ASSESSING THE ECONOMIC FEASIBILITY OF A CARBON TAX ON ENERGY INPUTS IN ONTARIO'S PULP AND PAPER INDUSTRY:

AN ECONOMETRIC ANALYSIS

By

HE, MIAOFEN

Department of Agricultural Economics

Macdonald Campus, McGill University

May 2001

A thesis submitted to the Faculty of Graduate Studies and Research of McGill University in partial fulfillment of the requirements for the degree

of

Masters of Science

0-612-70429-7

For my families

ABSTRACT

Knowledge of price responsiveness of energy is important for designing effective price-based controls to curb the GHG emissions in Canada. The translog and logit models are developed in this study to analyze the demand for four types of energy inputs: coal, electricity, natural gas and refined petroleum products in Ontario's pulp and paper industry. The results suggest that the industry is inelastic to price change of energy consumed. Tests indicate that the translog model behaves slightly better than the logit model. The translog model was then applied to study the feasibility of imposing a carbon tax on energy inputs on Ontario's pulp and paper industry, which indicated that this sector does not seem to response to changes in energy inputs prices. Therefore, a carbon tax does not seem to be a good policy option for decreasing greenhouse gas emissions in this sector.

Keywords: Carbon tax; Ontario pulp and paper industry; the translog model; the logit model

RÉSUMÉ

La connaissance des fluctuations des prix de l'énergie est importante pour être capable de concevoir efficacement les prix de base pour contrôler la courbe du GHG d'émission au Canada. Le translog et le modèle logit sont développés dans cette étude pour analyser la demande pour les quatre types d'énergie: charbon, électricité, gaz naturel et le pétrole raffiné produit dans l'industrie des pâtes et papiers de l'Ontario. Les résultats nous suggérent que l'industrie est invariable au changement du prix de l'énergie consumée. Les tests nous indiquent que le modèle translog réagi un peu mieux que le modèle logit. Le modèle translog est appliqué pour étudier la fiabilité de l'imposition du dioxyde de carbon dans l'industrie des pâtes et papiers. Les résultats indiquent que cet secteur ne réspond pas aux changements des pâtes prix d'entrée de l'énergie. Donc, une tax du carbon n'est pas une option politique pour réduire les émissions de gaz dans ce lieu.

Mots clés: la taxe du carbon, l'industrie des pâtes et papier de l'Ontario, le modèle translog, le modèle logit

ACKNOWLEDGEMENTS

The author would like to acknowledge her profound appreciation to her supervisor, Dr. Paul J. Thomassin of Department of Agricultural Economics. This thesis has reached its results with his guidance and counsel.

The author would like to express her appreciation to her co-advisor, Dr. Mark Brown, for his assistance. The appreciation should be extended to Dr. John Henning for his great advice during the author's research and studies. The author is also grateful to Dr. Laurie Baker for his help in the author's course selection during her studies.

The author sincerely thanks Mr. Steve Seres for his help to complete this thesis. In addition, thanks must be expressed to Ms. Patricia Atkinson, secretary of Department of Agricultural Economics, for her great comfort to the author during the researches.

The author truly appreciates Dr. Melvyn A. Fuss of Department of Economics, University of Toronto, for his valuable advice for the translog model application in this thesis. The appreciation should also be expressed to Dr. John Galbrith, Department of Economics, McGill University, for his constructive advice for the logit model application in this thesis. The acknowledgement should be addressed to Dr. Carlisle E. Moody of Department of Economics, College of William and Mary, and Dr. Timothy J. Considine of Department of Mineral Economics, Pennsylvania State University, for their kindness and generosity providing the SAS codes for the logit model used in this thesis. Furthermore, this acknowledgement should be extended to Mr. Fabrice Rouah and Mr. David Walfson of Department of Mathematics, McGill University, for their great help using the SAS program.

The acknowledgement must be expressed to following people for their patient cooperation in data collection during the researches: Mrs. Nathalie Trudeau, Office of Energy Efficiency, Natural Resources Canada; Mr. Hertsel Labib, Chief of Emissions Analysis and Modelling, Analysis and Modelling Division, Energy Policy Branch, Natural Resources Canada; Mr. Randall Sheldrick, Manufacturing, Construction and Energy Division, Statistics Canada; Mr. Gilles Simard, Energy Section, Statistics Canada; Mr. David Beaulieu, Manufacturing, Construction and Energy Division, Statistics Canada.

The author also would like to thank Ms. Susan Czarnocki of Faculty of Arts and Science for offering the account to access to the SAS program in the Faculty of Arts and Science computing lab.

Thanks should be expressed to my colleagues in the Department of Agricultural Economics: Miss Monica Kjollerstrom, Mr. Yann Hebert, Mr. Quan Yongxin, Mr. Hughes Morand; Mr. Heminthavong Khamla, Mrs. Darlene Dessureault, Mr. Peter Varga, Miss Jennifer Tkac, Mr. Frank Amankwah, Mr. El Mamoun Amrouk, Mr. Ben Budu, and Mr. Alejandro de Maio, for their friendship and encouragement.

The author must express her special and deepest gratitude to her parents, Mr. and Mrs. He, and her sisters for their great patience, support, and love. The thanks should also be expressed to her friends Miss Jean Chang, Miss Irene Liu. Finally, the author is deeply grateful to her friend, Mr. Chun-Chieh Yang, for his assistance and encouragement during the thesis. Thank you.

TABLE OF CONTENTS

APPENDIX

FIGURES LIST

TABLES LIST

CHAPTER 1 INTRODUCTION

1.1 Background

Although the notion that the climate is changing was a controversial claim ten years ago, there is now a consensus that substantial change has occurred (IPCC, 2000; IPCC, 1996a, 1996b and 1996c; IPCC, 1994; IPCC, 1992a; IPCC, 1990; Drake, 2000; Portman, 1993; Jones, 1994; Jones *et al*, 1990; Cermak *et al*, 1992; Bindoff and Church, 1992; Beltrami and Mareschal, 1991; Balling and Dso, 1990). Scientists have observed that the average global climate temperature has risen by 0.3-0.6°C since the late nineteenth century and recent years have been the warmest on record (IPCC, 1996a). Moreover, it has been predicted that the temperature will continue to rise if greenhouse gas emissions remain at current levels (IPCC, 1996a). A changing climate has far-reaching impacts on the natural environment and human population (Grubb *et al*, 1999; IPCC, 1996a, 1996b, 1996c; IPCC, 1994; IPCC, 1992b; IPCC, 1990). Consequences of climate change range from an increase in sea level (IPCC, 1996a; Titus and Narrayanan, 1995; Wigley and Raper, 1992; Church *et al*, 1991), the melting of existing glaciers (Weidick 1995), a change in ocean circulation patterns (Hurrell and Trenberth, 1996; Wang, 1995; Trenberth and Hurrel, 1994), land degradation and desertification (IPCC, 1996c; Favis-Mortlock, 1994; Lal, 1994; Favis-Mortiock *et al*, 1991) to a series of social and economic impacts, such as human health and poverty (Burtraw and Toman 1992; Ewah, 1994; Ghosh and Jaitly, 1993; Grubb, 1995; Grubb *et al*, 1992; Hayes and Smith, 1993; Parikh, 1992).

A small group of greenhouse gases (GHG), principally carbon dioxide, methane, nitrous oxide, and halocarbons, have been identified as the main causes of climate change. Heat is trapped by these gases and stays in the atmosphere thus warming the surface of the planet. This raises the temperature and changes the planet's climate. Two major human activities have been identified as changing the proportion of greenhouse gases. These are: (1) the burning of fossil fuels, which is the major source of human emissions of carbon dioxide, accounting for 75% of human-induced GHG emissions, and (2) widespread deforestation, which results in increased atmospheric carbon dioxide levels. Stored carbon dioxide is released into the atmosphere in the process of burning or decomposing of woods from felled trees, and the capacity of the trees to absorb carbon is eliminated.

Canada is likely to experience greater temperature changes than most regions of the world because of its higher northern latitudes (Environment Canada, 1998a). A detailed governmental review of potential impacts on Canada shows that such changes would have wide-ranging implications for its economy, social well-being, including human health, and ecological systems (Environment Canada, 1998b; Environment Canada, 1998c; Environment Canada, 1998d; Environment Canada, 1998e; Environment Canada, 1998f; Environment Canada, 1998g; Environment Canada, 1998h; Environment Canada, 1998i). In response to the issue of climate change, Canada joined 160 other countries in Kyoto, Japan, for the Third Conference of the Parties to the United Nations Framework Convention on Climate Change in 1997. At this conference the Kyoto Protocol was signed with a target set to reduce the emissions of GHG (see

Appendix 1). As a signatory of the Kyoto Protocol Canada was committed to reducing its GHG emissions by 6% below its 1990 emissions levels by the year 2010.

This target for Canada is somewhat formidable considering its energy-intensive economy, the extensive demand for space heating in winter, and the energy demand for transportation due to long distance (Environment Canada 1998a; Environment Canada 1998b). Canada's GHG emissions were 601 megatonne of CO_2 equivalent in 1992 (NRCan, 1999). While in 1997, they had increased to 682 megatonne, a growth of 13 percent (NRCan, 1999). As projected, Canada's GHG emissions will rise to 764 megatonne by 2010 without policy regulation (NRCan, 1999). Therefore, GHG emissions would be some 27 percent above the 1990 level. It is unlikely that Canada can achieve this goal without governmental intervention (Environment Canada 1998b).

While various meanings of curbing GHG emissions have been considered, much attention has been given to various price-based control tools. Historically, it is clear that in terms of sources, the use of fossil fuel energy is responsible for the major share of increasing emissions of GHG (NRCan, 1997). Thus much analysis has been devoted to assessing the cost of reducing emissions of GHG by means of economic instruments, such as a carbon tax on fossil fuels weighted according to carbon content (Barker *et al*, 1995; Mabey and Nixon, 1997; Smith *et al*, 1995; Hoeller and Coppel, 1992; Ingham *et al*, 1991; McKitrick, 1997; Hamilton and Cameron, 1994).

Investigating aggregate energy price elasticities and those for individual energy inputs are an important component of assessing the feasibility of policies targeted to reduce

GHG emissions. Understanding how demand responds to a change in price is critical to designing an appropriate policy. It is hoped that the imposition of a carbon tax would cause little harm to the economy if it is cautiously enforced, since changes in energy prices may have little impact on output (Ingham *et al*, 1991; Fuss, 1977). The translog and logit models have often been used to investigate these types of questions (Fuss, 1977; Moody, 1996; Considine, 1989; Considine, 1990; Considine and Mount, 1984; Griffin, 1992; Atkinson and Manning, 1995). These two models have been applied in this analysis in order to investigate the energy elasticities in Canada.

Manufacturing industries have played an important role in producing GHG emissions and thus present a potential area where reduction of GHG emissions can occur. Emissions of GHG from Canadian manufacturing accounted for one-third of the total emissions in Canada throughout the 1990s (NRCan, 1999) (Appendix 2). Therefore, these industries should be considered whenever public policies concerning the mitigation of GHG emissions are being analyzed.

This analysis will concentrate on the pulp and paper industry because this industry produced 9 percent of the manufacturing sectors GHG emissions (Appendix 2). In this sector, various types of energy inputs are used across Canada. Hydro is the main source of energy input in Quebec, NGL (Natural Gas Liquid) is widely used in Saskatchewan, while steam is playing a more important role in energy consumption. The pulp and paper industry in Ontario was chosen for this analysis because of its contribution to GHG emissions and its variety of energy inputs used. Carbon dioxide is the major component of GHG (IPCC, 1990, 1992a, 1996a), thus it will be the focus of this analysis.

1.2 Objectives

The effectiveness of any industrial policy targeted to decrease the output of GHG in the atmosphere depends on how firms will react to economic incentives; that is, the influence of changing prices on the energy use. Knowledge of the own and cross price elasticities of demand for energy inputs is therefore essential to assessing the feasibility of the policy. According to the theory of cost-minimizing behavior, the demand for energy will vary depending upon the relative prices of the energy inputs, and will result in producers choosing the mix of energy sources so as to minimize their production costs. By imposing a carbon tax on energy inputs, based on the amount of carbon dioxide released, it is hoped that government can regulate the level of carbon dioxide emitted. This would contribute to the Canadian effort to meet its Kyoto commitment.

The translog and logit models are two popular means of estimating demand structure and will be employed in this analysis (Fuss, 1977; Moody, 1996; Considine, 1989; Considine, 1990; Considine and Mount, 1984; Griffin, 1992; Atkinson and Manning, 1995). Specification and effectiveness of the models will be discussed. Estimates from the model with performance better will be used to analyze the impact of a carbon dioxide tax on the Ontario pulp and paper industry.

Briefly, the objectives of this study are:

Estimate the demand change with a variation in price to examine if demand will change when inputs prices vary.

In the process of estimating the demand function, test which model, the translog or the logit models, performs better in the analysis.

Estimate the impact of a carbon tax on Ontario's pulp and paper industry. This will be done taking into account Canada's commitment set in the Kyoto Protocol.

1.3 Scope

The period starting 1982 was adopted in this analysis to avoid the significant variation of refined petroleum products prices occurred during the oil crisis in 70s. The data set was composed of quarterly data from 1982 to 1999, consisting of prices, consumption of individual energy used in the Ontario pulp and paper industry, and shipments of goods manufactured by the sector which can be used to represent the output of the industry. The types of energy consumed in the industry included coal, electricity, natural gas and petroleum. Steam energy started to be used in the sector in 1998, but was excluded from the analysis because of its short period of use and small portion in terms of cost share. Predicted future prices for energy inputs and shipments are also required to assess the feasibility of the carbon tax. This data set included yearly data on predicted prices of energy and output in the Ontario pulp and paper industry for the year 2005 to 2010.

As the purpose of the paper is to examine the response of energy demand due to a change in price, only elasticities for and between individual energy inputs will be investigated. The impact of energy price increases on other inputs, such as capital and labor, will not be explored in this study. When assessing the implication of imposing a carbon tax for energy demand, the analysis will be set in a "pure" economy, which means external influences, such as international economies and political factors will not be considered. This paper will analyze the changing demand for energy inputs corresponding to the price increase due to the imposition of a carbon tax.

CHAPTER 2 LITERATURE REVIEW

2.1 Energy Economics

Numerous econometric analysis of energy was undertaken in the 1970's to explore the effect of price increases and demand control associated with the energy crisis (Griffin, 1992). Major methodological advances to the estimation of more generalized production functions and econometric techniques were significant during this period. In the 1980s, McFadden *et al* (1978, 1984) developed discrete choice models that predicated stock choices using random utility maximization (Griffin, 1992). Other functional forms, such as production, distance functions and profit functions, were applied to the economic analysis of factor demand in production (Fuss and McFadden, 1978). The various models employed to analyze energy demand are discussed in section 2.2.

Translog models have typically utilized time-series data to produce price elasticities for energy and other production inputs, and between individual energy inputs (Berndt and Wood, 1975; Pyndick, 1979). This method was criticized because it often produces implausible estimates (Griffin, 1992; Bohi, 1981). For example, using time series studies, the estimated own and cross price elasticities among fuels were close to zero (Hudson and Jorgenson, 1974). Also, times series studies of electricity and gasoline demand found rather inelastic demand responses to price changes (Bohi, 1981). In contrast, larger price elasticities were estimated using cross sectional and panel data sets (Griffin, 1992; Bohi, 1981). It has been argued that these types of data provide better forecasting potential (Griffin, 1992).

Two major categories of econometric methodologies have been used: single-equation and system-based models (Atkinson and Manning, 1995). A number of approaches were used when complete demand systems of equation were estimated. These included full-information maximum likelihood, seemingly unrelated regression and iterative seemingly unrelated regression. For the single-equation models of energy demand, the co-integration approach was applied concentrating on time-series econometrics (see Nachane *et al*, 1988).

2.2 Overview of Energy Models

2.2.1 Translog Based Modelling

Although the translog function (Christensen *et al*, 1973) is only one of a set of flexible functional forms, this model has been preferred by most researchers dealing with energy demand problems (Atkinson and Manning, 1995; Griffin, 1992). The system of equations used in the translog function is based on a Cobb-Douglas function. This enables it to adapt easily to the range of substitution possibilities in the production system. In the translog systems, the Allen-Uzawa elasticities of substitution can be reliably derived since the translog is considered to be a second-order approximation of an arbitrary production function (see Christensen *et al* 1973; Fuss and McFadden, 1978), on which no restrictions are placed. Given the duality between cost and production and exogeneity of output and factor prices, a set of cost share equations can be derived by using Shepherd's lemma.

A basic model, with the imposition of symmetry and homogeneity, is estimated for the aggregate elasticities of energy, material, labor and capital (see Berndt and Wood's 1975 influential study) or is estimated for the elasticities of individual energy inputs (see Fuss, 1977).

2.2.2 Discrete Choice Based Modeling

Fisher and Kaysen (1962) analyzed the stock of appliances and electricity consumption. This study helped economists to realize that the stock of energy consuming equipment, the efficiency with which the fuel is utilized, and utilization rate of appliances should be included into the model (Griffin, 1992). McFadden *et al* (1978, 1984) made this model more appealing by modeling appliance choice as a discrete choice using utility maximization. Their model has been further developed to better suitable in the field of energy demand (Considine and Mount, 1984; Lutton and LeBlanc, 1984; Considine, 1990; Moody, 1996).

2.2.3 Modeling Based on Other Methodologies

Increasingly, new methodologies are being applied to energy demand. The Cobb-Douglas production function has been used to estimate energy demand (Nordhaus, 1977). Disregarding the second-order terms, Nordhaus derived a simple demand function by taking the Taylor expansion. Constant elasticity of substitution (CES) was applied in Prywes's (1986) study to estimate elasticities of substitution between capital, labor, energy and materials for American manufacturing over the period 1971-1976. Vector autoregressions (VARs) was also used to study the demand for fossil fuels (Moody, 1996; Boone *et al*, 1992). Currently, various different approaches are being used to estimate the demand functions for energy and price responsiveness of industry, such as *ad-hoc* linear and logarithmic models (see Kouris, 1976; Prosser, 1985; Fiebig *et al*, 1987; Welsch, 1989; Patry *et al*, 1990; Watkins, 1991).

2.3 The Translog Function

2.3.1 Literature Review

The translog model has been an important approach for estimating energy demand since Christensen, Jorgenson, and Lau (1973). An influential study on energy demand was undertaken by Berndt and Wood (1975), in which they analyzed the derived demand for energy and non-energy (capital, labor and all other material) input for American manufacturing from 1947 and 1971. Using a static translog model, the study used time-series data to estimate substitutability of energy and other inputs. In addition to the assumption of constant returns to scale, they assumed that aggregate production between four gross outputs and four inputs was twice differentiable, and that any technical change affecting the inputs was Hicks-neutral. Given the level of aggregation employed in the paper, Berndt and Wood suggested it may be inappropriate to assume that prices were exogenous and that the independent variables, in the cost-share-equations, were uncorrelated with the disturbances. Based on estimated results from a three-stage least squares (3SLS) model, they demonstrated that positivity of the input demand functions and concavity of the cost function were both satisfied. As a result, they concluded that their estimated KLEM (Capital, Labor, Energy and Material) translog cost function was well behaved over the region included in their data for American manufacturing. Energy demand was found to be responsive to the change in its own price with an own price elasticity of –0.47. Energy and labor showed a slight level of substitution with an Allen partial elasticity of substitution (AES) of approximately 0.65 while the cross-price elasticities E_{LE} and E_{EL} of 0.03 and 0.18, respectively. Energy and capital were found to be complementary with an AES of about –3.2 while cross-price elasticities E_{EK} and E_{KE} were approximately –0.15 and –0.18, respectively. Moreover, capital and labor were substitutes with an AES of 1.01, while the cross-price elasticities E_{KL} and E_{LK} were estimated to be 0.28 and 0.06.

Fuss (1977) examined the fossil fuel mix question for Canadian manufacturing using a two-stage translog model, with both time series and cross-section data. Fuss assumed weak separability and imposed this on the production structure for major categories of energy, capital, labor and other materials. According to Fuss (1977) and Denny and Fuss (1977), weak separability implies aggregates which are homothetic in their components, and this is sufficient for the existence of the underlying two-stage optimization. Incorporating six different energy types (coal, liquid petroleum gas, fuel oil, natural gas, electricity and motor gasoline) and three other inputs (labor, capital and materials) Fuss estimated both interfuel substitution and substitution between energy and non-energy factors of production. Elasticities were calculated at the mean values of the exogenous variables for Ontario. In the energy sub-model, except for motor gasoline, all of the own price elasticities were negative and significant at the conventional level, which was consistent with the postulates of cost-minimizing factor demand theory. Substantial scope for interfuel substitution were found, as shown by the own price elasticities of liquid petroleum gas, coal, fuel oil and natural gas, which were less than –1, except for those of motor gasoline and electricity. The demand for liquid petroleum gas, coal fuel oil and natural gas were all price elastic while the demand for elasticity was price inelastic. Excluding motor gasoline, the ranking of the fuels in terms of declining (absolute value) price elasticities of demand were: liquid petroleum gas (own-price elasticity was –2.39), coal (-1.41), fuel oil (-1.22), natural gas (-1.21) and electricity (-0.52). The aggregate models examine the relation between energy, material, labor, and capital, assuming total cost to be constant. Although all of the own price elasticities of demand were found negative and significantly different from zero, at a conventional significance levels, all factors display price inelasticity. The cross-price elasticities were small, below 0.3 in absolute value assuming output was held constant. Although substantial interfuel substitution exists in the Canadian manufacturing sector, there was only slight substitution between aggregate energy and other aggregate inputs. Fuss also found that substantial increases in energy prices resulted in relatively small effects on average production costs. It is reported that a tripling of the price of energy inputs would only lead to an increase in average production cost of less than 10%. This finding was very important with respect to imposing carbon taxes on energy, and it was consistent with other econometric work which found that tax-induced increases in energy prices had a very small impact on total production costs (Ingham *et al*, 1991).

In the study by Griffin and Gregory (1976), a static translog cost function was used to estimate energy substitution responses in the manufacturing sector in Belgium, Denmark, France, West Germany, Italy, the Netherlands, Norway, United States and the United Kingdom. Similar to the approach used by Fuss (1977), labor and capital were assumed to be weakly separable from material inputs, which was necessitated by an absence of reliable data on materials. Estimates from cross-section studies were interpreted as long-run elasticities while estimates from time-series studies as short-run elasticities. Griffin and Gregory noted that higher energy prices might induce short-run substitution towards labor and material inputs and away from capital. Thus, in the short run, labor and materials were likely substitutes for energy while capital and energy were complementary. In the long run, however, capital and energy were more likely to be substitutes. They found that energy and labour were substitutes, but in contract to Berndt and Wood's (1975) results, energy and capital were also found to be substitutes. This finding supported their argument that time-series studies failed to measure the long run responses in the translog model. The authors concluded that the possibility of sign reversals in elasticity estimates depending on whether the short run or long run was being analyzed. They admitted to potential measurement error, simultaneous equation bias and specification error problems in their approach.

Another analysis of capital to energy substitution was conducted on the United States manufacturing sector by Field and Grebenstein (1980). They examined the energy demand over a cross-section of ten two-digit manufacturing industries in 1971. In order to remedy data deficiencies in their data sample, they assumed that four inputs (energy, capital, labor and materials) were separable from inputs of all non-energy intermediate materials. Results obtained varied over sectors but many estimated coefficients were found to be insignificant. It is reported that physical capital was statistically significant as a complement to energy in four sectors, weak signs of complementarity existed between them in three sectors, while estimates were insignificant for the remaining three sectors. There was significant substitution between working capital and energy in five sectors, while insignificant results were found for the other five sectors. With respect to the other cross-price elasticities, significant substitutability existed between the rest of the inputs and all own-price elasticities had the correct sign.

Using a model based on the translog function, Estrada and Fugleberg (1989) analyzed the own-price elasticities of natural gas and cross-price elasticities between natural gas and other fuels with no lagged and lagged price variables (one or two-year lag) in France and West Germany. This one or two-year lag period was chosen to incorporate the time for replacement of old equipment and installations in new equipment, and a time lag from the occurrence of a price change to the time when firms took decisions to renew the equipment. The own-price elasticities of natural gas, at the industrial sector, for France was estimated to be –0.30 without lag and –0.77 with a two-year lag. These same elasticities varied from –0.67 without lag to –0.84 with a two-year lag in Germany. The increase in the elasticities with lagged price variables confirmed their hypothesis that effects on natural gas consumption of a price change in year *t* became stronger one or two years later. The cross-price elasticities for the industrial sector, if the alternative was oil, in France were estimated to vary from 0.15 (without lag) to 0.53 (with one-year lag), and from 0.11 to 0.47 for West Germany. If paired with electricity, it was reported that the range was from 0.21 without lag to 0.72 with a two-year lag for France, while from 0.44 without lag to 1.31 with a two-year lag for Germany. The same analysis showed that, if the substitution was with coal, the estimated elasticities varied from –0.08 without a two-year lag to 0.02 for France, and from –0.49 with a two-year lag to 0.40 without a lag for Germany.

Similar analysis was conducted to estimate factor substitution in Greek manufacturing industries by Caloghirou, Mourelatos and Thompson (1997). They used pooled data in both a static and a dynamic translog expenditure share models. In their paper, inputs were grouped into capital, labor, electricity and non-electricity (liquid, solid and gas). From the short-term model, inelasticity was reported for labor and capital, with own-price elasticities ranging from –0.17 to –0.44 and -0.43 to –0.66, respectively. Electricity and non-electricity were observed relatively more elastic, ranged from –0.51 to –0.91, and –0.63 to –0.91, respectively. Allen elasticities of substitution indicated substitutability among all factors in the short run. In the long-term model, complements were observed for capital and electricity, non-electric energy and labor, with small cross-price elasticities of –0.09 and –0.21, respectively. While non-electric energy and capital showed rather significant substitution in their analysis, with a cross-price elasticity of 0.67. They also used a dynamic homothetic model to forecast input use based on predicted fuel prices. Results indicated the Greek manufacturing sectors would continue to use more electricity and less other-energy products.

Previous studies have demonstrated that the translog model is a well-established methodology for analyzing the energy demand, providing helpful insight into the nature of interfuel substitution. Its primary drawback is its potential to yield negative predicted cost shares. But if non-negativity of predicted cost shares is ensured this model remains an efficient method for estimating inputs demand. Though the translog model has been widely applied to investigate the demand response among energy and non-energy inputs, this thesis was restricted to address the demand response to price change of individual energy when a carbon tax was imposed in Ontario's pulp and paper industry.

2.3.2 Deriving the Translog Function

2.3.2.1 Separability in Production Function

Prior to the mid-70s, empirical studies of production structure were concerned with the estimation of the elasticity of substitution between two inputs, capital and labor, assuming constant elasticity substitution between the inputs. This assumption has been demonstrated to be too restrictive (McFadden, 1963). Production functions allowing the estimation of non-restrictive substitution production structure was proposed and applied in the studies of production structure with many inputs (Christensen *et al*, 1973).

