Three Essays On The Optimal Degree of Enforcement of Property Rights: Determination and Impact

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Abstract

This dissertation formulates and analyzes three original models dealing with aspects of optimal property rights protection, in varying contexts.

Chaper 1 is a survey of the literature on the importance of property and property rights in economic thought beginning from the Physiocratic regime up to the recent literature which deals with implications of imperfect property rights.

Chapter 2 considers an overlapping generations model where households accumulate wealth and influence the political process of determing the optimal property rights regime through maximization of the household welfare function with respect to the tax rate which yields revenue to finance the cost of enforcement of property rights. Both the cases of homogeneous and heterogeneous households are considered. The long run equilibrium levels of income are calculated and stability properties analyzed. It is shown that the optimally determined levels of property rights enforcement evolves over time, and depends on a number of factors, such as the discount rate and the share of capital in output.

Chapter 3 uses a principal-agent approach to model a joint venture, where a multinational firm transfers technological knowledge to a local firm during their partnership. The local firm may defect on acquiring adequate knowledge to operate as a monopolist. Anticipating this, the multinational chooses to transfer an amount of technology just sufficient to pre-empt defection, given the rate of compensation earned. The optimal level of enforcement of property rights, represented by the optimal rate of compensation, is determined by maximizing the social welfare of the home country. It is found that the optimal rate of compensation is higher when the goods are produced solely for the home market than in the case where the goods are produced only for the export market.

Chapter 4 finds a basis for the determination of an optimal patent length in the pharmaceutical industry, in a North South model, where the North undertakes R&D and the South carries out reverse engineering. In absence of a legal barrier, the Southern firms can produce replicated antibiotics that erode the monopoly power of the Northern firm. This works against the North's R&D incentives. However, a ban on reverse engineering implies the prevalence of high Northern monopoly prices. An optimal patent length must balance the two opposing forces. It is demonstrated that, for plausible lengths of the South's planning horizon, the optimal patent length varies positively with the R&D cost parameter and negatively with the parameter for production cost mark-up of the South.

Résumé

Cette dissertation se compose de trois modèles originaux concernant des aspects variés du problème de détermination du niveau de l'application des droits de propriété dans des contextes différents.

Le premier chapitre est un aperçu de la littérature sur l'importance de la propriété et des droits de propriété, depuis le régime physiocratique jusqu'à la littérature récente sur différents aspects des droits de propriété imparfaits.

Le deuxième chapitre considère un modèle aux générations imbriquées dans lequel les ménages accumulent de la richesse and influencent le processus de détermination du régime optimal de droits de propriété, en maximisant leur bien-être par rapport au taux de taxation qui finance l'application des droits de propriété. On étudie le cas des ménages homogènes ainsi que le cas des ménages hétérogènes. On calcule le niveau de revenue à l'équilibre stationnaire, et détermine la stabilité de l'équilibre. On démontre que le niveau optimal de l'application des droits de propriété évolu au fil de temps et dépend des facteurs tels que le taux d' actualisation et le partage de capital dans le revenu.

Le troisième chapitre utilise l'approache principal-agent pour modéliser un joint venture dans le quel une entreprise multinationale transfère la technologie à une entreprise locale. Celle-ci a l'intérêt d'annuler le contrat de joint venture quand elle a accumulé un savoir suffisant, pour devenir un monopole. L'entreprise multinationale, anticipant l'incitation à la defection

de son partenaire, décide de transférer un niveau réduit de technologie dans l'objectif de préempter la défection, en tenant compte du taux de compensation dans le cas de défection. Le niveau optimal de la protection des droits de propriété, représenté par le taux optimal de compensation, est déterminé par la maximisation du bien-être du pays domestique. On montre que le taux optimal de compensation est plus élevé dans le cas où l'output est vendu au marché domestique que dans le cas où est destiné au marché étranger.

Le quatrième chapitre cherche la fondation pour la détermination de la longueur optimale des brevets de l'industrie pharmaceutique. On étudie un modèle Nord-Sud, dans lequel une entreprise du Nord effectue de la recherche et les entreprises du Sud font la rétro-ingénierie. S'il n'y a pas d'obstacles juridiques, les entreprises du Sud produisent des antibiotiques répliqués, ce qui érode le pouvoir de monopole de l'entreprise du Nord. Cela n'encourage pas la recherche dans le pays Nord. Par contre, la prohibition de la rétro-ingénierie implique des prix élevés du monopole. La longeur optimale des brevets balances les deux forces opposantes. Pour les horizons de temps raisonables, on montre que la longeur optimale des brevets est une fonction croissante du paramètre de coût et une fonction décroissante du paramètre de mark-up des coûts de production dans le pays Sud.

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Preface

Institutions have been defined in the literature, as a systems of prevailing rules that structure and govern, social interactions[1]. Institutions are therefore responsible for setting and enforcing the norms to be followed, during interactions between individuals, firms etc. who may either be intrinsically differently behaved or used to following varied norms. While the creation and enforcement of any institution is difficult, the creation of economic institutions is particularly difficult because they are aimed at altering the cost-benefit ratios of cooperation between agents engaged in an impersonal exchange. Agents engaged in an impersonal exchange using commodities as a medium are likely to have conflicting interests at any given point in time or at least at some point in time. Therefore, any norm of cooperation set between them is less likely to be spontaneous. Economic institutions that lay down rules for self-interested individuals having conflicting interests must therefore be formed by some third organisation, like the government, that aims at the well-being of the economy as a whole. Thus economic institutions must in essence be an amalgamation of economic and political institutions. The extent of enforcement of the elements of these economic institutions will be given by the welfare considerations at that point of time and by the interests of those that constitute the political insitutions, even though the ultimate aim must be to initiate and enhance growth incentives of the economy.

[1]Hodgson G.M. (2006), JEI, "What Are Institutions?"

This dissertation is concerned with 'property rights' as one of the most important constituents of the economic institutions. Propery rights are defined as the set of rules applicable to an individual that define his relationship with goods or property. In other words, the user rights, the right to exclude others from using the property and rights to transfer or sell the property are collectively called property rights. Property rights become particularly important when individuals take decisions concerning production, exchange, capital accumulation etc. Specifically, one undertakes productive activites only if he is reasonably certain of being able to appropriate the profits from its sale, and one accumulates capital only if he is reasonably certain of earning the stream of returns from it over time. The prevailing property rights regime provides this certainty.

On the one hand, lack of strong enough enforcement of property rights distorts investment decisions by the private sector, allocation of labor time between productive and rent-seeking activities, allocation of investment by the public sector and certainty in trade. On the other hand, strong enforcement of property rights not only entails high enforcement costs, but also carries the risk of creating monopolies in the economy. Thus optimal enforcement of property rights is on one hand an instrument to enhance incentives of capital accumulation and growth and on the other hand, a tool to monitor concurrent issues that may otherwise pose a hindrance to social welfare. Even though it is assumed that property right is an instrument in the hands of the government which is impartial to agents with conflicting interests interacting between themselves, this may not be universally true. In that case, the extent of enforcement of property rights may also be subjected to the interests of those individuals who influence political decision-making. So, even though enforcement of property rights must intrinsically be aimed at protecting profit interests of agents at the level of an individual and enhancing the rate of growth at the level of an economy, there are a number of other concerns that may necessitate changes in a given property regime. Therefore, rather than striving to build a general theory of enforcement of property rights and growth, this dissertation has tried to illustrate some principles on which a property rights regime may be optimally determined and factors that might lead to a change in such regimes.

