphasized the contrasts between psychological studies of values, attitudes and equitable behaviour which focus on what people might want to do, and those more ethically oriented studies which focus on what people should or ought to do. There are, further, a large number of ethical theories, as was demonstrated in Chapters Two and Three, which are still competitive, in the sense that no theory has been shown to be satisfactory, or acceptable to all, or even to be clearly dominant or to express a majority consensus. This conclusion applies to utilitarianism which lies at the basis of the ethical evaluation of most market operations. At this point in time, therefore the most that can be said is that the market offers one of several possible solutions to the finite resource use problem.

Should it be the case that individuals are dissatisfied with the market process, or solution, and wish on ethical grounds to pursue alternatives, their choices cannot be condemned on economic grounds. Koopmans (1965) notes this in the following:

> "...the balancing of the interests of different generations is an ethical or political problem, in which the competitive market solution has no valid claim to moral superiority over other solutions that depend for their realization on action by the state."[1]

Individuals may wish to have a non-market solution to the finite resource use problem, one which implies or results in a pattern of natural gas use over time, different from the market pattern.

This may be true for a variety of reasons. It may reflect specific attitudes toward risk, perhaps a refusal

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[1] Koopmans (1965), p. 286.

to accept nuclear power until all of its safety and waste disposal problem have been solved. This could put additional emphasis on the immediate use of gas stocks, or in the realization that the nuclear problems will not be solved for possibly several generations, suggest a rationing of gas use, through price or non-price measures. Gas is a clean-burning, relatively environmentally harmless energy source, and is highly prized, there are many reasons why rules or restrictions on its rate of usage relative to market rates may be encouraged.

The gas industry is a complex industry, and it is difficult to imagine how many of these types of rules would affect the industry, and if certain of these rules would achieve their desired results.

Beyond the issue of gas use, or the use of a finite resource, we are also concerned with some other influences, notably investment and industry employment. One might even pursue the effect of such rules on the national economy, but such a study is beyond the scope of this paper. The industry simulation model helps one to see the effect that certain types of rules would have on this complex industry.

As shown earlier in this chapter, current deliverability, future deliverability, and current reserves test rules on exports have little effect on the usage rate of natural gas relative to the market solution. Or more precisely, given an initial situation where rules have been in place for some time (and inventories and associated costs incurred over a long period of time, say twenty years, there is little difference between the "NEB" and "no NEB" solutions.[2] A difference in the two scenarios is evidenced, only after about twenty-five years, when

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[2] A "no exports" rule is very conservative, however.

inventories are reduced, and the more rapid response of exports under the "no NEB" analysis is noted. The differences however, cannot really be considered dramatic. The conclusion of this analysis is, therefore, that the use of the NEB rules described can only be considered to have a small intergenerational effect on finite resource usage, in the context of this model, and the assumptions and data used. These types of rules, at the level at which they have been set, modify the pattern of development relatively little. Differences are apparent from year to year but not across generations. The existing level of rules do little to protect the interests of future generations of Canadians.

The rules may be strengthened, i.e., setting longer and longer protection periods, until exports are reduced with the extreme position becoming the "no exports" case.[3]

Considerable attention has been given to the role of exports in this analysis, for the following reason. The most rapid drawdown of the resource is only possible under trade with the United States. This is the short-term action which could potentially do Canada the most good, or cause it the most harm, from the point of view of resource use - and we do <u>not</u> have clear long-term vision on the value of the finite resource. Koopmans (1967) used the following analogy in the context of optimal economic growth:

> "The problem takes on some of the aspects of the ascent of a mountain wrapped in fog. Rather than searching for a largely invisible optimal path, one may have to look for a good rule for choosing the next stretch of the path with the help of all information available at the time. Simulation

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[3] Of course, other types of rules could constrain domestic consumption as well, and prolong even further the exhaustion of the gas reserves of the western basin.

studies in various hypothetical technological landscapes may help in the evaluation of alternative rules."[4]

In the exercise of this chapter I have not recommended the use of one set of rules or another, but have shown how these different types of rules affect finite resource use. Given the costs and complications involved in the types of rules used by the NEB, in the context of exports policy and in the range within which the NEB was free to move, they appear to have little or no beneficial effect, on either industry performance, or preservation for future generations.

Canadian supplies could potentially support very high levels of exports, especially if the U.S./Canada relative gas prices favour high levels of exports to the U.S. Once adequate levels of reserves and deliverability are established, the rate of exhaustion is unconstrained until final exhaustion approaches, causing the rules to become binding. In the absence of rules, this protection is only slightly smaller, in the intergenerational time context. There is a one year difference, thirty-one rather than thirty years for the discovery of the 150 EJ of WCSB reserves in the NEB case versus the "no NEB" case.

In the absence of strong rules on exports, the time of exhaustion in Canada, and the level of protection of the resource stock for future Canadians is largely a function of U.S. demand. This may not be a bad thing, I emphasize, because one may take the perspective that the only protection that matters is protection of future energy needs, not specific fuels, which may imply a specific economic/environmental structure. In that case, reinvested profits from massive early sales may be exactly what one

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[4] Koopmans (1967), p. 2.

wants. From an alternative ethical point of view, it may not, however, be necessarily what one wants or should want. Individuals are not always willing to exchange lifestyles for financial compensation.

Summary

This chapter presented the results of the simulation analyses outlined in Chapter Four. Descriptions of the experiments are presented, and cautions regarding both the validity of the model, and the interpretations of results are stated. Emphasis is placed on the base case or "NEB" analysis, and on contrasts with the more market oriented "no NEB" case, and the conservative "no exports" case. On the basis of the simulation model analysis results there appears to be little difference between the "NEB" and "no NEB" cases, and a striking contrast between these two cases and the "no exports" case.

A discussion of the choices between market and non-market rules in the context of equity in natural gas use follows the discussions of the base case analysis, the class one sensitivity analyses on key model parameters and the class two sensitivity analyses on rules. Results from earlier chapters are recalled in noting that at the present time we cannot choose between market and non-market solutions on economic grounds, nor can we necessarily favour one or the other on ethical grounds (and achieve a reasonable degree of consensus). However, if a set of rules imposes costs without offering any clear benefits, then one may be led to the rejection of those rules. In the context of the simulation model used, this is the case for the NEB-type rules examined in this chapter - at least this seems to be true within the range of rule parameters that were adopted by the NEB.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

The primary arguments and conclusions of this thesis can be summarized very simply. First, the economics literature, which is the most influential academic literature relating to public policy on finite resource use in Canada, has little to say about equity in finite resource use. This is clearly evident from the review in Chapters One, Two and Three, where the neoclassical economic ideology was elaborated. It is clear from the literature review that almost all economists writing in the area pursue the same market "paradigm" or "research program" regarding the optimal use of finite resources.

Second, this literature strongly encourages the use of the competitive market mechanism, to the exclusion of any other alternative, in resolving claims, rights, or access to finite resources, by ignoring other alternatives. The market may be seen as a clever mechanism for auctioning off things that do not belong to us. The ethical superiority of that market model is shown to be very much in doubt in Chapter Two in the static context, and in Chapter Three in the intertemporal and intergenerational context. The problems with the utilitarian approach which lie at the foundations of that market model were examined, and other alternative ethical approaches were briefly reviewed, including Rawls' theory and intuitionism. This study leads to the third conclusion, that on extra-economic grounds there are (may be) good reasons to impose non-market constraints on finite resource use, the exploitation of natural environments, and other key areas where intergenerational impacts can be identified. As shown in Chapters Two and Three, most of these arguments come from "outside" the competitive market model, and cannot be countered by an appeal to the economics

literature of Chapter One.

Fourth, the previous comments relating generally to finite resources are applicable to natural gas depletion by Canadians, and non-market rules can equally well be rationalized in this context. Some potential non-economic interests may include the preservation of an industry and lifestyle, responses to "environmental shock", and others. Fifth, on the basis of the simulation analysis (and strictly conditional on the simulation model's validity which is subject to at least some doubt), the rules adopted by the NEB (which lie within the bounds of political practicality) would be likely to have very little intergenerational impact on the rate of natural gas (finite) resource use.

AN OVERVIEW OF THE STUDY

The approach to this problem which was selected for this thesis is somewhat unusual in the context of the more traditional literature of natural resource economics. However, I believe that it does make a useful contribution to the literature. Economists frequently produce results which show the effects that various policies may have, based on theoretical market models. It would not have been a difficult matter to show that the use of an arbitrary rule by government would reduce social welfare within the confines of the neoclassical market model. This thesis goes beyond that type of analysis, however, in questioning the adequacy of the neoclassical market model to assess issues relating to equity in finite resource use. In a sense, it deals with foundational issues. I have presented evidence and argument from a variety of literatures to show that there are good reasons, on non-economic grounds to use rules or alternative processes rather than markets alone to achieve some particular social goals. It may also be the case that the use of certain alternative processes may themselves reflect specific ethical

decisions or the pursuit of certain values. This is to say that the neoclassical market paradigm may not offer an acceptable process or adequate assurance that specific and desirable social goals will be achieved.

The problems with the market include a great variety of items including the sole promotion of exchange value, reliance solely on market power for the acquisition and use of finite resources, problems within the market model itself due to failures in assumptions, the inadequacies of the underlying ethical model which is used for evaluating the optimality of finite resource use, the inadequacy of the economic models to deal with person-effecting policies which may determine the population and membership of future generations, the problem that the economic actors do not behave as they should optimally, i.e., defective future vision, resulting in excessive discount rates, and other problems discussed in Chapters Two and Three.

The purpose of the exercise was not just to evaluate critically some of the basic elements of the economic approach to the problem of finite resource use. It was to find out what was so optimal about the "equitable use" of finite resources so frequently mentioned in the economics literature. By carefully studying the use of the term equity, and the dimensions of equity in the economics and other literatures, I show that this optimality, and equity for the economist must be seen as concepts with highly specialized usages, and need not at all be those which most individuals - policy makers or other members of a society would consider to be equitable or optimal in the common uses of the words.

Because of the many problems cited with a blind reliance on the market model, and the issue that the "faith" which allows the market to evolve a price directed future for us may not be justified, the analyst may consider the use of non-market rules. If we choose not to control price, then

quantity must be rationed in the case of finite resources, or both price and quantity must be regulated simultaneously. In the case of Canadian natural gas, a variety of rules were proposed and implemented over the last thirty years, which may essentially restrict exports of natural gas. They were intended, in part, to protect the interests of present and future Canadians.

The key question which was pursued in Chapters Four and Five was what were the likely effects these rules would have, primarily, in an intergenerational context. The results indicated, conditional on model validity, that the rules used in 1982 by the NEB, and most likely any similar set of rules would have very little if any significant effect on the availability of finite resource supplies for future generations. Only in the case of a drastic rules change, such as a "no exports" policy, which may not be politically feasible, would there be any significant intergenerational impact. The results of this simulation work suggest that in relaxing its rules on exports, the NEB has not jeopardized the country, or badly affected future generations, but probably has added to the viability of the industry. This may be seen as a somewhat counter-intuitive result, I know that most of the individuals in the industry with whom I spoke, thought of a thirty-year CRT, and a ten-year FDT as pretty strong rules, rules which offer significant protection. Seemingly only a drastic rule, such as no exports, or no exports along with a demand constraint on domestic use are the only types of rules likely to have effects over several generations. The use of the model allows one to arrive at a rough estimate of what it would cost Canada to get that particular level of intergenerational protection as well. In my opinion, the study makes the discussion of rules for intergenerational equity a little more tangible, and in that way may make a useful contribution to public policy decisions.

Given the burdensome nature of export hearings, in professional time, and cost to the public, in the context of intergenerational issues, one can applaud the recent trend of the National Energy Board to the use of less restrictive policies. This should, in no way, be taken as a vote for the dissolution of the NEB, because in my opinion it provides very useful and valuable public services on several fronts. These include protection of the environment, quality and security in energy transmission, and market stabilization through its activities in gathering and disseminating information, among other services.

In Chapters Two and Three, I attempted to develop a clear presentation of the dimensions of equity while examining the related literatures of economics, ethics, psychology, sociology, and law. There does not appear to be obvious agreement about how one can be equitable in finite resource use or in any other resource allocating area. Examination of psychological decision rules, values, and ideology give us insights concerning what people want to do, perhaps reflecting decisions or dimensions relating to equity. These types of studies do not inform us about what people <u>should</u> want with respect to equity. The emphasis on the choices that <u>should</u> or <u>ought to</u> be taken, the identification of the <u>right</u> thing to do, shifts the focus of the analysis to ethical issues. Economic analysis per se, does not offer any clearly morally superior solution to problems, but can be used as an instrument to assist in ethical decision-making. The ethical superiority of the competitive market solution is strictly conditional on the acceptance of the underlying evaluative model, usually a utilitarian formulation, and the acceptance of all processes in the system as well. There are possibly many more dimensions to the ethical analysis of a market system, than the utility of final consumption alone. Equality of access or opportunity, freedom, health, etc. are

all dimensions of the lifestyle choices which are a part of the economic system choices. A key factor which is often ignored is that the process may be as important as the outcome. Economic analysis on intergenerational equity has encouraged the view that the utility maximizing strategy in the context of a market model, which we seek today, will be that which will be sought by future generations. This type of approach, as discussed in Chapter Three, can wrongly deny future generations the freedom of choice they may well desire.

The direct contribution of this thesis to the traditional economics literature on natural resources is perhaps small because I have not pursued a direct extension to the literature of Chapter One, rather I have focused on the foundations of that literature with respect to equity in finite resource use. The more significant contribution of the thesis is in the integration of ideas from economics and other literatures relating to equity, and intergenerational equity with respect to finite resource use and economic analysis more generally. Progress has been made in developing an understanding of the dimensions of equity, although no single hard and fast definition, scale, measure, or objective function has been found. I feel that I have clarified the nature of the problem of equity in finite resource use. From the preceding comments in this chapter, it may seem that I oppose the use of the market model. I do not. However, I do see it as merely one possible mechanism to the solution of the finite resource use problem, and one with many benefits as well as some serious problems and limitations which must not be ignored. I do not believe that the blind faith in the marketplace, implicitly if not always explicitly encouraged by many economists is justified. Other alternative solutions are also problematic, however I believe that the single-minded pursuit of the competitive market approach alone is not appropriate. The use of labels like "optimal depletion" in

the context of problems of intergenerational equity, as well as other "optimal use" designations related to equity generally have been very misleading. The equitable solutions promoted at least implicitly by economists would, I think, be found seriously lacking by the general public on close scrutiny. I do not mean to condemn economic analysis, but merely wish to venture my opinion that after completing this study, I believe that on the issue of equity, economists may have tried to claim a little bit too much for their analytical methods on finite resource problems, and other problems as well. Economists have developed many very powerful analytical methods which have proven to be of great assistance to society over the last few centuries. I wish to promote the reintegration of political and ethical analysis into the mainstream of research, more in the older tradition of political economy. I feel that such a reintegration will be an essential step in finally coming to a solution to the problem of intergenerational equity and the optimal depletion of finite resources. Finally, I hope that this thesis will be seen as a contribution to the literature, which reflects this more interdisciplinary approach to the problem of intergenerational equity.

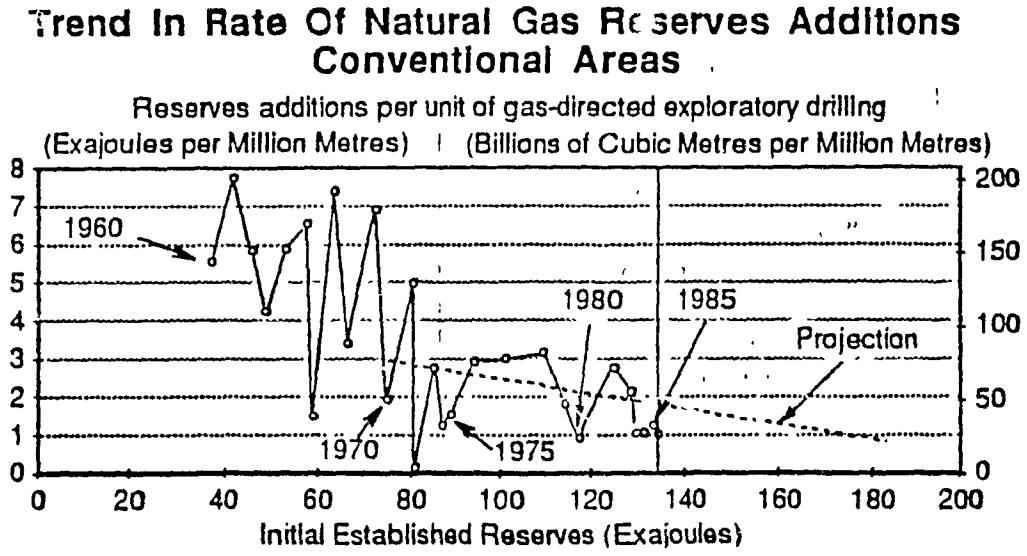
APPENDIX ONE

THE NATURAL GAS INDUSTRY

The purpose of the following discussion is to provide a brief introduction to the natural gas industry, in particular, a discussion which points to the occurrance of various economic costs at the various levels of industry activity. All of the costs (excluding financing costs) of natural gas from geological survey to final distribution will be described as they are normally incurred. At times, tables and figures for oil will be used to illustrate parallel ideas for gas where appropriate due to the greater availability of oil-related studies.

The literature of natural resource economics has shown us that finite natural resource stocks like natural gas, oil, or coal should be treated as economic assets. These assets have some positive value in use, or benefits associated with their use, however, they are not free goods, and costs must be incurred to obtain the benefits associated with the given resource stock. A pool of gas may be discovered in some given geographic area on the basis of a single exploration well drilled. In order to estimate the size of the resource stock, i.e. the size of the pool, the geologist and geophysicist may rely on previous geological surveys and seismic work to make judgements on the pool size at some probability levels. At this point, the geologist is usually

quite uncertain as to the extent of the reserve. It has already cost some money to get this far, and yet there may not be sufficient information to embark on a large scale or small scale distribution project. At a more aggregate level, the problem mat be somewhat easier. In a region where there have been large numbers of finds, and lots of wells drilled, such as in Alberta, Canada, or Texas, USA, then one may be able to identify a probabilistic relationship between money spent on exploratory drilling, and size of probable reserves additions. For example, the NEB recently produced the following figure in its 1988 report on Canadian energy. The problem of identifying (ex post) gas directed drilling is not an easy one, as discussed in Chapter Four.