The application of many inputs necessitates the assumption of separability to reduce multicollinearity problems associated with it (Fuss, 1977), such as between major categories of labor, capital, materials and energy. This assumption of separability ensures the two-stage optimization procedure. As discussed in Section 2.2, Berndt and Wood (1975) considered it valid to assume that substitution possibilities between capital and labor were independent from energy and material. They observed that none of the conditions: the Leontief, Hicksian aggregation, or separability conditions, for a value-added specification was satisfied by their data on manufacturing in the United States. The Leontief, Hicksian aggregation, and separability conditions were generally made as sufficient assumptions for value added specification in all previous empirical studies of investment demand and capital-labor substitutability in United States manufacturing. Berndt and Wood's (1974) finding questioned the reliability of investment of factor demand studies for United States manufacturing based on this value added specification. Griffin and Gregory (1976) assumed that three factors- capital, labor and energy – were weakly separable from materials input, partly necessitated by the absence of reliable data on materials. Fuss (1977) assumed weakly separable production in the categories of capital, energy, labor and materials. According to Denny and Fuss (1977), this assumption is sufficient for the existence of a two-stage optimization and implies aggregates which are homothetic in their components.

Following Fuss (1977), assume E, K, L, M are aggregate inputs of energy, capital, labor and materials, respectively, and $E(E_1 \ldots E_e)$, $K(K_1 \ldots K_k)$, $L(L_1 \ldots L_l)$, $M(M_1 \ldots M_m)$ are aggregator functions. If the production function

$Q = f(E_1 \ldots E_e, L_1 \ldots L_l, K_1 \ldots K_k, M_1 \ldots M_m)$

is weakly separable in the aggregate inputs, it can be written as

$Q = f[E(E_1 \ldots E_e), L(L_1 \ldots L_l), K(K_1 \ldots K_k), M(M_1 \ldots M_m)]$

Then the marginal rate of substitution between E_i and E_j is independent of the demanded quantities of L_l, K_k and M_m, $i, j = 1 \ldots E$; $l = 1 \ldots L$; $K = 1 \ldots K$; $M = 1 \ldots M$ (Leontief, 1947).

2.3.2.2 The Sub-model of Individual Energy Demand

As indicated above, weak separability ensures the two-stage optimization procedure. To better present the model, it is a good place to start with the sub-model, demand for energy inputs.

Following Fuss (1977) and Pindyck (1979), suppose there are a number of energy types, E_i, $i = 1 \ldots N$, being consumed. The production function can be written as:

$Q = f(E_1, \ldots, E_N, L, M, K)$

The weak separability indicated above allows the production to be written as

$$Q = f(E(E_1, \ldots, E_N), L, M, K) \tag{1}$$

Assuming that input prices and production levels are exogenously determined, and cost-minimizing behavior of firms, the theory of duality between cost and output implies that the production function (1) can be represented by a cost function as below:

$$C = g\,[P_E(P_{E1}, \ldots, P_{EN}), P_L, P_M, P_K, Q] \tag{2}$$

The cost function for energy inputs is represented by the translog second-order approximation (Christensen *et al.*, 1973), which is of the form

$$\ln P_E = ln\beta_0 + \sum_i \beta lnP_{Ei} + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln P_{Ei} lnP_{Ej} \tag{3}$$

The demand functions for individual energy types, in terms of shares in the cost of the energy aggregate, can be derived by logarithmically differentiating (3)

$$\frac{\partial \ln P_E}{\partial \ln P_{Ei}} = S_{Ei} = \beta_i + \sum_j \beta_{ij} \ln P_{Ej} \qquad i,j = 1 \ldots N. \tag{4}$$

Following Christensen *et al* (1973), certain cross-equation restrictions (adding-up, homogeneity and symmetry restriction) can be imposed on the parameters to satisfy the adding up criterion of the system of share equations (4) and the properties of neoclassical production theory.

$$\sum_i \beta_i = 1,$$
$$\sum_j \beta_{ij} = \sum_i \beta_{ij} = 0, \qquad (5)$$
$$\beta_{ij} = \beta_{ji} \qquad i \neq j$$

2.3.2.3 The Model of Aggregate Inputs

The aggregate model is much like the lower level model. Suppose there exists a production function

$$Q = f(E, L, M, K) \qquad (6)$$

Where

Q = gross output,

E = energy input,

L = labor input,

M = materials input,

K = capital input.

By the theory of duality of cost and production (Shepard, 1953), the cost function (6) can be written as

$$C = g(P_E, P_L, P_M, P_K, Q) \qquad (7)$$

Where

C = total cost,

P_i = factor prices, $i = E, L, M, K$.

According to Christensen *et al* (1973), a non-homothetic production function can be represented by a cost function of the form

$$\ln C = \ln \alpha_0 + \sum \alpha_i \ln P_i + \alpha_Q \ln Q + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j + \sum_i \gamma_{iQ} \ln Q \ln P_i + \frac{1}{2}\gamma_{QQ}(\ln Q)^2 \tag{8}$$

Where $i, j = E, L, M, K$

From Shepard's lemma (Diewert, 1971), the quantity demanded of the *ith* input can be obtained by $\partial C/\partial P_i = X_i$, if cost-minimizing behavior is assumed. Then the cost shares can be derived as:

$\partial \ln C/\partial \ln P_i = P_i X_i/C = S_i$

So, from function (3), the input demand function can be formed in terms of cost share as

$$S_i = \alpha_{ii} + \sum_j \gamma_{ij} + \ln P_j + \gamma_{iQ} \ln Q \tag{9}$$

Where $i, j = E, L, M, K$.

Similar parameter restrictions are required to satisfy the adding up criterion and properties of neo-classical production theory.

$$\begin{aligned} &\sum_i \alpha_i = 1, \\ &\sum_j \gamma_{ij} = \sum_i \gamma_{ij} = 0, \\ &\sum_i \gamma_{iQ} = 0, \qquad i, j = E, L, M, K \\ &\gamma_{ij} = \gamma_{ji} \qquad i \neq j. \end{aligned} \tag{10}$$

To measure the price responsiveness, two elasticities are commonly used, the Allen-Uzawa partial elasticity of substitution (Σ_{ij}) and the price elasticity of demand (ε_{ij}). The measures for the translog function can be calculated as (Berndt and Wood, 1975):

$$\Sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2}, \qquad i = E, L, M, K \tag{11}$$

$$\Sigma_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j}, \qquad i, j = E, L, M, K; i \neq j \tag{12}$$

$$\varepsilon_{ii} = S_i \Sigma_{ii}, \qquad i, j = E, L, M, K \tag{13}$$

$$\varepsilon_{ij} = S_j \Sigma_{ij} \qquad i, j = E, L, M, K; i \neq j \tag{14}$$

Each aggregate input consists of a certain number of components. The aggregate energy inputs are composed presumably of six energy types for each firm. This proposition is also applicable to the other aggregate inputs. However, this paper concentrated on the energy demand of Ontario's pulp and paper industry, attention was thus given to the problem of investigating the energy components in the models.

Procedure for estimating the model:

1) Estimate the demand for individual energy inputs. Solving function (4) subject to the restrictions (5) provides the estimates of the parameters in function (5). This procedure provides an understanding of the structure of substitution relationships between each energy type. P'_E, an estimate of aggregate price index of energy, can be obtained by substituting the estimated parameters into function (3). The estimate can serves as an "instrumental variable" (Fuss, 1977: p95) in the second stage of calculation.

2) Estimate the model (9) subject to restrictions (10), substituting P_E by the "instrumental variable" (Fuss, 1977: p95) P'_E.

2.4 The Logit Model

2.4.1 Literature Review

Logit models have been applied to consumer demand (Theil, 1969) although they are often associated with discrete choice problems (Considine and Mount, 1984). The logit model is a flexible functional form that can be used to represent a system of cost share equations. Other variables can be added into the model without affecting the constraints derived from economic theory (Considine and Mount, 1984). In contrast to the translog model that can produce erroneously negative fitted share values, the logit model is guaranteed to yield positive shares in the system. Because of these features, logistic models have been applied in the empirical analysis of energy demand.

Considine and Mount's paper (1984) delved into the analysis of energy input demand. Their data set included a pooled cross-sectional and time-series sample from 14 Northeastern and North Central states in the USA from the years 1964 to 1977. Demonstrating a linear logit model with appropriate constraints, they specified a set of cost share equations and elasticities equations that satisfied neoclassical economic theory. They demonstrated that parameter estimates were invariant with respect to the selection of the base (N^{th}) input when cross equation constraints on the parameters existed. At the same time, they developed the dynamic adjustment mechanisms in the application of the logistic model.

Their empirical results indicated that there could be sizeable differences in the estimated coefficients when comparing static and dynamic models. The dynamic model featured the gradual response of producers, which resulted from price expectation of producers, constriction of technological factors to adjust to other energy inputs with relative cheaper prices. While the static model assumed that demand responded instantaneously to long-run equilibrium level. Standard errors from the static model were substantially higher than for the dynamic model. Similarly, R-square statistics for the dynamic models was better than the static model. The long-run elasticities were the same as the short-run in the static model. All of the estimated own-price elasticities in the static model were lower than the dynamic long-run estimates. They found electricity and natural gas were complements in the static model, while in the dynamic model they were substitutes. Limited substitution possibilities among fuels in the short run were indicated by the short-run price elasticities estimated by the dynamic model. Using the static model, they found that it underestimated the long-term price elasticities and overestimate the short-term price effects. They concluded that, because of the flexibility of the model and empirically convenient specification, the use of the linear logit model allowed for the dynamic adjustment of input levels to price changes within a set of demand functions when information on capital stocks and other fixed input was lacking.

Considine's (1990) studied energy and non-energy demand of U.S. manufacturing from 1947 to 1971, using the same data as Diewert and Wales (1987), which was also used in

Berndt and Wood (1975), for comparison purposes. Traditionally, symmetry is only imposed by linear restriction for a specific set of cost shares such as mean shares. Considine (1990) used a recursive estimation procedure to impose symmetry conditions for all predicted cost shares. First, the linear logit model is guaranteed to be symmetric for all predicted cost shares in the sample by redefining the point-symmetric version of the model. Then the model is iterated to convergence (Condidin, 1990). Finally, predict shares from the logit equations were used as instruments in a log quadratic cost function. The cost function can thus be estimated recursively.

For his model, Considine (1990) reported the estimates for the cost elasticity with respect to output were very close to those found by Diewert and Wales (1987). He also found that the effect of technological change on total cost and input use was very small. Capital was found to be a complement with energy and materials. However, energy and materials display complementarity, which contradicts the results presented by Diewert and Wales. Considine compared his results with the estimates from other papers. He found the most notable difference between estimates from the logit model and other functional forms concerns the input elasticities with respect to output changes. In his results, the labor and material output elasticities were relatively close to the range reported by Diewert and Wales (1987), while the estimated output elasticities for energy and capital were greater than 1 and substantially greater than the estimates obtained from the other forms. He concluded that the results presented in his paper seem more plausible given that energy use and capital spending were more sensitive to the fluctuation of output as found in many studies.

In comparing the fitness of the translog function and logit model for energy and non-energy input cost share analysis, Lutton and LeBlanc (1984) estimated the translog and logit models using annual data on input prices and cost shares for the food-processing sector for the period 1954-1976. Both models were employed to investigate the price responsiveness between eight input categories: fuel oil, coal, electricity, natural gas, capital structures, capital equipment, labor and intermediate materials. They found the own-price elasticities were negative as expected, the demands for input were responsive to input price changes in both models and elastic for all inputs except labor. The cross-price elasticities derived from the translog model showed greater substitutability than those derived from the logit model. Oil and coal, electricity and oil, gas and coal, equipment and structures, equipment and labor, and structures and labor were all substitutes in the translog model, though complements in the logit model. This also provided an example that the derived price elasticity was sensitive to the specification of the model. Assuming output was held constant, if the rental price of equipment increased, for example, with an increase in interest rates, there was a slight decrease in labor demand in the logit model while an increase in the translog model. Demand for oil and electricity were substitutes in the logit model, but complements in the translog. They indicated that the logit model generated greater complementarity and smaller input price elasticities; while the translog model estimated greater substitutability among boiler fuel energy inputs.

Although the translog model fitted the data better over the sample period, Lutton and LeBlanc (1984) reported that the translog model generated negative cost shares, which were theoretically implausible, while for the logit model, the predicted shares were restricted to fall within the zero-one range. In addition, the logit model was straightforward and allowed for homogeneity and symmetry restrictions; it was not restricted to be monotonic in factor prices. They concluded that, despite the drawback in the logit estimation procedure, it represented a potentially useful tool for estimating and simulating cost share systems.

In another paper that compared the logit model and translog function, Moody (1996) estimated the demand for four fuels, natural gas, residual fuel, distillate fuel and coal in nine census divisions in the USA over the time period 1985 to 1990. Tests for negative demands, concavity violation and positive own-price elasticities at each observation were performed in Moody's (1996) analysis to diagnose the models. It was reported that the translog model yielded only nine negative shares. Regarding non-concavity, both the logit and translog models yielded positive eigenvalues, yet the translog model yielded 50% more positive values than the logit model. The logit model, however, yielded erroneous own-price elasticities. As a simulation model, the logit model was found to behave only slightly better than translog model. Based on his out of sample forecast tests, the logit model was slightly more accurate in forecasting compared to the translog model, although no single model predicts uniformly better than the other. He indicated that both behaved remarkably well at the regional level and at the national level, nevertheless, they were less useful for forecast than a pure forecasting model. On balance, he concluded, the linear logit model was favorable for short-term simulation and forecasting of utility fuel demand.

The non-negativity of cost shares in the logit model contributes to more stable concavity conditions, which is important for empirical applications. Analysis of the logit model has demonstrated that the logit model represents a potential useful tool for estimating and simulating share equation models. This approach was applied in Ontario's pulp and paper industry to examine the demand change with variation of fuel prices. It would also be useful to compare the results obtained from this model with those from the translog model to investigate which model behaved better in simulation work.

2.4.2 Deriving the Logit Model

For a cost function, the sufficient conditions for its existence are that the function is non-decreasing, homogeneous, concave and a continuous function over input prices. Moreover, the Hessian matrix derived from the cost function should be symmetric and negative semidefinite. The logit model was developed following Considine (1990) and Moody (1996). Suppose there is a demand function for input *i*, consistent with a given level of output and with cost minimization behavior. By Shepard's Lemma, the demand function can be derived by differentiating the cost function:

$$x(p,q)_i = \frac{\partial C}{\partial p_i}$$

$$s_i = \frac{p_i x_i}{C} = \frac{p_i(\frac{\partial C}{\partial p_i})}{\sum_{j=1}^{n} p_j x_j} = \frac{p_i(\frac{\partial C}{\partial p_i})}{\sum_{j=1}^{n} p_j(\frac{\partial C}{\partial p_j})} \qquad (15)$$

Where

$x\ (p,\ q)$ is conditional demand function,

p is a vector of factor prices,

C is the cost function;

s_i is the cost share for input i.

To specify the logit model of input demand, Considine and Mount (1984) proposed a convenient formulation of the logistic function with non-homotheticity to represent a set of cost shares:

$$s_i = \frac{e^{f_i}}{\sum_{j=1}^{N} e^{f_j}} \qquad for\ i = 1, 2, \ldots, N \tag{16}$$

Where f_i is a function with a flexible form of the n input prices and level of output, Y, expressed as

$$f_i = a_i + \sum_{j=1}^{N} c_{ij} \ln p_j + g_i \ln Q \tag{17}$$

Where a_i, c_{ij} and g_i are unknown parameters and Q is the level of output,

Properties of the factor demand functions are:

1) all level of input should not be less than zero;

2) the conditional demand functions should be homogeneous of zero-degree in prices of input factors;

3) the N×N matrix of the second partial derivatives of the cost function, $\partial x_i/\partial p_j$, should be symmetric and negative semi-definite, implying that signs of cross-price elasticities are symmetric and own-price elasticities are negative.

Logit models have some advantages over the translog model for estimating input demands. The linear logit model of cost shares developed by Considine and Mount (1984) permits dynamic adjustments and ensures non-negativity of predicted fuel shares. Considine (1990) demonstrates that global concavity was guaranteed if the model satisfies the concavity requirements at the point where symmetry is imposed. Translog models frequently do not meet the concavity restrictions (Diewart and Wales, 1987).

Considine and Mount's (1984) model, however, only ensures the symmetry at one set of cost shares, usually the mean shares. To remedy this drawback, Considine (1990) proposed that symmetry be imposed at more than one set of cost shares by redefining the point-symmetric version of the model to hold for each set of cost shares in the sample. Symmetry is guaranteed for all predicted cost shares in the sample by doing so. However, symmetry for cost shares is not guaranteed out of sample (Moody, 1996).

The price coefficients vary across the sample points so that equation (16) generates a family of cost shares. Given the exponential form of the logistic function, the predicted cost shares sum to 1 and must be positive. As noted by Chavas and Segerson (1986), the multiplicative error structure of the model has two advantages. First, the normality assumption is more applicable. Second, the logit specification has no restrictions on the autoregressive process of the structural error terms.

In equations (16) and (17), homogeneity of degree zero can be imposed if,

$$\sum_{j=1}^{n} c_{ij} = d \qquad all\ i \tag{18}$$

where d is an arbitrary constant. Symmetry can be imposed if,

$$s_i c_{ij} = s_j c_{ij} \qquad \textit{for all } i \neq j \tag{19}$$

which can be imposed at the predicted cost shares if

$$c^{\bullet}_{ij} = c^{\bullet}_{ji} \qquad \textit{for all } i \neq j \tag{20}$$

where

$$c^{\bullet}_{ij} = c_{ij}/s^{p}_{j} \qquad \textit{for all } i \neq j \tag{21}$$

and s^{p}_{j} *is* the predicted share of the jth fuel.

The cost share equations can be restated using the redefined parameters (21) to substitute for the homogeneity constraints (18) and imposing (20),

$$\begin{aligned} \ln\left(\frac{S_i}{S_n}\right) = (a_i - a_n) + \sum_{k=1}^{i-1} (c^{\bullet}_{ki} - c^{\bullet}_{kn}) s^{p}_{k} \ln\left(\frac{w_k}{w_n}\right) + \left(d - \sum_{k=1}^{i-1} s^{p}_{k} c^{\bullet}_{jk} - \sum_{k=i+1}^{n} s^{p}_{i} c^{\bullet}_{ik} - s^{P}_{i} c^{\bullet}_{in}\right) \ln\left(\frac{w_i}{w_n}\right) \\ + \sum_{k=i+1}^{n-1} (c^{\bullet}_{ik} - c^{\bullet}_{kn}) s^{\bullet}_{k} \ln\left(\frac{w_k}{w_n}\right) + (g_i - g_n) \ln y + (\varepsilon_i - \varepsilon_n) \end{aligned} \tag{22}$$

where

$$s^{p}_{i} = \frac{\exp(f_i - f_n)^{p}}{\sum_{j=1}^{n-1} (\exp(f_j - f_n)^{p} + 1)} \tag{23}$$

and $(f_i - f_n)^{p}$ is the predicted logarithmic share ratio from equation (22).

One equation is deleted from the estimation system to avoid the singularity of the variance-covariance matrix. The results are invariant with respect to selection of the nth equation (Considine and Mount, 1984). The identifying restrictions required for estimation are

$a_n = g_n = h_n = d = 0$

The cost function can be derived by the method developed by Considine (1990) as,

$$\ln c = a_0 + \sum_{i=1}^{n} s_i^p \ln p_i + g_j \ln Q + g_{jj}(\ln Q)^2 + e_0 \qquad (24)$$

Applying Shephard's lemma to (24) shows that the share errors are independent of the error term for total cost. The share elasticities can be calculated from the logit model as logarithmic derivatives of input quantities with respect to prices.

The own-price elasticities can be written as:

$$E_{ii} = s_i^p(c_{ii}^p - \sum_{j=1}^{N} s_j c_{ji}^{*}) + s_i - 1 \qquad i = 1,2,\ldots,N \qquad (25)$$

And the cross-price elasticities are represented by

$$E_{ik} = s_k^p(c_{ik}^p - \sum_{j=1}^{N} s_j c_{jk}^p) + s_k \qquad j \neq k \qquad (26)$$

2.4.3 Estimation Procedure

The model was usually estimated three steps (Considine and Mount, 1984; Considine, 1990; Moody, 1996). First, iterated seemingly unrelated regression (ITSUR) was applied to the cost share equations (22). This approach insures that the estimation was invariant with respect to the choice of fuel to be omitted. Observed shares for the endogenous variables substitute the predicted shares on the right-hand side of the equation (22). This procedure provided the initial estimates for the coefficients in the cost share equations.

The second step of the estimation process substitutes the initial predicted cost shares from (23) into equation (22), re-iterating using ITSUR. The predicted cost shares from this iteration were used on the right-hand side of the next ITSUR estimation of (22). This procedure was iterated to convergence, concluding the estimation of the cost share equations.

The last stage of the estimation was to estimate the cost function (24) using the predicted cost shares from the final iteration of the second step. Ordinary Least Square (OLS) was applied to estimate the cost funct(.Uion (24).

CHAPTER 3 METHODOLOGY

3.1 Structure of Pulp and Paper Industry

The pulp and paper industry in Canada is an economically important industry in terms of value of production and total wages paid, and one of the world's largest pulp and paper producers (Sinclair, 1990). It contributed over 0.47% of GDP in 1997 (CANSIM, Statistics Canada, series I600350 and I600001); employed 0.51% of national labor force in 2000 December (Statistics Canada, 2000) and is the primary source of income for 350 communities (Environment Canada, 1993). Being the largest net export industry in Canada, its payments to federal and provincial governments amount to $3.8 billion in 1999 (CPPA, 1999). Tax and regulatory policies to accomplish the reduction of greenhouse gases emissions should take into consideration the industry's need to be competitive and it's importance to the Canadian economy.

With a long history of energy-intensiveness, the pulp and paper industry is ranked the second largest carbon dioxide producer in Canadian manufacturing, only after the iron and steal sector. Because of its intensive energy consumption and low energy productivity, the pulp and paper industry has become a particular focus of concern as environmental issues have become more important.

The environmental problems occurring within the pulp and paper industry range from biological oxygen demand (BOD), chemical oxygen demand (COD) and carbon dioxide emissions due to energy use. Considering the purpose of this study to assess the feasibility of a carbon tax, attention will only be put on the carbon dioxide emissions. In addition to the government's effort to curb its carbon dioxide emissions to meet its international commitment, the industry spent some $2.1 billion on environmental protection between 1989 and 1991 (Madore, 1992), and since 1990, over $5 billion has been invested in pollution prevention technologies. This industry's direct emissions were 16 percent below 1990 levels in 1998, and this occurred during the same time that production increased by 21% (CPPA, 1999). Ontario's pulp and paper industrial sector was chosen to be analyzed to examine the feasibility of a carbon tax on this sector because of its potential GHG emissions deduction.

Coal, petroleum, natural gas and electricity have been traditionally used in this sector. The trend has been that coal and refined petroleum products are losing their importance while electricity and natural gas are gaining share dominance as the major types of energy consumed in the industry (Figure 1). Starting in 1998, steam was introduced into Ontario's pulp and paper industry as an alternative energy input. The consumption of steam is becoming more important in terms of its cost share of energy used.

Due to problem with the collection of steam data by Statistics Canada and Natural Resources Canada, consumption and prices of steam were not available and therefore steam, as an energy input, was not included in this study.

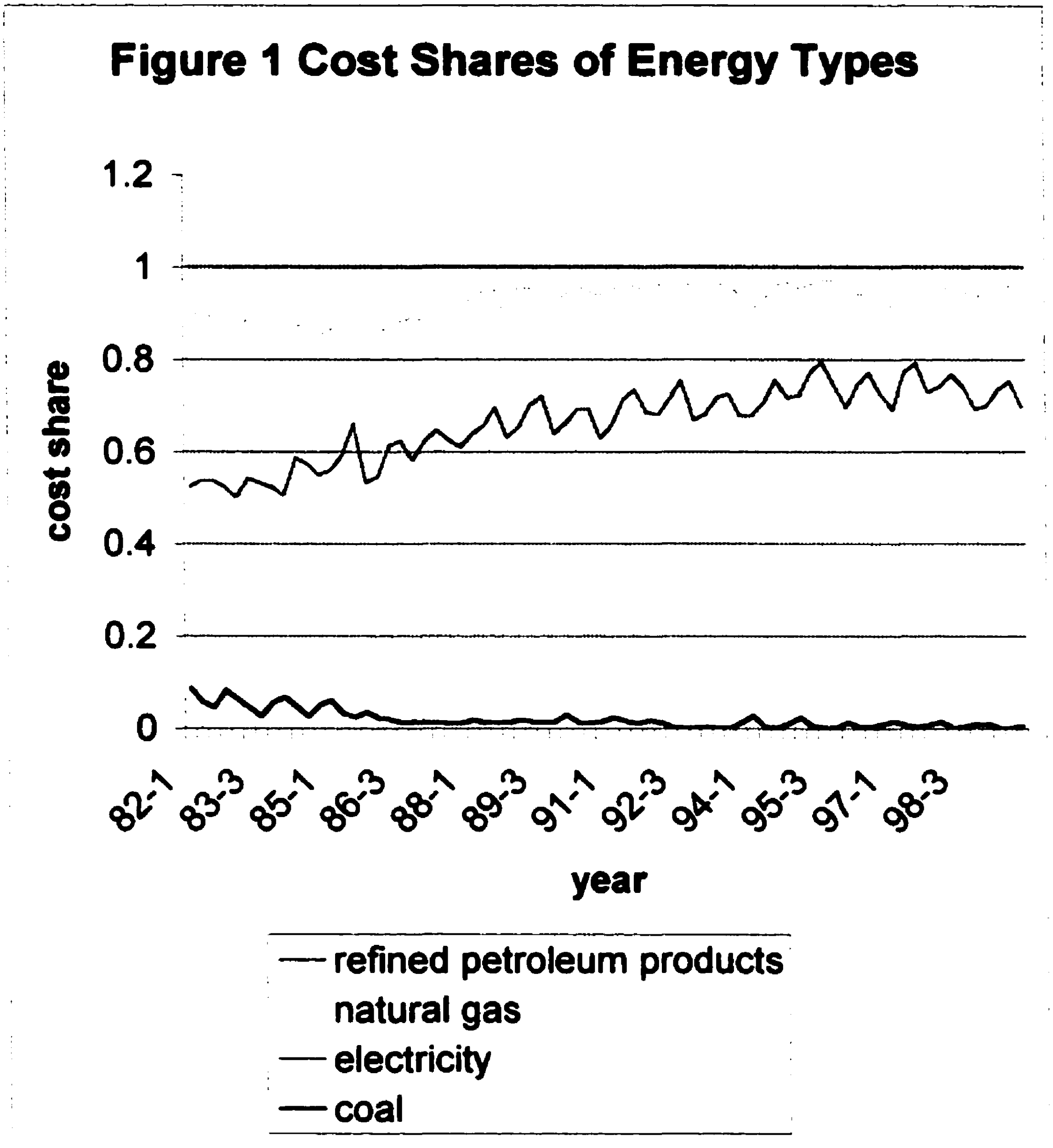


Figure 1 Cost Shares of Energy Types
1.2
1
0.8
0.6
0.4
0.2
0
cost share
82-1
83-3
85-1
86-3
88-1
89-3
91-1
92-3
94-1
95-3
97-1
98-3
year
refined petroleum products
natural gas
electricity
coal

3.2 Collection of Data

The time period over which the analysis occurs is from 1982 to 1998. This time period was chosen because of the availability of data. To estimate the demand for coal, electricity, natural gas and refined petroleum products with the translog and logit model input prices and cost shares of individual energy inputs and total output from the pulp and paper industry were needed. Quarterly data were obtained from a variety of secondary sources. Consumption of energy in pulp and paper industry is available from CANSIM (Statistics Canada) series D387326, D387328, D387327, and D387329 (Sannes, 2000; Sheldrick, 2000). Prices of energy were not directly observable for confidentiality reasons. Price Indices of coal, electricity, natural gas and petroleum, however, were available from CANSIM, series P1003, P1907, P1005 and P3276. The base year for this series was 1992 (Sheldrick, 2000). Expenditures on each energy inputs were obtained from the ASM (Annual Survey of Manufacturers) CPFE (consumption of purchased fuels and electricity) (in 1986 dollars) (Statistics Canada, 1992). The average cost per energy unit was then obtained by dividing the total expenditures on a particular fuel by the total quantity consumed (Trudeau, 2000). Implicit prices of each fuel were then derived by multiplying each type of energy's price in 1992 with each fuel's corresponding price index (Sannes, 2000). Seasonally unadjusted values of outputs of the pulp and paper industry in Ontario were obtained from CANSIM series D320045 (Beaulieu, 2000). It should be noted that the energy data obtained from CANSIM did not take into account electricity generated by the industry for their own use.