This dissertation contributes to the literature by providing a simple microenomic insight into why a property right regime may change, and what determines the optimal enforcement of property rights at any given point in time. In chapter two, an overlapping generations model has been built, to show how an economy may move from a regime of partially secure property rights to a regime where property rights are fully secure. In chapters three and four, cases have been built to analyze the basis for and the determination of optimal property rights regimes. While chapter three deals with physical property rights, the good in question being a produced and marketable commodity, chapter four deals with the enforcement of intellectual property rights, the good in question being non-rival in nature.

The first chapter is a survey of the literature on the importance of property and property rights, beginning from the Physiocrats and continuing through the opinions during the periods of Utopian Socialism, Liberalism, Marxism, the Austrian school, the school of New Institutional Economics up to the recent works on property in conflict theory and economic growth.

In the second chapter, entitled "Evolution of property rights regimes," the movement of an economy has been illustrated, from a regime of partially secure propery rights to a regime where property rights are fully secure. Inspired by Gradstein (2004, 2007, 2008) an overlapping generations model has been built where each generation lives for two periods and the economy goes on forever. A partially secure property right regime has been depicted by the presence of rent seeking acitivies. As the economy moves towards full security of property rights the effectiveness of the rent seeking acitvity reduces to zero. The choice of the optimal property right regime is given by the maximization of the optimized welfare function of a representative household. Since the cost of enforcement of property rights is completely financed by tax revenues, the optimal degree of enforcement of property rights is given by the tax rate that maximizes the optimized individual welfare function. The case has been analyzed both for homogenous and heterogenous agents. While all agents have a similar influence on the choice of the optimal property rights in the first case, only the rich have the right to determine the optimal property rights in the second. The results have been compared, the steady-state equilibria have been calculated and their stability properties analyzed.

The third chapter, entitled "Optimal technology transfer under partial enforcement of property rights protection in a joint venture," provides a theoretical basis on which the optimal enforcement of property rights could be based, in a situation of joint venture between a multinational and a local firm. A local firm, apart from receiving a share of profits, also gains technological knowledge from the multinational firm, over the duration of the joint venture. With time, it gains enough technological knowledge to be able to defect from the partnership and start earning monopoly profits. Since the multinational is assumed to be forbidden to continue production in the home country, this clearly creates a conflict of interest. Thus, the multinational wishes to control the extent of technological transfer allowed to the local firm, such that the latter no longer has an incentive to defect. The extent of control of technology transfer is given by the degree of enforcement of property rights in the country while the degree of enforcement of property rights is determined by maximizing the social welfare. The extent of enforcement of property rights, which in this case is given by the rate of compensation payable to the mutlinational by the local firm, in the event of defection, is determined by the government, ex-ante. Knowing this rate of compensation, and thus calculating the retained monopoly profits of the local firm, post defection, the multinational firm transfers only that amount of technological knowledge such that the local firm, does no better by defecting than it does by remaining in the partnership. The optimal rate of compensation in a case where the goods are produced for the home market, has been compared with a case where the goods are produced for the export market.

In the fourth chapter, entitled "A North South model of optimal enforcement of property rights in the pharmaceutical industry," the enforcement of property rights for the protection of a non-rival good, i.e. R&D, has been explored. The optimal enforcement of property rights in this case is a restriction which on the one hand retains the incentive for R&D investment and on the other hand prevents the formation of monopoly prices in the market. It has been assumed that the technologically advanced North undertakes research activites in the pharmaceutical industry, in anticipation of profits from the production and sales of antibiotics. If the South employs reverse engineering and captures the market by undercutting prices, the profit margin anticipated by the North, falls. With this prior knowledge and with the potential for a considerable fall in the profit margin, the North will have no incentive to undertake R&D investments to begin with. This has obvious adverse health effects. A sufficient protection of the R&D incentives, that implies protection of monopoly rights over the use of the proceeds of R&D, necessitates enforcement of intellectual property rights. On the other hand, it remains important from the perspective of the Southern market, not to debar the South from reverse engineering, and consequent production and sales of the antibiotics at lower prices, since the availability of essential drugs at low prices are beneficial to large sections of the society. The chapter models this, as the basis of determination of optimal intellectual property rights or, optimal patent length. The patent length has been defined as period of time over which the North retains monopoly rights over the production and sale of antibiotics and beyond which the South has the right to reverse engineer.

Chapter 1
Literature Survey

This chapter presents a selective survey of the economic literature dealing with the role of private property and the importance of property right protection. The chapter consists of two main sections. Section 1 is concerned with the evolution of the concept of private property from the eighteen century to the beginning of the twentieth century. Section 2 surveys contemporary views (the Austrian School and the School of New Institutional Economics) and models which deal with various aspects of imperfect property rights.

1.1 The evolution of the concept of property in the history of economic thought

This section is a brief exposition of the evolution of the concept of property through the different phases in the history of economic thought, from the days of the Physiocrats, Smith, and Ricardo, up to the beginning of the twentieth century. Following Gide and Rist (1956), it is convenient to divide this long period into five epochs. The first epoch, from the the eighteen century to the beginning of the nineteenth century, was dominated by the Physiocrats, Smith, and Ricardo. The second epoch spans the first half of the nineteeth century and includes economists such as Sismondi, Saint-Simon, and Proudhon. The third epoch, stretching over the middle of the nineteenth century, was dominated by the liberal school, which includes John Stuart Mill from the Manchester School and Bastiat from the French School. The fourth epoch, extending over the second half of the nineteeth century, was the age of the dissenters from Liberalism. These include the Historical School advocating the inductive method, the State Socialists, and the Marxian economists. The fifth epoch, from the late nineteenth century to the beginning of the twentieth century, includes the Hedonistic doctrine representing a revision of the Classical theories, Solidarism which is a bridge between individualism and socialism and Anarchism that Gide and Rist describes as an "impassioned Liberalism".

The first epoch

The doctrine of the *Physiocrats* revolves around the concept of a "natural order" within which property was considered the basis. This was a crucial reason for the supreme importance of property in the Physiocratic system. Therefore, despite the belief in "laissez-faire"[1], the government, according to the Physiocrats, was responsible for protecting the rights of private property and individual liberty by removing all artificial barriers and punishing anyone who threatened the existence of these rights. The importance of land emerged from the following. Some amount of wealth, according to the Physiocrats, is destroyed during the production of new wealth. The difference between the

[1] Laissez-faire has been justified by the belief that "The movements of society are spontaneous and not artifical, and the desire for joy which manifests itself in all its activities unwittingly drives it towards the realization of the ideal type of state" (Mercier de la Riviere, Vol II, P 617)

value of the new product and the old, which is the "net product" constitutes the net increase in wealth. The Physiocrats believed that this net product was forthcoming only from agriculture, since in other classes of production like commerce or transport, labor produced nothing new, but only replaced previously produced goods. Even though it were true that such modification or replacement increases the value of product, the increase is only in proportion to the amount of wealth consumed, in order to produce it, given that price of labor equals the cost of the consumption by the worker. On the other hand, the "net product" constituting additional value, originated from agriculture, because labor worked in cooperation with land. Land, therefore, was considered the basic source of an increase in value.

Quesnay described a tripartite division of society to explain the importance of agriculture.