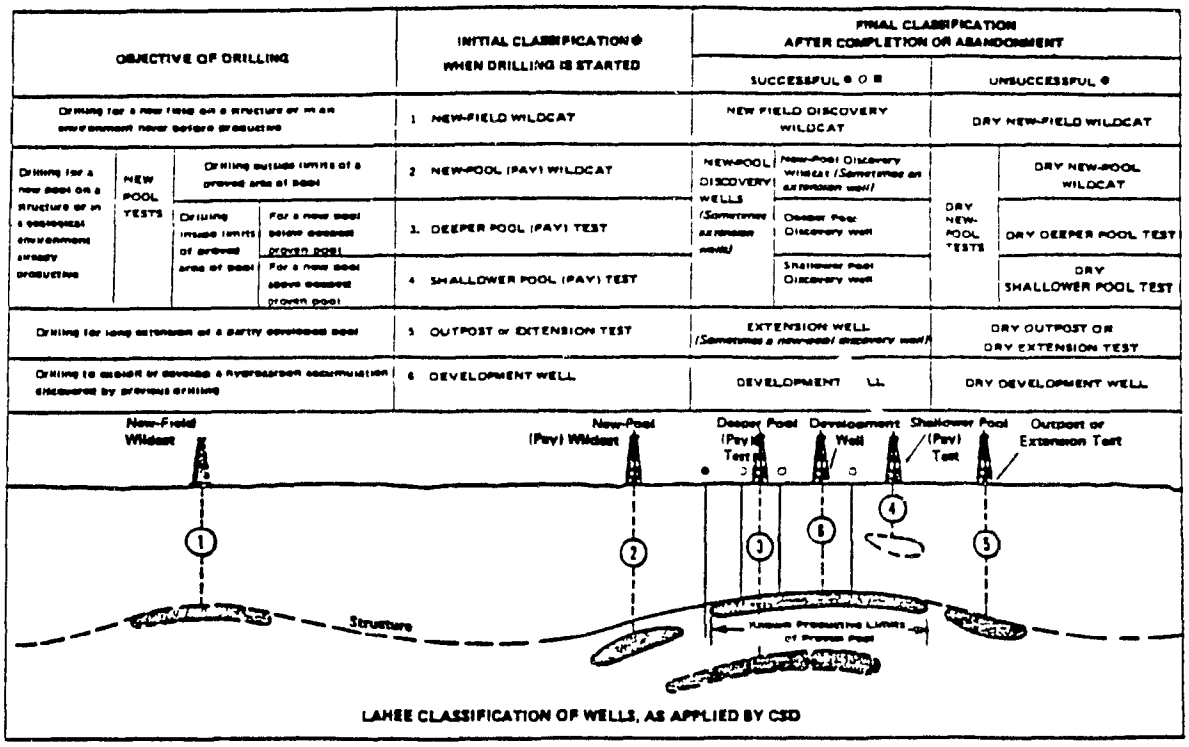


(NEB 1988, fig.6-3)

Returning to the discussion at the more disaggregated level, beyond differentiating between oil and gas directed drilling,

the analyst is often interested in focussing on exploratory drilling alone, and its relationship to reserve additions. Well classification is fairly complex and the use of correctly designated wells is essential if one wishes to appropriately test for exploration success to generate data such as the marginal cost of new reserves.[1]

AAPG and API Classification of Wells.



Source: The American Association of Petroleum Geologists, "North American Drilling Activity," *AAPG Bulletin* (Annual Drilling Issue) 63, no. 8 (1979) Figure 8, titled "AAPG and API Classification of Wells," p. 1202. © American Association of Petroleum Geologists, Tulsa, Oklahoma. Reprinted with permission.

[1]Adelman (1983), p. 42.

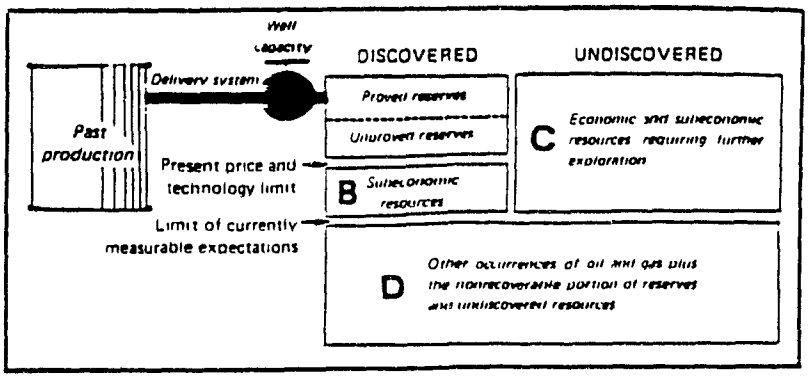
Success and costs associated with drilling in a specific region depends on familiarity with underlying structures and a variety of related, area specific factors. For specific projects, a higher or lower requirement for assurance of supplies may be required.

In areas where such a history is not available, then we must rely more on the geologists' interpretation of information as previously described. If the cost of a reserve's shortfall is deemed to be very high, for example, if a major pipeline expansion project of long life or an LNG project is contemplated, the government or customer may require a high level of precision regarding the estimates of the size of reserves. This is one place where dry holes are important. Just as both dry holes and discoveries give meaning to seismic work, as both convey information at different levels of net benefit, deliniation wells are used to identify the extent of reserves associated with a discovery.

Hopefully, the deliniation well will not be a dry well, in which case one has a larger reserve, perhaps, and the well can be used as a development well. In combination with survey and seismic work, however, deliniation wells will tend to determine the extent of a gas reserve with a high level of probability. It is clear, therefore, that this information is only gained at the cost of drilling wells, which is an expensive way to obtain information, and this

cost must be contrasted with the value of that information in planning and contracting.

It is necessary to distinguish between resources and reserves. Reserves are discovered resources above the current price and technology limit, as indicated in the diagram below.[2] I do not believe that it can be said that this is universally accepted, but I believe that it is generally accepted.



At the present price and technology limit, there are undiscovered reserves, a part of area C, the other part of C beyond the current limits, but within the limits of measurable expectations. Thus, in the following diagram in NEB 1988[3], implicitly we move from category A reserves into categories B and C, as time goes on. The different levels of ultimate potential reflect uncertainty regarding the size of areas A, B, C. The transitions from A to B occur as we move through

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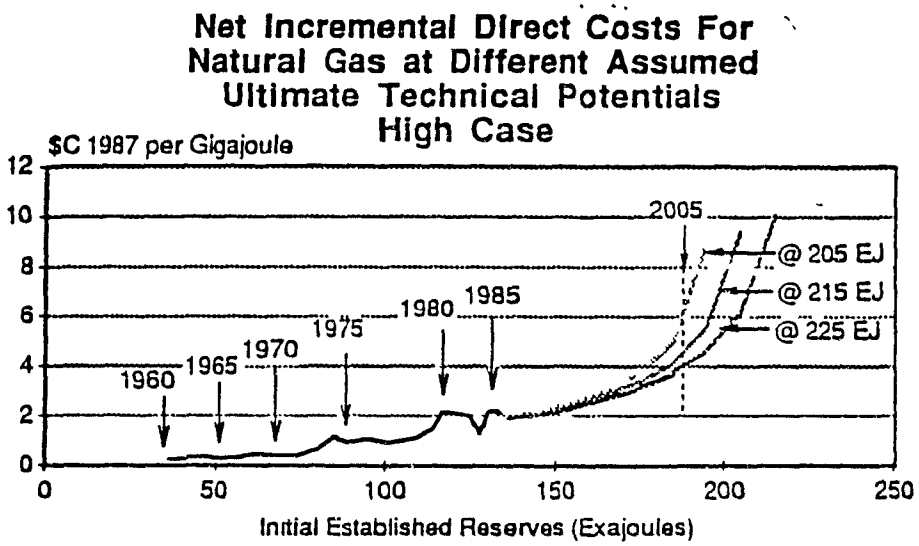
[2] Source: Wildavsky and Tenenbaum (1981) p. 330.

[3] NEB (1988), Figure 6-11

time, where technology changes, and the price limit is allowed to increase.



It is important to separate out these factors, because, for example, a change in technology moves reserves from area B into A and increases the available (below the price limit) undiscovered resources of area C. It has the effect of shifting the NEB projection curves downward. A change in technology radical enough to change future expectations moves resources of area D into B and C as well. It is essential to keep these distinctions in mind, because they influence our notions of scarcity. While it may be likely that we may exhaust our 1988 proven reserves of gas (upper A) in the next twenty years, we may be very far from exhausting the technically viable resources over that horizon, possibly including lower A, B, C, and parts of D. Having some level of discovered reserves is a result of many more individual decisions, and I return again to that perspective in the

following discussion of productibility.

Having a known reserve (with some level of probability) is a first step in natural gas supply. The time sequence of supply or supply availability at the well head is referred to as the producibility of the well. The producibility of the well will be a function of several factors, including the porosity of the rock in which the gas is found, and the type of drive which is responsible for the reservoir pressure. For example, gas under water pressure is often producible at more rapid rates than gas under simple reservoir pressure, but the former tends to be associated with lower levels of total recovery from comparable wells. Tiratsoo (1982) compares typical numbers for recovery of water and gas pressure driven reserves at 70% and 96% respectively, solely as indicative of a general relationship. Putting the issue of pressure drive aside for the moment, the other characteristics of the field provide information which is useful in determining the optimum depletion pattern for a field. On geological and engineering bases, there may be a rate or rates of production over time which provide maximum production from a given reserve at given levels of expenditure over time. This may coincide with the best or optimal rates of production from an economic point of view, however, this best pattern of depletion will also be a function of the intertemporal pattern of demand for this gas by final users.

Thus far, as regards producibility, reference has been made to producibility for a single well associated with a given field. If the producibility for a field is too low, it can often be enhanced by the drilling of "development wells", so call "in-fill drilling". Again, if wet deliniation wells are drilled, they will be used as development wells to enhance producibility.

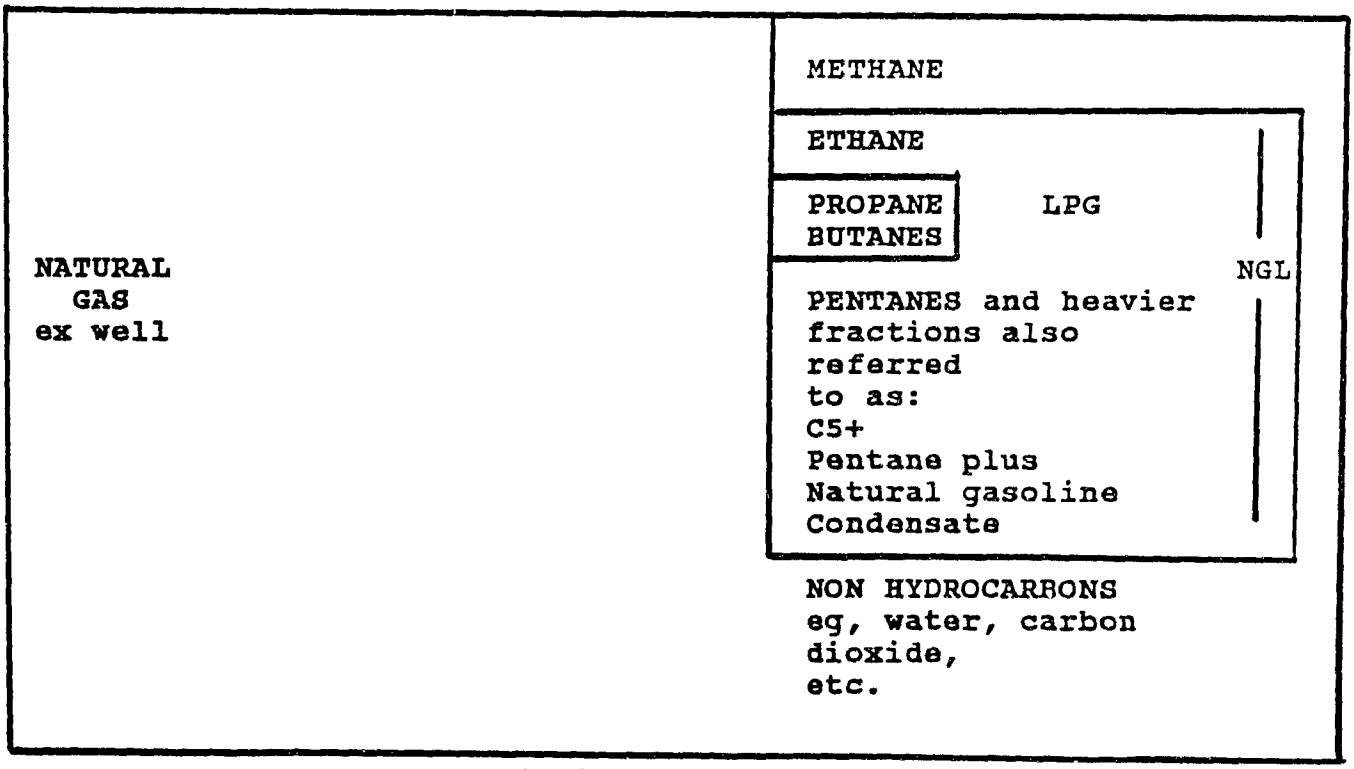
Development wells usually enhance producibility and at the same time usually increase the potentially recoverable reserve. Additional producibility costs, however, must be compared with benefits associated with more rapid usage of the reserve. Typically, a well draws on an area of about 640 acres. Directional drilling away from a main well site may be used for several reasons. Although the footage of drilling is greater than if vertical wells are drilled at the appropriate site, this option may reduce site preparation, road construction, gathering system, and plant costs.

Having briefly considered field development and simple production of raw natural gas, we must now turn to issues in the production of pipeline quality gas. Raw gas, as described in the following figure contains, several other items besides methane. Some of these may enhance the value of the natural gas while others may detract from it.

Natural Gas and Gas Liquids[4]

Natural gas is a simple hydrocarbon that exists in association with oil or separately as non-associated gas. It is generally a composite product. The simplest member, methane (C1), is by far the most abundant component, and is always present in a gaseous form. Both associated and non-associated gas often include a high proportion of natural gas liquids (NGLs). The NGLs include ethane (C2) and LPGs [propane (C3), and butane (C4)], as well as pentanes and natural gasoline condensate (C+5).

Terminology and Constituents of Natural Gas



CHARACTERISTICS: LNG = Liquified natural gas
LPG = Liquified petroleum gas
NGL = Natural gas liquids
SNG = Synthetic (or substitute) natural gas

[4]Source: World Bank Energy Department, Report November 10, 1983.

Calorific Value Kcals/Metre[5]

Methane	9,495
Ethane	16,515
Propane	23,675
Butane	30,690
Pentane	35,685

The natural gas is passed through pipes from the wellhead to a vertical separator, at wellhead pressure. The pressure of the gas is reduced as the gas expands and cools in the large diameter separator. The gas is forced to the top of the separator, while the pentanes plus the condensates or liquids are exited through a trap in the base (usually controlled by a simple level guage). The gas pressure is then increased as the gas is forced into a more narrow diameter pipe going to the dehydrator. The separation process must be done first, as the condensate contaminates the glycol used in dehydration. The gas processing plants which are usually located on a major pipeline, remove some or all of the other components of the gas except methane. These other components include more complex hydrocarbons and condensates which have much higher calorific values than methane alone. These other hydrocarbons may be removed and sold separately, if they occur in sufficiently high quantities, and if markets exist for them in more high valued uses than as pipeline gas components. It should be noted that much of the gas in known reserves does contain these more

[5]Measured at 0oC and 760 mm hg dry (Gross).

complex hydrocarbons in sufficient quantities to increase the calorific value of the gas and should be accounted for in calculations based on thermal value. Gas processing with its attendant revenues and costs should, if done, be factored into system costs. Next, if more than very small amounts of sulphur are found in the gas, they must be removed, as the hydrogen sulfides may corrode pipelines, and restrict its value as a chemical feedstock. It is, moreover, lethal. If sulphur removal is done, the hydrogen sulfide (H_2S) is removed prior to dehydration and after separating. The process is similar to the glycol water separation described below.

The natural gas, still at wellhead pressure, is carried from the separator through large diameter pipes and may enter a vertical dehydrator (one process for water removal). As the gas expands, it cools somewhat and passes up through a hot glycol bath. The glycol for the bath is pumped into the top end of the dehydrator at a pressure equal to that of the gas in the dehydrator. The liquid glycol "cascades" down a series of trays in the dehydrator, mixing with the water approximately equal to its own weight, and exits through a trap in the base of the dehydrator. The dry gas exits from the contractor tower into the regulatory and metering reader. The glycol-water mixture is then pumped to a "reboiler unit" where the water (which has a lower boiling point than the glycol) is allowed to escape as steam, or is condensed and exited through a trap. The glycol is then recycled to the

dehydration tower. Alternatively, a solid dessicant procedure may be used, the net results for the gas are approximately the same. Generally speaking, on a per unit basis, the cost of dehydration tends to be quite small as a proportion of the delivered gas price, moreover, depending on the gas composition, processing can, and on average usually does, provide a tidy return to the producer. A heater is sometimes used to heat the gas prior to its passage through the regulator which reduces the wellhead pressure to about 1000 p.s.i. (in the case of many systems). Elements in the gas (hydrates) can be kept from freezing when passing through a constricted area either by dehydration or heating. The gas then enters main lines. In most cases, the cost of transport, or delivery to the final user forms the largest element of supply costs for natural gas. Once a reserve is identified, producibility established, and gas preparation and processing facilities are in place, the next issue is the cost of obtaining deliverability of gas supplies at certain geographical locations. The key issue for deliverability cost is in creating a certain flow rate and total quantity available at a specific location, at certain points in time. These costs include the costs of transmission pipeline, operation and maintainance, compression costs, as well as administrative and general expenses.