3.3 Model Development

In both models, energy was assumed to be weakly separable from capital, labor and materials, which implied a two-stage optimization procedure as stated in Fuss (1977). Only the sub-model that estimated the energy demand was investigated in this study.

3.3.1 The Translog Model

A translog model was developed to estimate the demand for energy in Ontario's pulp and paper industry.

As is well known (Christensen *et al*, 1973; Berndt and Mood, 1975; Fuss, 1977; Lutton and LeBlanc, 1984), the system of share equations form a singular system. For estimation purpose, one equation is dropped from the system and the rest are estimated simultaneously. Singularity of the estimated variance-covariance matrix was introduced because of indeterminacy of inter-equations. This means that the reverse of *(X'X)* does not exist. There were no solutions or no unique solution to the estimated system due to singularity. The deleted equation can be estimated by the adding-up criteria, symmetry and homogeneity constraint. Barten (1969) demonstrated that parameter estimates are invariant to which equation is deleted. The petroleum-equation was then arbitrarily chosen to be omitted from the model, and its parameters were calculated by using the adding condition. The estimation model was developed as follow.

Variables	Label
$Scoal_t$	Cost share of coal in the total cost of energy at time *t*
$Selec_t$	Cost share of electricity at time *t*
$Sgas_t$	Cost share of natural gas at time *t*
$Spet_t$	Cost share of refined petroleum products at time *t*
LPcoal	Logarithm of the price of coal (thousands of dollars per terajoule)
LPelec	Logarithm of the price of electricity (thousands of dollars per terajoule)
LPgas	Logarithm of the price of natural gas (thousands of dollars per terajoule)
LPpet	Logarithm of the price of refined petroleum products (thousands of dollars per terajoule)
Q	Output (thousands of dollars)
P_I	Dummy variable of seasons, i = 2, 3, 4, indicating summer, autumn and winter
A_i, b_{ij}, c_i, g_i, d_i	Unknown parameters

$$S_{it} = a_i + \sum_{j=1}^{4} b_{ij} * \ln(P_{it}) + g_i * \ln(Q) + d_i * P_j + c_i * S_{i,t-1} \tag{27}$$

$$\sum_{j=1}^{4} b_{i,j} = 0 \qquad \textit{for all } i \tag{28}$$

$$b_{i,j} = b_{j,i} \tag{29}$$

where i = coal, electricity, natural gas and refined petroleum products

3.3.2 The Logit Model

Similar to the translog model, the multivariate logit model had an indeterminacy problem due to the constraint that the equations must sum to zero. This problem was avoided by normalizing the *nth* parameters for each share (Considine and Mount, 1984;

Considine, 1989; Considien, 1990; Lutton and LeBlanc, 1984; Moody, 1996). Following Considine's (1990) method, the logit system was estimated with the following form:

$$f_1 = a_1 - (Selec * c_{12} + Sgas * c_{13} + (Scoal + Spet) * c_{14}) * r_1 + (c_{12} - c_{24}) * Selec * r_2 \\ + (c_{13} - c_{34}) * Sgas * r_3 + g_1 * \log(Q) + d_1 * p_2 + d_2 * p_3 + d_3 * p_4 + lag1(f_1);$$

$$f_2 = a_2 + (c_{12} - c_{14}) * Scoal * r_1 - (Scoal * c_{12} + Sgas * c_{23} + (Selec + Spet) * c_{24}) * r_2 \\ + (c_{23} - c_{34}) * Sgas * r_3 + g_2 * \log(Q) + d_4 * p_2 + d_5 * p_3 + d_6 * p_4 + lag1(f_2);$$

$$f_3 = a_3 + (c_{13} - c_{14}) * Scoal * r_1 + (c_{23} - c_{24}) * Selec * r_2 - (Scoal * c_{13} + Selec * c_{23} + (Sgas \\ + Spet) * c_{34}) * r_3 + g_3 * \log(Q) + d_7 * p_2 + d_7 * p_3 + d_8 * p_4 + lag1(f_3);$$

In addition to the definition of the variables in section *3.3.1*, the other variables included in the model were:

f_1: logarithm of the ratio of cost share of coal to cost share of refined petroleum products;

f_2: logarithm of the ratio of cost share of electricity to cost share of refined petroleum products;

f_3: logarithm of the ratio of cost share of natural gas to cost share of refined petroleum products;

r_1: logarithm of the ratio of price of coal to price of refined petroleum products;

r_2: logarithm of the ratio of price of electricity to price of refined petroleum products;

r_3: logarithm of the ratio of price of natural gas to price of refined petroleum products;

$lag1(f_i)$: one time period lagged of f_i.

3.3.4 Regression Method

Single equation methods were not applicable for these systems of equations since there were joint estimates in the estimated equations. Each equation had its own error term while correlation may exist in the joint dependent variables. Iterative Zellner's Seemingly Unrelated Regression (ITSUR) method was applied to solve the translog and logit models (Fuss, 1977; Considine, 1990; Griffin and Gregory, 1976; Pindyck, 1979; Patry *et al*, 1990; Moody, 1996; Berndt and Wood, 1975; Lutton and LeBlanc, 1984; Field and Grebenstein, 1980; Considine and Mount, 1984).

The ITSUR estimates the system as a whole. The approach first uses ordinary linear squares (OLS) to estimate individual equations, then derived residuals from equations i and j are used to estimate elements of the variance-covariance matrix Ω_{ij}. Each equation is then stacked and estimated by OLS using Ω_{ij} as a weighting matrix (Atkinson and Manning, 1995). This two-stage estimation-weighting procedure was repeated to satisfy the parameter convergence criteria. Application of ITSUR allows for the imposition of cross-equation restrictions and correlation between the error terms from individual equations in the model (Atkinson and Manning, 1995).

The translog model was estimated using small STATA 6.0. The logit model was estimated with PROC MODEL in the SAS, version 6.0 statistical system.

CHAPTER 4 EMPIRICAL RESULTS

It is hoped that the underlying hypothesis is to be made clear whether the pulp and paper industry in Ontario remain responsive to relative fuel price changes and will substitute one fuel input for another in order to minimize production costs. The translog model and the logit model, which attempt to capture this behavior, were estimated following the diagnostics of both models, and the results were summarized in this section.

4.1 Diagnostics of the Models

4.1.1 Examination for Multicollinearity

It is expected that if the price of electricity increases, consumption of natural gas or some other energy input will correspondingly increase to replace electricity. A certain degree of multicollinearity in the models might be expected due to this substitution and complementarity between demands of energy. The question that needed to be addressed was whether the multicollinearity was serious enough to warrant caution.

For the translog model, multicollinearity was assessed by examining the correlation matrix for the explanatory variables for each equation and these matrices are reported in Appendix 3.1. As expected, this examination revealed a high correlation between pairs of variables. Regression of each explanatory variable on the others indicated that high inter-dependence existed between some of the variables. This is common since application of generalized functional forms to the many-inputs case has always been plagued by multicollinearity problems resulting from an inadequate variation in input and factor price data (Fuss, 1977). Weak separabilty is often assumed among the major categories, such as labor, energy, capital and energy. In this paper, the purpose was to examine the substitution and complementarity between the four types of energy inputs. The correlation existing between explanatory variables was thus ignored and these correlated explanatory variables were not dropped from the model.

Similar analysis was conducted with the logit model. The Pearson Correlation Coefficients indicated that some of the variables were significantly correlated. As the same data set was used in the logit model, the same explanation can be used in this case.

4.1.2 Autocorrelation

As the lagged cost share variables were included into the systems, the time series may introduce autocorrelation between the error terms. One way to detect the autocorrelation is by graphing the residuals against the time period. If a pattern emerges, it is likely that the independence requirement is violated.

The tests of autocorrelation are reported in Appendix 3.2. For the translog model, no apparent patterns were identified that would indicate autocorrelation. Thus it was concluded that the error terms were independent. This conclusion was strengthened by looking at the correlation of the residual with the residual at incremental lags. For three equations, the low correlation coefficients confirmed very little correlation exists between the error terms. Regressions were performed on the same residuals. Two statistics, the coefficient's t-statistics and the model's adjusted R-square, both provided additional evidence that serial correlation would not affect the model's behavior.

Similar analysis was performed on the multivariate logit model. The statistics would indicate that the variables were not significantly correlated between the three equations. Thus no adjustments had to be made for autocorrelation.

4.1.3 Normality and Heteroscedasticity

Normality and homoscedasticity are required conditions for the validity of regression analysis. Simply put, the error variable must be normally distributed with a constant variance, and the errors must be independent of each other.

To test the normality of the error terms, the histograms and its kurtosis and skewness of the errors for the three equations were produced for each system. The histograms of the residuals can be found in Appendix 3.3. For the translog model, the error terms resemble a bell shape, which supports the conclusion that the normality requirement has been met. The test for the kurtosis and skewness for the four-equations provide further evidence that there was no strong evidence to reject the null hypothesis that the errors were normally distributed.

The results of normality tests for the logit model were not as conclusive as those for the translog model. The first histogram is a bit right skewed, but the test of skewness and kurtosis show the distribution of error terms can be assumed normally distributed. The other two appear more normal, and the normality conclusion was supported by the other two tests on the errors.

One method of diagnosing heteroscedasticity of the models is to plot the residuals against the predicted values of individual share. As reported in Appendix 3.4, for the coal share equation, the change in the spread of variation of the plotted points appears to be small when predicted share was small and large when predicted share was large. The figures for the other two equations illustrate no apparent change in the variation of the residuals. To explain such an unusual change pattern in the first graph, the nature of the translog should be restated here. The translog model has been criticized for producing negative share data, even though it has been used successfully for simulation. Examination of the predicted shares showed that for the electricity and natural gas equation, no negative share data was produced, while there were nine negative shares out of seventy-two data points for coal. The negative shares were caused by the zero or almost-zero actual coal shares. This can explain why the figure of residuals against predicted share provided such a pattern. Few negative shares were produced in the predicted shares, which indicates the model behaves quite well.

The tests for the logit model are given in Appendix 3.4. For the first equation, the change in the spread of variation of the plotted points appears to be large when predicted share was small and large when predicted share was small. Error terms in the third equation appear to have some degree of correlation with predicted value. Examining the cost share ratio data, one can find that in the 1990's, the share of coal decreased while those of refined petroleum products remained the same. This introduced considerable variation in the cost share ratio, and may be the one with heteroscedasticity, the same as in the f_3 equation. The estimators, however, can still be unbiased even with the presence of heteroscedasticity (Kmenta, 1971: p270-298). In the end, these fundamental tests provided evidence that heteroscedasticity problems will not seriously affect the model and so more exhaustive diagnostics were unwarranted.

It should be noted that the diagnostics performed above were based on individual equations. The approach of ITSUR solves the system as a whole. Additional diagnostics on the equation systems were not undertaken.

4.2 Estimates of the Models

In order to analyze the price responsiveness of individual fuels, own and cross-price elasticities of demand were calculated from the translog and logit models and are presented in the following sections. These models were derived under the assumption that the total energy input was held constant to emphasize the interfuel substitution effects. The regression results were also valid when the energy input was variable and depends only on the assumption that the energy demand function was linear homogeneous with respect to the total energy input (Fuss, 1977).

4.2.1 The Translog Model

4.2.1.1 Estimates of the Translog Model

Following the steps outlined in chapter 3, estimates of the translog model were obtained and are reported in Table 4.1. The R-square of the equations, 0.84, 0.96 and 0.86 respectively, indicates that the model has a good fit. The *F*-test indicates that the hypothesis that the estimated coefficients of the model are all equal to zero is rejected.

Equations were not significantly correlated as indicated by the magnitude of the coefficients of the correlation matrix of residuals and the Breusch-Pagan test of independence for the three equations. The test statistic for each coefficient allows for the rejection of the hypothesis that the coefficients are equal to zero.

Coefficients for the prices of coal and natural gas in the coal share equations and coefficients for the prices of coal and refined petroleum products in the natural gas share equation appear to be insignificant. This may be due to multicollinearity and heteroscedasticity that was found in the model. As the model was estimated as a system, these variables were kept in the equation.

4.2.1.2 Price Elasticities

To design a policy targeted to mitigate carbon dioxide emissions, knowledge of the price responsiveness of individual energy and inter-energy input is essential to understand the change in consumption within the industry. In order to analyze the price responsiveness of individual fuels, own and cross-elasticities of energy inputs were calculated throughout the data sample.

Table 4.1 Estimates of the Translog Model

Equation	Observations	Parms	RMSE	R-sq	F-Stat	P
Scoal	71	9	.0080238	0.8365	45.05146	0.0000
Selec	71	9	.0189744	0.9647	246.2606	0.0000
Sgas	71	9	.0191307	0.8663	59.38241	0.0000

Eq.Scoal	Coef.	Std. Err.	T	P>|t|	[95% Conf. Interval]	
LPcoal	.0099234	.0190793	0.520	0.604	-.0277203	.0475671
LPelec	-.0229181	.0078534	-2.918	0.004	-.0384129	-.0074234
LPgas	-.0013517	.0114902	-0.118	0.906	-.024022	.0213187
LPpet	.0143464	.0089537	1.602	0.111	-.0033193	.0320121
LnQ	-.0096728	.0056674	-1.707	0.090	-.0208547	.0015091
p2	-.0132886	.0026714	-4.974	0.000	-.0185592	-.008018
p3	-.0128989	.0026123	-4.938	0.000	-.0180529	-.0077448
p4	-.0018753	.0027922	-0.672	0.503	-.0073843	.0036338
Scoal	.4158412	.091122	4.564	0.000	.2360565	.5956259
_cons	.1719134	.0781911	2.199	0.029	.0176415	.3261853

Eq.Selec	Coef.	Std. Err.	T	P>|t|	[95% Conf. Interval]	
LPcoal	-.0229181	.0078534	-2.918	0.004	-.0384129	-.0074234
LPelec	.1368462	.020623	6.636	0.000	.0961568	.1775357
LPgas	-.05241	.0125217	-4.186	0.000	-.0771153	-.0277046
LPpet	-.0615181	.0171544	-3.586	0.000	-.0953639	-.0276723
LnQ	.0567047	.0152311	3.723	0.000	.0266536	.0867558
p2	.0507729	.0059786	8.492	0.000	.038977	.0625688
p3	.048806	.0074081	6.588	0.000	.0341897	.0634222
p4	-.0173631	.0086771	-2.001	0.047	-.0344831	-.0002431
Selec	.3996965	.084052	4.755	0.000	.2338608	.5655322
_cons	-.5581691	.1871515	-2.982	0.003	-.9274212	-.188917

Eq.Sgas	Coef.	Std. Err.	T	P>|t|	[95% Conf. Interval]	
LPcoal	-.0013517	.0114902	-0.118	0.906	-.024022	.0213187
LPelec	-.05241	.0125217	-4.186	0.000	-.0771153	-.0277046
LPgas	.0432542	.0218974	1.975	0.050	.0000503	.0864581
LPpet	.0105075	.0152892	0.687	0.493	-.0196584	.0406733
LnQ	-.0340705	.0145593	-2.340	0.020	-.0627962	-.0053448
p2	-.0157864	.0060656	-2.603	0.010	-.0277538	-.0038189
p3	-.019637	.0064159	-3.061	0.003	-.0322957	-.0069783
p4	.0213374	.0069448	3.072	0.002	.0076353	.0350396
Sgas	.4579634	.0854528	5.359	0.000	.289364	.6265628
_cons	.6758556	.2136135	3.164	0.002	.2543936	1.097317

Correlation matrix of residuals

	Scoal	Selec	Sgas
Scoal	1.0000		
Selec	-0.1945	1.0000	
Sgas	-0.1540	-0.4403	1.0000
Breusch-Pagan test of independence: chi2(3) = 18.133, Pr = 0.0004			

Table 4.2 Own and Cross-price Elasticities[a]

	Coal	Electricity	Natural Gas	Petroleum
Coal	-0.42*	-0.02	0.01	0.22
Electricity	-0.21*	-0.14	0.43	-0.24
Natural Gas	0.17*	0.17	-0.57	0.41
Petroleum	0.64*	-0.01	0.13	-0.39

[a]In order to interpret the elasticities, one should read the number row by row, that is, the effect of a change in the price of coal on the other three fuels is contained in the first row, etc.

*The coal share values below 10^{-3} are deleted to obtain more accurate elasticities

There is a different elasticity for each data point. Presented in Table 4.2 are the mean values for each fuel. The translog model can neither be constrained to yield positive shares nor can it be constrained to yield concavity. If concavity is not guaranteed, the energy demand equations are not likely to behave well and are therefore less useful for simulation purposes. Fitted cost shares by the translog model were then produced (Appendix 4). Only nine out of 288 shares were negative. Negative shares were produced when the observed shares for coal were equal to zero or less than 10^{-3}. Considering that coal is not the dominant fuel in the industry and the relatively few number of negative fitted shares, positivity of the fitted cost shares was ensured. With respect to concavity, table 4.2 above shows that relationship between different types of energy inputs, and indicates a high level of substitution with weak complementarity (coal and electricity, electricity and refined petroleum products), which indicates concavity was ensured in the Hicksian sense (Fuss, 1977). With these tests, one can conclude that the translog model behaves well with this data set.

From these results a number of conclusions can be drawn:

1) All of the own price elasticities were negative, these results therefore do not violate the postulates of cost-minimizing factor demand theory.
2) There appears to be no substantial scope for interfuel substitution by examining the price elasticities throughout the data space. For all the energy types, cross-price elasticities were less than 1 in absolute value.
3) Only slight substitution exists between individual fuels as price elasticities overall appear to be in the inelastic range. They are ranked in the following order of declining (in absolute value) price elasticities of demand: natural gas, coal, refined petroleum products and electricity.
4) Demand for electricity was found to be inelastic, which is consistent with the finding in many studies (Berndt and Mount, 1975; Griffin and Gregory, 1976; Fuss, 1977; Pindyck, 1979).

4.2.2 The Logit Model

4.2.2.1 Estimates of the Model

In the estimation of the logit model, observations were deleted when the consumption of coal was zero. This was done because the specification for coal was Ln(Scoal/Spet), which resulted in a meaningless calculation when the share of coal was zero. Based on the model in Section 3.3.2, the results of the logit model can be found in Table 4.3.

Concerning the fitness of the equations, equations of coal shares and refined petroleum products shares did not fit well. The R-square for these equations were 0.45 and 0.44, respectively. The equation of electricity shares seemed quite good (R-square = 0.82). The significance test for each variable indicated that 13 coefficients were insignificantly non-zero. The correlation of residuals matrix provided indirect evidence of the independence of the three equations.

4.2.2.2 Price Elasticities

For comparison reasons, own and cross-price elasticities of demand were calculated based on the estimated coefficients from the model and are reported in Table 4.4. The logit model produced consistent results with those from the translog model in terms of signs of elasticities, ignoring the magnitude of the elasticities. Own-price elasticities were all negative. All cross-price elasticities, except for coal to natural gas, fall within the inelastic range, indicating limit scope for interfuel substitution. This result is consistent with the outcome from the translog model. It was demonstrated that non-positive eigenvalues for all positive factor prices ensured the negative semi-definite Hessian matrix in the entire domain, by which global concavity of the logit model was assured for non-negative parameters (Morey, 1986). The eigenvalues were checked at each sample point. Presented in Table 4.5 are average eigenvalues and those for the sample endpoints. Over the entire sample, 14 out of 66 eigenvalues were positive, resulting a positive 8_1, of which 12 are less than 10^{-1}. This result indicated that the logit model was concave.

Table 4.3 Estimates of the Logit Model

Equation	DF Model	DF Error	SSE	MSE	Root MSE	R-Square	Adj R-Sq	Durbin Watson
F1	8	57	45.47197	0.79775	0.89317	0.4522	0.3850	2.000
F2	8	57	4.62001	0.08105	0.28470	0.8041	0.7801	1.920
F3	8	57	5.86562	0.10291	0.32079	0.4357	0.3664	1.949

Nonlinear ITSUR Parameter Estimates

Parameter	Approx. Estimate	Std Err	'T' Ratio	Approx. Prob>|T|
A1	0.666737	9.37540	0.07	0.9436
A2	-2.672381	3.07824	-0.87	0.3890
A3	0.790775	3.48606	0.23	0.8214
C12	-2.488334	1.04944	-2. 37	0.0211
C13	7.216481	5.66618	1.27	0.2080
C14	-0.276221	4.52896	-0.06	0.9516
C23	-0.681745	0.09670	-7.05	0.0001
C24	-1.263624	0.25894	-4.88	0.0001
C34	0.722573	0.76470	0.94	0.3487
G1	-0.010069	0.68900	-0.01	0.9884
G2	0.221266	0.22502	0.98	0.3296
G3	-0.021889	0.25367	-0.09	0.9315
D1	0.335676	0.12347	2.72	0.0087
D2	0.265826	0.07950	3.34	0.0015
D3	0.384861	0.07818	4.92	0.0001
E1	-0.751964	0.32830	-2.29	0.0257
E2	-1.087927	0.33675	-3.23	0.0021
E3	-0.401728	0.32562	-1.23	0.2224
E4	0.337305	0.09983	3.38	0.0013
E5	0.268349	0.10617	2.53	0.0143
E6	-0.012242	0.10546	-0.12	0.9080
E7	0.192536	0.11259	1.71	0.0927
E8	0.078583	0.11795	0.67	0.5079
E9	0.072581	0.11631	0.62	0.5351

Correlation of Residuals

Corr S	F1	F2	F3
F1	1.0000		
F2	0.1379	1.0000	
F3	0.1771	0.9296	1.0000

Table 4.4 Own and Cross-price Elasticities

	Coal	Electricity	Natural Gas	Petroleum
Coal	-0.98	-0.95	2.16	0.057
Electricity	-0.03	-0.36	0.08	-0.02
Natural Gas	0.15	0.20	-0.74	0.14
Petroleum	0.01	-0.17	0.45	-0.92

[a]In order to interpret the elasticities, as indicated in Table 4.2, one should read the number row by row, that is, the effect of a change in the price of coal on the other three fuels is contained in the first row, etc.

Table 4.5 Eigenvalues Evaluated at Average and Sample Endpoints

Eigenvalues	Average	1998.4
λ_1	0.004965	-0.006096
λ_2	-0.064801	-0.060983
λ_3	-0.161343	-0.154886
λ_4	-0.281661	-0.269191

Compared to the translog model, different price elasticities were produced with the logit model, indicating the sensitivity of the price elasticities to the formulation of the models. From the logit model, all of the own- and cross-price elasticities (exclude natural gas to coal) were inelastic. Coal and electricity, coal and refined petroleum products, electricity and refined petroleum products display complementarity, while all the other were substitutes.

4.2.3 Comparison of the Translog and Logit Models

Comparing the results from the translog and logit models, all the signs of inter-fuel elasticities were the same in both models. Although the logit model yielded slightly larger price elasticities, both models indicate that there was not much room for inter-fuel substitution. This was the result of small cross-price elasticities estimates.

The logit model is constrained to yield positive shares, while the translog model can not. This has been a major criticism of the translog model. In this analysis, data may appear to favor the logit model as coal share was nil or close to zero. According to the study by Considine and Mount (1984) that the positivity of cost shares in the logit models were quite desirable in applications where some of the cost shares were very small. Results from the logit model confirm this, though yielding low R-square for two of the cost share equations.

It appears that no single model behaves better than the other. Both models comply with factor demand theory. The translog model, however, was chosen to simulate the greenhouse gas tax because of its relatively high R-square and ease of calculation.

4.2.4 Likelihood Ratio Tests

The small interfuel elasticities raise an interesting question: Is any price of energy input independent from the cost share of another fuel? To answer this question, the likelihood ratio test is a good way to test the independence of sets of variables for multivariate analysis (Anderson, 1958: p60-96).

Table 4.6 displays the likelihood ratio tests between the complete system of equations for the translog model. The results are from the original model and that with one of the explanatory variables of energy prices is dropped.

Table 4.6 Results of Likelihood Ratio Tests

Model without coal price variable	chi2(1) =2.77; Prob. > chi2 =0.0959
Model without electricity price variable	chi2(1) =36.90; Prob > chi2 =0.0000
Model without natural gas price variable	chi2(1) =10.54; Prob > chi2 = 0.0012
Model without refined petroleum products price variable	chi2(1) =12.68; Prob > chi2 = 0.0054

The tests of the variables, except coal price, indicate that the null hypothesis, that the tested variable is independent from the other variables, can be rejected at the significance level. For the test of coal, the null hypothesis, however, was rejected at the 0.10 significance level but not at the 0.05 or lower levels. According to the results of these tests, one can conclude that energy price has a certain level of influence on the cost shares of other energy type, however this influence has limited scope according to the small interfuel elasticities. This finding is important for the simulation of the greenhouse gas tax. The primary purpose of a carbon tax is to encourage industry to move to cleaner energy if a heavier carbon tax is imposed on the energy input with the largest amount of greenhouse gas. The results above indicate that a carbon tax may not be a good method to reduce greenhouse gas emissions since there is not much room for energy substitution. The simulation will explore the feasibility of a carbon tax on energy inputs for the Ontario pulp and paper industry.