1. *Productive class*, consisting of agriculturists, fishermen and miners.

2. *Proprietory class,* comprising the landed proprietors and those who have some title to sovereignty of any kind.

3. *Sterile class,* including merchants, manufacturers, domestic servants and members of the liberal professions.

The productive class included the suppliers of the flow of wealth. The proprietory class lived upon the rents earned and received food from the productive class and manufactured goods from the sterile class in exchange of payment from the rents received. The sterile class produced nothing given that manufacturers were assumed only to modify raw materials, the value created by modification being only equal to the consumption cost of labor. Receipts from the productive class was in exchange for the payment by the productive class in exchange for the manufactured goods and the payment by the proprietory class in exchange for the manufactured goods. These were paid to the agriculture class while buying the necessities of life and the raw material for the industry. In this manner, the total that had gone out of the hands of the productive class, went back to them. The productive class, therefore, was assumed to be the sole source of sustenance of the entire system. Despite this, the singular position that the proprietory class held in the tripartite division of the society is worthy of note, since it was the class that enjoyed two-fiths of the national revenue[2] and contributed nothing in return. Further, the term "sterile" had been attributed to manufacturers instead of the proprietors. This arose from the reverence that the Physiocrats had for the landed class since according to them, it was from their hands that the rest received the elements of nutrition.[3] The premier position according to their principles should have been given to the productive class. However, since land was not of their making, the proprietor class took precedence because they were the first dispensers of wealth.[4] The Physiocrats did not recognize

[2] Gide and Rist, page 40

[3] "It is impossible not to recognize the right of property as a divine institution, for it has been ordained that this should be the indirect means of perpetuating the work of creation" (Riviere, p. 618)

"The order of society presupposes the existence of a third class in society, namely, the proprietors who make peparation for the work of cultivation and who dispense the net product" (Quesnay, p. 186)

[4] "Immediately below the landed proprietors come the productive classes, whose labour

the importance of labour since according to them labour was not the creator of wealth. This applied to both agricultural and industrial workers, where the former was considered productive solely because it worked in cooperation with nature. So it was nature that produced wealth and not the worker. The Physiocrats believed that landed ownership was the direct outcome of personal property. This right includes the right of personal estate, which in turn involves the right of landed property.[5] Accordingly, the preservation of the "natural order" and the defending of its basis, i.e. private property, is the first duty of a sovereign.[6]

Apart from the division of labor and the invention of money, *Adam Smith* thought there was no phenomenon of greater importance and no more essential form of national wealth than capital, since the larger the stock of capital, the greater is the number of productive workers and the further will the division of labour extend. To increase a nation's capital therefore is to expand its industry and to enhance its well-being.[7] Smith thought that a nation

is the only source of their income, but who cannot excercise that labour unless the landlord has already incurred some outlay in the way of ground expenses" (Baudeau, Philosophie economique, p. 691).

[5] According to Quesnay,"The safety of private property is the real basis of the economic order of society". This view has been expressed metaphorically as follows."Property may be regarded as a tree of which social institutions are branches growing out of the trunk" - Mercier de la Riviere (Vol I, p 615, 617)

[6] "No order of any kind is possible in society unless the right of possession is guaranteed to the members of that society by the force of a sovereign authority" (Dupont, Discours en tete des Ceuvres de Quesnay, Vol I, p., 22).

[7] "The annual produce of the land and labor of any nation can be increased in its value by no other means, but by increasing either the number of its productive laborers, or the productive powers of those labourers who had before been employed. The number of its productive labourers, it is evident can never be much increased, but in consequence either

should employ its capital in order to give preference to agriculture and then engage in other branches as permitted by the capital stock. Even in the industries, every capitalist will preferably choose that which results in the production of the greatest exchange value, noticing that his profit varies with the amount of the exchange value. The simultaneous desire of keeping one's capital within reach and of finding the most profitable area for investment, leads every capitalist to employ his capital in the manner, which is most advantageous for the nation. According to Adam Smith, this expected profit from "improving one's stock of capital" depends on private property rights. Accordingly, it is an assumption central to capitalism that property rights encourage their holders to develop property, generate wealth, and efficiently allocate resources based on the operation of markets. It is from this, that the modern conception of property has evolved as a right enforced, in the expectation that this will produce more wealth and higher standards of living.

After the phase of economic thought where discoveries of new facts and the ensuing benefits on individuals and nations were the identifying factor, there was a phase of the Pessimists, 'who cast a shadow across the radiant dawn of economics'[8] that led Carlyle to term Economics as a "Dismal Science." One of the best-known representatives of this school was Ricardo, whose theory of rent affords a target for Marxians in their general attack

of some addition and improvement to those machines and instruments which facilitate and abridge labour; or of a more proper division and distribution of employment. In either case an additional capital is almost always required." - Wealth of Nations, Book II, chapter iii,Vol. I, p. 325.

[8]Gide and Rist, pg 133

upon private property. Ricardian rent is the difference in value created by usage of additional labour in cultivating the same quantity of produce on a marginal piece of land, which is inferior in quality. The theory of rent, endangered the reputation of landowners by showing that their income is not the product of labour. According to this theory, rent, unlike profit and wages, does not figure in cost of production because it makes no contribution to the price of corn, but is rather determined by the price, such that the landed proprietor does not produce rent, but rather accepts it. Therefore, the interest of the proprietors are the following. First that population and its demands should increase as rapidly as possible, so that labour may be forced to cultivate new lands. Second, that the new pieces of land should be as sterile as possible, so that more effort required may cause an increase in rents. This suggests that labour is the only means of production while land is dismissed because rent contributes nothing to the creation of value, but is rather entirely dependant on value. In this sense, land or landed property or the sense of property in general, lost much of its importance in comparison to the Physiocratic doctrine.

The second epoch

In a phase of a direct attack, criticisms and objections on the newly and incompletely formulated science of political economy by the classical economists, the *Antagonists* or the *Utopian Socialists*, demanded the suppression of private property, the extinction of inheritence, and centralized control of industry by the government. The famous doctrine belonging to this school, i.e. the "Doctrine de Saint-Simon" resolves itself into an elaborate criticism of private property. The criticism is directed from two points of view - that of distribution and production of wealth, and that of justice and utility. On the first point, their justification is as follows. Property is defined as consisting of wealth which is not immediately consumed, but which entitles its owner to a revenue. Within this category is owned two agents of production - land and capital. Distribution takes place through a series of operations which give rise to the economic phenomena of interest and rent. Consequently the worker is forced to share the fruits of his labour. Whatever is received by the few individuals who own land and capital must come forth as result of labour from others. This is basically exploitation.