Transmission and distribution may be very simple to describe at a general level for some fields and users and

very complex for other fields and users. A simple case is that in which a single field is tied into a "dedicated" transmission pipeline, which moves gas to a single end user plant, say fertilizer or electric power. The allocation of pipeline peak and average capacity is obvious, and later cost allocation is simple. The analysis is only slightly more difficult if we add a second enduse plant. If the field has sufficient producibility for a second plant, as well as sufficient dehydration and processing capabilities, then the added plant is allocated the incremental transmission cost. This may involve a separate line if the two plants are not close together, or some looping or compression on a common line, and then the full cost of a lateral to the new plant from the common line as well as the cost of a regulator and meter station. The plant usually pays the cost of the meter station as well as the cost of the service line. If the field did not have sufficient producibility over the plant life, then the cost of enhanced producibility when incurred would be assigned to the second user. This enhanced producibility refers only to that which is beyond that available to the first user alone. If the expected producibility of a well is such that the first user would have had to incur development expenses in the near term anyway, the incremental development expenses alone should be assigned to the second user. The difficulty is, that development can only be done in a "lumpy" fashion not in small marginal increments and

these are all long-lived investments. Because of this cost expenditure pattern, very often only a change in the longevity of producibility for the first user is associated with the the identified cost. To identify the incremental cost of the second user, we should compare the expected long run costs for the first user alone, and the same costs for both users together. One standard procedure is to calculate the present value of incremental capital costs and annuitize them. Most of the bulk user situations are quite straight forward. The more difficult to describe and evaluate distribution problems relate to the relatively small residential, commercial, and industrial users, and these will be dealt with after a further elaboration of transmission lines.

The size of main transmission lines, and the number of compression stations, from the plant gate (after processing) to the city gate station (when the line pressure is reduced using regulators for local distribution), is determined approximately by the sum of the peak loads on the line. Line pack pressure can mitigate the influence of some peak demand loads, but if pressure is caused to drop below some minimum level in a given time period due to excess demand, transmission facility expansion must occur.

Two ways in which transmission line capacity can be increased are by the addition of compressors and by line looping. Looping usually refers to the construction of a new parallel line next to the original line. In particular

situations looping and/or compression may prove to be the economically superior solution over a given time period. From the perspective of total system cost and overall reliability, it is often desirable to have load centers (cities, for example, which are supplied by different fields) connected together. In many situations, the use of such a gas grid system can result in very significant cost savings. This may be important, for example, when one of two fields supplying two load centers on a grid is nearing exhaustion, and excessive expenditures would have to be made to get sufficient deliverability from the single field. Supply from the newer field, via another load center on a grid may gradually be increased as producibility from the tired field dwindles, without incurring the additional direct cost of a new transmission line from the newer field. A similar situation arises if the one load center outgrows the producibility of a given single supply source. The shared initial costs of development may be difficult to assign if expected future producibility is not known with high confidence. There are of course many other types of problems with shared main lines, but hopefully the foregoing gives a sufficient flavor for the class of problems and usual approaches to solutions.

The terminus of the main transmission line is referred to as the city gate station. At the city gate, where the main line of usually six to thirty inches in diameter

carrying pressures to about one thousand p.s.i.g. (pounds per square inch, gauge) arrives, regulators reduce the pressure to about three hundred p.s.i.g. for transmission in six to ten inch "mains". These "main" lines feed other regulators at various locations in the load center, which reduce the line pressure to about one hundred and fifty pounds p.s.i.g. to "feeder mains", again usually six to ten inches in diameter. The "feeder mains" may form a "backbone" in the load center, or together with the "mains" form a "high pressure loop" around the load center. Regulators finally connect these "feeder mains" to small (three quarter inch in diameter) street distribution lines, which supply "laterals" to residential and commercial users. The industrial users would probably be on a slightly larger, may be two to four inch line at sixty p.s.i.g. Most residential, commercial, and some industrial appliances run at about four ounces of pressure above atmospheric pressure (14.4 p.s.i.g.) or about 14.7 p.s.i.g. Clearly, there is a lot of pipe between the field and the average kitchen stove,not to mention pumping stations, metering devices, and pumping stations.

The reason for elaborating on the physical characteristics of the system is to provide some idea of how costs are incurred as incremental users are signed up. Cost allocation to particular users is not easy. Also, it is desirable to describe the very elaborate nature of the delivery system for gas so that it can be compared with that

for competing fuels like fuel oil. It may be noted that because so many of the feeder and main line costs are high, it may be appropriate to treat a local residential/commercial flock of customers over a given time frame, as the appropriate unit of analysis, for estimating average incremental, or long run marginal transmission and distribution costs.

A Further Note on Estimating Undiscovered Resources

Kaufman (1983) identifies six major approaches to indentifying amounts of undiscovered oil and gas, and cites several principal papers associated with each in the table, reproduced below.

Life cycle
Hubbert 1962, 1966, 1974
Moore, C.L. 1966
Ryan, J.M. 1965, 1966
Wiorskowski 1977

Discovery process
Arps-Roberts 1958
Ryan, J.T. 1973
Barouch-Kaufman 1976a, b
Drew-Schuenemeyer-Root 1978
Ecko-Jacoby-Smith 1978
Smith-Ward 1981

Rate of effort
Hubbert 1956 1972, 1974
Hartigan-Bloomberg 1976

Subjective probability
USGS, Circular 725 1975
Energy, Mines, and Resources (Canada) 1977

Geologic-volumetric
Zapp 1962
Hendricks 1965
Mallory 1975
Jones 1975

Econometric
Erickson-Spann 1971
MacAvoy-Pindyck 1973, 1975
Khazzoom 1971
Attanasi 1979[6]

[6]Kaufman (1983), p. 92.

Kaufman claims that the above fairly represents the "principal ideas behind methods currently in use and those under development."[7] He notes also, that in practice, combinations of the above methods are used frequently.

Kaufman indicates the mass of conflicting evidence reported using each of the methodologies or approaches, and focuses on the differences in the use of the approaches by different researchers in particular applications. For example, in the Life-Cycle Models approach, logistic, Gompertz, Richards and Weibull functions have been used to estimate U.S. ultimate oil potential onshore, with widely divergent estimates for the variable of interest. In one example where both the Richards function and the Weibull function were fit to a data set, both functions fit the data equally well, Kaufman notes that the residuals were identical to two decimal places, but the former estimates ultimate potential at 446BB almost twice the latter at 235BB.

Similar problems of fit, and conflicting projections plague econometric approaches, and rate of effort approaches. While the geologic-valuation subjective probablity, and discovery process approaches, seem to work acceptably well on small scales, they do not seem to perform very well at a macro or national level. Kaufman states the following,

"No single overarching concept links these

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[7]Ibid., p. 92.

> approaches to one another. They are like ships passing in the night, heading for different ports. In the hold of one is a cargo of non-geologic methods of projecting petroleum supply designed to extrapolate exploitation history, while the other carries a cargo of methods based on assumptions about geologic and statistical attributes of deposits, how they are discovered, and economic decision making by oil and gas operators.
>
> ...The territory that lies between aggregated and unit specific disaggregated approaches is as yet uncharted. No logically tight methodology for aggregating projections of supply over different time frames from individual geological units in varying stages of exploratory maturity is in sight."[8]

His final appeal is for a good data set, with useful variables accurately measured, which he claims is holding back progress in this entire area. It is not to be wondered that ic Canada one researcher can find that gas costs are rising while another finds that costs per gigajoule are flat or falling.

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[8]Kaufman (1983), pp. 293-294.

APPENDIX 2[1]

Evolution of the Board's Natural Gas Surplus Determination Procedures

This appendix outlines how the Board's surplus determination procedures have evolved over the years. It begins with a few extracts from the report of the 1957 Royal Commission on Energy (Chairman: Mr Henry Borden) which led to the establishment of the NEB, and some of the discussion relating to the protection of domestic requirements which ensued when the NEB Act was debated in Parliament in 1959.

The Establishment of the NEB

(i) The Borden Report

In October 1957 an Order-in-Council appointed the Borden Commission to "enquire into and make recommendations concerning the policies which will best serve the national interest in relation to the export of energy and sources of energy from Canada" One of the major recommendations of the Borden Commission was that a National Energy Board be established. Other recommendations included the following:

- "that, having regard to the proven reserves of natural gas in Canada and trends in the discovery and growth of reserves, the export from Canada of natural gas, which may from time to time be surplus to the reasonably foreseeable requirements of Canada, be permitted under licence",
- "that an export permit may be granted for a period of not more than 25 years from its date", and
- "it is clear from the very great differences in market estimates presented to the Commission ..that decisions to export must be based on continuous appraisal of the supply and demand situation as it develops in Canada..."

(ii) Statements: House of Commons

Following the release of the Borden Commission's report, the NEB Act was introduced into Parliament. The following remarks of Mr. Gordon Churchill, then Minister of Trade and Commerce, are indicative of the philosophy of the government of the day regarding the determination of surplus, and how the Board subsequently interpreted its mandate in this regard (House of Commons Debates, Official Report (Hansard), May 22, 1959, p. 3929)

- "The term of export licences is not to exceed 25 years. This upper limit is regarded as the term likely to be required to enable financing of gas export pipelines",
- "Gas and power ..move by fixed channels under long-term contracts at the source and long-term contracts in the area of consumption, so that once committed to a market they cannot be withdrawn without hardship. A gas export service once established must continue for a substantial period to enable the enterprise to attract capital in the first place, and to permit amortization of the necessary investment. Interruption of such export service is apt to be a source of international friction Hence there is a clear case for being cautious about permitting exports of any power or gas which we are likely to require ourselves..."

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[1] **Source: NEB(1986), pp. 69-75 and pp. 23-26.**

Evolution of NEB Surplus Determination Procedures

(i) Reasons for Decision, March 1960

In March 1960, the Board undertook its first calculations to determine the extent of exportable gas. At that time two types of surplus were calculated – a Current Surplus and a Future Surplus.

To calculate the Current Surplus the Board first estimated the future requirements for Canadian natural gas by considering:

(a) future Canadian requirements, estimated by forecasting demand for four years and projecting the fourth year requirement over the remaining years of a 21 year term,

(b) commitments under then existing export licences, and

(c) gas required under export applications then being considered by the Board.

The rationale for (a) was as follows:

> "The 21 year period 1960 to 1980 has been selected as that for which requirements should be met from presently established reserves. In the case of Alberta the estimated provincial requirements for the period are met completely from established reserves. This protection for Alberta consumers is a condition of the Government of Alberta before permitting removal of gas from the Province. The requirements elsewhere in Canada have been levelled at the 1963 rate for the balance of the 21 year period. According to evidence filed before the Board, in general it has not been considered practicable for pipe line companies to obtain contracts for the purchase or sale of gas for incremental requirements commencing more than three or four years in the future. Incremental requirements beyond the 1963 level accordingly have been allocated to future discoveries of gas (future reserves). In every case, all requirements accruing after 1980 are assumed to be met from future reserves."

The reserves necessary to satisfy the requirements of the Current Surplus Test were calculated according to a formula which had been developed by Alberta's Oil and Gas Conservation Board (now called the Energy Resources Conservation Board). These were then compared to the Board's estimate of established reserves which were defined to include all proven reserves plus a varying percentage not exceeding 50 per cent, of probable reserves. If this comparison did not indicate a Current Surplus the export application was rejected. If a Current Surplus did exist the Board proceeded to determine whether a Future Surplus existed as well.

To calculate the Future Surplus, Canadian requirements were estimated for a 30 year period by forecasting requirements over the full 30-year term rather than assuming annual requirements would not grow beyond the fourth year level. The reserves necessary to satisfy those requirements were estimated in the same manner as for the Current Surplus calculation, however, the Board's estimate of available future gas reserves also included expected additions to reserves. If a comparison of Board estimates of available and required future reserves indicated a surplus, an export application could be approved.

(ii) Reasons for Decision, July 1965

In July 1965 the Board reviewed the surplus procedures which had been articulated in its 1960 report and concluded that its basic approach was still sound. However the following modifications were made:

(a) 50 percent of the Alberta and British Columbia reserves then considered to be beyond economic reach were accepted as available to meet Canadian requirements and export commitments.

(b) reserves not expected to be available for reasons of conservation by the Alberta Oil and Gas Conservation Board were excluded from the calculation of available reserves,

(c) reserves which had been allocated for the protection of peak-day requirements in the terminal year of an export commitment and which would become available for other use after the termination of the licence were included in the surplus, and

(d) the Board adopted the practice of the Alberta Board in making allowance for Alberta requirements by setting aside an amount equal to 30 years of requirements less two years growth in reserves to be met from reserves available (established reserves as adjusted by the factors in (a) to (c) above)

(iii) Reasons for Decision, August 1966

The Board's surplus determination procedures were next modified in an August 1966 decision regarding an export application by TransCanada. In that decision, the Board outlined the following principles (which became known as the 25A4 rule) for determining the exportable surplus.

(a) "Available reserves will include the remaining volumes under existing import Licences, plus contractable reserves The Board considers contractable reserves to be those established reserves which it believes a purchaser will be able to contract for, with delivery to begin within the next four years "

(b) "Protection of Canadian gas requirements at an adequate level will be achieved if an amount of reserves equal to 25 times the estimated requirement level for the fourth year is set aside The multiplier of 25 was selected not only because it appears to the Board to supply adequate protection under presently foreseeable circumstances, but also because it corresponds with the 25-year maximum for export Licences which can be granted by the Board The fourth-year level was selected because it corresponds with the current policy of the pipe line companies in contracting for the purchase and sale of gas These contracts provide for a time interval of not more than four years before acceptance and delivery of gas to meet forward requirements "

"In cases where authorization for removal of gas from the province in which it is produced is required by a statute of that province, the amount of protection provided for markets in the province will be the amount set by the province to be its requirement or the amount computed by the above rule, whichever is greater "

(c) "Canadian market requirements, existing export Licences, and those for which applications are under consideration, will not be given terminal year peak-day protection from established reserves provided that a surplus is indicated by calculating the difference between

(1) the established reserves plus those indicated by the trends in the growth of reserves, and

(2) the forecast Canadian requirements over a 30-year period, including terminal year peak-day protection plus export commitments and further, provided that in the opinion of the Board, the trend in the growth of reserves justifies continued confidence "

The application of these principles significantly modified the current surplus calculation By limiting its consideration to contractable reserves, the Board excluded reserves which were beyond economic reach from its estimate of available reserves The multiplier in the formula was increased from 21 to 25, and the requirement to meet the peak-day demand in the terminal year was dropped.

The future surplus calculation remained unchanged

(iv) Reasons for Decision, August 1970

In an August 1970 decision on seven natural gas export applications, the Board liberalized its surplus calculation. Specifically, it allowed 50 percent of reserves beyond economic reach and a part of the reserves deferred for supply conservation by Alberta to be included in its estimate of available reserves which was used to calculate the current surplus. Further, the period of protection provided by the future surplus test was reduced to 20 years from 30.

The Board also concluded that considerations as to future increases in price and lower deliverability suggested a 15-year limit should be placed on incremental licences for existing export systems. The following reasons were cited:

- "... the Board views with concern the trend to accelerated rates of take because the shortening of the life index of the remaining available reserves tends to open an increasing gap between that life index and any of the formulae proposed for the protection of Canadian requirements. The corollary of this is that the deliverability showing of the Applicants, in relation to the proposed terms of the export licences they seek, leaves a considerable portion of that term to be provided for out of future discoveries. Strictly on the analysis of gas supply available to the individual Applicants, it appears to the Board that in respect of companies already in the export business, it is increasingly difficult to justify new licences for periods much in excess of 15 years, and that a shorter period would possibly be more appropriate. A new export system might have to be given a longer initial licence to enable the project to be financed.

  ...if, once the exporting pipe line transmission systems are going concerns, their increments of export throughput were licensed for relatively short terms, United States and Canadian customers would share more equitably in whatever may be the costs of future increments of supply to be committed to Canadian and export markets."

- "An obvious objection to the adoption of approximately 15 years as the normal period for incremental licences for an established exporting company, is that pipe line facilities, gathering facilities and processing facilities are not normally financible on the basis of sales contracts of less than 20 years. The Board is not convinced that this conventional wisdom is applicable in the case of established pipe line enterprises operating in the current circumstances of the energy market.

  The Board would be prepared to consider further whether licences for periods longer than 15 years are necessary to make feasible the financing of a complete new pipe line system, or a major looping for an existing system."

Some export licences were granted despite the calculation of a small negative "future surplus" and the Board stated it was "essential to emphasize the vital importance of an increased rate of discovery if it is to be possible to undertake substantial new exports in the future".

(v) Reasons for Decision, November 1971

In November 1971 in its decision related to additional gas export applications the Board estimated a deficiency of 1.1 Tcf from its current surplus calculation without taking into account the volumes being considered for export. As a result the export applications were dismissed despite confidence at the time that new discoveries would augment existing reserves beyond the indicated deficiency.

(vi) Canadian Natural Gas - Supply and Requirements, April 1975

Subsequent to the Board's November 1971 decision there was growing public debate and concern about the outlook for the Canadian natural gas industry and on appropriate policy responses to the industry situation. The Board therefore called a public hearing "to obtain a clearer insight into matters related to Canada's natural gas supply and

requirements' and invited submittors to provide an evaluation of the Board's 2SA4 gas surplus calculation procedure

There was virtually unanimous agreement among participants at the hearing that 2SA4 no longer adequately protected Canadian requirements and that it appeared "...in light of the changing circumstances now unfolding, that more weight should have been given to deliverability as distinguished from reserves" In considering alternatives to the 2SA4 formula the Board expressed its view that any procedure for determining an exportable surplus should have as many of the following characteristics as possible.