CHAPTER 5 SIMULATION FOR A CARBON TAX

5.1 Data Forecast

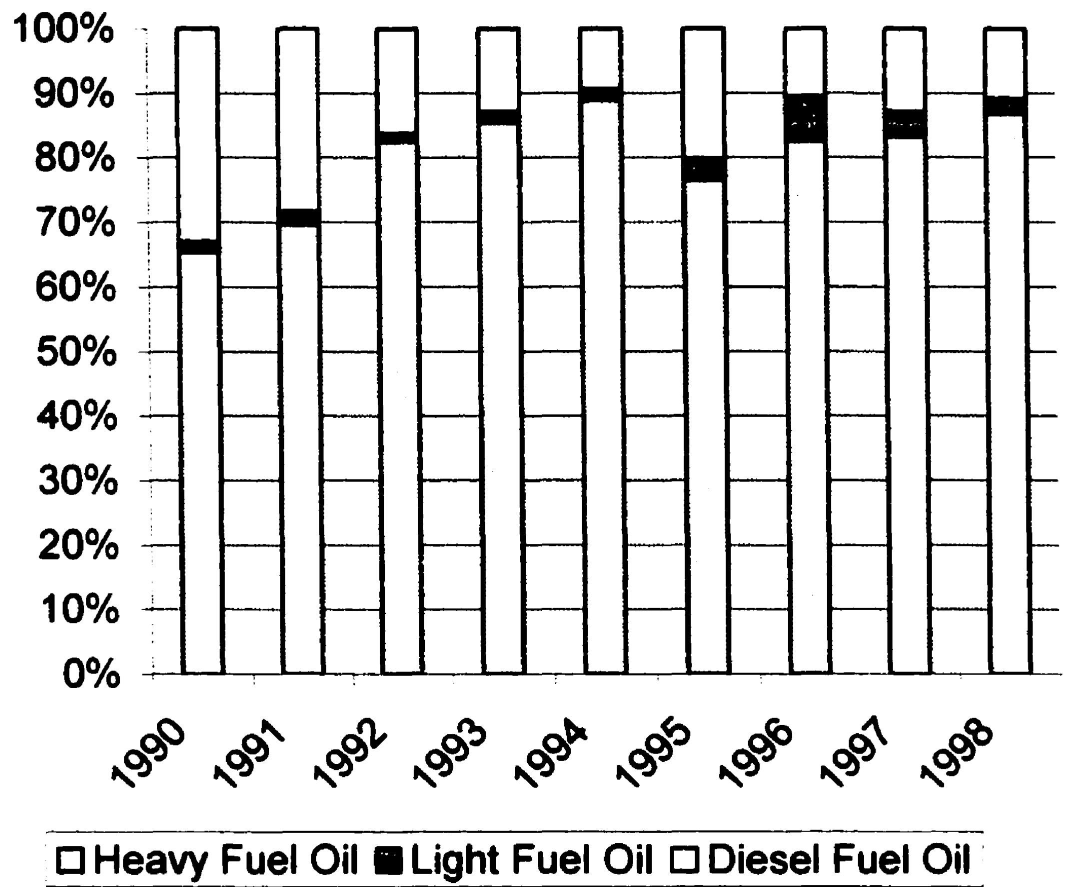
The Canadian government has committed to reduce its GHG emissions to 6% below its 1990 emissions levels. One means of achieving this goal would be to introduce a carbon tax on energy inputs. Such a carbon tax would increase the price of energy inputs according to their carbon dioxide content. This would provide an incentive for firms to switch to fuels with less carbon dioxide emissions, assuming the total energy input is held constant. Whether a carbon tax is successful or not depends upon the degree of interfuel substitution. Results obtained from Chapter 4 indicated there is not much room for inter-fuel substitution within the pulp and paper sector of Ontario. The estimates from the translog model were used to assess the feasibility of a carbon tax on Ontario's pulp and paper sector.

Energy demand and carbon dioxide emissions are strongly influenced by external economic and political factors, such as the growth of international and domestic economies. Therefore, macroeconomic assumptions were used to construct the framework within which future demand for energy inputs was projected in the forecasting model for Ontario's pulp and paper sector. First, Natural Resources Canada has estimated that the pulp and paper industry will experience a growth rate of 1.8% annually from 2000 to 2010 (NRCan, 1999). This estimated growth in output was used in this analysis. Second, the prices of individual energy inputs have been forecast by NRCan for the period 2000 to 2010 (Labib, 2001). These were incorporated in the model to complete the data requirements to simulate the demand change that would be accompanied by future price changes.

The discrepancy between the data on refined petroleum products from Natural Resource Canada and the data used in Chapter 4 was that NRCan estimated individual fuel prices, while in Chapter 4, several fuels were aggregated into one category as refined petroleum products. To obtain a price for the refined petroleum category, average prices of refined petroleum products were weighted by the historic use of individual fuels in the industry, as a ratio of consumption of each fuel outlined in Figure1. The ratios of 0.80:0.03:0.17 were used for heavy fuel, light fuel and diesel fuel to calculate the weighted price of refined petroleum products. Predicted energy prices are presented in Appendix 7. It should be noted that the prices of individual energy inputs at the national level were used in the estimation procedure. However, in the energy demand forecasts, used prices of energy inputs are at the provincial level. The price of coal after 2000 was estimated to remain at the same level as in 2000 (NRCan, 1999). Units used for prediction were different from those for estimation. These were converted into the same units given conversion factors in Table 3 of Annex b in the book of Canada's Emissions Outlook (NRCan, 1999) if carbon tax is imposed.

One difficulty with the simulation was that the cost of energy in the future was not available in Natural Resource Canada forecast data set. As the purpose of both models was not to forecast the cost of energy inputs, C_y was denoted to represent to cost of energy in the year y. The simulation was set in a "pure" economy context, in which the demand for individual energy would be only influenced by the fuel price. Change of

Figure 2
Ratio of Individual Energy Consumption



price of one fuel caused by the imposition of carbon tax will not have an impact on the other fuels.

5.2 Simulation of a Carbon Tax

The translog model was employed to simulate the energy demand because it behaved better in the simulation tests. Coefficients of three equations were estimated and stated above. For the last equation, coefficients can be obtained by the homogeneity and symmetry constraints as developed in the Table 5.1. Estimates of the model were stated below.

Table 5. 1 Cost Share Equations

Eq.	Coefficients Estimates									
	LnP1	LnP2	LnP3	LnP4	LnQ	D2	D3	D4	LnS	Const.
Scoal	.0099234	-.0229181	-.0013517	.0143464	-.0096728	-.0132886	-.0128989	-.0018753	.4158412	.1719134
Selec	-.0229181	.1368462	-.05241	-.0615181	.0567047	.0507729	.048806	-.0173631	.3996965	-.5581691
Sgas	-.0013517	-.05241	.0432542	.0105075	-.0340705	-.0157864	-.019637	.0213374	.4579634	.6758556
Spet	.0143464	-.0615181	.0105075	0.036664	-.0129614	-.021698	-.01627	-.002099	.4401635	0.7104

Consumption of coal tended to be close to zero in 1990's, and it is predicted that the demand for coal will be zero in the future (NRCan, 1999). Thus, substitution between coal and other energy inputs may not be considered due to the zero demand for coal and the logarithmical form of price in the translog model. As natural gas and refined petroleum products release a certain amount of carbon dioxide, it is hoped that consumption patterns of energy use will move towards cleaner energy inputs. In this analysis, electricity is assumed to be purchased off-site, and only direct GHG emissions is taken into account. GHG emissions of electricity are then assumed be zero and electricity will not be taxed. Imposition of a carbon tax might indirectly increase the price of electricity, but this effect is excluded from the simulation model to simplify the analysis. The effect of a carbon tax on the consumption of energy is derived entirely

from the effect on prices. Other energy types are taxed by an energy fee based on the amount of carbon calculated by NRCan (1999) as indicated in table 5.2.

Table 5.2 Carbon Factors

Fuels	Coal	Electricity	Natural Gas	Refined Petroleum Product
CO_2 Emissions factors (t/TJ)	71.8	0[P]	48.77	73.39*

[P]: Electricity is assumed to be purchased off-site in this analysis, and only direct GHG emissions is considered.
*: Emissions factor is calculated based on the ratio of 0.17:0.03:0.80 between diesel fuel, light fuel and heavy fuel.

Table 5.3 Carbon Effects on the Demands for Fuels

2005 yr.	Price[a] (10^3\$)	Share[a]	Demand (Terajoule)	Price[b] (10^3\$)	Share[b]	Demand (Terajoule)	±deamnd (Terajoule)
Coal	2615	0	0	6205	0	0	0
Electricity	7469	0.74	C_{2005}*9.9E-05	7469	0.69	C_{2005}*9.2E-05	C_{2005}* (-6.7E-06)
Natural Gas	3974	0.22	C_{2005}*5.5E-05	6413	0.25	C_{2005}*3.9E-05	C_{2005}* (-1.6E-05)
Refined Petroleum Product	6885	0.04	C_{2005}*5.8E-06	10555	0.06	C_{2005}*5.7E-06	C_{2005}* (-1.3E-07)

[a] indicating prices and cost shares before carbon tax,
[b] indicating prices and shares after tax

Before assessing the impact of a carbon tax on energy inputs several assumptions were made to simplify the analysis. As indicated above, this analysis is set in a "pure" economy, a price change of any fuel will not have an impact on the price of other energy inputs. Changes in the price of energy inputs were assumed to have little impact on the output of the industry. This was based on Fuss's (1977) finding that substantial increases in energy prices had relatively small effect on average production cost. Suppose a carbon tax of $50/tonne carbon dioxide would be imposed on individual energy inputs, correspondingly increasing the fuel price according to its carbon contents, the result would be an increase in the cost of production.

Total expenditure on energy inputs was assumed to remain constant in this analysis. Price increases of natural gas and refined petroleum products decreased the total energy output in terajoules. Increases of cost shares of natural gas and refined petroleum products were caused by the near-to-double increase in their prices. As seen in Table 5.3, there was not much change in the demands for electricity and refined petroleum products. Recall the own and cross-price elasticities calculated in the previous chapter, four fuels appear to be inelastic to the inter-fuel price changes, which was consistent with the results in Table 5.3. It can be inferred that introducing a carbon tax, a tax of $50/tonne carbon dioxide, did not lower the carbon dioxide emissions much in the context of interfuel substitution. As a result, a carbon tax seems to have failed to meet the primary purpose of the study, i.e. to decrease carbon dioxide emissions. According to the analysis, a carbon tax does not appear to be suitable for Ontario's pulp and paper industry as a means of decreasing carbon dioxide emissions from this sector.

As stated in Chapter 3, the pulp and paper industry is an important industrial sector in the Canadian economy. If a carbon tax is imposed on this industry's energy inputs, regardless of its inelasticity to inter-fuel price change, it might harm economic development and its competitiveness in the world, thus to the Canadian economy. Other more appropriate methods should be investigated to curb carbon dioxide emissions in order for Canadian government to meet its commitment in the Kyoto Protocol.

A trading system based on the allocation of carbon dioxide emissions at the sectoral level may be an alternative way to achieve the overall reduction. This approach allows the trading of permits of carbon dioxide emissions between sectors. Traditional energy-intensive industries, such as the pulp and paper industry could trade emissions permits with other sectors that are not energy-intensive, or trade between provinces. Transaction cost of a trading system depends on different scenarios. Incorporating national sectors and provinces, Natural Resource Canada (NRCan, 1999) examined and assessed the feasibility of various path-scenario combinations based on different degrees of reliance on specific measures and tradeable permit systems. It has been found that moving to a cross-sector emissions target with a trading system would achieve the target at a lower national cost and is more feasible than having a sector acting alone (NRCan, 1999).

Steam may also be an alternative energy input to substitute other energy inputs with higher carbon content. This energy input is gaining more importance in this sector. Steam is produced from nuclear sources and relative less or no GHG are produced with its use (Statistics Canada, 2000). It is difficult to measure the price responsiveness between steam and other fuel due to the current data problems with steam. Government may encourage the sector to move to cleaner energy inputs, in terms of greenhouse gas emissions, by subsidizing the use of steam.

CHAPTER 6 CONCLUSION

Knowledge of price responsiveness in the industry is essential for designing effective price-based controls to curb the greenhouse gas emissions. Two models, the translog and logit models, were formulated to estimate the inter-fuel substitution and complementarity. Four fuels: coals, electricity, natural gas and refined petroleum products, were examined with the two models over the period 1982 to 1999 for the Ontario pulp and paper industry.

Both estimated models complied with neo-classical factor demand theory. The translog model appears to be a better model than the logit model because of its relatively higher R-square and ease of calculation. However, this conclusion is only valid for the studied data set.

Empirical results from the models indicate that the pulp and paper industry in Ontario would show very little response to an energy input price change. Own and cross-price elasticities from both models fall in the inelastic range, which suggests that price-based policies targeted to encourage firms to switch to cleaner energy may not work well.

To confirm the hypothesis above, a simulation was performed to assess the feasibility of imposing a carbon tax of $50/tonne carbon dioxide on energy inputs based on their carbon content. Predicted prices of the energy inputs: coal, electricity, natural gas and refined petroleum products and output from the year 2000 to 2010 in the sector were incorporated into the translog model. Results from the simulation of a carbon tax of

50$/tonne carbon dioxide indicate that demand decrease only 0.17%, 7.1% and 29% for refined petroleum products, electricity and natural gas, respectively, holding total cost of energy fuel constant. These indicate that a carbon tax may not be an effective approach to accomplish the emissions target due to the in-elastic nature of energy inputs in the industry. Two approaches may help the industry to mitigate its GHG emissions with good economic development. First is a trading system that would allow the industry to trade emissions permits for GHG emissions. Second is a governmental subsidy program that compensates for the inefficiency of steam use, encouraging the industry to adopt steam as an alternative energy to meet its energy demand.

A detailed examination of a trading permit system should be undertaken. This would require estimating energy input price elasticities across industrial sectors and estimating pollution abatement costs curves by sector.

Due to data limitations, steam energy was not included in the models. Understanding the demand for this energy input is extremely important because steam is gaining in terms of its energy share and it may provide an excellent opportunity for the industry to lower its GHG emissions. Whether steam is a good alternative energy input is still under examination, since no information was available concerning steam as a substitute for other energy inputs consumed in the industry.

It should be noted that analyzing the demand for energy and non-energy inputs might display substitutes in the long term, which may strengthen the case for a carbon tax. But this is beyond the scope of this thesis. Further studies of the economic feasibility of a carbon tax should examine the relationship between energy and other inputs in the long run.

Finally, this study should be viewed as a first step to analyze the policy designed to help the Canadian government meet its GHG emissions commitment. Ontario's pulp and paper was chosen to be the subject here, so the result obtained in this paper only represents a small portion of Canadian manufacturing. The steps developed in this analysis can be expanded to include other sectors of the economy.

REFERENCE:

Anderson, T.W., 1958. *An Introduction to Multivariate Statistical Analysis*. New York, London and Sydney: John Wiley & Sons, Inc.

Atkinson, J. and N. Manning, 1995. A Survey of International Energy Elasticities. In Barker, T., P. Ekins and N. Johnstone *eds*. *Global Warming and Energy Demand* London and New York: Routledge.

Balling, R.C. and S.E.I dso, 1990. Effects of Greenhouse Warming on Maximum Summer Temperatures. *Agricultural and Forest Meteorology* 53: 143-147.

Barker, T., P. Ekins and N. Johnstone *eds*. 1995. *Global Warming and Energy Demand* London and New York: Routledge.

Barten, A.P., 1969. Maximum Likelihood Estimation of a Complete System of Demand Equations. *European Economic Review* 1: 1-67.

Beaulieu, D. Manufacturing, Construction and Energy Division, Statistics Canada. Ottawa. Interview, December 2000.

Beltrami, H. and J.-C. Mareschal, 1991. Recent Warmings in Eastern Canada Inferred from Geothermal Measurements. *Geophysical Resource Letter* 18: 605-608.

Berndt, E. R. and D.O. Wood, 1975. Technology, Prices, and the Derived Demand for Energy. *The Review of Economics and Statistics* Vol. 57(3): 259-268.

Bindoff, N.L. and J.A. Church, 1992. Warming of the Water Column in the Southwest Pacific Ocean. *Nature* 357: 59-62.

Bohi, D.R., 1981. *Analyzing Demand Behavior*. Baltimore and London: the Johns Hopkins Univeristy Press.

Boone, B., S. Hall and D. Kemball-Cook, 1992. Fossil Fuel Demand for Nine OECD Countries. Discussion Paper DP 21-92, Centre for Economic Forecasting.

Burtraw, D., and M.A. Toman, 1992. Equity and International Agreements for CO_2 Constraint. *Journal of Energy Engineering* 118(2): 122-135.

Caloghirou, Y.D., Mourelatos, A.G. and Thompson, H., 1997. Industrial Energy Substitution during the 1980s in the Greek Economy. *Energy Economics* 19: 476-491.

Cermak, V., L. Bodri andJ. Safanda, 1992. Underground Temperature Fields and Changing Climate: Evidence from Cuba. *Global and Planetary Change* 97: 325-337.

Chavas, J.P. and K. Segerson, 1986. Singularity and Autoregressive Disturbances in Linear Logit Models. *Journal of Business and Economic Statistics* 4: 161-69.

Christensen, L.R., Jorgenson, D.W. and Lau, L.J., 1973. Transcendental Logarithmic Production Frontiers. *Review of Economics and Statistics* 55 (Feb): 28-45.

Church, J.A., J.S. Godfrey, D.R. Jackett and T.J. McDougall, 1991. A Model of Sea Level Rise Caused by Ocean Thermal Expansion. *Journal of Climate* 4: 438-456.

Considine, T. J. and T. D. Mount, 1984. The Use of Linear Logit Models for Dynamic Input Demand Systems. *The Review of Economics and Statistics* 66(3): 434-443.

Considine, T.J., 1989. Estimating the Demand for Energy and Natural Resource Inputs: Trade-offs in Global Properties. *Applied Economics* 21: 931-45.

Considine, T. J., 1990. Symmetry Constraints and Variable Returns to Scale in Logit Models, *Journal of Business and Economic Statistics* 8: 347-353.

CPPA (Canadian Pulp and Paper Association): www.cppa.org

Denny, M. and M.A. Fuss, 1977. The Use of Approximation Analysis to Test for Separability and the Existence of Consistent Aggregates. *American Economic Review* 67: 404-418.

Diewert, W. E., 1971. An Application of the Shephard Duality Theorem: A Generalized Leontief Production Function. *Journal of Political Economy* 79 (May/June): 481-507.

Diewert, W.E. and T.J. Wales, 1987. Flexible Functional Forms and Global Curbature Conditions. *Econometrica* 55: 43-68.

Drake, F., 2000. *Global Warming : The Science of Climate Change.* London : Arnold, New York : Oxford University Press.

Environment Canada, 1993. *Environmental Regulations and the Canadian Pulp and Paper Industry.* Ottawa: National Round Table on the Environment & Economy.

Environment Canada, 1998a. Climate Change. *National Environmental Indicator Series.* SOE Bulletin No. 98-3.

Environment Canada, 1998b. *The Canada Country Study: Climate Impacts and Adaptation.* Volume I: Responding to Global Climate Change in British Columbia and Yukon.

Environment Canada, 1998c. *The Canada Country Study: Climate Impacts and Adaptation.* Volume II: Responding to Global Climate Change in Canada's Arctic.

Environment Canada, 1998d. *The Canada Country Study: Climate Impacts and Adaptation.* Volume III: Responding to Climate Change in the Prairies.

Environment Canada, 1998e. *The Canada Country Study: Climate Impacts and Adaptation.* Volume IV: Adapting to Climate Variability and Change in Ontario

Environment Canada, 1998f. *The Canada Country Study: Climate Impacts and Adaptation.* Tome V: Impacts et Adaptation à la Variabilité et au Changement du Climat au Québec.

Environment Canada, 1998g. *The Canada Country Study: Climate Impacts and Adaptation.* Volume VI: Climate Change and Climate Variability in Atlantic Canada.

Environment Canada, 1998h. *The Canada Country Study: Climate Impacts and Adaptation.* Volume VII: National Sectoral Volume.

Environment Canada, 1998i. *The Canada Country Study: Climate Impacts and Adaptation.* Volume VIII: National Cross-Cutting Issues Volume.

Estrada, J. and O. Fugleberg, 1989. Price Elasticities of Natural Gas in France and West Germany, *The Energy Journal* 10 (3): 77-90.

Ewah, O.E., 1994. Africa's Decline and Greenhouse Politics. *International Environmental Affairs* 6(2): 133-148.

Favis-Mortlock, D.T., R. Evans, J. Boardman, and T.M. Hariss, 1991. Climate Change, Winter Wheat Yield and Soil Erosion on the English South Downs. *Agricultural Systems* 37: 415-433.

Favis-Mortlock, D.T, 1994, Modelling Soil Erosion on Agricultural Land under a Changed Climated. In Scharpenseel, H.W., M. Schomaker, and A. Ayoub *eds. Soils on A Warmer Earth. Scharpenseel,*. NATO, ASI Series 1, Global Environmental Change, Vol.23, Heidelberg, Germany: Springer-Verlag.

Fiebig, D.G., J. Seale and H. Theil, 1987. Then Demand for Energy: Evidence from A Cross-Country Demand System. *Energy Economics* 9(3): 149-153.

Field, B.C. and C. Grebenstein, 1980. Capital-Energy Substitution in US Manufacturing. *Review of Economics and Statistics* 61(2): 207-212.

Fisher, F. and C. Kaysen, 1962. *A Study in Econometrics: The Demand for Elecricity in the United States*. Amsterdam, New York and Oxford: North-Holland.

Fuss, M.A., 1977. The Demand for Energy in Canadian Manufacturing, *Journal of Econometrics* 5: 89-116.

Fuss, M.A. and D. McFadden *eds*. 1978. *Production Economics: A Dual Approach to Theory and Applications* Vol.1. Amsterdam, New York, Oxford: North-Holland.

Ghosh, P., and A. Jaitly, 1993. *The Road from Rio: Environmental and Development Policy Issues in Asia*. New Delhi: Tata Energy Research Institute.

Griffin, J.M., 1992. Methodological Advances in Energy Modelling: 1970-1990. *The Energy Journal* 14(1): 111-124.

Griffin, J. and P. Gregory, 1976. An Inter-Country Translog Model of Energy Substitution Responses. *American Economic Review* 66(5): 845-857.

Grubb, M., J. Sebenius, A. Magalhaes, and S. Subak, 1992. Sharing the Burden. In I.M. Mintzer, *ed*., *Confronting Climate Change: Risks, Implications, and Responses.* Cambridge: Cambridge University Press.

Grubb, M.J., 1995. Seeking Fair Weather: Ethics and the International Debate on Climate Change. *International Affairs* 71(3): 463-496.

Grubb, M., C. Vrolijk and D. Brack, 1999. *The Kyoto Protocol: A Guide and Assessment*. Energy and Environmental Programme. London and England: Royal Institute of International Affairs.

Hamilton, K. and G. Cameron, 1994. Simulating the Distributional Effects of a Canadian Carbon Tax. *Canadian Public Policy* XX(4): 385-99.

Hayes, P., and K. Smith *eds*. 1993. *The Global Greenhouse Regime: Who pays?* London: UNU Press/earthscan.

Hoeller, P. and J. Coppel, 1992. *OECD Economic Studies* No.19 (Winter): 167-194.

Hudson, E. and D. Jorgenson, 1974. U.S. Energy Policy and Economic Growth. *Bell Journal* 5: 461-514.

Hurrell, J.W., K.E. Trenberth, 1996. Global Sea Surface Temperature Analyses: Multiple Problems and their Implications for Climate Analysis, Modeling, and Reanalysis. *Bulletin of the American Meteorological Society* 80(12): 2661-78.

Ingham, A., J. Maw and A. Ulph, 1991. Empirical Measures of Carbon Taxes. *Oxford Review of Economic Economics* 7(2): 99-122.

IPCC, 1990. Houghton, J.T., G.J. Jenkins and J.J. Ephraums *eds*. *Climate Change, The IPCC Scientific Assessment.* Cambridge: Cambridge University Press.

IPCC, 1992a. Houghton, J.T., B.A. Callander and S.K. Varney *eds*. *Climate Change, 1992: The Supplementary Report to the IPCC Scientific Assessment.* Cambridge: Cambridge University Press.

IPCC, 1992b. Climate Change: The IPCC Response Strategies. WMO/UNEP. USA: Island Press.

IPCC, 1994. Houghton, J.T., L.G. Meira Filho, J. Bruce, H. Lee, B.A. Callander, E. Haites, N.Harris and K. Maskell *eds. Climate Change 1994. Radiative Forcing of Climate Change and An Evaluation of the IPCC 1992 Emissions Scenarios.* Cambridge: Cambridge University Press.

IPCC, 1996a. Bruce, J., H. Lee and E. Haites *eds. Climate Change 1995: Economic and Social Dimensions of Climate Change.* Cambridge: Cambridge University Press.

IPCC, 1996b. Houghton, J.T., L.G. Meira Filho, B.A. Callander, N.Harris, A. Kattenberg and K. Maskell *eds. Climate Change 1995: The Science of Climate Change.* Cambridge: Cambridge University Press.

IPCC, 1996c. Watson, R.T., M.C. Zinyowera, R.H. Moss, and D.J. Dokken *eds. Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis.* Cambridge: Cambridge University Press.

IPCC, 2000. Nebojsa, N., J. Alcamo, G. davis, Bert de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grubler, Tae Yong Jung, T. Kram, Emilio Lebre La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl,, H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor, D. Zhou. *Special report on emissions scenarios : a special report of Working Group III of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

Jones, P.D., 1994. Hemispheric Surface Air Temperature Variations: A Reanalysis and an Update to 1993. *Journal of Climate* 7: 1794-1802.

Jones, P.D., P.Ya. Groisman, M. Coughlan, N. Plummer, W. –C. Wang and T.R. Karl, 1990. Assessment of Urbanization Effects in Time Series of Surface Air Temperature over Land. *Nature* 347: 169-172.

Kmenta, J. 1971. *Elements of Econometrics.* New York: MacMillan.

Kouris, G., 1976. The Determinant of Energy Demand in the EEC Area. *Energy Policy* 6(4): 343-355.

Labib, H., Chief, Emissions Analysis and Modelling, Analysis and Modelling Division, Energy Policy Branch, Natural Resources Canada. Interview, January, February 2001

Lal, R., 1994. Global Soil Erosion by Water and Carbon Dynamics. In Lal, R. *et al. eds. Soils and Global Change* Chelsea, MI: Lewis Publishers.

Leontief, W.W., 1947. Introduction to a Theory of the Internal Structure of Functional Relationships, *Econometrica* 15 (Oct): 361-373.

Lutton, T.J. and M.R. LeBlanc, 1984. A Comparison of Multivariate Logit and Translog Models for Energy and Nonenergy Input Cost Share Analysis. *The Energy Journal* 5 (4): 35-44.

Mabey, N., J. Nixon, 1997. Are Environmental Taxes a Free Lunch? Issues in Modelling the Macroeconomic Effects of Carbon Taxes. *Energy Economics* 19: 29-56.

Madore, O., 1992. *The Pulp and Paper Industry: the Impact of the New Federal Environmental Regulation.* Economics Division, Research Branch, Government of Canada.

McFadden, D., 1963. Further Results on CES Production Functions. *The Review of Economic Studies* 30: 73-83.