Like every socialist, *Proudhon* (whose influence continued beyond the revolution of 1848) considered labour alone to be productive. Land and capital were useless without labour. Hence the demand of the proprietor for a share of the produce as a return for the yield from his capital is unwarranted. Proudhon's own definition of property is "the right to enjoy the fruits of industry, or of the labour of others or to dispose of those fruits to others by will." The criticism of socialism helped Proudhon define the positive basis of his own system. The terms of the social problem as interpreted by him are as follows. On the one hand there is suppression of unearned income derived from property. On the other hand, property itself must be preserved, and liberty of work and right of exchange must be secured. In other words, the fundamental attribute of property must be removed without damaging the institution of property itself or endangering the principle of liberty. The fault Proudhon finds with liberalism is that it could never bring liberty and equality to every one. The all-powerful State, according to him, poses the supreme threat to modern communities.[9] Thus it is that "property, in its origin and nature a vicious and antisocial principle is yet destined to become by its very universality and the co-operation of other institutions the pivot and the mainspring of the entire social system."[10]

The third epoch

The combat having grown fierce amongst the critics of the Classical writers, the Classical School branched into two camps, the English and the French *Liberalists*, who were both defenders of the twin principles of Liberalism and Individualism. The first, under the leadership of John Stuart Mill and the second, with Bastiat as its chief, reaffirmed faith in the 'natural order' and laissez-faire. France having been the forerunner of socialism, was faced by both Socialism and Protection. Also, since the French School was characterized by optimism, Ricardo's law of rent went to their disfavour. If the theory of Ricardian rent were proved true, the intuition of property would have to be abandoned altogether, and victory would lie with the socialists,

[9] In his "Théorie nouvelle de la propriété" he regards property as " the greatest revolutionary effort in existence that can put up an opposition to power." The state, *"though constituted in the most rational and the most liberal fashion and animated by the purest intentions is none the less a mighty power, capable of wiping out everything around it if it is not given some counterweight. What is this counterweight to be? Where shall we find a power capable of counterbalancing this fordidable might of the state? There is no other except property. Take the sum total of all forces of property and you have a might equal to that of the State." (p. 137).*

[10] Gide and Rist, pg. 328

whom the economists regarded as somewhat of a social nuisance. Bastiat defended the paradox that nature or land gratuitously offers its products to all men. Though they possess some value, the price paid for them does not cover the natural utility of those products. Every product, according to Bastiat, contains two layers of superimposed utilities. One coming from 'onerous toil' that must be paid for and the other, a gift of nature which is unpaid. This lower stratum, though considerably important, is ignored simply because it is not revealed in price. A commodity that is free, like air or light, is a common possession. The same idea has been expressed by saying that below the apparent layer of value viz. individual property, there lies an invisible layer of common property, which according to Bastiat, is the essential law of social harmony. It is a general law of industry that with the progress of invention, the human effort necessary to obtain an equal amount of satisfaction diminishes. This is true, not only of the products of land, but also of land itself. Property then is considered as a sum of values, where every diminution of value must be interpreted as a constant restriction of property rights.

The fourth epoch

According to the Socialists, there existed neither capital nor a capitalist in period before the 16th century. Capital in the economic sense must have existed even before, but according to the socialists, it had a different significance then. Their employment of the term capital is anything that yields a rent as a result of the toil of others rather than that of the capitalists. Under the guild system, prior to this condition, most of the workers owned the instruments of production. After this, with new means of communication established, and new markets opened as the result of important maritime discoveries coupled with the consolidation of the great modern States, the rise of banks etc., there was concentration of capital in the hands of a few. If capital in this newer sense was to come to its own and develop, and if the surplus labour and surplus value were to contribute to the growth and upkeep of this capital, it was necessary that the capitalist should be able to buy labour in the open market. But labour-force can be bought only after it has been detached from the instruments of production. This suggests that labor must be free and saleable; or, in other words, it must be forced to sell itself because the labourer has nothing else to sell. Such was the *Marxian* concept of creation of this new kind of property based upon the labour of others.

The fifth epoch

The doctrine of the *Anarchists*, was a mix of Liberal and social doctrines. Its criticism of the State, its enthusiasm for individual initiative and incorporation of a spontaneous economic order are features it owes to Liberalism. Its hatred of private property and its theory of exploitation were borrowed from socialism. Peter Kropotkin, one of the most important anarchists, thinks that every law must belong to one or other of three categories. The first category includes all laws concerned with the security of the the individual. The second one consists of all laws concerned with the protection of the government. The third one is made of all those enactments where the chief object in view is the inviolability of private property. Property, according to the anarchists, as according to the Socialists, is an organisation which allows a minority of proprietors to exploit the masses. However, whether the extinction of private property, which would liberate the worker from being exploited by the rich, would also render the State unnecessary, is a issue upon which the anarchists are divided.

1.2 Contemporary approaches to property rights

Despite the general recognition by most economists that private ownership provides powerful incentives for the efficient allocation of scarce resources, those sympathetic to socialism believed that socialism could transcend these incentive problems. To counter socilalism, Ludwig von Mises, one of the forerunners of the *Austrian* school, argued that even if the assumed change in human nature took place, socialism would fail because of the economic planners' inability to rationally calculate alternative uses of resources. According to Mises, without private ownership of the means of production, there would be no market for the means of production and no money prices for the means of production. And without money prices reflecting the relative scarcities of the means of production, economic planners would be unable to rationally calculate the alternative uses of the means of production. According to the free market view, in which Mises had a significant influence, a secure system of private property rights is a necessary part of economic freedom. Such systems include the right to control and benefit from property and the right to transfer property by voluntary means and rights to offer people the possibility of autonomy and self-determination according to their personal values and goals. A secure system of property rights reduces uncertainty and encourages investments, creating favorable conditions for a successful economy.

The *New Institutional Economics* is a modification of neo-classical theory to the extent that, in addition to modifying the rationality axiom, it adds institutions as a constraint and analyzes the role of transaction costs. It focuses on the dichotomy between private or individual and common or state property, and regards property rights as an eternal and universal instrument of society to help its members interact with each other through economic exchanges. Property rights are defined as the exclusive, transferable and legal rights to the physical use of scarce resources and the returns from them. Unlike the neoclassical model however, the new institutional economics regards trasaction costs to be the determinant of the way by which property rights are allocated and enforced. Douglas North and Robert Thomas were among the initial researchers who argue that institutions are prerequisites for economic growth. Institutions include social norms, educational and political systems of a country, along with attitudes such as openness to trade etc. Strong institutions enable individuals, groups, and firms to engage in the specialization and exchange that is required for the process of growth.

The "property rights" literature postulates that modifications must be made in the conventional analytical framework if economic models having wider applicability are to be developed. Accordingly, it has introduced a number of extensions into the theory of production and exchange. First, a new interpretation has been given to the role of individual decision makers within the productive organization, where individuals rather than an organization are the central focus. They are assumed to be self-interested and to maximize utility subject to the constraints established by the current organizational structure. Second, it has been noted that more than one pattern of property rights can exist and that profit maximization is not assured. Third, transactions costs are recognized as being significant. Property rights specify the norms of behavior with respect to things that every individual must observe during his interactions with other individuals. The prevailing system of property rights therefore is defined as the set of economic and social relations defining the position of each individual with respect to the utilization of a scarce resource. According to Demsetz (1967), a primary function of property rights is to act as a guiding incentive towards a greater internalization of externalities. Every cost and benefit associated with socially interdependent actions is a possible externality. A condition necessary to make costs and benefits externalities is that the cost of internalization, must be greater than the gains from it. Here, externality refers to external costs, external benefits, and include pecuniary as well as nonpecuniary externalities. A harmful or beneficial effect is turned into an externality because the cost of having these effects to affect the decisions of the interacting persons is too high. Internalization, therefore, refers to a change in property rights, such that these effects to bear to a greater extent on the interacting individuals.