1. It should be easily understood and applied
2. It should incorporate gas deliverability rather than reserves in the supply considerations
3. It should be flexible to respond to changing circumstances
4. It should provide continuing protection for Canadian demand throughout any period of export
5. It should provide incentive and encouragement to the gas industry
6. Licensed export commitments should be satisfied to the extent possible.
7. It should reserve for Canadians any benefits from conservation restraints undertaken by Canadians

At that time, the Board was very concerned about the adequacy of the protection of Canadian requirements given existing export licences and therefore did not anticipate additional export applications in the near future Given these circumstances the Board decided not to develop a specific surplus determination procedure until it would actually be needed. It did, however, establish the following general principles which could form the basis of a surplus determination procedure in the future

- "The surplus calculation procedure would be based on gas deliverability and gas demand schedules developed for as far into the future as reasonable forecasting accuracy and data dependability will permit The comparison of these two schedules will indicate the feasible volumes, rate and timing of exports'

(vii) Canadian Natural Gas - Supply and Requirements, February 1979

In 1979, following a supply/demand inquiry hearing, the Board defined both a current deliverability test and a future deliverability test in addition to a reserves test.

Under the Current Reserves Test natural gas could be deemed surplus to the extent that available established reserves were calculated to exceed a quantity equal to 25 times the current year s Canadian demand plus the total authorized exports

Under the Current Deliverability Test, annual quantities of gas could be deemed to be surplus if forecast annual deliverability from established reserves exceeded expected Canadian demand plus authorized exports for a minimum of five years.

Finally, under the Future Deliverability Test, annual quantities of gas could be deemed to be surplus provided forecast deliverability from established reserves and forecast reserves additions exceeded expected Canadian demand plus authorized exports for some ten years.

The following rationale was given for these tests:

- "The potentially large economic dislocations that could result from unanticipated shortfalls in natural gas deliverability make it imperative that there be a high degree of confidence that deliverability will meet annual Canadian requirements

in the immediate future. Such confidence is also necessary to meet the planning requirements of gas distributors. The difficulties that unanticipated reductions in authorized exports would cause export customers make it important to provide similar protection for authorized exports. The Board believes that a test utilizing deliverability from established reserves will provide the requisite high degree of assurance.

- Tests solely relying on deliverability could lead to excessive industry activity to increase deliverability at the expense of developing new reserves. Therefore the Board believes that a reserves test is necessary to maintain a reasonable relationship between established reserves and deliverability.

A test utilizing remaining established reserves compared with 25 times projected demand four years in the future introduces the uncertainty of a future projection on the demand side but not on the supply side. A formula based on the current year's demand would be more appropriate and a suitable amount of protection would be afforded by setting aside established reserves to provide coverage of current Canadian demand for a period of 25 years plus authorized exports.

- "The Board believes it is important not only to ensure that requirements be afforded the highly assured protection from established reserves as provided under the Current Deliverability Test but also that a longer period of surplus be foreseen when measuring requirements against forecast deliverability from a combination of established reserves, reserves additions and when appropriate new sources of gas such as frontier reserves. It would be necessary, in considering proposed new exports which could meet the Current Deliverability Test and the Current Reserves Test to ensure that such exports would not result in deficiencies in the longer protection period."

The Future Deliverability Test would be used to:

"ensure that any proposed exports which might otherwise be authorized on the basis of satisfying the first two surplus tests would not cause a future deliverability shortfall within a 10 year period. Secondly, in any case where the Board finds that it would be in the public interest to grant a licence term in excess of that indicated by deliverability from established reserves, the extended portion of the licence, both with respect to the annual quantities and term would be limited by the projected deliverability from future reserves. All exports under this extended portion of the licence would be subject to reduction if subsequent deliverability determinations indicated a deficiency within the extended term."

(viii) Reasons for Decision, May 1982

The most recent changes to the gas surplus test were made following Phase II of the Board's 1982 Gas Export Omnibus Hearing.

Although the procedure of comparing the established reserves base with 25 times the current year's Canadian demand plus licensed exports was continued, the allowance in the Reserves Formula for exports under existing licences was reduced. Rather than continuing to incorporate the remaining term quantities in the licences (whether exportable or not), the new procedure set aside only those quantities considered exportable under existing licence conditions.

Also, the Current and Future Deliverability Tests were combined into a single Deliverability Appraisal which contained features of both the previously employed tests. The Deliverability Appraisal is to be used as a guideline rather than as a test, compared estimates of annual deliverability from both established reserves and future reserves additions, with expected annual Canadian requirements and estimated annual exports under existing licences.

The Board's report stated.

"The Deliverability Appraisal will not contain rigid minimum periods of protection as previously used in the Board's Deliverability Tests. Rather, the Board will use its judgement to determine the annual deliverability profile which may be deemed surplus to Canadian needs. While the Board might authorize exports which exceed the deliverability by minor amounts in any one year, the Board would not expect to exceed the sum of the annual differences between requirements and deliverability over the effective term of the Deliverability Appraisal, that is, in the period to cross-over taking place

In coming to the above decisions, the Board agrees with submittors that suggested more flexibility is desirable in determining the amount of surplus gas. While the Board will rely on the Reserves Formula to determine the maximum exportable surplus, it will use the Deliverability Appraisal as a guideline rather than as a specific test to determine the annual quantities of gas surplus to foreseeable Canadian requirements. It is not expected that these procedures would result in the authorization for export of all the surplus calculated using the Reserves Formula."

Description of New Procedure - 1986

The procedure may be described in four steps.

The first step is to calculate the maximum potential surplus A potential surplus is calculated for each year of a forecast period. In the illustrations in Section 4 5, this is the 20-year period 1986-2005. The potential annual surplus is the amount by which annual supply,

as defined below exceeds the estimated total annual demand. The maximum potential surplus is the sum of these estimated annual quantities. The calculation is made on the assumption that each annual surplus is, in fact, produced.

In the calculation of the potential annual surpluses, the procedure is as follows.

(i) annual supply is calculated by dividing the forecast reserves at the end of the year by 15,

(ii) the forecast reserves at the end of each year consist of the reserves available at the beginning of the year plus forecast reserves additions during the year, less forecast production during the year,

(iii) the estimated total annual demand comprises the estimate of Canadian demand plus export volumes expected to flow under existing licences and short-term orders and

(iv) the potential annual surplus is the difference between the annual supply in (i) above and the annual demand in (iii) above.

The surplus calculated in this first step of the procedure is termed maximum potential because it is likely, especially in the early years, that neither pipeline capacity nor markets could accommodate the amounts of potential annual surplus derived by the calculation. In addition an allowance must be made out of the surplus shown for the fuel and losses and reprocessing shrinkage associated with any new exports.

The next three steps in the procedure involve the determination of the appropriate annual level and duration of exports under new or extended licences.

In the second step the Board uses its judgement to select an array of trial profiles and durations for possible additional exports, taking into account such factors as the exports applied for and the results of the first step. However the total of each such profile of additional exports will be less than the maximum potential surplus calculated in step 1. The Board then calculates the reserves to production ratio for each year of each export profile and identifies years in which the R/P ratio drops below 15.

The third step is the Productive Capacity Check which replaces the Board's previous Deliverability Appraisal. In this step, the Board assesses the productive capacity year by year to ensure that forecast total demand can in fact be met. This verification is especially important for any years in which the R/P ratio resulting from the contemplated new exports is forecast to fall below 15.

In the fourth step, the Board determines the most appropriate export profile using the information from the first three steps. This assessment of each export profile takes into account a number of factors, some of which are

- the security of supply for Canadian markets as apparent from the extent to which R/P ratios exceed or fall short of 15 and from the relationship between productive capacity and demand, particularly when the R/P ratio is below 15,
- the capacity of the existing infrastructure to produce and transport the new exports, and
- the estimated net benefits to Canada, taking into account the costs of any new infrastructure which would be required.

Illustrative surplus calculations using the first three steps of the Board's new procedure are provided in Section 4.5.

The new procedure embodies a combination of security of supply and flexibility which the Board considers to be appropriate in the context of market-sensitive pricing and the maturity of the Western Canada Sedimentary Basin.

As an important adjunct to its new surplus determination procedure, the Board intends to conduct reviews at appropriate intervals in order to update its projections of Canadian demand, forecast exports, reserves additions and productive capacity. The publication of the results of these periodic reviews will provide, on the one hand, a forewarning of potential supply problems and time for any necessary adjustments to be made, for example, to the pace of exploration or connection of reserves. On the other hand, such reviews may provide an early indication of continuing or increasing surplus volumes and hence possible further exports.

In carrying out these reviews the Board intends to seek input from interested parties. In accordance with the general nature of views expressed during the hearing, the gathering of information and advice for the periodic reviews will be informal, involving consultation rather than a hearing process, although it may include written submissions. The Board sees such periodic reviews as the establishment of an ongoing consultative mechanism for the benefit of all concerned.

In addition to the informal process described above, there will be public hearings on export applications from time to time which will provide an opportunity for a full and formal examination of all the parameters, including the appropriate R/P ratio, which enter into the determination of surplus. As discussed in Section

4.6.1, such hearings may be held to consider individual export licence applications or may be omnious proceedings.

4.3 The Selection of a Reserves to Production Ratio

As indicated above, the Board intends, at the present time, to use an R/P ratio of 15 in determining surplus. The choice of this ratio depends on evaluating two factors

(i) the Board's estimate of the R/P ratio if Canada's gas supply were called upon to produce steadily at capacity (the productive capacity R/P ratio), and

(ii) the Board's view of the appropriate relationship to be maintained between productive capacity and actual production. This would be expressed in terms of the desired margin between the productive capacity R/P ratio, referred to in (i) above, and the actual R/P ratio.

This section discusses in general terms how these two factors are evaluated and why the Board has decided that an R/P ratio of 15 provides protection for Canadian requirements during and after the period over which new gas exports might be licensed. The more technical details are provided in Appendix 9.

When reserves are being produced at less than their productive capacity, the R/P ratio will be higher than it would be if the reserves were being produced at their productive capacity. (This is simply because the lower the production, the longer the reserves will last and the higher the reserves to production ratio will be.) Thus, an actual R/P ratio higher than would prevail at productive capacity is indicative of spare capacity.

The R/P ratio for reserves in the Western Canada Sedimentary Basin is expected to be about 22 in 1986. When the R/P ratio in future years has declined to 15, because production from a greater proportion of gas reservoirs will have passed its peak and will be steadily declining, there will still be present a significant amount of spare capacity to produce relative to total demand.

Also explained in Appendix 9 are the reasons why the Board believes that this spare capacity would not disappear until the R/P ratio has declined to at least the 12 to 13 range for the Western Canada Sedimentary Basin.

Therefore, the use of an R/P ratio of 15, in conjunction with the Productive Capacity Check, ensures that production during the period of exports will be lower than capacity. The difference between productive capacity and actual production should ensure that Canadian requirements will be met not only during the period of export but also for a number of years thereafter. This will provide, in the Board's view, time for any necessary corrective actions to occur such as changes in the pace of exploration and in connecting reserves.

The Board's estimate of the R/P ratio when Canada's gas supply is called upon to produce steadily at capacity (the above-mentioned 12 to 13 range) may change as gas reservoirs mature and as reserves are added. This change, should it occur, may affect the Board's perception of the appropriate value of the R/P ratio to be used in determining maximum potential surplus. The appropriate relationship between productive capacity and actual production may also be affected by the efficiency of the market under market-sensitive pricing and by the resulting changes in perception regarding the need for protection. The Board is prepared to receive evidence at future proceedings as to whether 15 remains an appropriate R/P ratio to use in its procedure, but, at the present time, it is of the view that the reasonable range for such an R/P ratio is a relatively narrow one centring on 15.

The Board appreciates the potential impact upon the gas producing industry, gas consumers, regional economies and the overall economy of Canada that would occur if a somewhat different ratio were to be chosen. These impacts would occur because of the resulting changes in exportable surplus volumes. The Board also recognizes that the appropriate relationship between productive capacity and actual production, which is one component in the selection of the R/P ratio, is a matter for judgement, recognizing the trade-off between security of supply and the benefits from exports. In this regard the Board believes that cost-benefit analysis can play a role, along with other means, in assessing the appropriate R/P ratio value.

4.4 Merits of the New Procedure

As discussed in Section 4.3, a key feature of the reserves to production ratio procedure is the level of protection and the security of supply which it will provide to Canadian consumers. The maintenance of a suitable R/P ratio over the period of any new export will ensure both that a reasonable amount of spare productive capacity will exist over total requirements on a year-to-year basis and that Canadian requirements will continue to be met for a reasonable period after exports cease.

As was the case with the 25A1 Reserves Formula, the R/P Ratio Procedure explicitly identifies the relevant inputs to the calculation of surplus and the methodology underlying the calculation. Such an explicit methodology for surplus determination allows potential applicants for new export licences to make their own es-

timates of surplus before they incur costs to prepare an application. Such was not necessarily the case with some of the other methods proposed during the hearing.

The new procedure takes into account both the reserves and deliverability aspects of supply. In contrast with the Board's former 25A1 Reserves Formula which provided a static picture at one point in time, the R/P Ratio Procedure embodies dynamic estimates of changes in levels of demand and additions to reserves throughout the forecast period. It is affected less by changes in the current year's requirements than the 25A1 Reserves Formula in which even small changes in demand became magnified, as a result of being multiplied by 25, with concomitant large changes in the resultant surplus calculation. The R/P Ratio Procedure specifically addresses the question of the maturity of the Western Canada Sedimentary Basin and its ability to supply both Canadian and export markets during the inevitable decline of productive capacity as that Basin matures.

The procedure should encourage a reasonable balance between the exploration and development phases of the gas industry - exploration being the basic activity for increasing reserves and development being the basic activity for increasing deliverability.

The R/P Ratio Procedure is based upon a consistent treatment of physical and economic factors in an integrated, forward-looking framework. The procedure is also flexible and capable of responding to changing circumstances, in that the value of the R/P ratio can be changed as evidence accumulates on the trend of the R/P ratio estimated to occur when supply is steadily at capacity, on the working of market-sensitive pricing and on the appropriate relationship between productive capacity and actual production. It also lends itself to the inclusion of new gas-producing regions such as the frontiers.

Under the assumptions incorporated in the illustration of the procedure in Table 4-1 of Section 4.5, a maximum potential surplus of some 10 EJ could result from the new procedure using an R/P ratio of 15. Although this is about the same amount of surplus as would result from the application of the Board's former Reserves Formula, modified to a 20A1 coverage of Canadian requirements, instead of 25A1, the Board would caution that the procedures are not directly comparable since the R/P Ratio Procedure is unlike the Reserves Formula being based on a different concept, and incorporating entirely different parameters.

The Board estimated, using cost benefit analysis, that under a variety of assumptions there could be

substantial net benefits to Canada from exporting an additional 10 EJ of natural gas

The Board is of the view that its surplus determination procedures must be flexible and capable of responding to changing circumstances if they are to be durable. The new market-sensitive pricing policy requires a more responsive and predictive assessment than has been the case in the past. Rigid tests in the emerging new environment could quickly become inappropriate. The Board believes that the new surplus determination procedure set out in this chapter will meet these requirements