McFadden, D., D. Kirschner and C. Puig, 1978. Determinants of the Long-Run Demand for Electricity. in *Proceedings of the American Statistical Association.*

McFadden, D. and J. Dubin, 1984. Econometric Analysis of Residential Electric Appliance Holdings and Consumption. *Econometrica* 52: 345-62.

McKitrick, R., 1997. Double Dividend Environmental Taxation and Canadian Carbon Emissions Control. *Canadian Public Policy* XXIII(4): 417-31.

Moody, C.E., 1996. A Regional Linear Logit Fuel Demand Model for Electric Utilities. *Energy Economics* 18: 285-314.

Morey, E. R. 1986: An Introduction to Checking, Testing, and Imposing Curvature Properties: The True Funcion and the Estimated Function. *Canadian Journal of Economics*: 207-235.

Nachane, D., R. Nadkarni and A. Karnick, 1988. Co-integration and Causality Testing of the Energy-GDP Relationship: A Cross-country Study. *Applied Economics* 20: 1511-31.

NRCan, 1997. *Canada's Energy Outlook.* Energy Forecasting Division, Energy Policy Branch, Energy Sector, Natural Resources Canada.

NRCan, 1999. *Canada's Emissions Outlook: An Update.* Analysis and Modelling Group of the National Climate Change Process, Natural Resources Canada.

Nordhaus, W.D. 1977. The Demand for Energy: An International Perspective. In Nordhaus, W.D. *ed. International Studies of the Demand for Energy.* Amsterdam: North-Holland.

Parikh, J., 1992. IPCC Strategies Unfair to the South. *Nature* 360: 507-508.

Patry, M., C. Nappi and H. Taghvai, 1990. Energy Demand in Seeven OECD Countries: A Comparison of the Impact of the Oil Price Shocks. *Conference Proceedings, Energy Supply/Demand Balances: Options and Costs.* Ottawa: International Association of Energy Economists.

Pindyck, R.S., 1979. *The Structure of World Energy Demand.* London: The MIT Press.

Portman, D.A., 1993. Identifying and Correcting Urban Bias in Regional Time Series: Surface Temperature in China's Northern Plains. *Journal of Climate* 6: 2298-2308.

Prosser, R.D., 1985. Demand Elasticities in OECD Countries: Dynamic Aspects. *Energy Economics* 7(1): 9-12.

Prywes, M., 1986. A Nested CES Approach to Capital-Energy Substitution. *Energy Economics* 8(1): 22-28.

Sannes, G.M., Census of Manufactures, Manufacturing, Construction and Energy Division, Statistics Canada. Ottawa. Interview, December 2000.

Sinclair, W.F., 1990. *Controlling Pollution from Canadian Pulp and Paper Manufacturers: A Federal Perspective.* Environment Canada.

Sheldrick, R. Manufacturing, Construction and Energy Division, Statistics Canada. Ottawa. Interview, November, December 2000.

Shephard, R.W. 1953. *Cost and Production Functions.* Princeton, N.J: Princeton University Press.

Smith, C., S. Hall and N. Mabey, 1995. Econometric Modelling of International Carbon Tax Regimes. *Energy Economics.* 17(2): 133-146.

Statistics Canada, 1992. *Manufacturing Industries of Canada: National and Provincial Areas.* Catalogue 31-203.

Statistics Canada, 2000. *Quarterly Report on Energy Supply-demand in Canada.* Catalogue 57-003-XPB.

Statistics Canada, 2000 December. *Employment, Earnings and Hours. Catalogue* 72-002.

Theil, H., 1969. A Multinomial Extension of the Linear Logit Model. *International Economic Review* 10: 251-259.

Titus, J.G. and V. Narrayanan, 1995. *The Probability of Sea Level Rise*. U.S. Environemtnal Protection Agency, Office of Policy, Planning, and Evaluation, Climate change Division. EPA 230-R-95-008. EPA, Washington, D.C..

Trenberth, K.E. and J.W. Hurrell, 1994. Decadal Atmosphere-ocean Variations in the Pacific. *Climate Dynamics* 9: 303-319.

Trudeau, N., Office of Energy Efficiency, Natural Resources Canada. Ottawa. Interview, December 2000, January, February 2001.

Wang, B., 1995. Interdecadal Changes in El Niño Onset in the Last Four Decades. *Journal of Climate* 8: 267-285.

Weidick A., 1995. Greenland. In Satellite Image Atlas of Glaciers of the World. In Williams, R.S. and J.G. Ferrigno *eds. U.S. Geological Survey Professional Paper* 1386-96.

Wigley, T.M.L. and S.C.B. Raper, 1992. Implications for Climate and Sea Level of Revised IPCC Emissions Scenarios. *Nature* 357: 293-300.

Watkins, G.C., 1991. Short- and Long-Term Equilibria. *Energy Economics* 13(1): 1-9.

Welsch, H., 1989. The Reliability of Aggregate Energy Demand functions. *Energy Economics* 11(4): 285-292.

APPENDIX 1 EXCERPTS FROM KYOTO PROTOCOL

"2.1 Each Party included in Annex I … shall:

♦ enhancement of energy efficiency in relevant sectors;

♦ protection and enhancement of sinks and reservoirs;

♦ promotion of sustainable forms of agriculture in the light of climate change consideration;

♦ promotion, research, development and increased use of new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies;

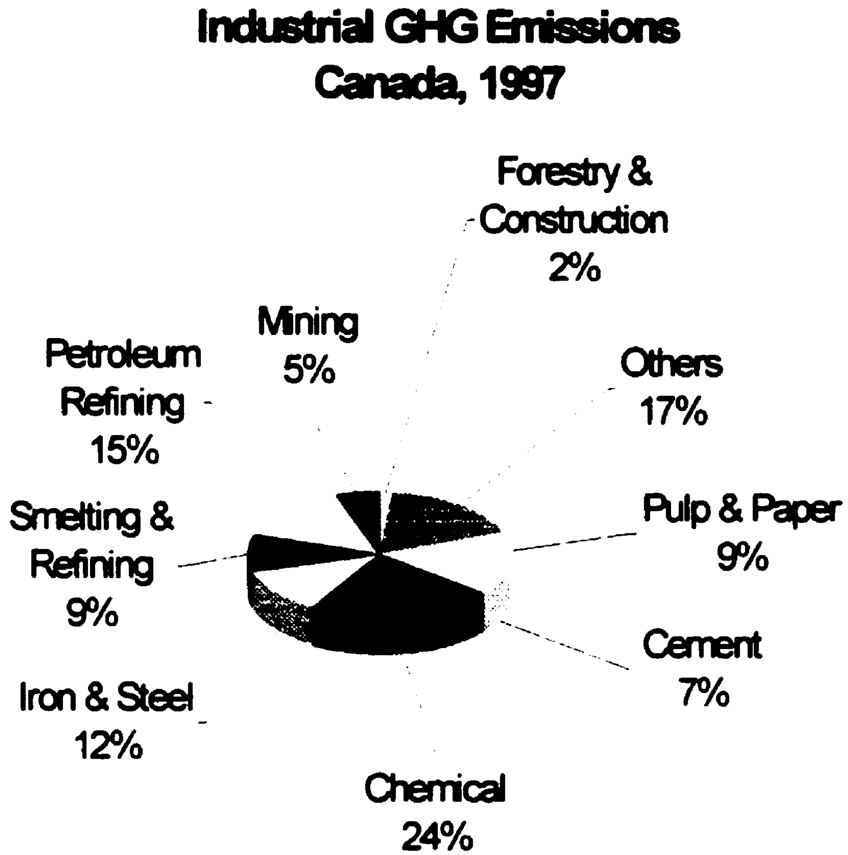
♦ progressive reduction or phasing out of market imperfections … that run counter to the objective of the Convention, and apply market instruments;

♦ measures to limit and/or reduce emissions … in the transport sector;

♦ limitation and reduction of methane … through recovery and use in waste management … and [provision of] energy."

—from (Grubb *et al*, 1999; p125).

APPENDIX 2 GHG EMISSIONS



Source: NRCan, National Climate Change Process, Analysis and Modelling Group. Dec. 1999

APPENDIX 3 DIAGNOSTICS

3.1 Examination for Multicolinearity

1) The Translog Model

. corr LPcoal LPelec LPgas LPpet p2 p3 p4 Scoal1 Selec1 Sgas1 Spet1 lnQ
(obs=71)

	LPcoal	LPelec	LPgas	LPpet	p2	p3	p4
LPcoal	1.0000						
LPelec	0.5745	1.0000					
LPgas	0.1745	-0.3460	1.0000				
LPpet	-0.0699	-0.5967	0.3309	1.0000			
p2	0.1170	-0.0161	-0.1165	-0.0300	1.0000		
p3	-0.0632	-0.0161	-0.1291	0.0019	-0.3396	1.0000	
p4	-0.1581	-0.0161	0.0905	0.0620	-0.3396	-0.3396	1.0000
Scoal1	-0.3186	-0.7869	0.3470	0.5966	0.2766	-0.0909	-0.2343
Selec1	0.3801	0.8968	-0.4333	-0.5874	-0.2106	0.1179	0.2366
Sgas1	-0.4956	-0.8186	0.3328	0.4015	0.1649	-0.0925	-0.2529
Spet1	-0.1421	-0.7660	0.4673	0.6324	0.1676	-0.1266	-0.1411
lnQ	0.3962	0.7050	-0.3708	-0.4343	-0.0045	-0.0179	-0.0020

	Scoal1	Selec1	Sgas1	Spet1	lnQ
Scoal1	1.0000				
Selec1	-0.8842	1.0000			
Sgas1	0.7573	-0.9110	1.0000		
Spet1	0.7039	-0.8529	0.5843	1.0000	
lnQ	-0.6754	0.7554	-0.7523	-0.5585	1.0000

a. Cost Share of Coal Equation

. regress LPcoal LPelec LPgas LPpet lnQ p2 p3 p4 Scoal1
. pisplay R-square
. 0.6273

. regress LPelec LPgas LPpet lnQ p2 p3 p4 Scoal1 LPcoal
. pisplay R-square
. 0.8220

. regress LPgas LPpet lnQ p2 p3 p4 Scoal1 LPcoal LPelec
. pisplay R-square
. 0.4385

. regress LPpet lnQ p2 p3 p4 Scoal1 LPcoal LPelec LPgas
. pisplay R-square
. 0.5441

. regress lnQ p2 p3 p4 Scoal1 LPcoal LPelec LPgas LPpet
. pisplay R-square
. 0.5700

. regress p2 p3 p4 Scoal1 LPcoal LPelec LPgas LPpet lnQ
. pisplay R-square
. 0.4326

. regress p3 p4 Scoal1 LPcoal LPelec LPgas LPpet lnQ p2
. pisplay R-square
. 0.4109

. regress p4 Scoal1 LPcoal LPelec LPgas LPpet lnQ p2 p3
. pisplay R-square
. 0.4847

. regress Scoal1 LPcoal LPelec LPgas LPpet lnQ p2 p3 p4
. pisplay R-square
. 0.7924

b. Cost Share of Electricity Equation

. regress LPcoal LPelec LPgas LPpet lnQ p2 p3 p4 Selec1
. pisplay R-square
. 0.6296

. regress LPelec LPgas LPpet lnQ p2 p3 p4 Selec1 LPcoal
. pisplay R-square
. 0.9446

. regress LPgas LPpet lnQ p2 p3 p4 Selec1 LPcoal LPelec
. pisplay R-square
. 0.4948

```
. regress LPpet lnQ p2 p3 p4 Selec1 LPcoal LPelec LPgas
. pisplay R-square
. 0.5273
```

```
. regress lnQ p2 p3 p4 Selec1 LPcoal LPelec LPgas LPpet
. pisplay R-square
. 0.7085
```

```
. regress p2 p3 p4 Selec1 LPcoal LPelec LPgas LPpet lnQ
. pisplay R-square
. 0.4000
```

```
. regress p3 p4 Selec1 LPcoal LPelec LPgas LPpet lnQ p2
. pisplay R-square
. 0.6687
```

```
. regress p4 Selec1 LPcoal LPelec LPgas LPpet lnQ p2 p3
. pisplay R-square
. 0.7826
```

```
. regress Selec1 LPcoal LPelec LPgas LPpet lnQ p2 p3 p4
. pisplay R-square
. 0.9645
```

c. Cost Share of Natural Gas Equation

```
. regress LPcoal LPelec LPgas LPpet lnQ p2 p3 p4 Sgas1
. pisplay R-square
. 0.6520
```

```
. regress LPelec LPgas LPpet lnQ p2 p3 p4 Sgas1 LPcoal
. pisplay R-square
. 0.8463
```

```
. regress LPgas LPpet lnQ p2 p3 p4 Sgas1 LPcoal LPelec
. pisplay R-square
. 0.4487
```

```
. regress LPpet lnQ p2 p3 p4 Sgas1 LPcoal LPelec LPgas
. pisplay R-square
. 0.4976

. regress lnQ p2 p3 p4 Sgas1 LPcoal LPelec LPgas LPpet
. pisplay R-square
. 0.6545

. regress p2 p3 p4 Sgas1 LPcoal LPelec LPgas LPpet lnQ
. pisplay R-square
. 0.3986

. regress p3 p4 Sgas1 LPcoal LPelec LPgas LPpet lnQ p2
. pisplay R-square
. 0.5179

. regress p4 Sgas1 LPcoal LPelec LPgas LPpet lnQ p2 p3
. pisplay R-square
. 0.6340

. regress Sgas1 LPcoal LPelec LPgas LPpet lnQ p2 p3 p4
. pisplay R-square
. 0.8653
```

2) The Logit Model

Pearson Correlation Coefficients
Prob > |R| under Ho: Rho=0 / N = 67

	F1	F2	F3	R1	R2
F1	1.00000	-0.48583	-0.23297	-0.47763	-0.54805
	0.0	0.0001	0.0578	0.0001	0.0001
F2	-0.48583	1.00000	0.85107	0.65543	0.83457
	0.0001	0.0	0.0001	0.0001	0.0001
F3	-0.23297	0.85107	1.00000	0.39705	0.55528
	0.0578	0.0001	0.0	0.0009	0.0001
R1	-0.47763	0.65543	0.39705	1.00000	0.89871
	0.0001	0.0001	0.0009	0.0	0.0001
R2	-0.54805	0.83457	0.55528	0.89871	1.00000
	0.0001	0.0001	0.0001	0.0001	0.0
R3	-0.16156	0.22689	0.18885	0.73521	0.53825
	0.1915	0.0648	0.1259	0.0001	0.0001
Scoal	0.67187	-0.74909	-0.43949	-0.66262	-0.78694
	0.0001	0.0001	0.0002	0.0001	0.0001
Selec	-0.59875	0.90371	0.54950	0.73639	0.89206
	0.0001	0.0001	0.0001	0.0001	0.0001
Sgas	0.56519	-0.66488	-0.17696	-0.65062	-0.76947
	0.0001	0.0001	0.1520	0.0001	0.0001
Spet	0.39863	-0.97853	-0.89225	-0.63187	-0.79738
	0.0008	0.0001	0.0001	0.0001	0.0001
Q	-0.38857	0.62201	0.28193	0.57638	0.69583
	0.0012	0.0001	0.0208	0.0001	0.0001
P2	-0.02765	0.11129	0.07089	0.04987	-0.01762
	0.8242	0.3699	0.5686	0.6886	0.8874
P3	-0.24291	0.11970	0.02899	-0.04143	-0.04940
	0.0476	0.3346	0.8159	0.7392	0.6914
P4	-0.03826	-0.06677	0.00094	-0.09074	0.01530
	0.7586	0.5914	0.9940	0.4652	0.9022

Pearson Correlation Coefficients

Prob > |R| under Ho: Rho=0 / N = 67

	R3	Scoal	Selec	Sgas	Spet
F1	-0.16156 0.1915	0.67187 0.0001	-0.59875 0.0001	0.56519 0.0001	0.39863 0.0008
F2	0.22689 0.0648	-0.74909 0.0001	0.90371 0.0001	-0.66488 0.0001	-0.97853 0.0001
F3	0.18885 0.1259	-0.43949 0.0002	0.54950 0.0001	-0.17696 0.1520	-0.89225 0.0001
R1	0.73521 0.0001	-0.66262 0.0001	0.73639 0.0001	-0.65062 0.0001	-0.63187 0.0001
R2	0.53825 0.0001	-0.78694 0.0001	0.89206 0.0001	-0.76947 0.0001	-0.79738 0.0001
R3	1.00000 0.0	-0.28972 0.0174	0.24085 0.0496	-0.14443 0.2436	-0.25566 0.0368
Scoal	-0.28972 0.0174	1.00000 0.0	-0.87888 0.0001	0.74689 0.0001	0.68315 0.0001
Selec	0.24085 0.0496	-0.87888 0.0001	1.00000 0.0	-0.90471 0.0001	-0.84203 0.0001
Sgas	-0.14443 0.2436	0.74689 0.0001	-0.90471 0.0001	1.00000 0.0	0.55612 0.0001
Spet	-0.25566 0.0368	0.68315 0.0001	-0.84203 0.0001	0.55612 0.0001	1.00000 0.0
Q	0.17971 0.1456	-0.68399 0.0001	0.76893 0.0001	-0.75703 0.0001	-0.56519 0.0001
P2	-0.09072 0.4653	-0.06604 0.5954	0.11220 0.3660	-0.10829 0.3831	-0.10277 0.4079
P3	-0.09967 0.4223	-0.19077 0.1220	0.16730 0.1760	-0.17477 0.1572	-0.08839 0.4769
P4	0.03094 0.8037	-0.00941 0.9398	-0.08844 0.4767	0.13599 0.2725	0.04856 0.6964

Pearson Correlation Coefficients

Prob > |R| under Ho: Rho=0 / N = 67

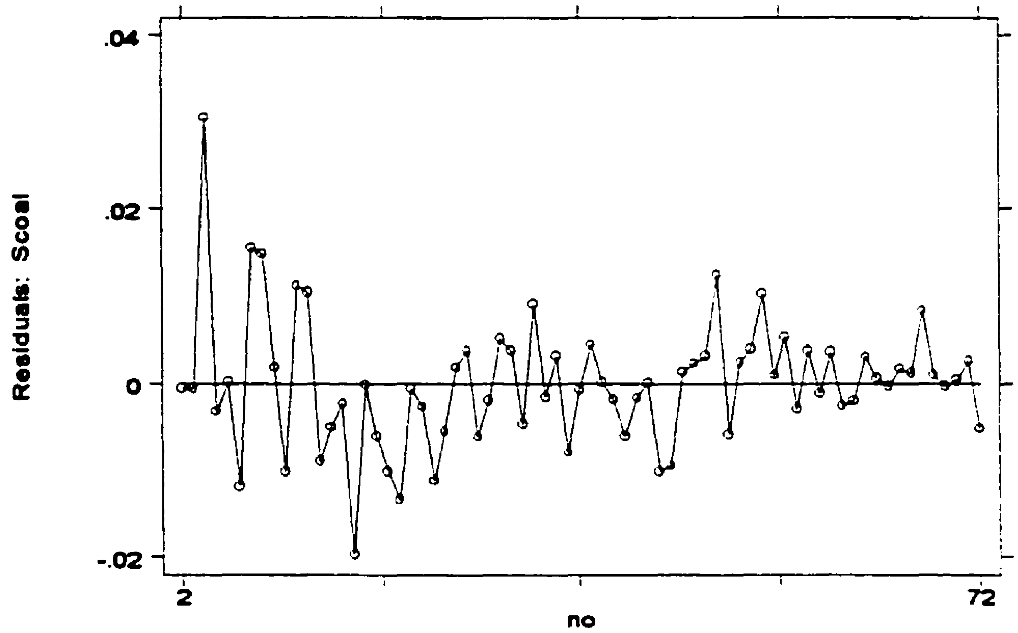
	Q	P2	P3	P4
F1	-0.38857	-0.02765	-0.24291	-0.03826
	0.0012	0.8242	0.0476	0.7586
F2	0.62201	0.11129	0.11970	-0.06677
	0.0001	0.3699	0.3346	0.5914
F3	0.28193	0.07089	0.02899	0.00094
	0.0208	0.5686	0.8159	0.9940
R1	0.57638	0.04987	-0.04143	-0.09074
	0.0001	0.6886	0.7392	0.4652
R2	0.69583	-0.01762	-0.04940	0.01530
	0.0001	0.8874	0.6914	0.9022
R3	0.17971	-0.09072	-0.09967	0.03094
	0.1456	0.4653	0.4223	0.8037
Scoai	-0.68399	-0.06604	-0.19077	-0.00941
	0.0001	0.5954	0.1220	0.9398
Selec	0.76893	0.11220	0.16730	-0.08844
	0.0001	0.3660	0.1760	0.4767
Sgas	-0.75703	-0.10829	-0.17477	0.13599
	0.0001	0.3831	0.1572	0.2725
Spet	-0.56519	-0.10277	-0.08839	0.04856
	0.0001	0.4079	0.4769	0.6964
Q	1.00000	0.02528	-0.09825	0.04914
	0.0	0.8391	0.4290	0.6929
P2	0.02528	1.00000	-0.30083	-0.33948
	0.8391	0.0	0.0134	0.0049
P3	-0.09825	-0.30083	1.00000	-0.32552
	0.4290	0.0134	0.0	0.0072
P4	0.04914	-0.33948	-0.32552	1.00000
	0.6929	0.0049	0.0072	0.0

3.2 Tests for Autocorrelation

1) The Translog Model

a. Cost Share of Coal Equation

. graph ecoal no, ylabel yline(0) border connect(l)



. generate ecoal1=ecoal[_n-1]

. generate ecoal2=ecoal[_n-2]

. generate ecoal3=ecoal[_n-3]

. generate ecoal4=ecoal[_n-4]

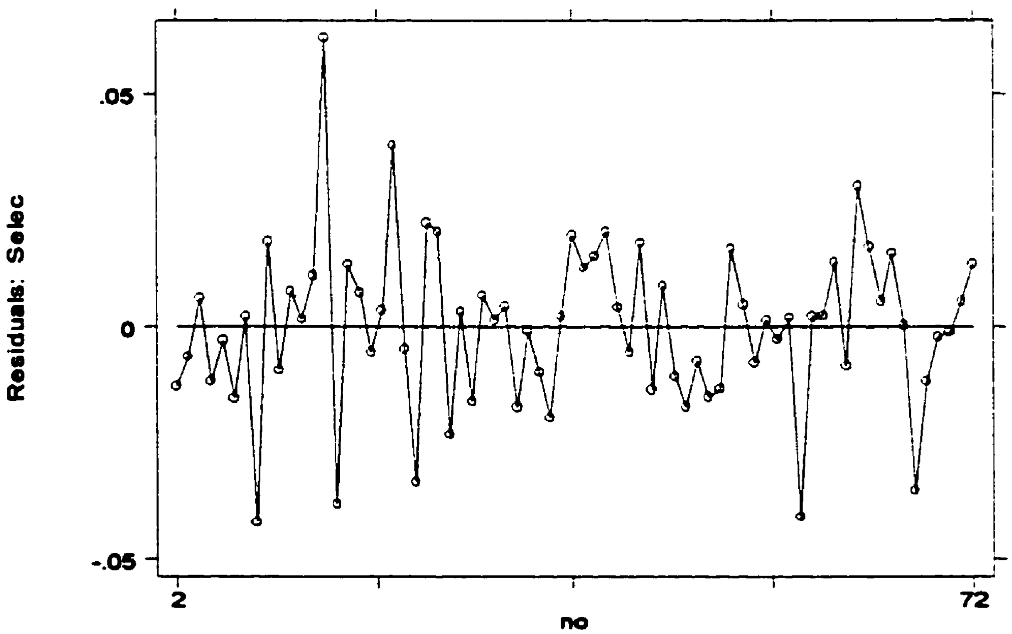
. corr ecoal ecoal1 ecoal2 ecoal3 ecoal4
(obs=67)

	ecoal	ecoal1	ecoal2	ecoal3	ecoal4
ecoal	1.0000				
ecoal1	0.1064	1.0000			
ecoal2	-0.0194	0.0660	1.0000		
ecoal3	0.0345	-0.0183	0.0523	1.0000	
ecoal4	0.4326	0.0344	-0.0209	0.0525	1.0000

```
. regress ecoal ecoal1 ecoal2 ecoal3 ecoal4

  Source |       SS       df       MS                  Number of obs =      67
---------+------------------------------               F(  4,    62) =    3.78
   Model |  .000562962     4  .00014074                Prob > F      =  0.0082
Residual |  .002309746    62  .000037254               R-squared     =  0.1960
---------+------------------------------               Adj R-squared =  0.1441
   Total |  .002872708    66  .000043526               Root MSE      =   .0061

------------------------------------------------------------------------------
   ecoal |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
  ecoal1 |   .0932382   .1144543      0.815   0.418      -.1355527    .3220291
  ecoal2 |  -.0151604   .0996395     -0.152   0.880       -.214337    .1840162
  ecoal3 |   .0127524   .0995498      0.128   0.898      -.1862449    .2117496
  ecoal4 |   .3731752   .0994738      3.751   0.000       .1743298    .5720206
   _cons |  -.0003609   .0007469     -0.483   0.631      -.0018539     .001132
------------------------------------------------------------------------------
```

b. Cost Share of Electricity Equation

```
. graph eelec no, ylabel yline(0) border connect(l)
```

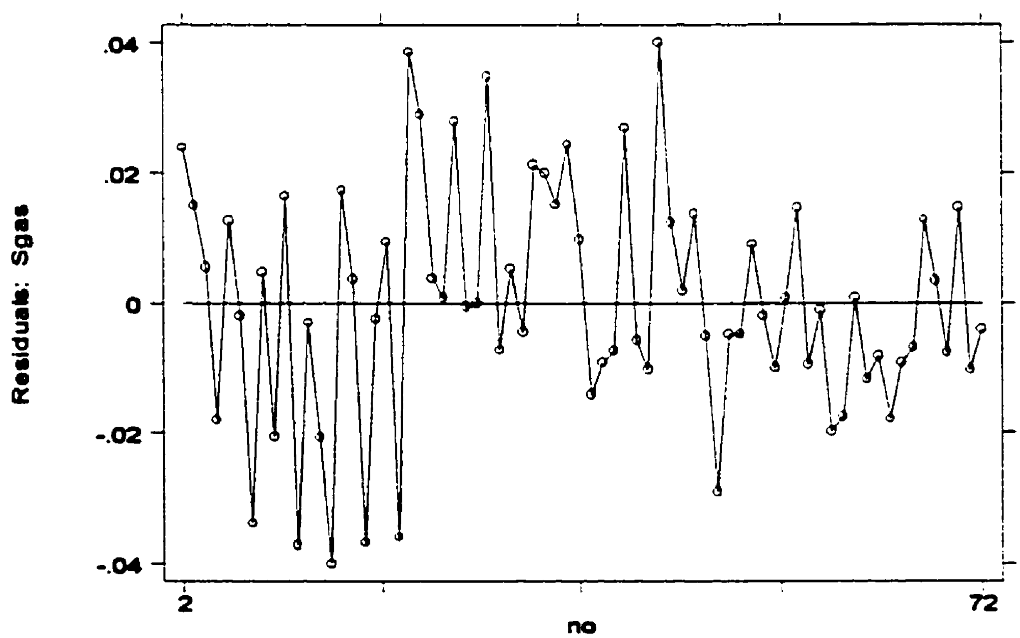


```
. corr eelec eelec1 eelec2 eelec3 eelec4
(obs=67)
        |  eelec  eelec1  eelec2  eelec3  eelec4
--------+---------------------------------------
  eelec |  1.0000
 eelec1 | -0.1204  1.0000
 eelec2 |  0.0189 -0.1285  1.0000
 eelec3 |  0.0761  0.0224 -0.1307  1.0000
 eelec4 |  0.0024  0.0847  0.0183 -0.1269  1.0000
```

```
. regress eelec eelec1 eelec2 eelec3 eelec4

  Source |      SS       df       MS              Number of obs =      67
---------+------------------------------          F(  4,    62) =    0.34
   Model | .000485293     4  .000121323           Prob > F      =  0.8505
Residual | .022179084    62  .000357727           R-squared     =  0.0214
---------+------------------------------          Adj R-squared = -0.0417
   Total | .022664377    66  .0003434             Root MSE      =  .01891

------------------------------------------------------------------------------
   eelec |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
  eelec1 |  -.1224572   .1272265    -0.963   0.340      -.3767792    .1318649
  eelec2 |   .0136958   .1276519     0.107   0.915      -.2414766    .2688682
  eelec3 |   .0834423   .1275358     0.654   0.515      -.171498     .3383827
  eelec4 |   .0229843   .1265715     0.182   0.856      -.2300285    .2759971
   _cons |   .0003415   .0023109     0.148   0.883      -.0042779    .004961
------------------------------------------------------------------------------
```

c. Cost Share of Natural Gas Equation

```
. graph egas no, ylabel yline(0) border connect(l)
```