In keeping with the above viewpoints and in an attempt to complete the idea by specifying the fact that a theory of property rights cannot be complete without a theory of a state that enforces them, Furubotn and Pejovich (1972) dealt with the effects of private property rights and state ownership on the allocation and use of resources. The right of ownership of an asset, by a private party or the state, consists of the right to use it, to change its form and to transfer the rights in the asset through sales etc. North (1973) argues that the state frequently trades inefficient property rights for revenue, thereby inhibiting economic growth. Changes in the structure of property rights depend on the relationship between an ex ante estimate of benefits to the ruling elite from changing the existing property rights and the enforcement costs to be incurred thereon. Given this, the efficient size of a political organization must be affected by the size of markets and the military endowment of the state. Besley and Persson (2007) find, that investments in legal and scale capacity are often complements.

In general, there can be four kinds of property rights regimes, from no or minimum property rights to maximum property rights held by individuals.

1. Open access property - Bromley (1991) considers the open access property rights regime as one in which there are no property rights. There

is no defined group of users or owners and benefit streams from the common pool resource are available to anyone. Individuals have privileges but no rights with respect to use rates and maintenance of the asset.

2. State property - is property owned by the state. In most states, a large number of libraries, schools, etc. are state owned.

3. Common property - Common pool resources handled under the common property regimes have two important characteristics. First, exclusion of resource users to these resources is difficult. Second, the use of resources by one person tends to reduce the welfare of other users. These resources are therefore potentially subject to depletion or degradation. Berkes and Farer (1988) define common-property resources as a class of resources for which exclusion is difficult and joint use involves substractability, while Bromley (1991) argues that a common property regime represents private property for the group of co-owners and individuals have rights and duties with respect to the relevant resource. Common property is similar to private property in the sense that there is exclusion of non-owners. The tragedy of the commons has long been well recognized (Gordon, 1954, Hardin, 1968).[11] If individuals have common access to a resource stock, they tend to over-exploit it. While some societies succesfully develop institutions and norms of behavior that to some extent mitigate the tragedy of the commons (Ostrom, 1990), there are obvious cases of extreme over-exploitation.[12]

[11] Gordon, H. Scott (1954), "Economic Theory of Common Property Resources," *Journal of Political Economy*, Vol. 62(2), 124-142.Hardin, G. (1968), "The Tragedy of the Commons," *Science* 162, 1243-8.

[12] Ostrom, E. (1990), *Governing the Commons: The Evolution of Institutions for Col-*

4. Private property - is the right of individuals or firms to obtain, own, use and dispose of land, capital and other forms of property. The three basic elements of private property are '(1) exclusivity of rights to choose the use of a resource (2) exclusivity of rights to the services of a resource, and (3) rights to exchange the resource at mutually agreeable terms.'

1.2.1 Formation of Property Rights and The Role of State

There have been many studies on contemporary cases of the evolution of property rights. Alston, Libecap and Mueller (1997, 1999a, 1999b, 2000) analyze the evolution and effects of property rights in the Brazilian Amazon. Besley (1995) focussed on the impact of property rights on land use in Ghana. Feder and Feeny, (1991) examined property rights in Thailand while Migot-Adholla et al.(1991) studied the effects of property rights in Sub-Saharan Africa. Other studies at a theoretical level are explained in detail below.

Anderson and Hill (1975) combine economic theory and history to analyze how a property rights structure comes into being. They use the dynamic process of property right development which enumerates the variables responsible for changing definition and enforcement activities and which explains the timing of these changes. By expressing the amount of property rights definition and enforcement activities as a function of marginal benefits and marginal costs and by specifying the shift parameter for each function,

lective Actions. Cambrige: Cambridge University Press.

they have explained the existing structure of property rights in a society and also used it to provide a vehicle with which to analyze changes in property rights over time. It has been argued that the social arrangements, laws and customs which determine asset ownership are established on the basis of variables endogenous to the system. On the benefit side of the investment decision of an individual are the value of the asset and productivity of the activity to enforce property rights. The higher the value of the asset and higher the probability of losing the right to use the asset, the greater is the degree of enforcement activity. On the cost side is the production function for such activities and the opportunity cost of resources devoted to enforcement. Technological change influences the property rights enforcement activity.

Umbeck (1981) uses the theory of competition to carry out a theoretical investigation into the factors that contribute to the formation of property rights, and points to violence as the major constraint to the formation of a property rights regime. Many economic models assumed that the rights to all scarce resources are clearly defined and have been rationed out to individuals according to some given initial endowment process. However, though individuals agreeing to respect each other's ownership rights may do so through customs or traditions, they may also use a contract and yet need to use some force or threat of force. This follows from the rule of individual maximization. One person will (if possible) violate the terms of agreement to deprive another of his assigned rights only if gains exceed costs. Thus the contracting group must agree to impose costs upon anyone who would take someone else's property. It has been argued therefore, that the relevant constraint upon the initial distribution of property is violence, i.e., if individuals are not in agreement, they are left with only one alternative; the use of force. Any contractual arrangement entered into by wealth maximizers therefore must assign to each individual the rights to at least as much property as they could acquire by personal force.

Meza and Gould (1992) point out that enforcement of private property rights is costly and private decisions to enforce rights in a perfectly competitive economy may result in either greater or lesser enforcement than is socially efficient. They find cases of multiple stable equilibria, where an equilibrium may be locally, but not globally efficient, since resources employed may not be socially optimal, and enforcement may be accompanied by inefficient investment in resource productivity. In general, the justification for enforcement of private property rights is that it facilitates socially efficient exploitation of resources, enable the owner to exclude others from his resource and thus internalize the externalities that would occur if access were free. This paper analyses the consequences of the fact that owners incur costs in order to enforce their private property rights. Though it might seem that an owner's decision to enclose his property, requiring a positive rent net of enforcement costs, is consistent with social efficiency, it is also possible that there may be too much enclosure. The most important result is that a perfectly competitive equilibrium may be inefficient though well-defined property rights are assigned over all inputs and outputs and are universally enforced such that externalities are absent (in the sense that they are only potentially active.) The government could revoke private property rights over the resource in a case where sites are enclosed in the current equilibrium and in a case where a potential equilibrium with free access to all sites is the global optimum, though this would destroy productivity improving investment incentives.

Alston and Mueller (2005) analyze how a country's institutions determine the evolution of property rights and whether it comes about through cooperation, conflict or by State intervention. Along with non-institutional factors such as the homogeneity of the population and relative endowments, the institutions find those groups that have the ability to block a change. Institutions can also choose to facilitate cooperation by providing low-cost means to make credible commitments. Using a demand-supply framework, with the State as the supplier of property rights, the demand for property rights is defined as follows. The potential rent generation from secure property rights increases as the resource becomes more scarce. The increase in the rental stream from an asset with more secure property rights generates a demand for secure property rights. The force that change property rights is the lost rent from a different set of property rights. In homogeneous societies the supply of property rights may come from the participants themselves.The supply of formal property rights tends to emerge from an increasingly heterogeneous composition of participants, or, an increase in the rents of an asset causing a race for property rights. The state however is seen to have a comparative advantage in violence and hence have better capabilities than private actors for the enforcement of formal property rights. Three situations have been pointed out, when the state may not be able to change formal property rights. First, there are rampant informational problems, such that citizens are unaware of the optimal policy changes that would improve on the status quo. Second, even when aware, there are problems with collective action, and third, insecurity in political property rights prevents the society from making the required side-payments in the political arena that would initiate change in property rights.