APPENDIX 3

SIMULATION PROGRAM LISTING

```
//ONE EXEC VSFTCLG,PARM.FORT='LANGLVL(77),NOSOURCE'
//FORT.SYSIN DD *
      IMPLICIT INTEGER(A,B,C,D,E,F,G,H,I,J,K,L,M,N,O,
     cP,Q,R,S,T,U,V,W,X)
      DIMENSION DS(100,100)
      REALFL(9),RES,FAC,FRES,R1(100),PR(100),CR(100),ZDD(100,100)
      REAL EFFRAT(10,2),DISCR,INVEFF,INVEF,ULTPOT,ZAT(100,10)
      DIMENSION REPRO(100)
      DIMENSION AE(100,100)
      DIMENSION DE(100,100)
      DIMENSION RA(100)
      DIMENSION DER(100,100)
      DIMENSION PERM(100)
      DIMENSION DD(100,100)
      DIMENSION EXALTA(100)
      DIMENSION ALTA(100)
      DIMENSION PD(100)
      DIMENSION DY(100)
      DIMENSION S(100)
      DIMENSION DUDER(100)
      DIMENSION ADDRES(100)
      DIMENSION PROD(100,100)
      DIMENSION SUM(100)
      DIMENSION TDER(100,100)
      DIMENSION TG(100)
      DIMENSION SURPL(100)
      DIMENSION TTG(100)
      DIMENSION TRANS(100)
      DIMENSION AS(100)
      DIMENSION CDER(100,100)
      DIMENSION CTDER(100,100)
      DIMENSION T(100)
      DIMENSION DFA(100,100)
      DIMENSION PRD(100)
      DIMENSION TDD(100)
      DIMENSION TPRD(100)
      DIMENSION LEDD(100)
      DIMENSION DDAENA(100)
```

```
      DIMENSION AY(100)
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      DIMENSION INVDEC(100)
      DIMENSION OPTINV(100)
      DIMENSION OPTDEC(100)
      DIMENSION EFFORT(20)
      DIMENSION FEFORT(100)
      DIMENSION INV(100)
      DIMENSION IINV(20)
      DIMENSION IRA(20)
      DIMENSION PRA(100)
      DIMENSION DELTA1(100)
      DIMENSION ERA(100)
      DIMENSION TRA(100)
      DIMENSION TTGL(100)
      DIMENSION TDEL(100,100)
      DIMENSION DELTA(100,100)
      REAL DMUPR(100)
      REAL DMUCST(100)
      REAL EXUPR(100)
      REAL EXUCST(100)
      DIMENSION DOMREV(100)
      DIMENSION DOMCST(100)
      DIMENSION EXREV(100)
      DIMENSION EXCST(100)
      DIMENSION PV(100)
      DIMENSION FIINV(100)
      DIMENSION APV(100)
      DIMENSION AEXC(100)
      DIMENSION ADMC(100)
      DIMENSION AEXR(100)
      DIMENSION ADMR(100)
      DIMENSION ANREV(100)
      DIMENSION ANCST(100)
      DIMENSION ANPRCP(100)
      DIMENSION ANEXPC(100)
      DIMENSION ANINV(100)
      REAL ZNV1SA(100)
      REAL ZNV2SA(100)
      REAL ZNV3SA(100)
      DIMENSION PVEVOL(100)
      DIMENSION PVDVOL(100)
      REAL LVINV(100)
      REAL LVPRCP(100)
      REAL LVEXCP(100)
      DIMENSION CUMPV(100)
      DIMENSION CUMRES(100)
      DIMENSION RRES(100)
```

```
C*********************************************************************
C INPUT PROVINCIAL DEMAND, FUEL AND LOSSES %,REPROCESSING SHRINKAGE
C SCHEDULE, ALL CURRENTLY AUTHORIZED EXPORTS
C*********************************************************************
      NOEXP=0
      FLOOR=0
      DEBUG=0
      DP=0
      FNLPR=1
      WRITE(6,4)
    4 FORMAT(' ALTA  BC  SASK  MAN  ONT  QUE  EXPANSION CASES')
      READ(5,5)((D8(I,J),J=1,9),I=1,25)
      WRITE(6,5)((D8(I,J),J=1,9),I=1,25)
    5 FORMAT(9I5)
      DO 7 I=26,50
      DO 6 J=1,9
      D8(I,J)=D8(25,J)
    6 CONTINUE
    7 CONTINUE
    3 FORMAT(1H0)
      WRITE(6,8)
    8 FORMAT('  FUEL AND LOSSES PERCENTAGES')
      WRITE(6,4)
      READ(5,10)(FL(J),J=1,9)
      WRITE(6,10)(FL(J),J=1,9)
   10 FORMAT(9F5.3)
      WRITE(6,3)
      WRITE(6,9)
    9 FORMAT('    REPROCESSING SHRINKAGES')
      READ(5,15)(REPRO(J),J=1,25)
      WRITE(6,15)(REPRO(J),J=1,25)
      WRITE(6,19)
   19 FORMAT(' AUTHORIZED EXPORTS   ')
   15 FORMAT(1X,25I3)
      READ(5,20)((AE(I,J),J=1,1),I=1,25)
C     WRITE(6,20)((AE(I,J),J=1,25),I=1,25)
      WRITE(6,20)(AE(I,1),I=1,25)
   20 FORMAT(10I5/15I5)
      WRITE(6,3)
      DO 28 I=1,25
      DO 27 J=1,25
      II=I+25
      JJ=J+25
      AE(II,JJ)=AE(25,J)
   27 CONTINUE
   28 CONTINUE
C LOWER TRIANGULAR AUTHORIZED EXPORTS MATRIX IS CONSTRUCTED
      DO 23 I=2,50
```

```
      DO 22 J=2,I
      J2=J-1
      AE(I,J)=AE(I,J)+AE(I,J2)
   22 CONTINUE
   23 CONTINUE
C INITIAL RESERVES ARE DEFINED HERE ULTIMATE POTENTIAL
C -CONVENTIONAL AND FRONTIER
      WRITE(6,29)
   29  FORMAT('  INITIAL  REMAINING  ESTABLISHED  RESERVES  AND
FRONTIER')
      READ(5,30)RES,FRES,ULTPOT
      WRITE(6,30)RES,FRES,ULTPOT
   30 FORMAT(3F6.2)
      RES=RES*1000
      FRES=FRES*1000
      WRITE(6,31)RES,FRES,ULTPOT
   31 FORMAT(10X,3F10.2)
C NEB RESERVES ADDITIONS FORECAST
      WRITE(6,34)
   34 FORMAT('    RESERVE ADDITIONS    ')
      READ(5,35)(RA(I),I=1,50)
      WRITE(6,35)(RA(I),I=1,50)
   35 FORMAT(10I5/15I5/15I5/10I5)
C     RESERVE ADDITIONS ADJUSTMENTS
      DO 32 I=1,50
      RA(I)=RA(I)*1.00
   32 CONTINUE
      WRITE(6,35)(RA(I),I=1,50)
C DELIVERABILITY FROM ESTABLISHED RESERVES AND FROM FRONTIER
 ADDITIONS ARE INPUT HERE AS SCHEDULES
      WRITE(6,39)
   39 FORMAT('  DELIVERABILITY FROM ESTABLISHED RESERVES')
      READ(5,40)((DER(I,J),J=1,1),I=1,50)
      WRITE(6,40)((DER(I,J),J=1,1),I=1,50)
      READ(5,40)((DFA(I,J),J=1,1),I=1,50)
      WRITE(6,40)((DFA(I,J),J=1,1),I=1,50)
   40 FORMAT(10I5/15I5/15I5/10I5)
      DO 2225 I=1,50
      DO 2226 J=1,1
      DER(I,J)=DER(I,J)+DFA(I,J)
 2226 CONTINUE
 2225 CONTINUE
C     DELIVERABILITY ADJUSTMENTS (ESTABLISHED RESERVES)
      DO 1666 I=1,50
      DO 1665 J=1,50
      DER(I,J)=DER(I,J)*1.00
 1665 CONTINUE
 1666 CONTINUE
```

```
C ALBERTA AND EX-ALBERTA PROTECTION PERIODS(YEARS) FOR THE CRT
      WRITE(6,1699)
 1699 FORMAT('EXALBERTA  AND ALBERTA PROTECTION PREIOD IN YEARS')
      READ(5,1700)M,AM
      WRITE(6,1700)M,AM
 1700 FORMAT(1X,2I4)
C  PERM IS A LIST OF YEARS 1-50 WHICH IS LATER MULTIPLIED BY A 0-1
C  VECTOR TO GENERATE THE TIMING LIST FOR NEB DECISIONS
      DO 1701 I=1,50
      PERM(I)=I
 1701 CONTINUE
      READ(5,1001)((EFFRAT(I,J),J=1,1),I=1,10)
      READ(5,1001)((EFFRAT(I,J),J=2,2),I=1,10)
      DO 1002 I=1,10
      EFFRAT(I,1)=EFFRAT(I,1)*1000
 1002 CONTINUE
      WRITE(6,1003)((EFFRAT(I,J),J=1,1),I=1,10)
      WRITE(6,1001)((EFFRAT(I,J),J=2,2),I=1,10)
 1001 FORMAT(1X,10F6.2)
 1003 FORMAT(1X,10F7.0)
C CONNECTION RATES AND PRODUCTION RATES ARE INPUT HERE
      WRITE(6,48)
   48 FORMAT('  CONNECTION RATES  ')
      READ(5,50)(CR(I),I=1,30)
      WRITE(6,50)(CR(I),I=1,30)
      WRITE(6,47)
   47 FORMAT('  PRODUCTION RATES')
      READ(5,50)(PR(I),I=1,30)
      WRITE(6,50)(PR(I),I=1,30)
   50 FORMAT(1X,10F6.4/1X,11F6.4/1X,9F6.4)
      DO 46 I=26,50
      CR(I)=CR(25)
      PR(I)=PR(25)
   46 CONTINUE
      READ(5,53)(DY(I),I=1,50)
      WRITE(6,53)(DY(I),I=1,50)
   53 FORMAT(1X,50I1)
      WRITE(6,52)
   52  FORMAT(1X,'ALLOCATION  PERIOD,PRCNT
CALLOCTD,FY,BCF,BASE,RULE1,2,3')
      READ(5,49)ALCPR,ZPRALC,FY,BCF,BASE,RULE1,RULE2,RULE3
      WRITE(6,49)ALCPR,ZPRALC,FY,BCF,BASE,RULE1,RULE2,RULE3
   49 FORMAT(1X,I3,1F4.2,2I2,1I4,3I3)
      READ(5,37)FD
   37 FORMAT(1X,1I3)
      WRITE(6,38)FD
   38 FORMAT(/1X,'THE F D T COVERS',1X,1I2,1X,'YEARS.'/)
C
```

```
C-----DEFINITIONS------
C      ALCPR - ALLOCATION PERIOD IN YEARS
C      ZPRALC - PERCENTAGE OF TOTAL SURPLUS ALLOCATED IN A DECISION
C      YEAR
C      DY(I) - 50 SLOTS - 1 IMPLIES DECISION YEAR, 0 NOT A DECISION
C      YEAR
C      FY - FIRST DECISION YEAR IE. YEAR 1, OR 2, OR 3
C      FD - NUMBER OF YEARS FOR THE FUTURE DELIVERABILITY TEST
C      BCF - IF EQUAL TO 1, A FACTOR OF .95 IS APPLIED TO ALL INPUT
C      DATA
C      BASE - INDICATES THE STARTING DATE IE. 1980
C      RULE 1 - A PERCENTAGE OF TREND GAS IS USED IN THE CURRENT
C                DELIVERABILITY TEST. THE PERCENTAGES ARE GIVEN IN
C               THE
C               SERIES R1 WHICH FOLLOWS.1 ACTIVATES THIS OPTION.
C       RULE 2 - IF EQUAL TO 0 CURRENT YEAR TREND FROM RESERVE C
ADDITIONS ARE USED IN THE CURRENT DELIVERABILITY TEST, 1 C
OTHERWISE.
C      RULE 3 - NOT DEFINED AT THIS TIME.
C
C
C      WRITE(6,51)
   51 FORMAT(1H1,1X)
C R1 ARE THE ANNUAL PERCENTAGES OF TREND USED IN THE CDT.
      READ(5,50)(R1(I),I=1,25)
      WRITE(6,50)(R1(I),I=1,25)
C IF BCF=1,THE THE PJ INPUTS ARE ALL CONVERTED TO BCF, AND ALL C
  OUTPUTS ARE REPORTED IN BCF.
      IF(BCF.EQ.0)GO TO 54
      WRITE(6,3008)
 3008 FORMAT(1X,' THE OUTPUT WILL BE PRINTED IN CUBIC FEET X
 10**9')
C
C  ADJUSTMENTS TO OBTAIN BCF OUTPUT FROM PJ INPUTS FOLLOW :
C
      RES=RES*(.95)
      FRES=FRES*(.95)
      DO 1053 J=1,50
      DO 1052 I=1,50
      AE(I,J)=FLOAT(AE(I,J))*(.95)
      DFA(I,J)=FLOAT(DFA(I,J))*(.95)
      DER(I,J)=FLOAT(DER(I,J))*(.95)
      DS(I,J)=FLOAT(DS(I,J))*(.95)
 1052 CONTINUE
      RA(J)=FLOAT(RA(J))*(.95)
      REPRO(J)=FLOAT(REPRO(J))*(.95)
 1053 CONTINUE
C     FUEL AND LOSSES FACTORS ARE APPLIED TO PROVINCIAL SALES.
```

```
   54 DO 60 J=1,9
      DO 65 I=1,50
      DD(I,J)=D8(I,J)*FL(J)+D8(I,J)
   65 CONTINUE
   60 CONTINUE
      IF(FY.EQ.0)GO TO 8010
      TFY=FY-1
      READ(5,3000)XX
C     WRITE(6,3000)XX
C NOTE XX EQUAL TO 0 INDICATES PRIMARY DEMAND TYPE INPUT.
C     XX EQUAL TO 1 INDICATES PROVINCIAL SALES TYPE INPUT DATA.
 3000 FORMAT(1X,I2)
      IF(XX.EQ.1)GO TO 3050
C PRIMARY DEMAND INPUTS
      READ(5,3005)(PRD(I),I=1,50)
      WRITE(6,3005)(PRD(I),I=1,50)
 3005 FORMAT(10I5/15I5/15I5/10I5)
      IF(BCF.EQ.0)GO TO 3007
C A POSSIBLE ADDITIONAL BCF CONVERSION FOR PRIMARY DEMAND
      DO 3006 I=1,50
      PRD(I)=FLOAT(PRD(I))*(.95)
 3006 CONTINUE
C  THE FOLLOWING PART OF THE PROGRAM PROPORTIONATELY ALLOCATES THE
C  QUANTITY
C  (PRIMARY DEMAND LESS REPROCESSING SHRINKAGE) TO PROVINCES BASED
C  ON THE
C  DATA INPUT ON SALES FOR THE PROVINCES. IE. SHELL PRIMARY DEMAND
C  INPUTS
C  COULD BE ALLOCATED BY DEDUCTING NEB REPROCESSING SHRINKAGE AND
C  THEN
C  ALLOCATING THE REMAINING SHELL INPUT, ESSENTIALLY USING THE NEB
C  PROVINCIAL
C  SALES DATA AS INDICES. OF COURSE THE USE OF A SINGLE DATA SOURCE
C  FOR
C   PROVINCIAL SALES, REPROCESSING SHRINKAGE, AND PRIMARY DEMAND
C  MIGHT BE
C  PREFERABLE, HOWEVER WE FREQUENTLY ONLY RECIEVED TIMELY DATA ON
C  PRIMARY
C  DEMAND AND HAD TO MAKE THE ASSUMPTION THAT THE NEB OR OTHER
C  PROVINCIAL
C  SALES SHARES WERE APPROXIMATELY CORRECT.
 3007 DO 3010 I=1,50
      DO 3009 J=1,9
      TDD(I)=TDD(I)+DD(I,J)
 3009 CONTINUE
C     WRITE(6,3005)TDD(I)
 3010 CONTINUE
      DO 3020 I=1,50
```

```
      DO 3019 J=1,9
      ZDD(I,J)=FLOAT(DD(I,J))/FLOAT(TDD(I))
 3019 CONTINUE
 3020 CONTINUE
C     WRITE(6,3011)((ZDD(I,J),J=1,9),I=1,50)
 3011 FORMAT(1X,9F6.3)
      DO 3030 I=1,50
      TPRD(I)=PRD(I)-REPRO(I)
 3030 CONTINUE
      DO 3040 I=1,50
      DO 3039 J=1,9
      DD(I,J)=TPRD(I)*ZDD(I,J)
 3039 CONTINUE
 3040 CONTINUE
C     YEARS 25-50 DEMAND IS ESTIMATED,USING YR25 DEMAND AND AN
C     ELASTICITY ESTIMATE OF -1 WITH FUTURE PRICE ESTIMATES
 3050 DO 6666 I=1,75
      INVDEC(I)=0
      DMUPR(I)=3.00*((1.05)**I)
      DMUCST(I)=1.00
      EXUPR(I)=1.33*(DMUPR(I))
      EXUCST(I)=0.70
 6666 CONTINUE
      DO 3042 I=26,75
      DO 3041 J=1,9
      K=I-1
      DD(I,J)=DD(K,J)+(((DMUPR(K)-DMUPR(I))/DMUPR(K))*DD(K,J))
 3041 CONTINUE
 3042 CONTINUE
C     WRITE(6,3015)((DD(I,J),J=1,9),I=1,50)
 3015 FORMAT(1X,9I7)
      DO 70 I=1,75
      DO 75 J=2,9
      EXALTA(I)=EXALTA(I)+DD(I,J)
   75 CONTINUE
   70 CONTINUE
      DO 80 I=1,75
      ALTA(I)=DD(I,1)
   80 CONTINUE
      DO 82 I=26,75
      REPRO(I)=REPRO(25)
   82 CONTINUE
      DO 85 I=1,75
      PD(I)=ALTA(I)+EXALTA(I)+REPRO(I)
   85 CONTINUE
C     WRITE(6,90)((DD(I,J),J=1,9),I=1,50)
C     WRITE(6,91)(ALTA(I),I=1,50)
C     WRITE(6,91)(PD(I),I=1,50)
```

```
C      WRITE(6,91)(EXALTA(I),I=1,50)
   90 FORMAT(9I7)
   91 FORMAT(10I5/15I5/15I5/10I5)
      DO 94 I=1,50
      DD(I,1)=PD(I)
   94 CONTINUE
    IF(TFY.EQ.0)GO TO 8010
C THIS SECITON IS CONCERNED WITH THE DEVELOPMENT OF A 'BUBBLE'
BETWEEN THE START OF THE ANALYSIS AND THE FIRST DECISION YEAR.
IF THE FIRST YEAR IS A DECISION YEAR, THEN FY=1, AND TFY=0 AND
THERE IS NO 'PAST' SURPLUS (FOR A BUBBLE) TO WORRY ABOUT.  IF FY>1,
THEN THE SURPLUS DELIVERABILITY FROM THE YEARS IN WHICH THERE WAS
A POSITIVE SURPLUS (AND NO HEARINGS TO SHIP IT OUT) IS ACCUMULATED
IN A STOCK CALLED 'PS' (PAST SURPLUS) AND IS ALLOCATED FROM THE
FIRST DECISION YEAR UNTIL THE END OF THE HORIZON (TO THE LAST YEAR
OF INPUT DATA) AT 5% PER ANNUM.  THIS 5% IS CLEARLY IS A DECISION
VARIABLE, AND MAY BE CHANGED OR REPLACED BY A FUNCTION IF DESIRED,
HOWEVER IT SEEMED TO BE A REASONABLE WORKING ASSUMPTION.
      PS=0
      DO 8000 I=1,TFY
      PS=PS+DER(I,1)-DD(I,1)-AE(I,1)
 8000 CONTINUE
      IF(DP.GT.2)WRITE(6,8005)PS,DER(1,1),DD(1,1),AE(1,1)
 8005 FORMAT(10X,4I6)
      DO 8010 I=FY,FY+20
      DER(I,1)=DER(I,1)+.05*(PS)
 8010 CONTINUE
      IF(DEBUG.EQ.1)WRITE(6,2010)((DER(I,J),J=1,25),I=1,50)
C  THE NEXT SECTION GENERATES THE DELIVERABILITY MATRIX FROM THE
RESERVES
C  ADDITIONS USING THE INPUT DATA FOR CONNECTION AND PRODUCTION
    RATES.
      DO 210 I=1,50
      DO 211 J=1,50
      PROD(I,J)=0
  211 CONTINUE
  210 CONTINUE
      DO 209 I=1,50
C     WRITE(6,9004)RA(I),CR(I),PR(I)
      PROD(I,1)=(FLOAT(RA(I))*CR(1))
C     WRITE(6,9003)(PROD(I,J),J=1,25)
 9003 FORMAT(1X,10I6/1X,15I6)
  209 CONTINUE
      K=1
      I1=0
      DO 214 J=2,50
      K=K+1
      I1=I1+1
```

```
C THE CONNECTION RATE IS APPLIED HERE.
C*****DO*2*3*I=K,50
      PROD(I,J)=(FLOAT(RA(I-I1))*CR(J))
  215 CONTINUE
  214 CONTINUE
C THE PRODUCTION RATE IS APPLIED HERE.
      DO 217 I=1,50
      DO 218 J=1,50
      PROD(I,J)=(FLOAT(PROD(I,J))*PR(J))
  218 CONTINUE
  217 CONTINUE
      DO 229 I=1,50
C     WRITE(6,9004)RA(I),CR(I),PR(I)
 9004 FORMAT(1X,1I10,2F10.2)
  229 CONTINUE
C THE PRODUCIBILITY MATRIX IS COMPLETE
      DO 230 I=1,50
      IF(DEBUG.EQ.1)WRITE(6,9005)(PROD(I,J),J=1,25)
 9005 FORMAT(1X,25I5)
  230 CONTINUE
C THE TREND GAS ESTIMATES ARE PRODUCED HERE, BASED ON THE RESERVES
C  ADDITIONS FORECAST.
      DO 221 I=1,50
      SUM(I)=0
      DO 222 J=1,50
      SUM(I)=PROD(I,J)+SUM(I)
  222 CONTINUE
  221 CONTINUE
 9010 FORMAT(1H1,1X)
      IF(DEBUG.EQ.1)GO TO 9250
      GO TO 250
 9250 DO 250 I=1,50
      WRITE(6,9006)I,SUM(I)
 9006 FORMAT(1H0,5X,I4,10X,I6)
  250 CONTINUE
      DO 220 K=1,50
      J=0
      DO 223 I=K,50
      J=J+1
      TDER(I,K)=PROD(I,J)
  223 CONTINUE
  220 CONTINUE
      DO 247 I=1,50
      DO 246 J=1,50
      T(I)=T(I)+TDER(I,J)
      CTDER(I,J)=T(I)
  246 CONTINUE
  247 CONTINUE
```

```
      DO 249 I=1,50
      DO 248 J=1,50
      CDER(I,J)=DER(I,1)+CTDER(I,J)
      TG(I)=DER(I,1)+SUM(I)
C   'TG' IS THE TREND LINE OR THE DIAGONAL OF THE DELIVERABILITY
MATRIX AT
C    THIS POINT IN THE PROGRAM.
  248 CONTINUE
  249 CONTINUE
      DO 225 I=1,50
      DO 226 J=1,50
      DER(I,J)=CDER(I,J)
  226 CONTINUE
  225 CONTINUE
      IF(DEBUG.EQ.1)WRITE(6,2010)((DER(I,J),J=1,25),I=1,50)