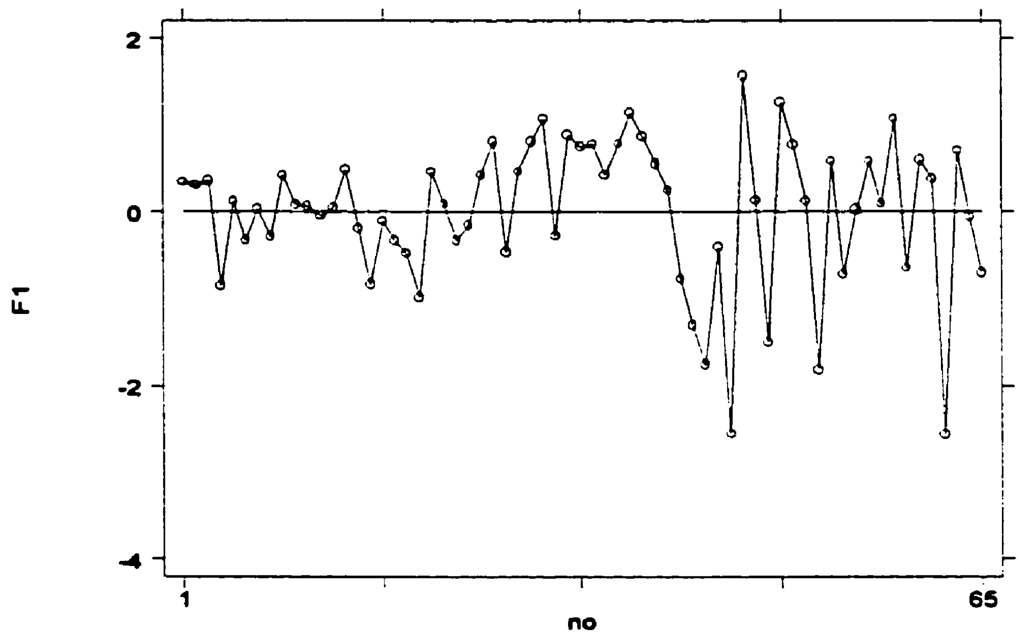


```
. corr egas egas1 egas2 egas3 egas4
(obs=67)

         |   egas   egas1   egas2   egas3   egas4
---------+---------------------------------------
    egas |  1.0000
   egas1 | -0.0034  1.0000
   egas2 |  0.0333 -0.0111  1.0000
   egas3 |  0.3363  0.0221  0.0007  1.0000
   egas4 |  0.0279  0.3077  0.0258  0.0228  1.0000


. regress egas egas1 egas2 egas3 egas4

  Source |       SS       df       MS                  Number of obs =      67
---------+------------------------------               F(  4,    62) =    2.01
   Model |  .00245928      4  .00061482                Prob > F      =  0.1039
Residual |  .018952322    62  .000305683               R-squared     =  0.1149
---------+------------------------------               Adj R-squared =  0.0578
   Total |  .021411602    66  .000324418               Root MSE      =  .01748

------------------------------------------------------------------------------
    egas |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
   egas1 |  -.0180323   .1245969     -0.145   0.885      -.2670979    .2310334
   egas2 |    .032019   .1187202      0.270   0.788      -.2052994    .2693373
   egas3 |   .3337271   .1186901      2.812   0.007        .096469    .5709852
   egas4 |   .0245713   .1233366      0.199   0.843       -.221975    .2711175
   _cons |  -.0002643   .0021385     -0.124   0.902       -.004539    .0040104
------------------------------------------------------------------------------
```

2) The Logit Model

a. f_1 Equation

. graph resid_f1 no, ylabel yline(0) border connect(l)



. corr resid_f1 f11 f12 f13 f14
(obs=61)

	resid_f1	f11	f12	f13	f14
resid_f1	1.0000				
f11	-0.0044	1.0000			
f12	0.1067	-0.0122	1.0000		
f13	0.2592	0.1120	-0.0089	1.0000	
f14	0.0147	0.2296	0.1204	0.0369	1.0000

. regress resid_f1 f11 f12 f13 f14

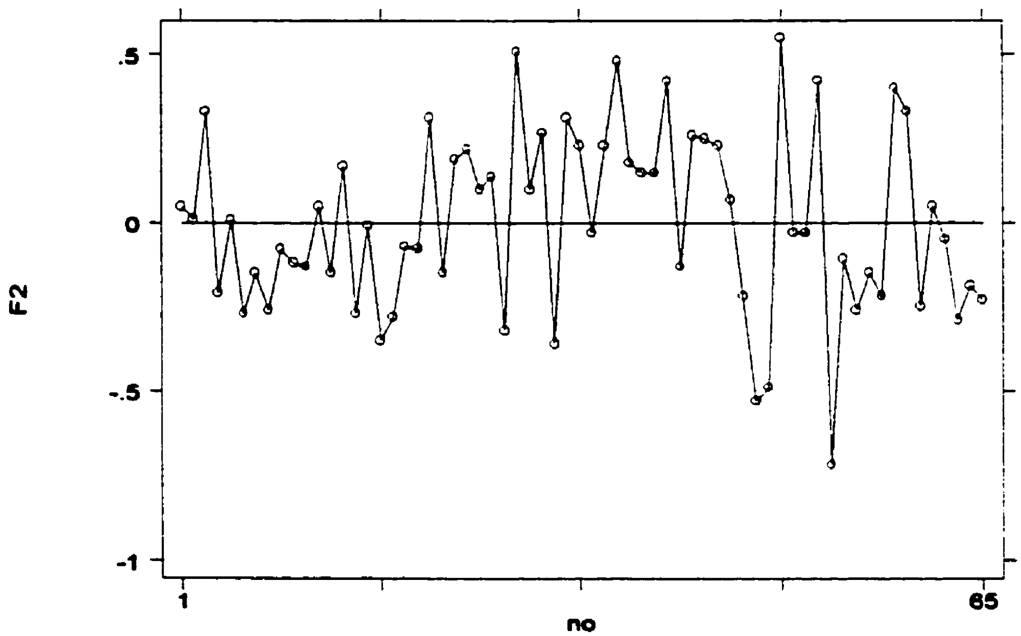
Source	SS	df	MS
Model	3.55314886	4	.888287214
Residual	40.7907816	56	.728406814
Total	44.3439304	60	.739065507

Number of obs = 61
F(4, 56) = 1.22
Prob > F = 0.3129
R-squared = 0.0801
Adj R-squared = 0.0144
Root MSE = .85347

resid_f1	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
f11	-.0323883	.1321715	-0.245	0.807	-.2971597	.232383
f12	.1082445	.1286748	0.841	0.404	-.1495221	.3660111
f13	.2639291	.1290282	2.046	0.046	.0054546	.5224036
f14	-.0006831	.1438497	-0.005	0.996	-.2888486	.2874825
_cons	-.0015348	.1094595	-0.014	0.989	-.2208087	.217739

b. f_2 Equation

. graph resid_f2 no, ylabel yline(0) border connect(l)



. corr resid_f2 f21 f22 f23 f24
(obs=61)

	resid_f2	f21	f22	f23	f24
resid_f2	1.0000				
f21	0.0495	1.0000			
f22	0.1645	0.0243	1.0000		
f23	0.0640	0.1510	0.0118	1.0000	
f24	-0.0103	0.0591	0.1501	0.0078	1.0000

. regress resid_f2 f21 f22 f23 f24

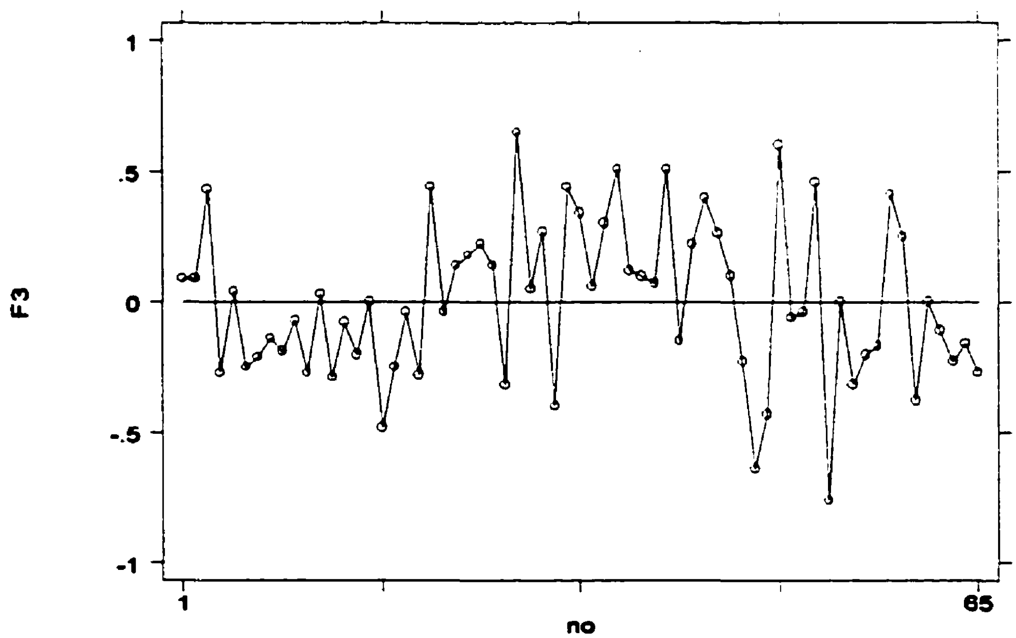
Source	SS	df	MS
Model	.150472909	4	.037618227
Residual	4.31687138	56	.077086989
Total	4.46734429	60	.074455738

Number of obs = 61
F(4, 56) = 0.49
Prob > F = 0.7445
R-squared = 0.0337
Adj R-squared = -0.0353
Root MSE = .27765

resid_f2	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
f21	.0391446	.1332568	0.294	0.770	-.2278009	.3060901
f22	.167491	.1319633	1.269	0.210	-.0968633	.4318453
f23	.0565289	.1332793	0.424	0.673	-.2104616	.3235195
f24	-.0384918	.1334999	-0.288	0.774	-.3059241	.2289406
_cons	-.0042229	.0356213	-0.119	0.906	-.075581	.0671352

c. f_3 **Equation**

. graph resid_f3 no, ylabel yline(0) border connect(l)

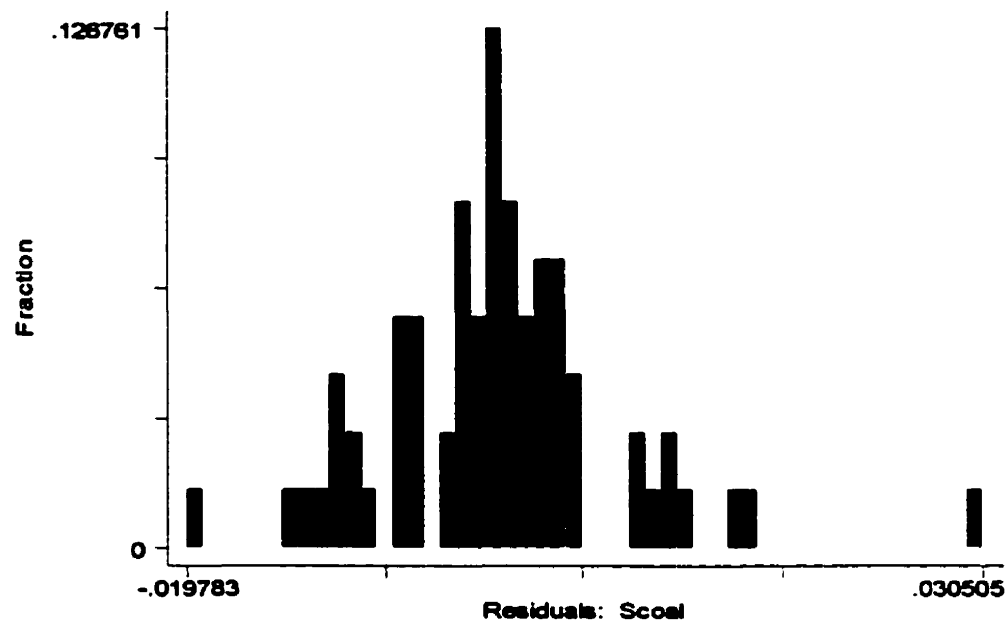


```
. corr resid_f3 f31 f32 f33 f34
(obs=61)

         | resid_f3    f31     f32      f33     f34
---------+--------------------------------------------
resid_f3 |  1.0000
     f31 |  0.0333  1.0000
     f32 |  0.1686  0.0053  1.0000
     f33 |  0.1105  0.1544  0.0050  1.0000
     f34 |  0.0519  0.1012  0.1549  0.0012  1.0000


. regress resid_f3 f31 f32 f33 f34

  Source |     SS        df      MS                Number of obs =     61
---------+-------------------------------          F( 4,    56) =   0.60
   Model | .231010611     4  .057752653            Prob > F      = 0.6619
Residual | 5.36088115    56  .095730021            R-squared     = 0.0413
---------+-------------------------------          Adj R-squared = -0.0272
   Total | 5.59189176    60  .093198196            Root MSE      =  .3094

------------------------------------------------------------------------------
resid_f3 |     Coef.   Std. Err.      t     P>|t|      [95% Conf. Interval]
---------+--------------------------------------------------------------------
     f31 |  .0132783   .1331356     0.100   0.921     -.2534244    .279981
     f32 |  .1618461   .1305912     1.239   0.220     -.0997595   .4234517
     f33 |  .106561    .1311465     0.813   0.420     -.1561571    .369279
     f34 |  .0247517   .1319357     0.188   0.852     -.2395474   .2890507
   _cons | -.0075849   .0396821    -0.191   0.849     -.0870777   .0719079
------------------------------------------------------------------------------
```

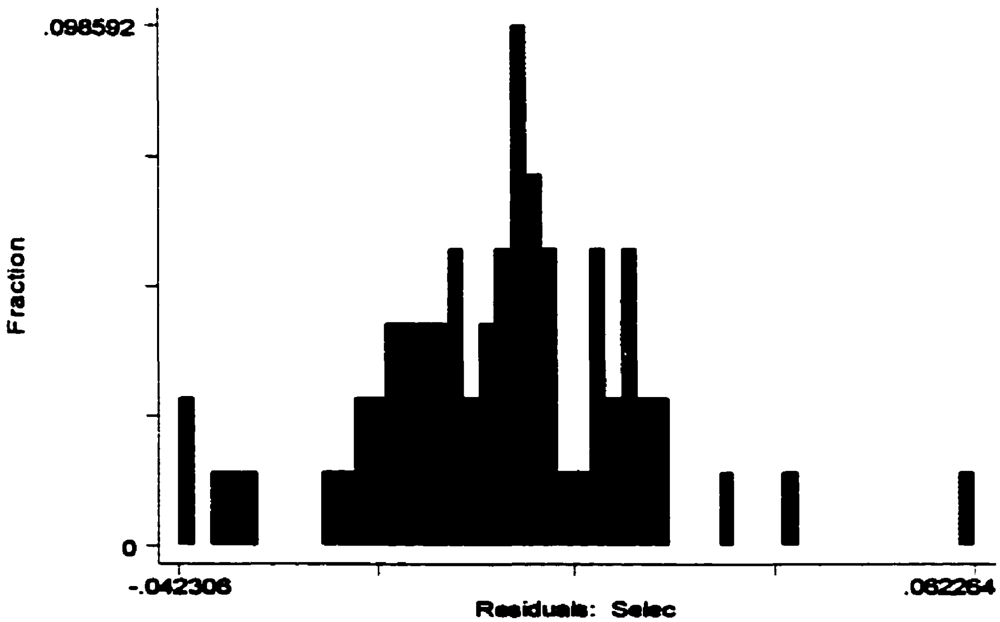
3.3 Test for Normality

1) The Translog Model

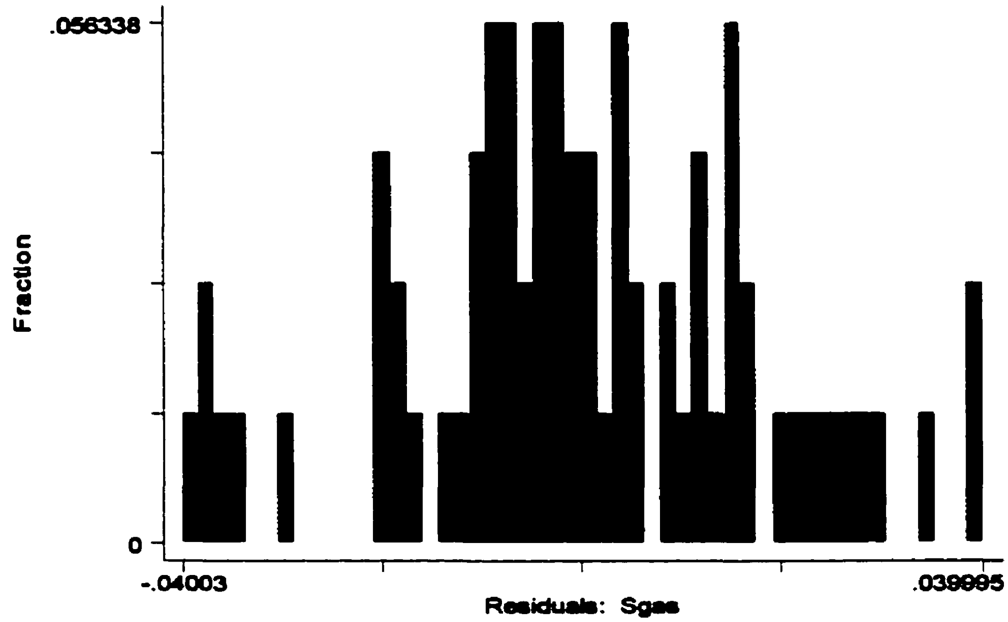
. graph ecoal, bin(50)



. graph eelec, bin(50)



. graph egas, bin(50)



. sktest ecoal

Skewness/Kurtosis tests for Normality

Variable	Pr(Skewness)	Pr(Kurtosis)	------- joint ------- adj chi-sq(2)	Pr(chi-sq)
ecoal	0.007	0.001	14.06	0.0009

. sktest eelec

Skewness/Kurtosis tests for Normality

Variable	Pr(Skewness)	Pr(Kurtosis)	------- joint ------- adj chi-sq(2)	Pr(chi-sq)
eelec	0.511	0.021	5.54	0.0625

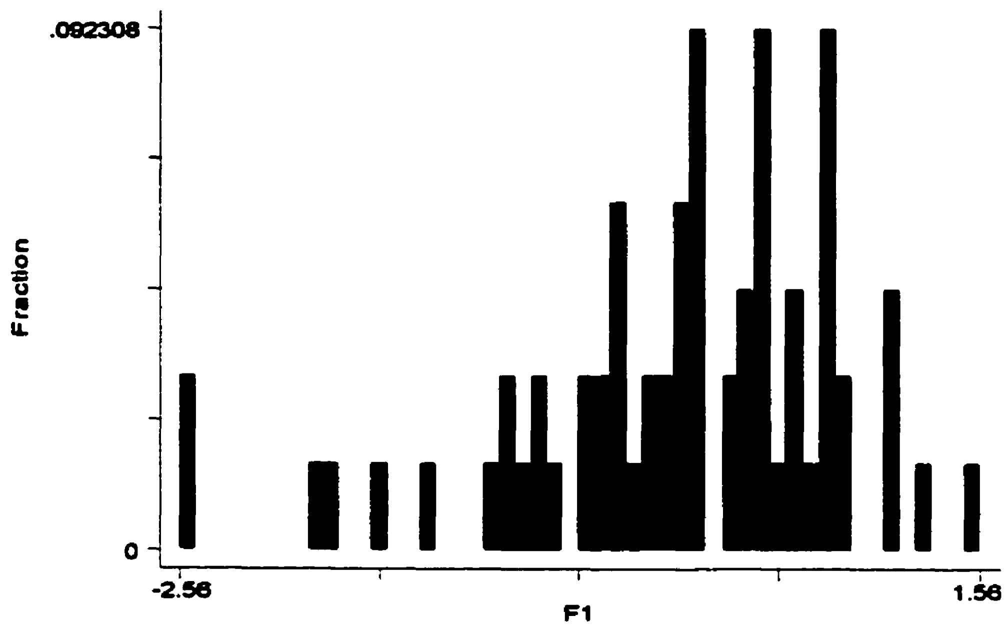
. sktest egas

Skewness/Kurtosis tests for Normality

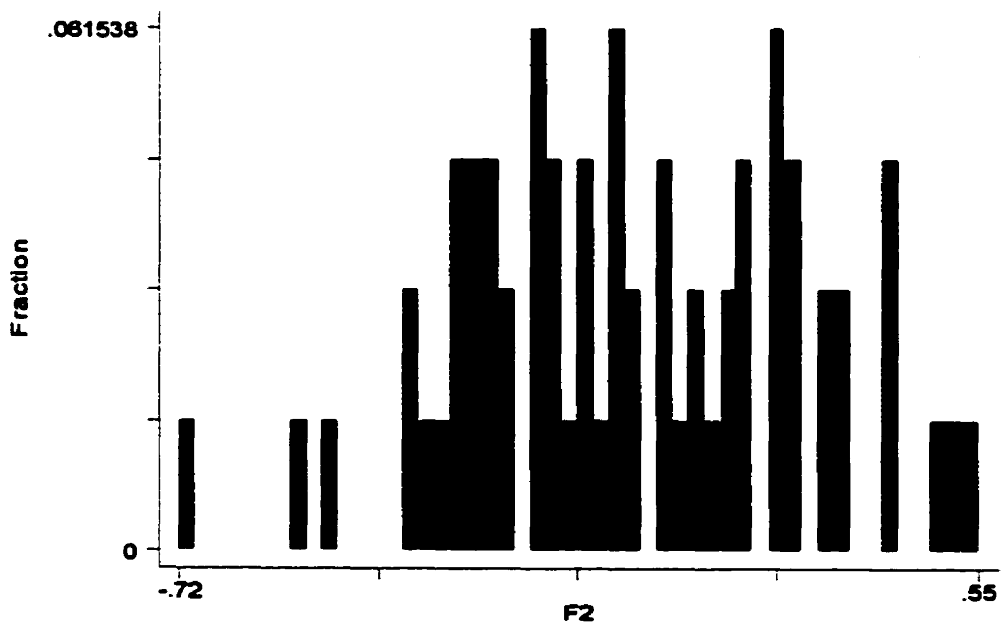
Variable	Pr(Skewness)	Pr(Kurtosis)	------- joint ------- adj chi-sq(2)	Pr(chi-sq)
egas	0.807	0.799	0.12	0.9398

2) The Logit Model

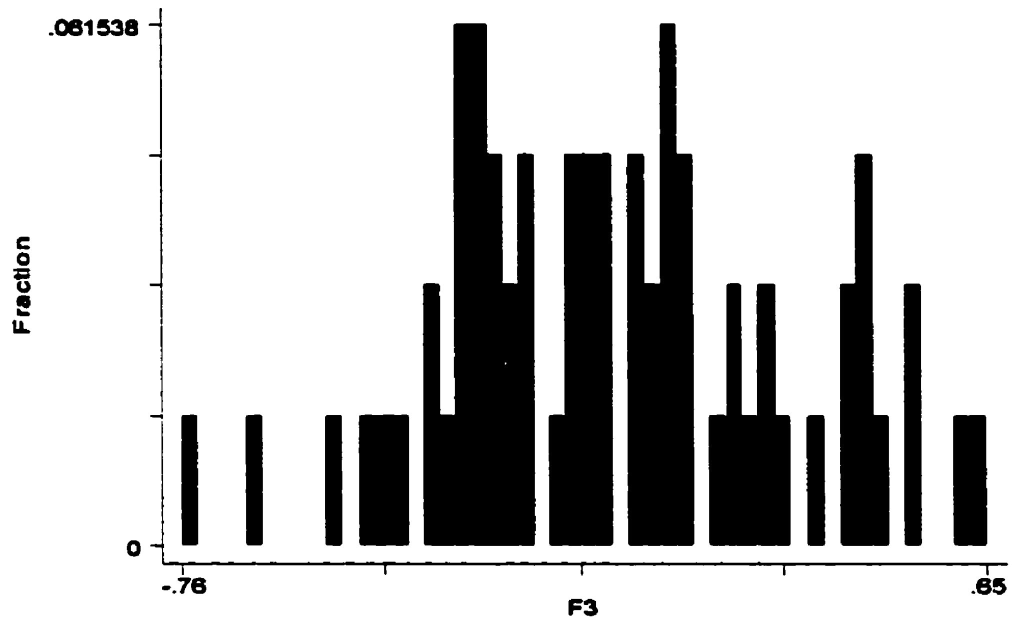
. graph resid_f1, bin(50)



. graph resid_f2, bin(50)



. graph resid_f3, bin(50)



. sktest resid_f1

Skewness/Kurtosis tests for Normality

Variable	Pr(Skewness)	Pr(Kurtosis)	------- joint ------- adj chi-sq(2)	Pr(chi-sq)
resid_f1	0.001	0.052	11.56	0.0031

. sktest resid_f2

Skewness/Kurtosis tests for Normality

Variable	Pr(Skewness)	Pr(Kurtosis)	------- joint ------- adj chi-sq(2)	Pr(chi-sq)
resid_f2	0.808	0.706	0.20	0.9042