Besley and Persson (2009) develop a framework where past investments in the legal and scale capacity of the state constrain policy choices in market regulation and taxation. Their paper aims to deal with empirical issues as so why rich countries are also high-tax countries with good enforcement of contracts and property rights, why parliamentary democracies have more secure property rights and higher taxes than presidential democracies. Using a framework where regulation of market supporting measures and tax rates are endogenous policy choices, constrained by the legal and the scale capacity of the state that have been inherited from the past, the model treats the state's legal and scale capacity as ex-ante investments under uncertainty.

1.2.2 Property Rights and Conflict Theory

Skaperdas (1992) started off by examining interactions in the absence of property rights when agents face a trade-off between productive and coercive activities. Other things remaining equal, an agent's power is inversely related to his resources when resources are valued according to marginal-productivity theory. Interactions in the absence of property rights come up with two things. First the agents are seen to cooperate in equilibrium when conflict is ineffective, which is possible, when win probabilities are significantly different and when their marginal contributions to production are similar. Second, it is shown that the more powerful agent always possesses less valuable productive resources when resources are valued as per the theory of marginal productivity, since the more powerful agent invests more in arms he must have a lower opportunity cost for it.

Grossman and Kim (1995) develop a general equilibrium model where resources are allocated between appropriative and productive activities. The analysis shows how the security of claims to property is determined in equilibrium. A non-aggressive equilibrium is found, in which no resources are allocated to offensive weapons and claims to property are fully secure. All economic agents, acting individually or collectively, face the choice of allocating resources among appropriative and productive activities. Moreover, it is difficult to find an economic agent who allocates no resources to appropriative activities. The model emphasizes the distinction between offensive weapons, i.e. the instruments of predation, and fortifications, providing defense against predation. The analysis focused on the possible existence of a non-aggressive equilibrium, in which no resources are allocated to predation and claims to property are fully secure. The authors showed that in a non-aggressive equilibrium, offensive weapons are not too effective against the defensive fortifications or the predation are sufficiently destructive. It was also found that if claims to property are less than fully secure in an equilibrium, then the security of claims to property is inversely related to the effectiveness of offensive weapons against defensive fortifications and positively related to the destructiveness of predation. Further, if claims to property are very secure, then the total cost of appropriative activities is greater with less secure claims to property. On the other hand, if the security of claims to property is low, then the total cost of appropriative activities is larger with more secure claims to property.

Gonzalez (2007) shows that the interaction between conflict and growth can give rise to a non-monotone relationship between property rights and social welfare. The author formulates an AK model of endogenous growth in which equilibrium diversion of resources is the cost of securing effective property rights. An equilibrium allocation of resources with more secure property rights and faster growth is shown to be Pareto dominated by an equilibrium with poorer property rights and slower growth. The aim is to argue why more secure property rights may not always be conducive to Pareto superior social allocations. The author considers the case of the individual incentive to engage in appropriative activities when the government cannot fully enforce the law and protect property rights. The security of property is seen to be the outcome of the resources allocated to a challenge of property claims, and the given structure of property rights.

The analysis by Gonzalez has shown that the interaction between conflict and growth can lead to an equilibrium allocation where a relatively greater security of property and faster growth is Pareto dominated by an equilibrium allocation associated with less property security and slower growth. The results suggest that pursuing economic growth independently of the structure of property rights is not advisable. Further, if the institutional structure is inappropriate, a substantial reform might be necessary for improvement in welfare.

1.2.3 Property Rights and Economic Growth

There is a significant strand of literature that analyzes the contribution of security of property rights to economic growth. De Soto (1990, 2000) argues that the protection of property rights is an important economic institution because of its major role as an engine of economic growth. Institutions and secure property rights give individuals incentives to innovate and produce value rather than trying to enrich themselves by inefficient methods such as rent-seeking, theft etc. Continuous economic growth through innovation, human capital formation, and lower transaction costs is dependant on the existence of property rights. De Sotto observes a significant disparity in formal private property protection between developed and developing countries, and believes this to be the main reason for divergence in growth. In other words, property rights are secure in successful countries and unsecure or unclearly defined in developing countries.

Leblang (1996), in attempting to identify institutional factors influencing the per capita growth rate of a nation, focussed on differences in political regimes. In other words, the explanation of why some countries grow faster than the others must come of an explanation of the relative strength of property rights. Usng new measures for property rights protection and democracy and building on an endogenous growth model the paper presents an approximate relation between property rights, democracy and economic growth. Testing the hypothesis using cross-country panel data from 1960-1990, the evidence supports two conclusions. First, economies of nations that protect property rights grow more rapidly than those of nations that do not protect property rights. Second, the nature of a political regime influences economic growth indirectly through its commitment to property rights.

Bridging the gap between the growth literature where agents optimize (in a given institutional framework) and the literature on institutional change that lacks frugal optimizing models, Tornell (1997) introduced endogenous institutional change into an optimizing growth model. The model is a combination of a preemption game between two rent-seeking groups and an AK model of growth. The property rights regime can shift between common property (each group has access to aggregate capital), private property (each group has access only to its own capital stock), and the leader-follower regime (one group has access to aggregate capital). At every instant each group decides on how much to save and on whether to incur a one-time loss as the cost of affecting a change in the property-rights regime. Each group makes these decisions in view of the strategy of the other group. At any moment either group can displace the other group from its access to the capital stock by incurring a one-time loss (think of the cost of building a wall around an estate). The model allows property rights to shift back and forth between regimes of private and common property, the shifts being generated by the attempts of rent-seeking groups to secure access to a larger share of the aggregate capital stock. The author considers an economy in which common property prevails initially. It is found that, depending on parameter values, the economy can get stuck in common property thereby suffering from low growth forever, or it can follow a cycle in which a shift to private property occurs when the economy becomes rich enough so that it is worthwhile for groups to incur the cost of creating institutions to defend private profits. Then, as the economy becomes richer, and rent-seeking becomes profitable, the interest groups erode these institutions and bring the economy full circle back to common property. The growth rate increases in the first phase of this cycle, declines in the second, and is constant at its minimum in the third.

Zak (2002) proposes a theory of growth in which property rights are insecure and costly to enforce. Violations of property rights occur between two groups in the society, one being the accumulator and the other the expropriator. This leads the former to establish institutions to protect property. The four main results of the paper are as follows. First, insecure property rights cause countries to be caught in a poverty trap. Second, even if countries escape the poverty trap, they will have permanently lower levels of per capita income as compared countries with well-enforced property rights. Third, property rights violations can lead to endogenous formation of government institutions to formulate policies for the enforcement of property rights. Fourth, developing countries with insecure property rights may not be able to escape a poverty trap even if an optimal amount of resources are allocated towards property rights protection. This paper was inspired by the conflict models presented by Grossman and Kim (1995, 1996). The former, incorporates the theory of predation into economic growth. It formulates a dynamic general-equilibrium model of interaction between two dynasties, a potential predator and the prey. Each generation of each dynasty allocates an endowment of inherited wealth into consumption and productive capital, and also to either defensive fortifications or offensive weapons. The paper finds that, if the current wealth of the potential predator is small relative to the current wealth of the prey, then the prey dynasty chooses to tolerate rather than deter predation. It further finds that over generations the security of the property and the rate of accumulation of the productive capital of the prey both steadily decrease, while the inherited wealth of the predator grows relative to that of the prey. Over time, a generation of the prey dynasty finds that with predation its property is so insecure that it is better off increasing its defensive fortifications to deter predation.