 2010 FORMAT(1X,'DER',1X,25I5)

C  DOMESTIC DEMAND MAY BE MODIFIED BY SOME PERCENTAGE AT THIS LINE.
C   THE % IS A CONSTANT BUT MAY ALSO BE
C   A FUNCTION OF TIME E.G.((1+R)**I).....
      DD(I,1)=DD(I,1)*1.00
 2999 CONTINUE
      DO 1 I=1,50
      DY(I)=DY(I)*PERM(I)
    1 CONTINUE
      DY(50)=-20
      X=1
      CUMEFF=0
      TEMPEF=0
      INVEFF=3.00
      DISCR=.15
      CDTCR=0
      TP=0
C
C     THE FOLLOWING INTRODUCES A DELAY BETWEEN EXPLORATION C
EXPENDITURES
C   AND THE CONNECTION AND PRODUCTION OF THE ASSOCIATED RESERVE
C   ADDITIONS.
C
 6600 DELAY1=0
      IF(DELAY1.EQ.0)GO TO 6620
      KK=50-DELAY1
      DO  6605 I=1,KK
      K=I+DELAY1
      CR(K)=CR(I)
      PR(K)=PR(I)
 6605 CONTINUE
      DO 6610 I=1,DELAY1
```

```
      CR(I)=0.0
      PR(I)=0.0
 6610 CONTINUE
 6620 CONTINUE
C     LINE 900 IS THE STOP
C     LINE 1004 IS AT THE END OF THE TEST LOOP, AND
C     GOING TO 1004 INCREMENTS X BY 1,
C     AND RETURNS TO STATEMENT 2 ABOVE
C
C THE INVESTMENT LOOP WILL BEGIN HERE
    2 IF(DY(X))900,6005,6010
 6005 TP=-1
      DZ=PERM(X)
      GO TO 6010
C     THIS ADJ IS NECESSARY LATER IN THE NO EXPORTS PROGRAM
 6010 IF(INVDEC(X).EQ.1)GO TO 6100
      DZ=PERM(X)
      DO 6012 I=X,50
      DO 6011 J=X,50
      TDEL(I,J)=DER(I,J)
      DELTA(I,J)=0
 6011 CONTINUE
      TTGL(I)=TG(I)
      DER(I,DZ)=0.0
      TG(I)=0.0
 6012 CONTINUE
      TRA(X)=RA(X)
 6100 DZ=PERM(X)
      IF(OPTINV(X).EQ.0)GO TO 6200
C     WRITE(6,2010)((DER(I,J),J=1,25),I=1,25)
      IF(II.GT.1)GO TO 6102
      II=2
 6102 INV(X)=FIINV(X)
      FEFORT(X)=INV(X)*INVEFF*((1.02)**X)
      FINEFF=CUMEFF+FEFORT(X)
      DO 6110 IJ=1,10
      IF(FINEFF.LE.EFFRAT(IJ,1)) GO TO 6115
 6110 CONTINUE
 6115 IF(FEFORT(X).EQ.0)RA(X)=0
      IF(FEFORT(X).EQ.0)GO TO 6120
      IF(IJ.EQ.1)RA(X)=FLOAT(FEFORT(X))*EFFRAT(IJ,2)
      IF(IJ.EQ.1)GO TO 6120
           I F ( C U M E F F . G T . E F F R A T ( I J - 1 , 1 ) )
RA(X)=FLOAT(FEFORT(X))*EFFRAT(IJ-1,2)
      IF(CUMEFF.GT.EFFRAT(IJ-1,1)) GO TO 6120

RA(X)=((CUMEFF+FEFORT(X)-EFFRAT(IJ-1,1))*EFFRAT(IJ,2))+((EFFRAT(IJ
     X-1,1)-CUMEFF)*EFFRAT(IJ-1,2))
```

```
 6120 CONTINUE
C      IF(X.GT.14)WRITE(6,2010)((DER(I,J),J=1,25),I=1,25)
       CUMEFF=CUMEFF+FEFORT(X)
       DO 6130 KK=1,50
       PRA(KK)=CR(KK)*PR(KK)*RA(X)
       ERA(KK)=CR(KK)*PR(KK)*TRA(X)
       DELTA(KK,X)=PRA(KK)-ERA(KK)
C        TRA(X)=TRA(X)-PRA(KK) OMIT FOR NOW TO ALIGN PROGRAMS
C
 6130 CONTINUE
       IF(DEBUG.EQ.1)WRITE(6,2010)((DER(I,J),J=1,25),I=1,25)
       DO 6140 I=X,50
       DO 6139 J=X,I
       DER(I,J)=TDEL(I,J)+DELTA(I-X+1,X)
       IF(DER(I,J).LT.0)DER(I,J)=0
 6139 CONTINUE
       TG(I)=DER(I,I)
       IF(TG(I).LT.0)TG(I)=0
 6140 CONTINUE
 6150 CONTINUE
       IF(DEBUG.EQ.1)WRITE(6,2010)((DER(I,J),J=1,25),I=1,25)
       IF(DEBUG.EQ.1)WRITE(6,2010)((DELTA(I,J),J=1,25),I=1,25)
       GO TO 6400
 6200 CONTINUE
       IINV(1)=250
       IF(X.EQ.1)GO TO 6205
       IF(FLOOR.EQ.1)GO TO 6205
       IF(IINV(DZ-1).LT.10)IINV(DZ-1)=10
       IF(DZ.GT.1)IINV(1)=INV(DZ-1)*(.70)
 6205 DO 6300 II=1,20
       EFFORT(II)=IINV(II)*INVEFF*((1.02)**X)
       TEMPEF=CUMEFF+EFFORT(II)
C       (LOOP STAYS OPEN)
       DO 6210 IJ=1,10
       IF(TEMPEF.LE.EFFRAT(IJ,1)) GO TO 6215
 6210 CONTINUE
 6215 IF(EFFORT(II).EQ.0)IRA(II)=0
       IF(EFFORT(II).EQ.0)GO TO 6220
       IF(IJ.EQ.1)IRA(II)=EFFORT(II)*EFFRAT(IJ,2)
       IF(IJ.EQ.1)GO TO 6220
            I F ( C U M E F F . G T . E F F R A T ( I J - 1 , 1 ) )
IRA(II)=EFFORT(II)*EFFRAT(IJ-1,2)
       IF(CUMEFF.GT.EFFRAT(IJ-1,1)) GO TO 6220
IRA(II)=((CUMEFF+EFFORT(II)-EFFRAT(IJ-1,1))*EFFRAT(IJ,2))+((EFFRAT
     X(IJ-1,1)-CUMEFF)*EFFRAT(IJ-1,2))
 6220 CONTINUE
       DO 6230 KK=1,50
       PRA(KK)=CR(KK)*PR(KK)*IRA(II)
```

```
      ERA(KK)=CR(KK)*PR(KK)*TRA(X)
      DELTA(KK,X)=PRA(KK)-ERA(KK)
C       TRA(II)=TRA(II)-PRA(KK) OMIT FOR NOW TO ALIGN PROGRAMS
 6230 CONTINUE
      DO 6240 I=X,50
      DO 6239 J=X,I
      DER(I,J)=TDEL(I,J)+DELTA(I-X+1,X)
      IF(DER(I,J).LT.0)DER(I,J)=0
 6239 CONTINUE
      TG(I)=DER(I,I)
      IF(TG(I).LT.0)TG(I)=0
 6240 CONTINUE
 6250 RA(X)=IRA(II)
      IF(DEBUG.EQ.1)WRITE(6,2010)((DER(I,J),J=1,25),I=1,25)
      IF(DEBUG.EQ.1)WRITE(6,2010)((DELTA(I,J),J=1,25),I=1,25)
      GO TO 6400
C THE INV LOOP WILL END HERE
C        THE TEST LOOP -CDT-FDT-CRT- BEGINS HERE
C
C        CURRENT DELIVERABILITY TEST
C
C  THIS PART OF THE PROGRAM GOES FROM DECISION YEAR TO THE END OF
C  ALLOCATION PERIOD, WRITING ANNUAL AND CUMULATIVE SURPLUSES FOR
C  PERIOD, AS WELL AS THE CROSSOVER YEAR IF IT OCCURS DURING THAT
C  PERIOD. IF THE TOTAL SURPLUS IS LESS THAN ZERO, THE TEST FAILS
C  THE PROGRAM CONTINUES TO THE NEXT TEST.
C
C   DECYR- DECISION YEAR, DY(X) IS NOW A 1-25 NUMBER,DECYR WILL BE
C                        A DECISION YEAR E.G. 1987
C    TS- TOTAL SURPLUS, ACCUMULATES A POTENTIAL BUBBLE BETWEEN THE
C       STARTING YEAR AND THE FIRST DECISION YEAR
 6400 WRITE(6,6401)II,DZ,INVDEC(X),OPTINV(X)
   6  4  0  1       F  O  R  M  A  T  (  1  X  ,  '  I  N  V
PASS=',1I2,'DZ=',1I2,'INVDEC',1I2,'OPTINV(X)=',1I2)
WRITE(6,6402)EFFORT(II),IINV(II),DELTA(X,DZ),IRA(II),CUMEFF,RA(X)
                6                    4                    0                    2
FORMAT(1X,'EFFORT(II)',I6,'IINV(II)',I6,'DELTA(X,DZ)',I6,'IRA(II)'
     X,I6,'CUMEFF',I8,'RA(X)',I6)
      TS=0
      DECYR=BASE+PERM(X)-1
      IF(OPTDEC(X).EQ.1)WRITE(6,999)
      IF(OPTDEC(X).EQ.1)WRITE(6,2000)DECYR
 2000 FORMAT(1X,'              THE DECISION YEAR IS ',1I4//)
      IF(OPTDEC(X).EQ.1)WRITE(6,3)
C***  DZ IS THE 1-25 NUMBER IN DY(X) AND IS USED AS A CONSTANT
C     DZ=DY(X)           ....THIS IS DONE USING PERM()
C     RULE2=0:CURRENT YEAR R.A. TREND GAS IS USED IN THE CDT
C      RULE2=1:NO CURRENT YEAR R.A. TREND GAS USED IN THE CDT
```

```
      IF(RULE2.EQ.0)GO TO 2003
C     DO 2003 I=DZ,50
C     DL=DZ-1
C     DER(I,DZ)=DER(I,DL)
C2003 CONTINUE
      RULE1=1:A % OF TREND GAS IS USED IN THE CDT
C     RULE1=0:NO TREND GAS IS USED IN THE CDT
C     R1(K)= THE ANNUAL SERIES OF THE % OF TREND USED IN THE CDT
C     IF(RULE1.EQ.0)GO TO 2002
C     K=0
C     DO 2002 I=DZ,50
C     K=K+1
C     DER(I,DZ)=DER(I,DZ)+(R1(K)*(TG(I)-DER(I,DZ)))
C2002 CONTINUE
C     WRITE(6,2010)((DER(I,J),J=1,25),I=1,25)
C     ALCPR-ALLOCATION PERIOD IN YEARS UNDER THE CDT
C      ALOCPR-THE YEAR THAT THE ALLOCATION PERIOD ENDS FOR THE C
   CURRENT DECISION YEAR.
      ALOCPR=DZ+ALCPR-1
      IF(X.GT.50)GO TO 199
      IF(OPTINV(X).EQ.1)WRITE(6,5099)
  5099    FORMAT(T4,'SURPLUS',T17,'YEAR',T23,'CUM.
SRPL',T36,'DELIV.',T44,'
     1DEMAND',T52,'AUTH. EXP.')
C      GO FROM THE CURRENT DECISION YEAR TO THE END OF THE C
ALLOCATION PERIOD,COMPUTING ANNUAL AND TOTAL SURPLUSES
C     S(J)-ANNUAL SURPLUS UNDER THE CDT
C     TS-CUMULATIVE SURPLUS UNDER THE CDT
      DO 100 J=DZ,ALOCPR
      S(J)=DER(J,DZ)-DD(J,1)-AE(J,DZ)
      TS=TS+S(J)
      IF(S(J).LE.0)WRITE(6,98)J
C     IF AN ANNUAL SURPLUS IS NEGATIVE,THE CROSSOVER NOTE IS OUTPUT
   98 FORMAT(' THE CROSSOVER YEAR FOR THE CDT IS ',1I4)
IF(OPTINV(X).EQ.1)WRITE(6,99)S(J),J,TS,DER(J,DZ),DD(J,1),AE(J,DZ)
   99 FORMAT(1X,6I10)
  100 CONTINUE
      IF(TS.LE.0)CDTCR=1
      IF(TS.LE.0)GO TO 160
C     IF THE CUMULATIVE SURPLUS -TS- IS <=0, (160) THE CDT FAILS
      IF(OPTDEC(X).EQ.1)WRITE(6,3)
C  IF THE SURPLUS AT THE END OF THE ALLOCATION PERIOD IS GREATER
C   ZERO, THE PROGRAM CONTINUES TO IF(OPTDEC(X).EQ.1)WRITE THE C
ANNUAL SUR, CUMULATIVE SURPLUS, UNTIL THE CROSSOVER YEAR IS C
REACHED
      IF(OPTINV(X).EQ.1)WRITE(6,5099)
      J=ALOCPR+1
      S(J)=DER(J,DZ)-DD(J,1)-AE(J,DZ)
```

```
      TAS=TS
      IF(S(J).LE.0)GO TO 120
      AA=ALOCPR+1
      DO 120 J=AA,50
      S(J)=DER(J,DZ)-DD(J,1)-AE(J,DZ)
      IF(S(J).LE.0)GO TO 124
      TAS=TAS+S(J)
      IF(OPTDEC(X).EQ.0)GO TO 1210
      WRITE(6,121)S(J),J,TAS,DER(J,DZ),DD(J,1),AE(J,DZ)
  121 FORMAT(1X,6I10)
 1210 CONTINUE
      IF(J.EQ.50)GO TO 130
  120 CONTINUE
      IF(OPTDEC(X).EQ.1)WRITE(6,3)
      IF(OPTDEC(X).EQ.1)WRITE(6,5122)
 5122 FORMAT(2X,' S(J)    J                          DER(J,DZ) DD(J,1)
AE(J,DZ)')
                                    1                   2                   4
IF(OPTDEC(X).EQ.1)WRITE(6,122)S(J),J,DER(J,DZ),DD(J,1),AE(J,DZ)
  122 FORMAT(1X,2I10,10X,3I10,'   CROSSOVER YEAR FOR THE CDT ')
C     WRITE(6,2010)((DER(I,J),J=1,25),I=1,10)
C     WRITE(6,5124)
 5124 FORMAT(1X,'   FORMAT  5124      IF(OPTDEC(X).EQ.1)WRITE(6,3)
  130 CONTINUE
C     TS-TOTAL SURPLUS
C     ALCPR-ALLOCATION PERIOD
C     ZPRALC-% OF TOTAL SURPLUS TO BE ALLOCATED OVER (ALCPR) YEARS
      IF(OPTDEC(X).EQ.1)WRITE(6,2050)TS,ALCPR,ZPRALC
 2050 FORMAT(25X,2I6,2X,1F4.2)
C     CLEAR AS(I)-ALLOCATED SURPLUS OF ANY PREVIOUS ALLOCATION
      DO 135 I=1,50
      ADDRES(I)=0
      AS(I)=0
  135 CONTINUE
      IF(TP.EQ.(-1))GO TO 780
C  HERE, WHERE THE TOTAL SURPLUS IS GREATER THAN ZERO, IS IS
C    ALLOCATED EQUALLY OVER ALCPR YEARS, AS IS THE UNUSED
DELIVERABILITY.
C     AS(J)-ALLOCATED SURPLUS
C     ADDRES(J)-ADDITION TO RESERVES(POSSIBLE % OF TS UNALLOCATED)
      IF(OPTINV(X).EQ.0) GO TO 140
      DO 140 J=DZ,ALOCPR
      AS(J)=(TS/ALCPR)*ZPRALC
      ADDRES(J)=(TS/ALCPR)*(1-ZPRALC)
  140 CONTINUE
      IF(OPTINV(X).EQ.1)WRITE(6,138)
                                    1                   3                   8
FORMAT(T2,'ALLOCATED',T13,'DECISION',T22,'ALLOCATION',T33,'ADDED
```

```
     10',/T3,'SURPLUS',T15,'YEAR',T24,'PERIOD',T34,'RESERVES'//)
C     WRITE THE ANNUAL ALLOCATION,DECISION YEAR,ALLOCATION PERIOD,
C           AND THE ANNUAL ADDITION TO RESERVES
C          ....CHECK THAT THE ADDRES ARE PROPERLY ACCUMULATED+USED
      IF(OPTINV(X).EQ.1)WRITE(6,141)AS(DZ),DZ,ALCPR,ADDRES(DZ)
  141 FORMAT(1X,4I10)
C
C  THIS STEP DEFINES NDY AS THE NEXT DECISION YEAR. IF THE NEXT
C  DECISION YEAR IS THE END OF THE DECISION FILE, THE PROGRAM GOES
C  THE NEXT TEST, AS THERE IS NO NEED TO ALLOCATE ANY CURRENT
C  (UNDELIVERED DELIVERABLE) SURPLUS OVER TIME.
C  NDY=NEXT DECISION YEAR
C
      J=DY(X)
  150 J=J+1
      IF(J.EQ.50)GO TO 199
      IF(DY(J))150,150,155
  155 NDY=DY(J)
C
C THIS SECTION DECIDES WHAT THE NEXT DECISION PERIOD, OR
C  THE END OF THE ALLOCATION PERIOD
C     NNDY-DIFFERENCE BETWEEN NDY AND ALOCPR
C     PROXY=THE ITEM WHICH COMES NEXT IN TIME,NDY OR ALOCPR
C
      NNDY=NDY-ALOCPR
      IF(NNDY)180,170,170
  170 PROXY=ALOCPR
      GO TO 190
  180 PROXY=NDY
C
C  THE UNDELIVERED DELIVERABLE FROM DY TO THE NEXT DECISION YEAR,
OR
C  THE END OF THE ALLOCATION PERIOD, WHICHEVER COMES FIRST IS C
SUBJECTED TO THE ALLOCATION DEVICE WHICH WILL FOLLOW.
C  IN THIS SECTION IT IS THE ADDITIONS TO RESERVES WHICH ARE ADDED
C  TO THE STORAGE AREA DUDER.  THESE ADDITIONS MAY COME FROM EITHER
C  OF TWO PLACES; CURRENT SURPLUS NOT ALLOCATED BY THE NEB, OR
C  ADDITIONS TO RESERVES FROM A REALLOCATION DURING THE FDT... C
DUDER-DELIVERABLE  FROM  UNDELIVERED  DELIVERABILITY  FROM  C
ESTABLISHED RESERVES ( SORT OF A POSTPONED DELIVERABILITY )
C
      DUDER(PROXY)=0
  190 PROXY=PROXY-1
      DO 195 I=DZ,PROXY
      DUDER(PROXY)=DUDER(PROXY)+ADDRES(I)
      IF(DP.GE.2)WRITE(6,191)DUDER(PROXY),I,PROXY,ADDRES(I)
  191 FORMAT(30X,4I6,'  AT STEP 190  ')
  195 CONTINUE
```

```
      GO TO 199
  160 WRITE(6,161)
  161 FORMAT(1X,'THE C D T FAILS')
      IF(PROXY.LT.DZ)PROXY=DZ
  199 CONTINUE
C
      IF(TP.EQ.(-1))GO TO 780
C
C   HERE, DUDER, THE RESERVE OF WELLS WHICH HAVE UNDELIVERED C
DELIVERABILITY IS INCREASED BY THE DIFFERENCE BETWEEN TREND LINE
C  AND DER LINE FOR THE PREIOD BETWEEN THE DECISION YEAR AND EITHER
C   THE NEXT DECISION YEAR OR THE END OF THE ALLOCATION PERIOD.
C
      DO 400 I=DZ,PROXY
      DUDER(PROXY)=TG(I)-DER(I,DZ)+DUDER(PROXY)
      IF(DP.GE.2)WRITE(6,401)DUDER(PROXY),I,TG(I),DER(I,DZ)
  401 FORMAT(10X,4I10,'  STEP 400  ')
  400 CONTINUE
C     IF(RULE2.EQ.0)GO TO 420
C     DO 420 I=DZ,50
C     DER(I,DZ)=CDER(I,DZ)
C 420 CONTINUE
C
C   THIS SECTION PRESENTS THE FUTURE DELIVERABILITY TEST. THE C
DIFFERENCE BETWEEN THE CURRENT(AT TEST DATE) TREND LINE AND THE C
SUM OF DOMESTIC DEMAND,EXPORTS, AND ALLOCATIONS UNDER THE C
PREVIOUS   CDT ARE STORED IN THE FILE SURPLUS.
C
C     WRITE(6,3)
C  THE FILES SRPL,SURPL(I),ADDRES(I) ARE CLEARED(=0)
      SRPL=0
      DO 501 I=1,50
      SURPL(I)=0
      ADDRES(I)=0
  501 CONTINUE
C    ANNUAL SURPLUSES-SURPL(I) ARE COMPUTED, AND STORED IN SRPL.
  500 DO 540 I=DZ,50
      SURPL(I)=TG(I)-DD(I,1)-AE(I,DZ)-AS(I)
      SRPL=SRPL+SURPL(I)
      IF(SRPL)510,505,505
  505 IF(I.GT.DZ)GO TO 1504
C  HEADINGS ARE PRINTED FOR THE FIRST YEAR
      IF(OPTINV(X).EQ.1)WRITE(6,504)
                                5                   0                   4
FORMAT(T5,'SURPLUS',T18,'YEAR',T29,'TREND',T36,'DEMAND',T44,'AUTH
     1EXP',T53,'ALLOCATED')
                   1                5                   0                   4
IF(OPTINV(X).EQ.1)WRITE(6,506)SURPL(I),I,TG(I),DD(I,1),AE(I,DZ),
```

```
     1AS(I)
  506 FORMAT(1X,6I10)
      GO TO 540
C
C THE VARIABLE SRPL IS USED TO CULCULATE A CUMULATIVE TOTAL FOR THE
C  SURPL(I), AND IF A NEGATIVE ANNUAL SURPLUS IS CALCULATED, THE
C   PROGRAM TESTS TO SEE IF 5 PERCENT OF THE ACCUMULATED C
SURPLUS(SRPL) WOULD SUFFICE TO ELIMINATE THE DEFICIT.  IF IT IS C
IN FACT SUFFICIENT OR OVERLY SO, THE PROGRAM TRACKS THE C
REQUIREMENTS.   IF IHE SHORT- FALL CONNOT BE MET IN SUCH A C
FASHION, THE YEAR IS GIVEN AS THE CROSSOVER YEAR. THIS MAY OR C
MAY NOT IMPLY THAT THE FDT IS FAILED.
C
      TDP=DZ+ALOCPR
      IF(TDP.GT.I)GO TO 541
      PC=SURPL(I)+(.05)*(FLOAT(SRPL))
      IF(PC.LT.0)GO TO 550
      TTG(I)=TG(I)-SURPL(I)
      SRPL=SRPL+SURPL(I)
  540 CONTINUE
  541 IF(I-50)550,552,552
  550 WRITE(6,551)I
  551 FORMAT(10X,'  THE CROSSOVER YEAR FOR FDT IS',1I4)
C     WRITE(6,2010)((DER(I,J),J=1,25),I=1,10)
C     WRITE(6,542)
C 542 FORMAT(1X,'    FORMAT 542       WRITE(6,3)
C
C  AT THIS POINT WE MAY TEST TO SEE IF THE FDT IS PASSED, THE
C  CROSSOVER YEAR HAS BEEN IDENTIFIED.
C     FD-PROTECTION PERIOD UNDER THE FDT
C    TPYFDT-EARLIEST YEARFOR A CROSSOVER WHICH WOULD PASS THE FDT
C     NPYFDT-DIFFERENCE BETWEEN THE CURRENT CROSOVER YEAR AND C
  TPYFDT
C
  552 TPYFDT=DZ+FD
      NPYFDT=I-TPYFDT
      IF(NPYFDT)560,570,570
  560 WRITE(6,561)
  561 FORMAT(2X,'THE FDT FAILS')
C
C   IF THE TEST FAILS, THE PROGRAM CALCULATES HOW LARGE THE C
SHORTFALL IS
C  FROM THE CALCULATED CROSSOVER TO THE PASSING DATE. THIS QUANTITY
C  IS DIVIDED BY .05(THE PRODUCTION RATE)TO  SEE IF THE CROSSOVER
C  COULD BE MET IF SMOE OF THE PREVIOUSLY ALLOCATED SURPLUS(UNDER
C  THE CDT) COULD BE USED TO PASS THE FDT AT THIS DECISION YEAR.