. sktest resid_f3

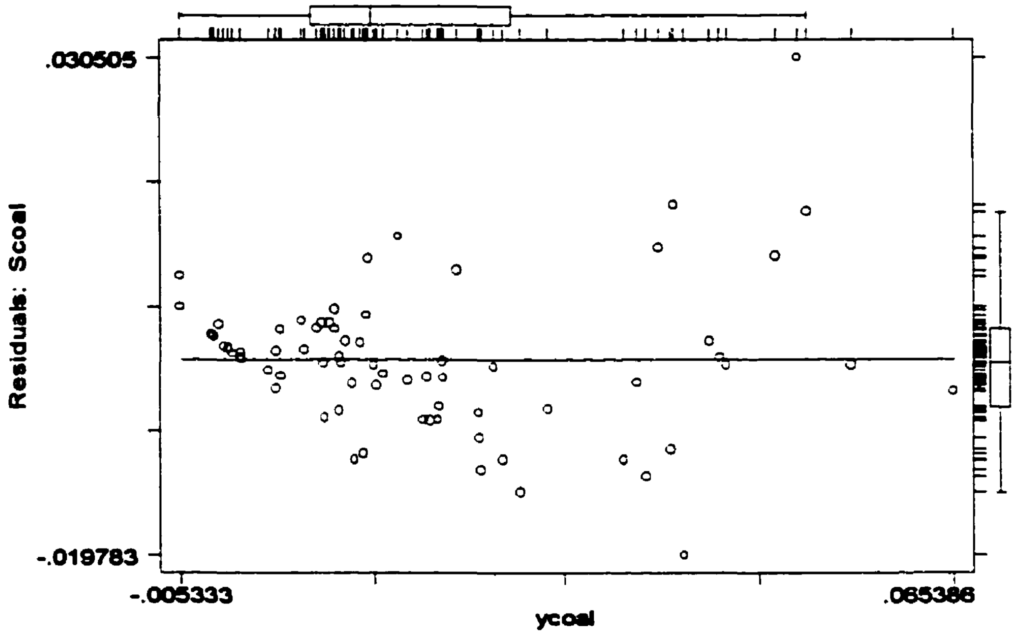
Skewness/Kurtosis tests for Normality

Variable	Pr(Skewness)	Pr(Kurtosis)	------- joint ------- adj chi-sq(2)	Pr(chi-sq)
resid_f3	0.822	0.707	0.19	0.9087

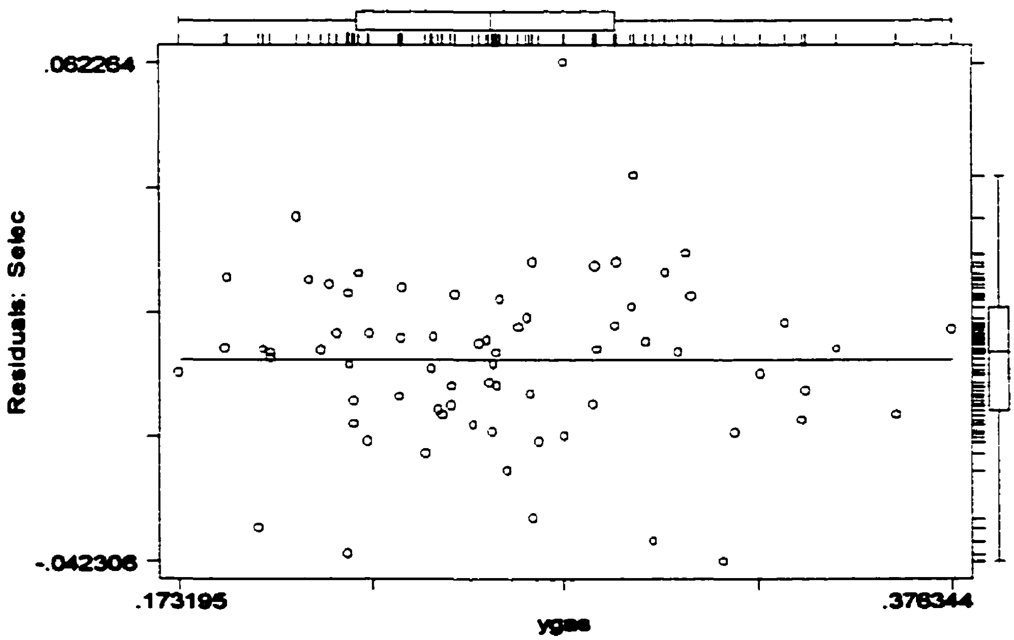
3.4 Test of Heteroscedasticity

1) The Translog Model

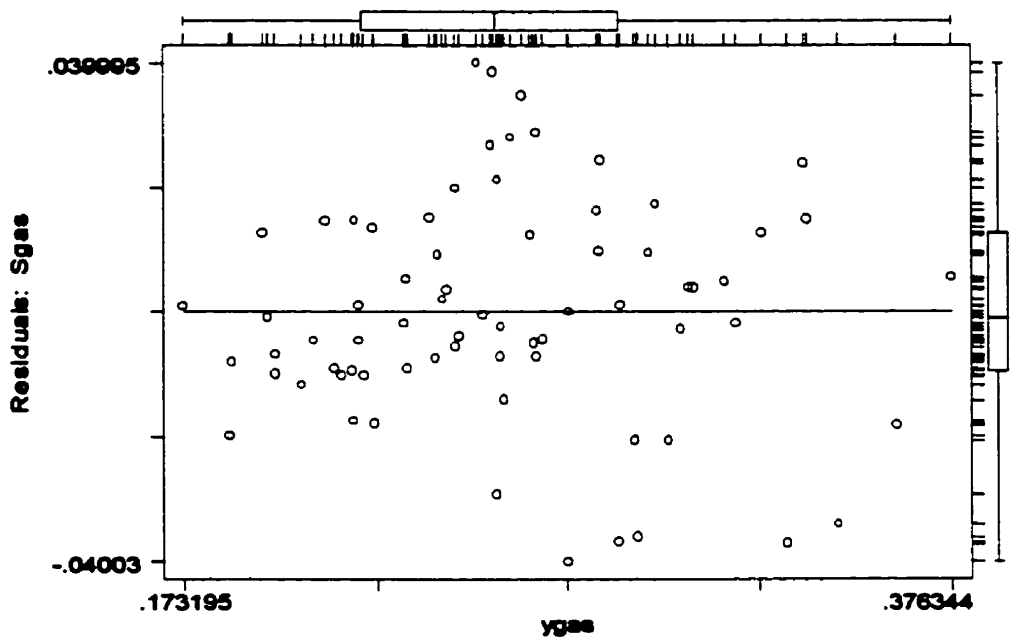
. graph ecoal ycoal, yline(0) oneway twoway box border



. graph eelec ygas, yline(0) oneway twoway box border

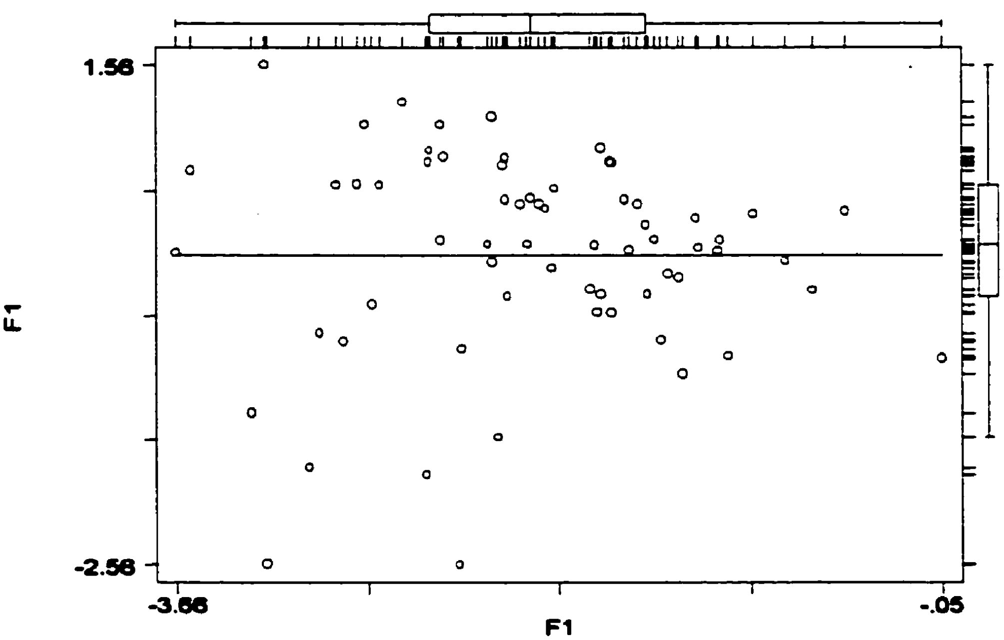


. graph egas ygas, yline(0) oneway twoway box border

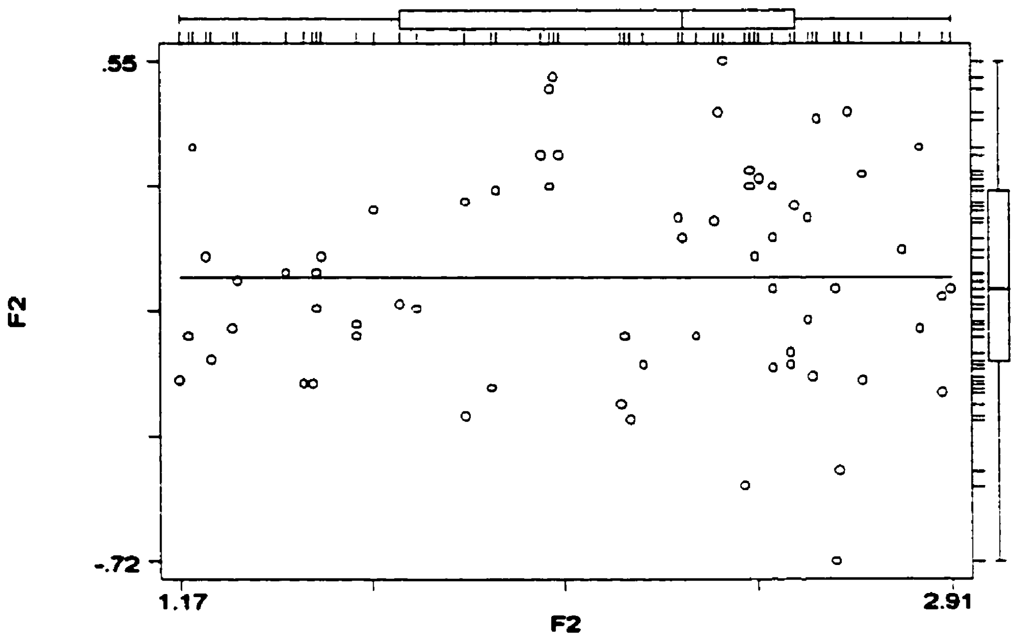


2) The Logit Model

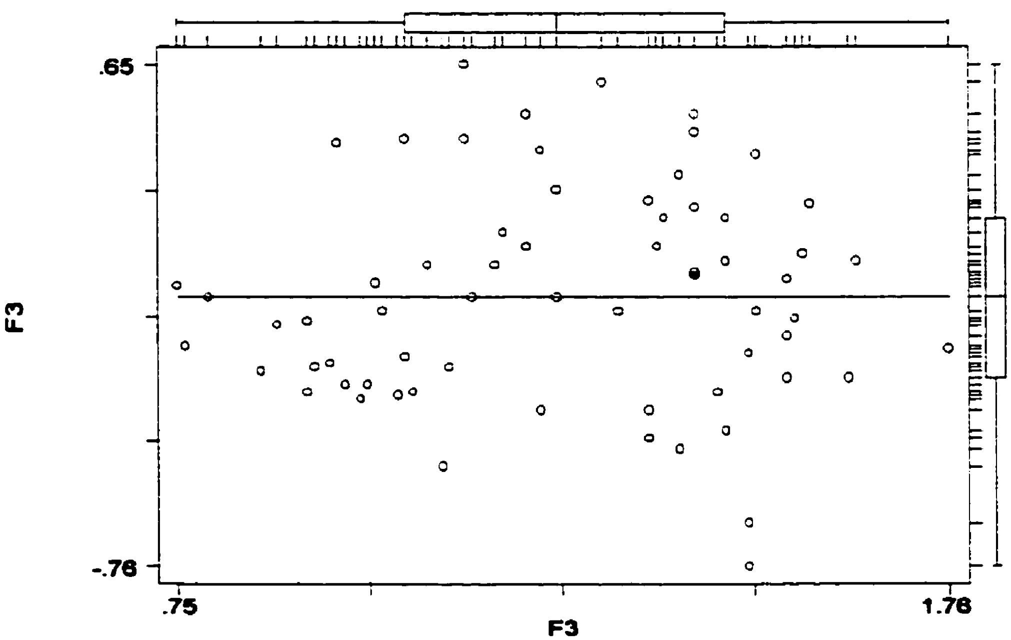
. graph resid_f1 pred_f1, yline(0) oneway twoway box border



. graph resid_f2 pred_f2, yline(0) oneway twoway box border



. graph resid_f3 pred_f3, yline(0) oneway twoway box border



APPENDIX 4 FITTED SHARES FROM THE TRANSLOG MODEL

Description of variables:
scoal: observed cost share of coal; ycoal: fitted cost share of coal;
selec: observed cost share of electricity; ycoal: fitted cost share of electricity;
sgas: observed cost share of natural gas; ycoal: fitted cost share of natural gas;
spet: observed cost share of refined petroleum products; ycoal: fitted cost share of refined petroleum products;

year	scoal	ycoal	selec	yelec	sgas	ygas	spet	ypet
82-1	.087673	.0319276	.4355692	.278071	.3645768	.182829	.1121811	.5071723
82-2	.056124	.0561822	.4788134	.4893571	.3623148	.3374057	.1027478	.1170551
82-3	.0446435	.0448944	.4910055	.4952757	.3538953	.3381935	.1104556	.1216364
82-4	.0819559	.0512119	.4401594	.4314261	.3827003	.3763439	.0951844	.141018
83-1	.0625967	.0653856	.4365965	.4464027	.3444675	.3617671	.1563393	.1264447
83-2	.0448876	.0441908	.4946327	.494388	.3406249	.326305	.1198548	.1351163
83-3	.0260121	.0375995	.5043308	.516983	.3187327	.3196526	.1509244	.1257649
83-4	.0557384	.0400427	.465783	.460141	.3136239	.3463107	.1648547	.1535056
84-1	.067291	.0520378	.4358775	.4746282	.3228681	.3165719	.1739633	.156762
84-2	.0457942	.0433416	.5385982	.5168623	.2830679	.3019149	.1325397	.1378812
84-3	.0257005	.0356077	.5459724	.552035	.3003068	.2831994	.1280203	.1291578
84-4	.0501084	.0387396	.4976261	.4866946	.2964012	.3327633	.1558643	.1418025
85-1	.0600236	.0491967	.4983416	.4931772	.3033397	.3050641	.1382951	.152562
85-2	.0311667	.0398287	.559425	.5452195	.2732657	.2928804	.1361425	.1220715
85-3	.0237554	.0285309	.6337807	.567979	.2359868	.2752089	.1064771	.1282811
85-4	.0345601	.0367749	.4972262	.5321578	.3159906	.2985665	.1522231	.1325008
86-1	.0215244	.0410539	.5217072	.5048395	.3136835	.30861	.1430849	.1454967
86-2	.0186001	.0186532	.5924538	.5818201	.2528456	.2885814	.1361005	.1109452
86-3	.0109143	.0168655	.6099893	.6118149	.255495	.2572982	.1236014	.1140215
86-4	.014294	.0243164	.5645661	.5573708	.3066268	.2967789	.1145131	.1215339
87-1	.0126027	.0259143	.6091802	.5674187	.258117	.2936128	.1201001	.1130542
87-2	.0118224	.0123301	.6333317	.6346743	.2941931	.255238	.0606528	.0977575
87-3	.0099529	.0125709	.6136696	.6451268	.2954995	.2668311	.080878	.0754711
87-4	.0111422	.0222781	.5971512	.5725029	.3112209	.3073042	.0804857	.0979147
88-1	.0166242	.0220025	.6189937	.5963252	.2899811	.2889727	.0744009	.0926997
88-2	.0115497	.0096118	.6430058	.6641612	.2879763	.2600208	.0574682	.0662062
88-3	.0113185	.0075439	.6823418	.677326	.2516739	.252535	.0546658	.0625951
88-4	.0114336	.0175447	.6167197	.6312295	.2750057	.2754799	.096841	.0757458
89-1	.0169623	.0187714	.6348056	.6252183	.2979448	.2629397	.0502872	.0930706
89-2	.0138301	.0087175	.6860588	.6831284	.2496116	.2571233	.0504995	.0510309
89-3	.0120255	.0082413	.7056297	.6995229	.2363657	.2316698	.045979	.0605659
89-4	.013684	.0183961	.6233727	.6391854	.2635303	.2685302	.0994129	.0738883
90-1	.0290943	.0200108	.6300599	.6281604	.2778623	.2564582	.0629835	.0953705
90-2	.0117282	.0131582	.6778371	.6857124	.2645153	.2448925	.0459194	.056237
90-3	.0103624	.007143	.680315	.6985736	.2526275	.2380811	.0566951	.0562023
90-4	.0142091	.0221141	.6128424	.6088324	.3078952	.2839423	.0650533	.0851112
91-1	.0227225	.0234345	.6316307	.6100127	.2931453	.2836449	.0525016	.082908
91-2	.0161655	.0116181	.6951144	.6809518	.2436962	.2581782	.0450238	.0492519
91-3	.0093924	.0090925	.7219279	.7052653	.2223359	.2320893	.0463438	.0535529
91-4	.0155415	.0173141	.6676333	.6455823	.2590117	.2668355	.0578135	.070268
92-1	.0122672	.0183052	.6664779	.6605	.28105	.2546041	.0402049	.0665908
92-2	.0021777	.0038075	.7115198	.7158974	.2387026	.2449171	.0475999	.035378
92-3	.0003802	.0002145	.7514691	.7318237	.2095609	.2203217	.0385898	.0476401
92-4	.0003541	.0105243	.6664003	.6786192	.2900161	.2507585	.0432296	.060098
93-1	.0018792	.0113597	.6772256	.6670304	.2770219	.2652397	.0438733	.0563703
93-2	0	-.0013223	.7151913	.7243854	.2430166	.2415928	.0417921	.0353441
93-3	.0001261	-.0022099	.7228599	.73868	.2357653	.2228903	.0412487	.0406396

93-4	.0117858	.0086823	.6637477	.6697172	.2604507	.2661372	.0640158	.0554632
94-1	.0270114	.0145833	.6506909	.6637954	.2267629	.2562326	.0955348	.0653888
94-2	.0021137	.0078179	.7030329	.7136319	.2141878	.2189034	.0806656	.0596468
94-3	0	-.002444	.7542509	.734882	.2023169	.2072914	.0434322	.0602706
94-4	.009703	.0057246	.7049962	.6986251	.2484381	.2401081	.0368628	.0555423
95-1	.0219728	.0117399	.6988225	.7053855	.2284804	.2311314	.0507243	.0517432
95-2	.0043175	.0033844	.7664263	.7633803	.1865641	.1971333	.0426921	.036102
95-3	0	-.0053279	.7936193	.7948541	.1732697	.1731948	.033111	.037279
95-4	.0004538	.0034011	.7420238	.738875	.2239495	.2102688	.0335728	.047455
96-1	.0119227	.0081773	.682136	.7218277	.2070969	.2173036	.0988444	.0526913
96-2	.0016995	.0027765	.7420442	.7367076	.1941861	.1952334	.0620702	.0652825
96-3	.0017362	-.0017905	.7673239	.762809	.1647435	.1851489	.0661964	.0538326
96-4	.007798	.0102849	.712936	.6966659	.1995502	.2175791	.0797158	.0754702
97-1	.0135021	.0155022	.6755943	.6815764	.219663	.2191462	.0912406	.0837752
97-2	.0068845	.0037926	.7635019	.7306193	.192152	.2039868	.0374616	.0616014
97-3	.0008637	.0002208	.7890403	.7704511	.1770637	.1858988	.0330324	.0434293
97-4	.0074108	.00774	.7196339	.7130288	.2044154	.2231383	.0685399	.0560928
98-1	.0127536	.0110148	.7257873	.7076076	.2030349	.2126613	.0584241	.0687164
98-2	.000339	-.0008985	.7649893	.7626461	.1898014	.1971609	.0448702	.0410916
98-3	.0030531	-.0053331	.7359079	.769519	.2060082	.19402	.0550308	.0417941
98-4	.0069976	.0059893	.682932	.692699	.2456494	.2427136	.064421	.058598
99-1	.0088872	.0092363	.6887811	.6888102	.2316951	.239649	.0706365	.0623044
99-2	0	-.0005623	.7334028	.7322444	.2322822	.2178966	.034315	.0504213
99-3	0	-.0025444	.7502623	.7435543	.2035066	.2145576	.0462311	.0444325
99-4	.0039604	.0091172	.6911069	.6759032	.2413948	.2460186	.0635379	.068961

APPENDIX 5 DATA FOR THE TRANSLOG MODEL

Variables Description

Variables	Label
$Scoal_t$	Cost share of coal in the total cost of energy at time t
$Selec_t$	cost share of electricity at time t
$Sgas_t$	cost share of natural gas at time t
$Spet_t$	cost share of refined petroleum products at time t
LPcoal	Logarithm of the price of coal (thousands of dollars per terajoule)
LPelec	Logarithm of the price of electricity (thousands of dollars per terajoule)
LPgas	Logarithm of the price of natural gas (thousands of dollars per terajoule)
LPpet	Logarithm of the price of refined petroleum products (thousands of dollars per terajoule)
Q	Output
P_i	Dummy variable of seasons, i = 2, 3, 4, indicating summer, autumn and winter
$a_i, b_{ij}, c_i, g_i, d_i$	Unknown parameters

year	Scoal	Selec	Sgas	Spet	LPcoal	LPelec	LPgas	LPpet	lnQ	p2	p3
82-1	.087673	.4355692	.3645768	.1121811	7.652883	8.456544	7.649179	8.245137	13.4469	0	0
82-2	.056124	.4788134	.3623148	.1027478	7.710504	8.457895	7.738807	8.299305	13.40915	1	0
82-3	.0446435	.4910055	.3538953	.1104556	7.722556	8.457895	7.788222	8.320285	13.31702	0	1
82-4	.0819559	.4401594	.3827003	.0951844	7.716193	8.457895	7.832866	8.353789	13.35113	0	0
83-1	.0625967	.4365965	.3444675	.1563393	7.699386	8.541358	7.819683	8.305539	13.38462	0	0
83-2	.0448876	.4946327	.3406249	.1198548	7.701907	8.541358	7.819127	8.354815	13.43584	1	0
83-3	.0260121	.5043308	.3187327	.1509244	7.706573	8.541358	7.801546	8.387702	13.4741	0	1
83-4	.0557384	.465783	.3136239	.1648547	7.721146	8.541358	7.780782	8.376691	13.55857	0	0
84-1	.067291	.4358775	.3228681	.1739633	7.723964	8.62183	7.780489	8.402521	13.6147	0	0
84-2	.0457942	.5385982	.2830679	.1325397	7.803414	8.62183	7.77386	8.386208	13.68235	1	0
84-3	.0257005	.5459724	.3003068	.1280203	7.778399	8.62183	7.782213	8.407407	13.63053	0	1
84-4	.0501084	.4976261	.2964012	.1558643	7.785044	8.62183	7.799855	8.432943	13.63867	0	0
85-1	.0600236	.4983416	.3033397	.1382951	7.792957	8.696306	7.808557	8.474174	13.66989	0	0
85-2	.0311667	.559425	.2732657	.1361425	7.767344	8.696306	7.796745	8.462467	13.64631	1	0
85-3	.0237554	.6337807	.2359868	.1064771	7.758546	8.696306	7.764841	8.449921	13.6111	0	1
85-4	.0345601	.4972262	.3159906	.1522231	7.804058	8.696306	7.772409	8.466615	13.65876	0	0
86-1	.0215244	.5217072	.3136835	.1430849	7.787028	8.736937	7.775595	8.443348	13.71251	0	0
86-2	.0186001	.5924538	.2528456	.1361005	7.775064	8.736937	7.777033	8.205629	13.73994	1	0
86-3	.0109143	.6099893	.255495	.1236014	7.763293	8.736937	7.769797	8.123866	13.70972	0	1
86-4	.014294	.5645661	.3066268	.1145131	7.785997	8.736937	7.745975	8.104239	13.75617	0	0
87-1	.0126027	.6091802	.258117	.1201001	7.770036	8.794946	7.73851	8.133855	13.81575	0	0
87-2	.0118224	.6333317	.2941931	.0606528	7.798194	8.794946	7.742998	8.163872	13.847	1	0
87-3	.0099529	.6136696	.2954995	.080878	7.79689	8.794946	7.721573	8.19573	13.88171	0	1
87-4	.0111422	.5971512	.3112209	.0804857	7.780396	8.794946	7.731886	8.195422	13.91818	0	0
88-1	.0166242	.6189937	.2899811	.0744009	7.716902	8.848404	7.720658	8.148184	13.93093	0	0