Lewer and Sanz (2002) provide empirical evidence supporting the role of property rights in the development process. In many countries today, significant barriers to obtain legal and formal property rights continue to exist.

Applying property rights data from 1990-2002, the property rights hypothesis is tested for a group of 101 countries. The results support the hypothesis suggesting a positive relationship between property rights and economic growth. Specifically, countries whose citizens have secure and legal property rights tend to grow faster than countries with weaker property rights. They suggest, that countries with secure property rights are able to grow faster partially because of faster technology growth and entrepreneurial activity.

Long and Sorger (2006) study economic growth in the presence of powerful groups in society where property rights are not secure. When legal or political institutions are weak, powerful groups can redistribute the aggregate capital stock among themselves. As per the models in Tornell and Velasco (1992) and Tornell and Lane (1999), if there are finitely many groups who access the capital stock, then capital becomes a common property so that the powerful groups do not internalize the negative effects which their appropriation efforts have on the production capacity of the economy. Therefore economic growth is inefficiently low. Extending the model from Tornell and Velasco (1992) and Tornell and Lane (1999), Long and Sorger (2006) add three features. First, extraction of the common property asset involves a private appropriation cost. Second, agents derive utility from wealth and consumption, and third, agents are heterogeneous. The most important result shows that a high cost of money laundering is detrimental to economic growth. Further, countries where powerful groups have equal appropriation costs have higher growth rates than countries where they have unequal costs.

2 Conclusion

This chapter has outlined the gradual evolution of the concept of property and thus rights to property, beginning from the Physiocrats up to the recent literature in property rights. It has been noticed that the importance that economists accorded to property had its ups and downs through the various phases of economic thought, up until the development of the New Institutional Economics where property rights an institution was formally introduced into the neo-classical theory. Thereafter, there have been analyses of the formation, impact and reasons for change in the structure of property rights in economic interactions between individuals or groups of individuals. It has been seen that while the interactions between individuals are governed by the existing property rights regimes, a change in the regime itself results from inefficiences in such interactions. The next chapter formalizes a model to show how a property right regime evolves.

Chapter 2
Evolution of Property Rights Regimes

2.1 Introduction

Property rights may be broadly defined as a set of rights pertaining to an individual or a legal entity (such as a corporation) with respect to the ownership of goods. The control of an invidual over the use of his properties, the right to transfer or sell, to derive benefits from and to exclude others from use of the properties are the major constituents of property rights. The incentive of an individual to increase his stock of capital (or wealth), which partly rests on the expected profits accruing from such capital, depends on the effectiveness of the existing property rights regime.

While the existing property rights regime in a given economy influences its economic performance, the evolution of an economy itself necessitates changes in the existing regime. In other words, if rules regarding property rights serve the interest of protection of capital and wealth accumulation of individuals, then individuals who can influence the construction of such rules, by virtue of their wealth or otherwise, would seek to influence changes in the property right regime for the sake of self-interest.

This chapter sets up and analyses a simple model to address this issue. The model shows how an economy may move from a regime of partially secure property rights, to a regime where property rights are more secure. A regime of partially secure property rights is characterized by the presence of rent-seeking activities.

The model has been built on the insight offered by the series of papers contributed by Gradstein (2004, 2007, 2008).

Gradstein (2004) points out that rich economies enforce property rights more effectively than poor economies. He assumes that individuals in the economy devote part of their resources to rent-seeking activities. Since enforcement of property rights is costly, enforcement occurs in richer economies where affluent individuals are willing to incur the cost. Stronger enforcement causes faster economic growth, which in turn increases willingness to secure property rights. In his model there are two steady states. One steady state is characterized by high income and full protection of property rights, while the other steady state exhibits minimal protection and a low level of income.

Gradstein (2007) considers the role of income distribution on the evolution of property rights. According to this paper, an economy's property right regime is a result of political decision making. A more equal income distribution tends to favor a more secure property rights regime. In an economy where income distribution is highly unequal, democratization is not possible. A movement away from political power in the hands of a small wealthy elite to democracy involves simultaneously a redistribution of wealth away from the elite towards the poor. Democracy will only be opted for if the ultimate growth benefits from democratization and secure property rights regime outweigh the impact of redistribution of wealth away from the rich.

In Gradstein (2008) it is argued that the ultimate determinants of economic performance is not so much the institutional blueprint per se, as the underlying economic structure, which in fact sustains the blueprint. This paper goes a step further than Gradstein (2007) to conclude that while the quality of institutions (i.e., the degree of enforcement of property rights) determines future incomes and growth, the institutions themselves are determined by the current economic structure and the decisions taken thereon. While decisions on institutions are political, it is basically the level of income inequality that determines the outcome in this regard. In developing economies, the richer are less interested in strong institutions than the poor owing to the fact that stronger institutions negate their capacity to appropriate wealth away from the poor. Further, in this model, if the political bias is substantial, then income inequality and poor institutional quality may reinforce each other potentially creating different developmental paths. While the good equilibrium includes low level of inequality, high institutional quality and rapid growth, the bad equilibrium is characterized by high income inequality, low institutional quality and slow growth. The existence of the latter leads to another major conclusion of the paper: poor institutional quality and economic backwardness can be persistent.

The model in this chapter differs from those of Gradstein in the following aspects. First, the degree of enforcement of property rights, λ, is modelled as a continuous variable that can move between 0 and 1. Second, the cost of enforcement is defined as a function of two variables, namely the degree of enforcement and the size of the economy. Third, the effectiveness of an individual's rent seeking activity is assumed to be function of three variables: (i) the amount of resource devoted to rent-seeking, (ii) the size of investment, and (iii) the degree of enforcement of property rights prevailing in the society. Fourth, the model postulates a subsistence level of consumption, x, below which there can be no capital accumulation. Using these assumptions, the model shows the presence of multiple steady-state agggregate capital stock levels, some of which are stable while others are unstable. The different equilibria are associated with different endogenously determined degrees of property rights enforcement.

The rest of the chapter has been organized as follows. Section 2 presents a survey of the literature. Section 3 lays out the basic model. Section 4 determines the optimal choice of property rights regime and equilibrium income levels for homogeneous households. Section 5 illustrates the case when the cost of enforcement is a non-linear function of degree two. Section 6 concludes the discussion.