C  THE NECESSARY QUANTITY IS LABELLED REQT.
C
```

```
      REQT=0
      DO 562 J=I,TPYFDT
      FAC=(1.00)
      S(J)=TG(J)-DD(J,1)-AE(J,DZ)-AS(J)
C
C     HERE S(J) IS THE ANNUAL SHORTFALL
C          IT IS CUMULATED IN REQT.
C
      IF(DP.GE.2)WRITE(6,559)REQT
  559 FORMAT(4X,'REQT',1I6,'   STEP  561   ')
      REQT=REQT-S(J)
      IF(REQT.LE.0)GO TO 570
  562 CONTINUE
      IF(PROXY.LT.DZ)PROXY=TDP
      REQT=(REQT/FAC)
      MAXPOS=0
C
C     THE FOLLOWING CUMULATES THE ALLOCATED SURPLUS UNDER THE CDT,
C     THE DECISION YEAR TO THE MIN(NEXT DECISION YEAR,END OF THE
C     ALLOCATION PERIOD(CDT),OR POSSIBLY THE PASSING YEAR FOR THE
C     FDT-IF THE ABOVE IF STMT WAS OPERATIVE)
C     IF(X.GT.14)WRITE(6,2010)((DER(I,J),J=1,25),I=1,25)
      DO 564 J=DZ,PROXY
      IF(J.EQ.PROXY)GO TO 564
      MAXPOS=MAXPOS+AS(J)
  564 CONTINUE
      IF(DP.GE.2)WRITE(6,1564)MAXPOS,REQT
 1564 FORMAT(30X,2I10)
      MAXALC=MAXPOS-REQT
      IF(MAXALC)565,566,567
C
C       MAXALC-MAXIMUM POSSIBLE ALLOCATION WHILE PASSING THE FDT-
C             (-)FDT CAN'T BE PASSED-565
C             (0)FDT CAN BE PASSED WITH NO ALLOCATIONS-566
C             (+)FDT CAN BE PASSED WITH A SMALLER ALLOCATION-567
C
  565 WRITE(6,1565)
      GO TO 590
  566 WRITE(6,1566)
      GO TO 590
  567 WRITE(6,1567)
C
C     TDP=THE END OF THE ALLOCATION PERIOD
C     DIV-DIVISOR-PERIOD OF REDUCED ALLOCATIONS AT DZ
C     MXPSAL=MAXIMUM ALLOCATIONS(PASSING)FDT/PERIOD OF REDUCED
C                                          ALLOCATIONS
      IF(PROXY.LT.DZ)PROXY=TDP
      DIV=PROXY-DZ
```

```
      IF(DIV.LT.1)DIV=1
      MXPSAL=(FLOAT(MAXALC))/(FLOAT(DIV))
C
CTHE FILE ADDRES(I) IS UPDATED BY THE AMOUNTS OF THE REDUCED
C     ALLOCATIONS UNDER THE FDT, RELATIVE TO THE CDT, TO MAKE
C     UP THE SHORTFALL UNDER THE FDT.
C
      DO 568 I=DZ,ALOCPR
      IF(DP.LE.2)GO TO 1501
      IF(MXPSAL.GT.AS(I))WRITE(6,1500)
 1500 FORMAT('  MXPSAL GT AS IN FDT...A PROGRAM CHECK')
 1501 CONTINUE
      AS(I)=MXPSAL
      IF(DIV.LT.1)DIV=1
      ADDRES(I)=ADDRES(I)+(FLOAT(REQT))/(FLOAT(DIV))
  568 CONTINUE
C
C     HERE THE REVISED ALLOCATIONS, AND ADDITIONS TO RESERVES TO
C     PASS THE FDT ARE PRINTED OUT,ALONG WITH SOME OF THE CRITICAL
C     COMPUTATIONAL COMPONENTS
C
      DO 1569 I=DZ,PROXY

IF(DP.GE.2)WRITE(6,1568)AS(I),ADDRES(I),REQT,DIV,PROXY,NDY,ALOCPR
 1568 FORMAT(7I10)
 1569 CONTINUE
C
C       TRANS(I)-AMOUNT OF GAS TRANSFERRED FROM THE FILE AS(I) TO
C        ADDRES(I).
C
      IF(DIV.LT.1)DIV=1
      DO 569 I=DZ,PROXY
      TRANS(I)=FLOAT(REQT)/FLOAT(DIV)
  569 CONTINUE
 1565 FORMAT(2X,'FDT CANNOT BE PASSED')
 1566 FORMAT(2X,'FDT CAN BE PASSED WITH NO ALLOCATIONS')
 1567 FORMAT(2X,'FDT CAN BE PASSED WITH A SMALLER ALLOCATION')
      WRITE(6,3)
      GO TO 580
  570 WRITE(6,571)
  571 FORMAT(2X,'THE FDT IS PASSED')
C
C  THIS SECTION PROVIDES THE FINAL UPDATE TO THE DER FILE DUE TO
C  ADDITIONS TO RESERVES FROM REALLOCATIONS DURING THE FDT  OR
C  LESS THAN FULL ALLOCATIONS BY THE NEB.  BOTH THE DER LINE
C  AND THE TREND GAS LINE ARE SHIFTED AT THIS POINT.  ALL PREVIOUS
C  TESTS INVOLVED TEMPORARY SHIFTS.
C
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```
      WRITE(6,3)
  580 DO 582 I=DZ,ALOCPR
      DUDER(PROXY)=DUDER(PROXY)+ADDRES(I)
  582 CONTINUE
  408 CONTINUE
      IF(DUDER(PROXY).LE.0)GO TO 590
      PROX20=PROXY+20
      DO 450 I=PROXY,PROX20
      DO 449 J=PROXY,PROX20
      DER(I,J)=DER(I,J)+(.05)*(FLOAT(DUDER(PROXY)))
  449 CONTINUE
      TG(I)=TG(I)+(.05)*(FLOAT(DUDER(PROXY)))
  450 CONTINUE
      DO 451 I=1,50
      DUDER(I)=0
  451 CONTINUE
C     WRITE(6,452)
C    452    FORMAT(1X,'                    FORMAT    452
WRITE(6,2010)((DER(I,J),J=1,25),I=1,10)
  590 CONTINUE
C
C               --END OF THE FUTURE DELIVERABILITY TEST--
C
C
C                         - CURRENT RESERVES TEST-
C
C  THIS IS THE BEGINNING OF THE CURRENT RESERVES TEST. ALBERTA AND
C  EXALBERTA REQUIREMENTS ARE CALCULATED USING THEIR RESPECTIVE
C  PROTECTION FORMULAS, AND THEN REPROCESSING SHRINKAGES ARE
C  ADDED TO THE  TOTAL.
C
C
C : ZERO OUT STORAGE VARIABLES
C     TREPRO-TOTAL REPROCESSING SHRINKAGES
C     TAE-TOTAL AUTHORIZED EXPORTS
C     NCHRES-NET CHANGE IN RESERVES FOR YEAR DZ
C     TOTAS-TOTAL NEWLY ALLOCATED SURPLUS AT DZ
C     DECVAR-DECISION VARIABLE
C     TR-TOTAL RESERVES AVAILABLE AT TIME DZ
C     SURCRT-SURPLUS TO THE CRT -(MAY BE NEGATIVE)
C     TOTAS-TOTAL ALLOCATED SURPLUS UNDER THE CDT AND FDT
C     DECVAR-TOTAL SURPLUS UNDER THE (CONSTRAINING) CRT
C     NDCVAR-NET DECISION VARIABLE-IF THE CRT CAN BE PASSED WITH
A
C            SMALLER  ANNUAL ALLOCATION, THIS IS IT.
C  ALTREQ-TOTAL ALBERTA REQTS,CURRENT DEMAND*PROTECTION PERIOD(AM)
C   EXALTREQ-TOTAL EX-ALBERTA REQTS,CURRENT DEMAND*PROTECTION C
PERIOD(M)
```

```
C
      TREPRO=0
      TAE=0
      NCHRES=0
      TOTAS=0
      DECVAR=0
      TR=0
      REQTS=0
      NDCVAR=0
      L=DZ
      ALTREQ=ALTA(L)*(AM)
      EXALRQ=EXALTA(L)*(M)
      PRE=0
      PE=0
      K2=DZ-1
C     DO 705 I=1,K2
C     PE=PE+AE(I,1)
C     PRE=PRE+REPRO(I)
C     WRITE(6,706)PE,PRE
C 706 FORMAT(20X,2I10,'    L 705    ')
  705 CONTINUE
      DO 710 J=DZ,50
      TAE=TAE+AE(J,DZ)+AS(J)
      TREPRO=TREPRO+REPRO(J)
  710 CONTINUE
C     TREPRO=TREPRO+REPRO(20)*(L-1)
      REQTS=ALTREQ+EXALRQ+TAE+TREPRO
      IF(OPTINV(X).EQ.1)WRITE(6,703)
  703 FORMAT(T5,'NCHRES',T16,'DEMAND',T25,'AUTH XP',T35,'RES ADD')
C
C     BDZ-YEAR PRIOR TO THE CURRENT DECISION YEAR
C    THE FOLLOWING CALCULATES THE NET CHANGE IN RESERVES FROM TIME
0
C
      IF(DZ.EQ.1)NCHRES=0
      BDZ=DZ-1
      IF(DZ.EQ.1)BDZ=1
      DO 750 N=1,BDZ
      NCHRES=NCHRES-PD(N)-AE(N,N)+RA(N)
      IF(OPTINV(X).EQ.1)WRITE(6,720)NCHRES,PD(N),AE(N,N),RA(N)
  720 FORMAT(1X,4I10,'LINE 720 ')
  750 CONTINUE
C
C     THE FOLLOWING COMPUTES THE TOTAL AVAILABLE RESERVES,
C     AND THE GAS SURPLUS UNDER THE CRT (GIVEN THE ALLOCATIONS
C     UNDER THE CDT AND FDT
C
      TR=RES+NCHRES
```

```
      SURCRT=TR-REQTS
      WRITE(6,3)
      IF(OPTINV(X).EQ.1)WRITE(6,1720)
 1720 FORMAT(T42,'CH   IN   RES',T63,'RES
AVAIL.',T76,'REQTS',T84,'SURPLUS')
      IF(OPTINV(X).EQ.1)WRITE(6,755)NCHRES,RES,TR,REQTS,SURCRT
  755 FORMAT(40X,1I10,1F10.2,3I10,'   L  755')
      IF(SURCRT)760,770,770
C
C     770- THE CRT PASSED
C     760- THE CRT FAILED- TRY TO PASS USING FRONTIER RESERVES
C
  760 IF(OPTINV(X).EQ.1)WRITE(6,1760)
 1760 FORMAT(2X,'THE CRT FAILED')
      FRES=FRES+SURCRT
      IF(OPTINV(X).EQ.1)WRITE(6,1755)SURCRT,FRES
 1755  FORMAT('     FRONTIER  RESERVES  ARE  REDUCED  BY',1I6,'
LEAVING',1F10.2)
      IF(FRES.GT.0)GO TO 770
C
C     IF FRONTIER RESERVES ARE SUFFICIENT TO PASS, NOTE THAT FACT
C     CONTINUE TO THE FINAL  COMPUTATIONS AND PRINTING
C
      DO 761 J=DZ,ALOCPR
      TOTAS=TOTAS+AS(J)
  761 CONTINUE
C
C     IF THE FRONTIER RESERVES ARE NOT SUFFICIENT TO PASS THE CRT
C    THEN COMPUTE THE TOTAL ALLOCATED SURPLUS(TOTAS-UNDER CDT+FDT
C     AND SEE IF A REDUCED ALLOCATION WOULD PERMIT A PASS
C
      DECVAR=SURCRT+TOTAS
      IF(OPTINV(X).EQ.1)WRITE(6,769)DECVAR,K,NDCVAR,AS(I),ADDRES(I)
  769 FORMAT(10X,5I10,' L 769 ')
      WRITE(6,3)
      IF(DECVAR)762,763,764
C
C     762-CRT CAN'T BE PASSED
C     763-CRT PASSES WITH ZERO ALLOCATION
C     764-CRT PASSES WITH A REDUCED ALLOCATION
C
  762 WRITE(6,1762)
      GO TO 780
  763 WRITE(6,1763)
  764 WRITE(6,1764)
 1762 FORMAT(2X,'CRT CANNOT BE PASSED')
 1763 FORMAT(2X,'THE CRT CAN BE PASSED WITH A ZERO ALLOCATION')
 1764 FORMAT(2X,'THE CRT CAN BE PASSED WITH A SMALLER ALLOCATION')
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C
C     THE REQUIRED SMALLER ALLOCATION IS COMPUTED, THE RESULTANT
C     ADDITIONS TO RESERVES ARE COMPUTED, AND THE CRT IS PASSED
C
      NDCVAR=FLOAT(DECVAR)/FLOAT(ALOCPR-DZ+1)
      IF(FRES.LT.0)FRES=0
      DO 765 I=DZ,ALOCPR
      AS(I)=NDCVAR
      ADDRES(I)=NDCVAR+20
  765 CONTINUE
      GO TO 580
  770 WRITE(6,1770)
 1770 FORMAT(2X,'THE CRT PASSED')
      DO 780 I=DZ,ALOCPR
      DO 779 J=DZ,50
      AE(I,J)=AE(I,J)+AS(I)
  779 CONTINUE
  780 CONTINUE
      IF(OPTINV(X).EQ.1)GO TO 7777
 7000 CONTINUE
 6500 CONTINUE
C     IF(X.GT.14)WRITE(6,2010)((DER(I,J),J=1,25),I=1,25)
      DO 6705 IK=1,50
      EXREV(IK)=0
      DOMREV(IK)=0
 6705 CONTINUE
C
C  THE NO EXPORTS MARKER IS HERE
C
      IF(NOEXP.EQ.1)GO TO 6730
 6706 EXCP=0
      EXCPCS=0
      TSUM1=0
      TSUM2=0
      DO 6707 K=X,CDTCR
      TMPAE=(AE(K,DZ))
      TSUM1=TSUM1+TMPAE
      TSUM2=TSUM2+AE(K,DZ)+PRA(K)
 6707 CONTINUE
      EXCP=(FLOAT(TSUM1)/5)
      RQCAP=(FLOAT(TSUM2)/5)
      EXCPCH=RQCAP-EXCP
      EXCPCS=FLOAT(EXCPCH)*1.50

WRITE(6,6708)EXCP,RQCAP,EXCPCH,EXCPCS,TSUM1,TSUM2,AE(1,DZ),AS(I)
 6708 FORMAT(1X,8I12,'  FORMAT  6708  ')
      IF(EXCPCH.LE.0.0)EXCPCS=0
      DO 6710 K=DZ,CDTCR
```

```
      EXREV(K)=FLOAT(PRA(K))*(EXUPR(K)-EXUCST(K))
 6710 CONTINUE
      DO 6720 K=CDTCR+1,75
      DOMREV(K)=FLOAT(PRA(K))*(DMUPR(K)-DMUCST(K))
 6720 CONTINUE
      GO TO 6750
 6730 EXCPCS=0
      CROSS=0
      KTDZ=0
      DO 6725 KT=DZ,75
      CROSS=DER(KT,DZ)-DD(KT,1)-AE(KT,KT)
      IF(CROSS.LE.0)GO TO 6726
 6725 CONTINUE
 6726 IF(KT.EQ.DZ)GO TO 6732
      KTDZ=KT-DZ-1
      DO 6732 K=1,KT
      PRA(K+KTDZ)=PRA(K)+PRA(K+KTDZ)
      PRA(K)=0
 6732 CONTINUE
      IF(KT.EQ.DZ)KTDZ=1
      DO 6740 K=1,75
      DOMREV(K)=FLOAT(PRA(K))*(DMUPR(K+DZ)-DMUCST(K+DZ))
 6740 CONTINUE
 6750 CONTINUE
      INVDEC(X)=1
 6800 PVNER=0
      PVNDR=0
      MAXPRA=0
      DO 6810 IK=1,75
      PVNER=(PVNER)+((FLOAT(EXREV(IK))/((1+DISCR)**(IK))))
      PVNDR=(PVNDR)+((FLOAT(DOMREV(IK))/((1+DISCR)**(IK))))
      IF(PRA(IK).GT.MAXPRA)MAXPRA=PRA(IK)
 6810 CONTINUE
C
C THE FOLLOWING ADDS PRODUCER COSTS BASED ON THE SIZE OF THE ADDED
C RESERVE ADDITION. THE NORMAL COST IS .50 AT 3000 (BCF/GJ) AND
C IS ADJUSTED FOR LARGER AND SMALLER RESERVES.
C
C
      DO 6812 IK=100,10000,100
      IF(RA(X).LT.IK)GO TO 6813
 6812 CONTINUE
 6813 PRCAP=FLOAT(MAXPRA)*.50*(FLOAT(IK)/3000)
      IK=0.0
      PV(II)=PVNER+PVNDR-IINV(II)-PRCAP-EXCPCS
 6815 IF(II.EQ.1) GO TO 6820
      IF(X.EQ.1)PSTINV=1750
      IF(X.GT.1)PSTINV=INV(X-1)
```

```
      IF(PSTINV.EQ.0)PSTINV=250
      MAXINV=(1+(1000/FLOAT(PSTINV)))*(FLOAT(PSTINV))
      IF(IINV(II).GT.(MAXINV))GO TO 6826
 6817 IF(II.EQ.20) GO TO 6825
      IF(PV(II)-PV(II-1))6826,6826,6820
 6820 CONTINUE
      GO TO 6830
 6825 IF(PV(20).LE.PV(19))GO TO 6826
      FIINV(X)=IINV(20)
      APV(X)=PV(II)
      OPTINV(X)=1
      OPTDEC(X)=1
      GO TO 6830
 6826 OPTINV(X)=1
      FIINV(X)=IINV(II-1)
      APV(X)=PV(II-1)
      OPTDEC(X)=1
 6830 INVDEC(X)=1
C     WRITE(6,2010)((DER(I,J),J=1,25),I=1,25)
      IF(OPTINV(X).EQ.1)GO TO 6010
      IINV(II+1)=IINV(II)+250
 6835 CONTINUE
      WRITE(6,6836)II,DZ,INVDEC(X),OPTINV(X)
   6  8  3  6       F  O  R  M  A  T  (  1  X  ,  '  I  N  V
PASS=',1I2,'DY=',1I2,'INVDEC',1I2,'OPTINV(X)=',1I2)
WRITE(6,6837)EFFORT(II),IINV(II),DELTA(X,DZ),IRA(II),CUMEFF,RA(X)
                6                   8                  3                  7
FORMAT(1X,'EFFORT(II)',I6,'IINV(II)',I6,'DELTA(X,DZ)',I6,'IRA(II)'
     X,I6,'CUMEFF',I8,'RA(X)',I6)
      WRITE(6,6838)PV(II)
 6838 FORMAT(1X,'PV(II)=',I8,10X,'AT LINE 6300')
      IF(OPTINV(X).EQ.0)GO TO 6845
 6841 DO 6842 IK=1,50,5
      WRITE(6,6843)IK,PRA(IK),DOMREV(IK),EXREV(IK)
      TOTRA=TOTRA+PRA(IK)
 6842 CONTINUE
      WRITE(6,6844)TOTRA,PVNDR,PVNER,INV(X),PRCAP,EXCPCS,RA(X)
 6843 FORMAT(1X,1I3,1X,4I8)
 6844 FORMAT(1X,7I10)
 6845 CONTINUE
      TOTRA=0
C     IF(X.GT.14)WRITE(6,2010)((DER(I,J),J=1,25),I=1,25)
 6300 CONTINUE
C              THIS IS THE END OF THE INVESTMENT LOOP
C
C     THE FOLLOWING PRINTING STATEMENTS PRODUCE OUTPUT FOR DIRECT
C     VISUAL INSPECTION, NOT FOR GRAPHICS
C
```

```
 7777 CONTINUE
C     THIS ADJ IS NECESSARY IN THE NO EXPORTS PROGRAM
       TP1=DER(DZ,DZ)-(DD(DZ,1)+AE(DZ,DZ))
       IF(TP1.LE.0)GO TO 783
       DO 6008 I=DZ,DZ+10
       DO 6007 J=DZ,I
       DER(I+1,J+1)=DER(I+1,J+1)+(FLOAT(TP1)/10)
 6007 CONTINUE
 6008 CONTINUE
C      WRITE(6,786)((AE(I,J),J=1,25),I=1,50)
C 786 FORMAT(1X,25I5)
  783 DO 785 I=1,50
       DDAENA(I)=DD(I,1)+AE(I,I)-AS(I)
       LEDD(I)=DD(I,1)+AE(I,I)
       AY(I)=PERM(I)+BASE-1
  785 CONTINUE
       AEXC(X)=0
       ADMC(X)=0
       AEXR(X)=0
       ADMC(X)=0
       IF(DER(X,X).GT.DD(X,1))GO TO 7210
       ADMR(X)=DMUPR(X)*DER(X,X)
       ADMC(X)=DMUCST(X)*DER(X,X)
       GO TO 7220
 7210 IF(DER(X,X).GT.LEDD(X))GO TO 7220
       ADMR(X)=DMUPR(X)*DD(X,1)
       ADMC(X)=DMUCST(X)*DD(X,1)
       AEXR(X)=DMUPR(X)*(LEDD(X)-DD(X,1))
       AEXC(X)=DMUCST(X)*(LEDD(X)-DD(X,1))
       GO TO 7230
 7220 ADMR(X)=DMUPR(X)*DD(X,1)
       ADMC(X)=DMUCST(X)*DD(X,1)
       AEXR(X)=DMUPR(X)*AE(X,X)
       AEXC(X)=DMUCST(X)*AE(X,X)
 7230 CONTINUE
       ANREV(X)=ADMR(X)+AEXR(X)
       ANCST(X)=ADMC(X)+AEXC(X)
       ANPRCP(X)=PRCAP
       ANEXPC(X)=EXCPCS
       ANINV(X)=INV(X)
       ZNV1SA(X)=(FLOAT(ANINV(X))/FLOAT(ANREV(X)))
       ZNV2SA(X)=(FLOAT(ANINV(X)+ANPRCP(X))/FLOAT(ANREV(X)))
ZNV3SA(X)=(FLOAT(ANINV(X)+ANPRCP(X)+ANEXPC(X))/FLOAT(ANREV(X)))
       IF(X.EQ.1)CMPV=0
       CMPV=(CMPV*((1+DISCR)))+APV(X)
       CUMPV(X)=CMPV
       IF(X.EQ.1)CMRES=0
       CMRES=CMRES+RA(X)
```

```
      CUMRES(X)=CMRES
      RRES(X)=(ULTPOT*1000)-CUMRES(X)
 7299 CONTINUE
C     WRITE(6,2222)
C2222 FORMAT(1X,'YEAR')
C     WRITE(6,2223)(AY(I),I=DZ,DZ+25)
C2223 FORMAT(1X,25I5)
C     WRITE(6,2224)
C2224 FORMAT(1X,'TREND LINE')
C     WRITE(6,2221)(TG(I),I=DZ,DZ+25)
C2221 FORMAT(1X,25I5)
C     WRITE(6,2230)
C2230 FORMAT('   DELIVERABILITY FROM E R ')
C     WRITE(6,2227)(DER(I,DZ),I=DZ,DZ+25)
C2227 FORMAT(1X,25I5)
C     WRITE(6,2232)
C2232 FORMAT('   DEMAND')
C     WRITE(6,2229)(DD(I,1),I=DZ,DZ+25)
C2229 FORMAT(1X,25I5)
C     WRITE(6,2234)
C2234 FORMAT('   AUTH EXPORTS')
C     WRITE(6,2231)(AE(I,DZ),I=DZ,DZ+25)
C2231 FORMAT(1X,25I5)
C     WRITE(6,2238)
C2238 FORMAT(' LE + DD - AS   LINE ')
C     WRITE(6,2233)(DDAENA(I),I=DZ,DZ+25)
C2233 FORMAT(1X,25I5)
C     WRITE(6,2236)
C2236 FORMAT('   LE DD LINE')
C     WRITE(6,2235)(LEDD(I),I=DZ,DZ+25)
C2235 FORMAT(1X,25I5//)
      WRITE(6,3)
      WRITE(6,5559)
 5559   FORMAT(T6,'TREND',T12,'DEL   ER   ',T23,'DEMAND',T30,'AUTH
XP',T39,'LE
     1+DD-AS',T51,'LE+DD',T60,'YEAR')
C     ZAT IS A FILE USED FOR PRODUCING DATA FOR A GRAPHICS ROUTINE
      DO 5557 I=DZ,50
      ZAT(I,1)=TG(I)
      ZAT(I,2)=DER(I,DZ)
      ZAT(I,3)=DD(I,1)
      ZAT(I,4)=AE(I,I)
      ZAT(I,5)=DDAENA(I)
      ZAT(I,6)=LEDD(I)
      ZAT(I,7)=AY(I)
 5556 FORMAT(1X,7F9.1)
      WRITE(6,5556)(ZAT(I,J),J=1,7)
 5557 CONTINUE
```