88-2	.0115497	.6430058	.2879763	.0574682	7.663406	8.848404	7.669625	8.105892	13.96158	1	0
88-3	.0113185	.6823418	.2516739	.0546658	7.648339	8.848404	7.603561	8.081856	13.9585	0	1
88-4	.0114336	.6167197	.2750057	.096841	7.650993	8.848404	7.608013	8.041878	13.99733	0	0
89-1	.0169623	.6348056	.2979448	.0502872	7.678248	8.896542	7.628639	8.046789	13.98521	0	0
89-2	.0138301	.6860588	.2496116	.0504995	7.680456	8.896542	7.583107	8.100266	13.97768	1	0
89-3	.0120255	.7056297	.2363657	.045979	7.675667	8.896542	7.584157	8.133537	13.9776	0	1
89-4	.013684	.6233727	.2635303	.0994129	7.658534	8.896542	7.622597	8.137696	13.9738	0	0
90-1	.0290943	.6300599	.2778623	.0629835	7.67972	8.96953	7.642597	8.17286	13.96616	0	0
90-2	.0117282	.6778371	.2645153	.0459194	7.677511	8.96953	7.590783	8.187247	13.9872	1	0
90-3	.0103624	.680315	.2526275	.0566951	7.673449	8.96953	7.592866	8.188159	13.90618	0	1
90-4	.0142091	.6128424	.3078952	.0650533	7.695773	8.96953	7.6273	8.34578	13.69099	0	0
91-1	.0227225	.6316307	.2931453	.0525016	7.730977	9.048826	7.677305	8.340834	13.74595	0	0
91-2	.0161655	.6951144	.2436962	.0450238	7.732024	9.048826	7.59978	8.145334	13.68033	1	0
91-3	.0093924	.7219279	.2223359	.0463438	7.721498	9.048826	7.592172	8.122894	13.65916	0	1
91-4	.0155415	.6676333	.2590117	.0578135	7.709075	9.048826	7.651145	8.117041	13.62946	0	0
92-1	.0122672	.6664779	.28105	.0402049	7.805032	9.163116	7.695622	8.049234	13.70377	0	0
92-2	.0021777	.7115198	.2387026	.0475999	7.813436	9.163116	7.618548	8.065507	13.73357	1	0
92-3	.0003802	.7514691	.2095609	.0385898	7.760583	9.163116	7.588695	8.128394	13.75674	0	1
92-4	.0003541	.6664003	.2900161	.0432296	7.730977	9.163116	7.624615	8.135143	13.72833	0	0
93-1	.0018792	.6772256	.2770219	.0438733	7.839163	9.234505	7.694053	8.099937	13.71464	0	0
93-2	0	.7151913	.2430166	.0417921	7.840733	9.234505	7.661234	8.105229	13.7312	1	0
93-3	.0001261	.7228599	.2357653	.0412487	7.805032	9.234505	7.660262	8.077115	13.70469	0	1
93-4	.0117858	.6637477	.2604507	.0640158	7.785044	9.234505	7.754572	8.053067	13.65431	0	0
94-1	.0270114	.6506909	.2267629	.0955348	7.868211	9.234505	7.846685	8.006448	13.73892	0	0
94-2	.0021137	.7030329	.2141878	.0806656	7.872469	9.234505	7.758989	8.06825	13.81822	1	0
94-3	0	.7542509	.2023169	.0434322	7.815364	9.234505	7.758398	8.138654	13.90706	0	1
94-4	.009703	.7049962	.2484381	.0368628	7.787692	9.234505	7.780782	8.095279	14.01636	0	0
95-1	.0219728	.6988225	.2284804	.0507243	7.895558	9.223269	7.692801	8.113118	14.17972	0	0
95-2	.0043175	.7664263	.1865641	.0426921	7.873987	9.223269	7.545636	8.167906	14.27309	1	0
95-3	0	.7936193	.1732697	.033111	7.77339	9.223269	7.540532	8.121268	14.2881	0	1
95-4	.0004538	.7420238	.2239495	.0335728	7.720792	9.223269	7.570772	8.108856	14.26404	0	0
96-1	.0119227	.682136	.2070969	.0988444	7.859648	9.214758	7.638957	8.166044	14.22148	0	0
96-2	.0016995	.7420442	.1941861	.0620702	7.898514	9.214758	7.550352	8.250854	14.07128	1	0
96-3	.0017362	.7673239	.1647435	.0661964	7.877008	9.214758	7.547815	8.219856	14.08191	0	1
96-4	.007798	.712936	.1995502	.0797158	7.859648	9.214758	7.632977	8.307159	14.07448	0	0
97-1	.0135021	.6755943	.219663	.0912406	7.889315	9.213808	7.738204	8.299582	13.99377	0	0
97-2	.0068845	.7635019	.192152	.0374616	7.908219	9.213808	7.573958	8.227183	14.00766	1	0
97-3	.0008637	.7890403	.1770637	.0330324	7.877913	9.213808	7.592172	8.223962	14.09918	0	1
97-4	.0074108	.7196339	.2044154	.0685399	7.830661	9.213808	7.683977	8.210391	14.12236	0	0
98-1	.0127536	.7257873	.2030349	.0584241	7.851012	9.213808	7.683654	8.107869	14.1256	0	0
98-2	.000339	.7649893	.1898014	.0448702	7.866994	9.213808	7.729774	8.055151	14.14367	1	0
98-3	.0030531	.7359079	.2060082	.0550308	7.830974	9.213808	7.783366	8.014069	14.00701	0	1
98-4	.0069976	.682932	.2456494	.064421	7.79131	9.213808	7.816076	8.005718	14.03438	0	0
99-1	.0088872	.6887811	.2316951	.0706365	7.874287	9.213808	7.874023	7.968581	14.08267	0	0
99-2	0	.7334028	.2322822	.034315	7.883626	9.213808	7.838848	8.145334	14.07886	1	0
99-3	0	.7502623	.2035066	.0462311	7.880625	9.213808	7.860316	8.29276	14.15774	0	1
99-4	.0039604	.6911069	.2413948	.0635379	7.836969	9.213808	7.936943	8.386955	14.17599	0	0

p4	Scoal1	Selec1	Sgas1	Spet1	no
0					1
0	.087673	.4355692	.3645768	.1121811	2
0	.056124	.4788134	.3623148	.1027478	3
1	.0446435	.4910055	.3538953	.1104556	4
0	.0819559	.4401594	.3827003	.0951844	5
0	.0625967	.4365965	.3444675	.1563393	6
0	.0448876	.4946327	.3406249	.1198548	7
1	.0260121	.5043308	.3187327	.1509244	8
0	.0557384	.465783	.3136239	.1648547	9
0	.067291	.4358775	.3228681	.1739633	10
0	.0457942	.5385982	.2830679	.1325397	11
1	.0257005	.5459724	.3003068	.1280203	12

0	.0501084	.4976261	.2964012	.1558643	13
0	.0600236	.4983416	.3033397	.1382951	14
0	.0311667	.559425	.2732657	.1361425	15
1	.0237554	.6337807	.2359868	.1064771	16
0	.0345601	.4972262	.3159906	.1522231	17
0	.0215244	.5217072	.3136835	.1430849	18
0	.0186001	.5924538	.2528456	.1361005	19
1	.0109143	.6099893	.255495	.1236014	20
0	.014294	.5645661	.3066268	.1145131	21
0	.0126027	.6091802	.258117	.1201001	22
0	.0118224	.6333317	.2941931	.0606528	23
1	.0099529	.6136696	.2954995	.080878	24
0	.0111422	.5971512	.3112209	.0804857	25
0	.0166242	.6189937	.2899811	.0744009	26
0	.0115497	.6430058	.2879763	.0574682	27
1	.0113185	.6823418	.2516739	.0546658	28
0	.0114336	.6167197	.2750057	.096841	29
0	.0169623	.6348056	.2979448	.0502872	30
0	.0138301	.6860588	.2496116	.0504995	31
1	.0120255	.7056297	.2363657	.045979	32
0	.013684	.6233727	.2635303	.0994129	33
0	.0290943	.6300599	.2778623	.0629835	34
0	.0117282	.6778371	.2645153	.0459194	35
1	.0103624	.680315	.2526275	.0566951	36
0	.0142091	.6128424	.3078952	.0650533	37
0	.0227225	.6316307	.2931453	.0525016	38
0	.0161655	.6951144	.2436962	.0450238	39
1	.0093924	.7219279	.2223359	.0463438	40
0	.0155415	.6676333	.2590117	.0578135	41
0	.0122672	.6664779	.28105	.0402049	42
0	.0021777	.7115198	.2387026	.0475999	43
1	.0003802	.7514691	.2095609	.0385898	44
0	.0003541	.6664003	.2900161	.0432296	45
0	.0018792	.6772256	.2770219	.0438733	46
0	0	.7151913	.2430166	.0417921	47
1	.0001261	.7228599	.2357653	.0412487	48
0	.0117858	.6637477	.2604507	.0640158	49
0	.0270114	.6506909	.2267629	.0955348	50
0	.0021137	.7030329	.2141878	.0806656	51
1	0	.7542509	.2023169	.0434322	52
0	.009703	.7049962	.2484381	.0368628	53
0	.0219728	.6988225	.2284804	.0507243	54
0	.0043175	.7664263	.1865641	.0426921	55
1	0	.7936193	.1732697	.033111	56
0	.0004538	.7420238	.2239495	.0335728	57
0	.0119227	.682136	.2070969	.0988444	58
0	.0016995	.7420442	.1941861	.0620702	59
1	.0017362	.7673239	.1647435	.0661964	60
0	.007798	.712936	.1995502	.0797158	61
0	.0135021	.6755943	.219663	.0912406	62
0	.0068845	.7635019	.192152	.0374616	63
1	.0008637	.7890403	.1770637	.0330324	64
0	.0074108	.7196339	.2044154	.0685399	65
0	.0127536	.7257873	.2030349	.0584241	66
0	.000339	.7649893	.1898014	.0448702	67
1	.0030531	.7359079	.2060082	.0550308	68
0	.0069976	.682932	.2456494	.064421	69
0	.0088872	.6887811	.2316951	.0706365	70
0	0	.7334028	.2322822	.034315	71
1	0	.7502623	.2035066	.0462311	72

APPENDIX 6 DATA FOR THE LOGIT MODEL

```
data da;
   input f1 f2 f3 r1 r2 r3 s1 s2 s3 s4 q p2 p3 p4;
   label
        f1 = 'Ln(Scoal/Spet)'
        f2 = 'Ln(Selec/Spet)'
        f3 = 'Ln(Sgas/Spet)'
        r1 = 'Ln(Pcoal/Ppet)'
        r2 = 'Ln(Pcoal/Ppet)'
        r3 = 'Ln(Pcoal/Ppet)'
        s1 = 'Ln(Cost share of coal)'
        s2 = 'Ln(Cost share of electricity)'
        s3 = 'Ln(cost share of natural gas)'
        s4 = 'Ln(cost share of petroleum)'
        q = 'ln(output)'
        pi = 'seasonal variables';

   cards;

-0.246500595   1.356539236   1.178622718   -0.5922547     0.211406932   -0.595957752
0.087672983    0.435569176   0.364576756   0.112181084    13.44689749   0   0   0
-0.604713049   1.539034074   1.260236451   -0.588801264   0.158590702   -0.560497482
0.056124022    0.478813438   0.362314789   0.102747751    13.40914705   1   0   0
-0.905905006   1.491841401   1.164387144   -0.597728858   0.137610855   -0.532062146
0.044643512    0.491005534   0.353895313   0.110455641    13.31702185   0   1   0
-0.149634626   1.531320607   1.391435908   -0.637596431   0.104105976   -0.520923628
0.081955926    0.440159365   0.382700292   0.095184417    13.35113108   0   0   1
-0.915315084   1.026981118   0.789971212   -0.60615414    0.235818323   -0.485857205
0.062596747    0.436596539   0.344467453   0.156339261    13.38462148   0   0   0
-0.982118409   1.417534695   1.044501156   -0.652908528   0.186542054   -0.535689336
0.044887634    0.494632688   0.34062491    0.119854768    13.43584477   1   0   0
-1.758215603   1.206453759   0.747574043   -0.681129649   0.153655934   -0.586156487
0.026012134    0.504330836   0.31873268    0.15092435     13.47410276   0   1   0
-1.084395915   1.038655142   0.643129933   -0.655545586   0.164666789   -0.595908686
0.055738368    0.465782972   0.31362393    0.16485473     13.55857493   0   0   1
-0.949817931   0.918516859   0.618399522   -0.678556966   0.219309579   -0.622031479
0.067291003    0.43587754    0.322868137   0.17396332     13.61470441   0   0   0
-1.062725162   1.402087748   0.758804398   -0.582793569   0.235622307   -0.61234794
0.045794182    0.538598269   0.283067849   0.132539699    13.68235509   1   0   0
-1.605679942   1.450379139   0.852615349   -0.6290087     0.214423289   -0.625194121
0.025700471    0.545972382   0.300306795   0.128020352    13.63053067   0   1   0
-1.134796771   1.160863296   0.642728138   -0.647899101   0.188887219   -0.633088172
0.050108415    0.497626114   0.296401176   0.155864295    13.63867433   0   0   1
-0.83465166    1.281896406   0.785463727   -0.681216954   0.22213246    -0.665617567
0.060023601    0.498341662   0.303339679   0.138295058    13.66989039   0   0   0
-1.474350388   1.413207248   0.696742593   -0.695123115   0.233839212   -0.665722009
0.03116675     0.559424985   0.273265757   0.136142509    13.64630817   1   0   0
-1.500118679   1.78377337    0.795846197   -0.691374537   0.246385816   -0.685079338
0.023755426    0.633780712   0.235986793   0.106477069    13.61109921   0   1   0
-1.482648971   1.183697738   0.730365099   -0.662556944   0.229691751   -0.69420571
0.03456005     0.497226226   0.3159906     0.152223124    13.65876084   0   0   1
```

-1.894249674	1.293668631	0.78494651	-0.65631961	0.293589265	-0.667752562		
0.021524423	0.52170723	0.313683479	0.143084868	13.71250948	0	0	0
-1.990228426	1.470879448	0.619385728	-0.430565883	0.531307241	-0.428596733		
0.018600064	0.59245381	0.252845642	0.136100484	13.73993751	1	0	0
-2.426986667	1.596379207	0.726140628	-0.360573413	0.613070827	-0.354069327		
0.010914318	0.609989264	0.255494984	0.123601434	13.70971995	0	1	0
-2.08084929	1.595368335	0.984942207	-0.314241502	0.632698542	-0.358262764		
0.014294	0.564566111	0.306626797	0.114513092	13.75617448	0	0	1
-2.254410652	1.623788762	0.765087944	-0.363818778	0.661090835	-0.395344594		
0.012602744	0.609180135	0.258117058	0.120100063	13.81575053	0	0	0
-1.635172112	2.345828498	1.579070643	-0.365677019	0.631074318	-0.420873457		
0.011822372	0.633331701	0.294193127	0.0606528	13.84699954	1	0	0
-2.095082292	2.026514195	1.295724813	-0.398840064	0.599215624	-0.474156985		
0.009952862	0.613669565	0.295499526	0.080878046	13.8817102	0	1	0
-1.977340003	2.004091042	1.352423634	-0.415026975	0.599523177	-0.463536825		
0.011142196	0.597151215	0.311220905	0.080485684	13.91818447	0	0	1
-1.498606727	2.118626766	1.360347436	-0.431281907	0.700220194	-0.427526325		
0.016624236	0.618993724	0.289981116	0.074400924	13.93093526	0	0	0
-1.604574696	2.414921358	1.611645891	-0.442486344	0.742512211	-0.43626737		
0.011549679	0.643005773	0.287976314	0.057468234	13.96158298	1	0	0
-1.574795871	2.524293316	1.52689686	-0.433517136	0.766548371	-0.47829495		
0.011318534	0.682341803	0.251673913	0.054665751	13.95850206	0	1	0
-2.136511785	1.851343827	1.043720911	-0.390885259	0.806526465	-0.433864871		
0.01143363	0.616719681	0.27500566	0.09684103	13.99733199	0	0	1
-1.086755765	2.535568487	1.779158058	-0.368540808	0.849753183	-0.41814987		
0.016962323	0.634805629	0.297944857	0.05028719	13.98521114	0	0	0
-1.295118552	2.608999267	1.597942057	-0.419810702	0.796275782	-0.517159345		
0.013830074	0.686058792	0.249611602	0.050499532	13.97768043	1	0	0
-1.341151885	2.730905752	1.637195496	-0.457870608	0.763004612	-0.549380279		
0.012025543	0.705629712	0.236365741	0.045979004	13.97759539	0	1	0
-1.983052805	1.835862253	0.974886003	-0.479162797	0.758845803	-0.515099565		
0.013684031	0.623372721	0.263530301	0.099412947	13.97380407	0	0	1
-0.772331133	2.302941836	1.484252752	-0.493140042	0.796670465	-0.530262596		
0.029094288	0.630059871	0.277862327	0.062983514	13.96616083	0	0	0
-1.364890925	2.692019169	1.751011173	-0.509736194	0.782283446	-0.59646415		
0.011728208	0.677837108	0.264515277	0.045919407	13.9872008	1	0	0
-1.699499952	2.484867994	1.494228012	-0.514709967	0.781371728	-0.595292535		
0.010362442	0.680314987	0.252627463	0.056695107	13.90618273	0	1	0
-1.521324817	2.242900399	1.554551835	-0.650007451	0.623749808	-0.718480855		
0.0142091	0.612842423	0.307895143	0.065053333	13.69099441	0	0	1
-0.837488917	2.487462018	1.719825753	-0.609856478	0.707992748	-0.663528418		
0.02272246	0.631630643	0.293145342	0.052501555	13.74594609	0	0	0
-1.024312293	2.736884395	1.688730466	-0.4133103	0.903491258	-0.545554996		
0.016165507	0.695114416	0.24369624	0.045023837	13.68032523	1	0	0
-1.596183745	2.745838436	1.568102221	-0.40139585	0.92593212	-0.530722055		
0.009392422	0.721927947	0.22233586	0.046343771	13.65915963	0	1	0
-1.3137075	2.446517458	1.499651799	-0.407965052	0.931785795	-0.465895345		
0.015541504	0.667633294	0.259011743	0.057813459	13.62945564	0	0	1
-1.187060949	2.808017377	1.944542852	-0.24420319	1.113880372	-0.35361297		
0.012267196	0.666477909	0.281049966	0.04020493	13.70376973	0	0	0
-3.084558237	2.704572173	1.61238754	-0.252071373	1.097608248	-0.446958817		
0.002177708	0.711519749	0.238702627	0.047599916	13.73356704	1	0	0
-4.620108411	2.969043391	1.692027662	-0.367810883	1.034720857	-0.539699172		
0.000380176	0.75146916	0.209560911	0.038589753	13.7567399	0	1	0
-4.804769696	2.735365477	1.903411261	-0.404166676	1.027971697	-0.510528616		
0.000354076	0.666400283	0.290016059	0.043229582	13.72832608	0	0	1

```
-3.150484525   2.736698637   1.842790615   -0.260774362   1.1345673      -0.405885344
0.001879153    0.67722566    0.277021887   0.043873299    13.71464437  0  0  0
-5.790338945   2.863596644   1.743217999   -0.272083158   1.1573904      -0.41685257
0.000126095    0.722859934   0.235765303   0.041248668    13.70468849  0  1  0
-1.692234594   2.338772594   1.403284155   -0.268023217   1.18143793     -0.298494652
0.011785794    0.663747708   0.260450723   0.064015774    13.65431193  0  0  1
-1.263230175   1.91854454    0.864415008   -0.138236814   1.228057643    -0.159762271
0.027011426    0.650690876   0.226762939   0.095534758    13.73891889  0  0  0
-3.641889207   2.165091057   0.976540879   -0.195780642   1.166255444    -0.309260833
0.002113665    0.703032854   0.214187853   0.080665628    13.81821689  1  0  0
-1.33476817    2.950990593   1.907991913   -0.307586787   1.139226429    -0.314496226
0.009702985    0.704996166   0.248438091   0.036862758    14.01635942  0  0  1
-0.836599799   2.622991465   1.505044913   -0.217560591   1.110150438    -0.420317703
0.021972805    0.698822522   0.22848036    0.050724313    14.17972302  0  0  0
-2.291328701   2.887724597   1.474760721   -0.293918838   1.055362765    -0.622270313
0.004317538    0.7664263     0.18656406    0.042692102    14.27309362  1  0  0
-4.303716935   3.09566426    1.89770356    -0.388064161   1.114412948    -0.53808452
0.000453845    0.742023814   0.223949513   0.033572829    14.26403516  0  0  1
-2.115105338   1.931682256   0.739640149   -0.30639631    1.048713701    -0.527087624
0.011922668    0.682136008   0.207096933   0.098844391    14.22147554  0  0  0
-3.597932211   2.481142815   1.140551233   -0.352339558   0.963904288    -0.70050233
0.001699499    0.742044165   0.194186139   0.062070197    14.07128392  1  0  0
-3.640927081   2.450282536   0.911763249   -0.342848062   0.994901989    -0.672040958
0.001736201    0.767323879   0.164743496   0.066196424    14.08191281  0  1  0
-2.324603898   2.190924506   0.917598618   -0.447510704   0.907599307    -0.674182122
0.007797969    0.71293607    0.199550206   0.079715755    14.07448447  0  0  1
-1.910651787   2.002092847   0.878594662   -0.410267352   0.914226367    -0.561377393
0.013502138    0.675594277   0.219662995   0.09124059     13.99377389  0  0  0
-1.694044009   3.014599579   1.63497058    -0.318964718   0.986624477    -0.653225775
0.006884497    0.763501929   0.192151986   0.037461587    14.00765868  1  0  0
-3.644061552   3.173329391   1.679021731   -0.346048407   0.989846137    -0.631790298
0.000863662    0.789040249   0.177063721   0.033032368    14.09918461  0  1  0
-2.224473201   2.351326859   1.092738743   -0.379730689   1.00341674     -0.526414721
0.00741083     0.719633849   0.204415446   0.068539874    14.12235535  0  0  1
-1.521913739   2.519528869   1.245649853   -0.256857016   1.10593914     -0.424215362
0.012753611    0.725787366   0.203034938   0.058424085    14.12560215  0  0  0
-4.885385009   2.836088362   1.442204914   -0.188156679   1.158656992    -0.325377553
0.000339049    0.764989333   0.189801434   0.044870184    14.14366977  1  0  0
-2.891745404   2.593211028   1.32002216    -0.183094782   1.199739603    -0.230702568
0.003053073    0.735907863   0.206008217   0.055030848    14.00700657  0  1  0
-2.219867618   2.360955295   1.338465242   -0.214407953   1.208089989    -0.18964199
0.006997636    0.682931973   0.245649372   0.064421019    14.03438099  0  0  1
-2.072939576   2.277376179   1.187875022   -0.094293821   1.245227201    -0.094557735
0.008887163    0.688781167   0.23169514    0.07063653     14.08267099  0  0  0
-2.775302444   2.386658252   1.334797676   -0.549986132   0.826852964    -0.450012495
0.003960356    0.691106916   0.241394847   0.063537881    14.17598527  0  0  1

;

data ac;set da;
* keep exogenous variables ;
    keep f1-f3 r1-r3 q p2 p3 p4;
* keep shares only ;
data shares;set da;keep s1 s2 s3 s4;
data initial;merge ac shares;
```

```
 proc model noprint data=initial outmodel=logit;
  parms a1 a2 a3 c12 c13 c14 c23 c24 c34 g1 g2 g3 d1 d2 d3 e1 e2 e3 e4 e5 e6 e7 e8 e9;
* declare variables;
endogenous f1 f2 f3;
exogenous  r1 r2 r3 s1 s2 s3 s4 q p2 p3 p4;

* share equations to be estimated;
 f1=a1 - (s2*c12+s3*c13+(s1+s4)*c14)*r1 + (c12-c24)*s2*r2
   + (c13-c34)*s3*r3 + g1*q + e1*p2 + e2*p3 + e3*p4 + d1*lag1(f1);
 f2=a2 + (c12-c14)*s1*r1 - (s1*c12+s3*c23+(s2+s4)*c24)*r2
   + (c23-c34)*s3*r3 + g2*q + e4*p2 + e5*p3 + e6*p4 + d2*lag1(f2);
 f3=a3 + (c13-c14)*s1*r1 + (c23-c24)*s2*r2
   - (s1*c13+s2*c23+(s3+s4)*c34)*r3 +g3*q + e7*p2 + e8*p3 + e9*p4 + d3*lag1(f3);

 fit f1 f2 f3/itsur dw out=work.out outpredict outest=est maxiter=100;

* initial coefficient estimates;
data logitest;set est;

%macro doit;
* the number of iterations must be ;
* determined by a previous program ;
%let max=5;
%do j=1 %to &max;

* initial results from above;
data in;set logitest;
data ps;set out;
f=exp(f1)+exp(f2)+exp(f3)+1;
s1=exp(f1)/f;
s2=exp(f2)/f;
s3=exp(f3)/f;
s4=1/f;
keep s1 s2 s3 s4;
data it;merge ac ps;

proc model noprint data=it model=logit ;
* takes equations from previous proc model statement ;
* dont use starting values from previous iteration ;

fit f1 f2 f3/itsur dw outest=est out=work.out outpredict out=work.resid outresid maxiter=100 ;

%end;
%mend;
%doit;

data in;set logitest;
data out;set out;
    f=exp(f1)+exp(f2)+exp(f3)+1;
```

```
     s1=exp(f1)/f;
     s2=exp(f2)/f;
     s3=exp(f3)/f;
     s4=1/f;
     keep s1 s2 s3 s4;
data it20;merge ac out;


/* do matrix stuff here */
/* compute Hicks-Allen elasticities */
/* compute elasticities of demand */
/* check for concavity of the cost function */
/* check for monotonocity */

proc iml;

use est; read all var{c12 c13 c14 c23 c24 c34} into cij;
use out; read all var{s1 s2 s3 s4} into shares;

a=0;
f=0;

do yr= 1 to 66;        * check concavity for each year;
     s=shares[yr,];
     * print s;
     c=j(4,4,0);
     c[1,2]=cij[1,1];
     c[1,3]=cij[1,2];
     c[1,4]=cij[1,3];
     c[2,3]=cij[1,4];
     c[2,4]=cij[1,5];
     c[3,4]=cij[1,6];
     c[2,1]=c[1,2];
     c[3,1]=c[1,3];
     c[3,2]=c[2,3];
     c[4,1]=c[1,4];
     c[4,2]=c[2,4];
     c[4,3]=c[3,4];
     c[1,1]=-c[1,2]#(s[,2]/s[,1])
          -c[1,3]#(s[,3]/s[,1])
          -c[1,4]#(s[,4]/s[,1]);
     c[2,2]=-c[2,1]#(s[,1]/s[,2])
          -c[2,3]#(s[,3]/s[,2])
          -c[2,4]#(s[,4]/s[,2]);
     c[3,3]=-c[3,1]#(s[,1]/s[,3])
          -c[3,2]#(s[,2]/s[,3])
          -c[3,4]#(s[,4]/s[,3]);
     c[4,4]=-c[4,1]#(s[,1]/s[,4])
          -c[4,2]#(s[,2]/s[,4])
          -c[4,3]#(s[,3]/s[,4]);
     * print c;;
```

```
/* use matrix formulas from jbes article */
    v=-1/-1/-1/-1;
    b=c-diag(c);
  print b;
    wd=diag(s);
    bd=diag(-b*wd*v);
    pi=bd+b*wd;
    w=s//s//s//s;
    * print w;
    e=pi+w-i(4);
    sigma=e*inv(wd);

    * hessian matrix of second derivatives;
    theta=wd*pi+(s`*s)-wd;

    * eigenvalues of the hessian matrix of second derivatives;
    eigs=eigval(theta);
   a=a+eigs;
   f=f+e;
   print eigs;
   print e;
   print yr;

end;

*calculate the average eigenvalue and elasticities;
c=a/66;
g=f/66;
print c;
print g;
  run;
```

APPENDIX 7 PREDICTED DATA FOR SIMULATION

year	lnpcoal	lnpelec	lnpgas	lnppet	lnq
2000	7.869051	9.076809	8.192161	8.753606	14.3415
2001	7.869051	9.028019	8.2161	8.796938	14.50701
2002	7.869051	8.989798	8.236988	8.807912	14.67253
2003	7.869051	8.950057	8.254366	8.817053	14.83804
2004	7.869051	8.894487	8.270304	8.826262	15.00356
2005	7.869051	8.918501	8.28759	8.837158	15.16907
2006	7.869051	8.937699	8.306355	8.848791	15.33459
2007	7.869051	8.954968	8.325854	8.860325	15.5001
2008	7.869051	8.970332	8.346912	8.8766	15.66562
2009	7.869051	8.98556	8.367732	8.894064	15.83113
2010	7.869051	9.000156	8.388493	8.909545	15.99664