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      WRITE(6,999)
      IF(DP.LT.2)GO TO 7005
      IF(DY(X).EQ.1)GO TO 7001
      GO TO 7005
 7001 DO 7002 IK=1,50
      WRITE(6,7003)IK,PRA(IK),DOMREV(IK),EXREV(IK)
      TOTRA=TOTRA+PRA(IK)
 7002 CONTINUE
      WRITE(6,7004)TOTRA,PVNDR,PVNER,INV(X),PRCAP,RA(X)
 7003 FORMAT(1X,1I3,1X,4I8)
 7004 FORMAT(1X,5I10)
 7005 CONTINUE
C     ZERO OUT AS() FILE FOR NEXT DECISION YEAR TESTS
      DO 788 I=1,50
      AS(I)=0
  788 CONTINUE
  790 CONTINUE
C    END OF TEST LOOP AT STMT. GO TO 2
C    X=X+1 INCREMENTS THE TEST YEAR FILE BY ONE YEAR AND
C          CONTINUES IN THE LOOP
C        CLEAR ALL NEW TESTING AND INVESTMENT FILES
 1004 TP=0
      CDTCR=0
      X=X+1
C     WRITE(6,2010)((DER(I,J),J=1,25),I=1,25)
      GO TO 2
  900 IF(FNLPR.EQ.0)GO TO 7200
      WRITE(6,7281)
 7281 FORMAT(1X,'      ANEX      ADMC     AEXR      ADMR      ANREV
  ANCST ANPRCP   ANEXPC     ANINV  ZNV1SA ZVN2SA ZVN3SA YEAR')
      DO 7280 L=1,50
WRITE(6,7290)AEXC(L),ADMC(L),AEXR(L),ADMR(L),ANREV(L),ANCST(L),
1ANPRCP(L),ANEXPC(L),ANINV(L),ZNV1SA(L),ZNV2SA(L),ZNV3SA(L),PERM(L)
 7280 CONTINUE
 7290 FORMAT(1X,9I9,1X,3F7.3,1I5)
      WRITE(6,3)
      WRITE(6,7291)
 7291 FORMAT(6X,'       INV      APV      CUMPV       RA      CUMRES
 RRES     TG       DER       AEDD        DD         AE      YEAR')
      DO 7295 L=1,50
WRITE(6,7296)INV(L),APV(L),CUMPV(L),RA(L),CUMRES(L),RRES(L),TG(L),
     1DER(L,L),LEDD(L),DD(L,1),AE(L,L),PERM(L)
 7295 CONTINUE
 7296 FORMAT(6X,5I9,1I9,5I9,1I5)
 7200 STOP
      END
```

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