2.2 A survey of related literature

In stark contrast to the standard general equilibrium model, known as the Arrow-Debreu model, which assumes perfect honesty and respect for property rights and takes for granted that individuals have complete control over their endowments and firms have complete control over their inputs, the literature on growth and development (Bardhan, 1997, Dixit, 2004) takes the view that corruption is a major fact of life[1]. Though Gould (1991) defines corruption as a moral problem[2], narrowing down the scope of corruption to a mere behavioural problem undermines the existence of it as a social, economic and a political phenomenon. To exist, corruption must be supported by discretionary power, weak institutional structure and the presence of economic rents (Jain, 2001). In other words, discretionary power, or authority to lay out laws and strictures, accompanied by the presence of economic rents (an essential bedfellow with power), must be supported by a weak legal system in order to nurture corruption within an economy. Thus corruption must imply the lack of enforcement of personal safety rights and individual rights to property. While there are enormous disparities in the level of corruption across economies (Rose-Ackerman, 2006), the methods of measurement of corruption have been subjected to enormous criticism, on grounds of non-reliability of survey information, that have a tendency to under report the extent of corruption, and on grounds of decreasing reliability of the index of measurement over time (Golden and Picci, 2005). Further, as Kaufmann and Kray (2002b) point out, while the cross country surveys serve as a good basis for comparison, the problem with such surveys is that they are typically

[1] "While corruption in one form or another has always been with us, it has had variegated incidence in different times at different places, with varying degrees of damaging consequences" - Bardhan (1997)

[2] "an immoral and unethical phenomenon that contains a set of moral aberrations from moral standards of society.." - Gould (1991), page 468.

based on the opinions of a handful of experts in each country. Seldayo and Haan, (2006), having examined 70 economic and non-economic determinants of corruption, and having deviced 5 new indices on the basis of these determinants to explain corruption, report problems of multicollinearity in regression owing to the interdependance among the determinants, apart from problems of missing data arising of multiple sources. Despite, these hindrances in the measurement and determination of the accurate level of corruption in an economy, and comparative levels of corruption across countries, it remains true that corruption has been singled out as the "single greatest obstacle to economic and social development"[3] Therefore, it remains essential to acknowledge corruption as an undesirable existing social phenomenon and to focus on the importance of enforcement of property rights as an effective deterrent.

In a seminal paper, to which much of the literature on property rights owes its origin, Grossman and Hart (1986) lay the microeconomic foundation of imperfect property rights. They consider a simple model where a buyer and a seller plan to trade a good that is yet undefined. The parties have the opportunity to invest in the relationship before this good is produced or its nature specified and thus gain from engaging in a prior agreement laid down by a renegotiable contract. Contractual rights consist of specific and residual rights. While it is costly to list all specific rights in the contract, ownership implies a purchase of the residual rights. Since ownership gained

[3] www1.worldbank.org/publicsector/anticorrupt/index.cfm.

by one party implies ownership lost by the other, it lends stronger bargaining power to the party having these ownership rights vis-a-vis the other. Such is the importance of ownership. Hart and Moore (1990), in an attempt to emphasize further on the importance of ownership, explain how changes in ownership affect incentives of employees and owner-managers of a firm. If it is profitable to gain ownership before entering a contract, as the two papers have emphasized, and if property rights provide legal validation and security to this ownership, then ownership, contracts and property rights must be inseperably related. Maskin and Tirole (1999) point out that most of the microeconomic models of property rights are largely based on three assumptions - renegotiable contracts, private benefits from the exercise of property rights, and risk neutrality of players.[4]

At an economy-wide level, one may argue that societies "choose" their own levels of property right enforcement taking into account considerations specific to their stages of development. These considerations, be it political unrest or the interest of select influencial groups within the economy, or the economic vialibity, must reduce to a cost-benefit analysis of enforcement in the ultimate analysis. Dixit (2004) analyzes the costs and benefits of private enforcement of property rights.

Earlier models of social conflicts (e.g. Hershel Grossman, 1995, Ades and Verdier, 1996) show how property rights are determined as a result of conflicting interests over claims to property. Grossman (1995), for example,

[4]The risk neutrality assumption is a simplifying device.

develops a model with two agents who allocate resources among offensive, defensive, and productive activities, to find the factors determining the extent of security of property claims in equilibrium. The paper finds the possibility of a non-aggressive equilibrium in which no resources are allocated to offensive weapons and claims to property are fully secure. This requires offensive weapons not to be too effective against defensive fortifications, or predation to be sufficiently destructive. A welfare analysis shows that a relatively richer agent is always better off in an equilibrium with more security of claims to property. Similarly, Gonzalez (2007) shows that the interaction between conflict and growth may give rise to a non-monotone relationship between property rights and social welfare, while Gonzalez (2005) claims that when property rights are sufficiently insecure, anticipation of conflict over economic distribution leads to technological backwardness despite superior technologies being costlessly available.

Providing an explanation as to how property rights regimes are determined in a post-communist economy, Guriev and Sonin (2009) consider in a dynamic game between two oligarchs and a dictator. They find conditions under which a dictator will choose either strong or no protection of property rights. Weak dictators, without popular support, can be overthrown by an oligarch while a strong dictator with substantial popular support, can be removed only with a consensus among oligarchs, who in turn suffer from the inability to coordinate. These authors show that a weak dictator cannot expropriate the oligarchs, and cannot resolve the rent-seeking problem either, since an oligarch can remove him from office. A strong dictator on the other hand can cease rent seeking, since his decisions are protected by the oligarchs' inability to coordinate. However he may collude with some oligarchs to expropriate others. Therefore the oligarchs may prefer a weak dictator in equilibrium even though he cannot enforce the property rights. A strong dictator once appointed can use the lack of coordination amongst oligarchs to his advantage but cannot be removed. Thus many oligarchic economies continue to remain in a persistent situation of rent seeking even though strong property rights, deterring rent seeking behavior may be better for everyone.

Since political regimes seem instrumental in determining the extent of property rights enforcement, it becomes important to understand what determines the political regimes in the first place. Acemoglu and Robinson (2001) consider redistribution as the mechanism in changing political institutions, and economic inequality as a crucial determinant of political instability because it encourages the rich to contest power in democracies and induce social unrest in non-democratic societies. They argue that democracy consolidates if inequality is limited, while instability occurs simultaneously with high inequality. In democratic societies the poor impose higher taxes on the rich than in nondemocratic societies, making the poor pro-democratic and the rich opposed to it. The threat of a revolution by the poor, specially during periods of crisis, force the rich to make preventive concessions in the form of income redistribution. Since temporary redistribution does not prevent revolution, the rich are forced to make a credible commitment to future income redistribution by extending voting rights, which changes the identity of the median voter. However, democracies are not permanent either since the rich can mount a coup, in an attempt to retake power, especially when taxes are high rendering democracy too costly. The poor in this case commit to low levels of future taxation as a preventive measure. Since taxes are high when the level of inequality is high, a highly unequal society is likely to move in and out of democracy. And since democracy is seen as crucial to the existence of strong property rights, a substantial inequality is likely to be conducive to weak property rights and retard growth.

The model of Acemoglu and Robinson (2001) draws on an earlier paper by Alesina and Rodrick (1994) who, in an attempt to model social conflict over distribution, specify a relationship between politics and economic growth in a model of endogenous growth, in which individuals are endowed with varying capital/labor shares. Financing productive government services with a small tax on capital benefits every individual. However, heterogeneity in ownership of factors implies that individuals differ on the ideal rate of taxation. A tax on capital affects the returns on capital net of taxes and increases instantaneous wage income. The lower is an individual's share of income from capital relative to labor, the higher is his ideal tax rate and lower the ideal growth rate. The optimal tax rate is determined by the tax rate selected by the median voter. The more equitable the distribution, the better endowed with capital is the median voter, the lower is the equilibrium level of capital taxation and the higher is the growth rate. The greater the inequality of wealth and income, the higher the rate of taxation and lower the growth rate. Thus inequality is confirmed as conducive to the adoption of growth-retarding policies.

A different class of models formulates differential games when property rights are not well defined. The focus is on the evolution of a stock of common asset, and a complete specification of dynamic strategies of agents.

Tornell (1997) presented a model of economic growth and decline with endogenous property rights. In his model, two groups of infinitely-lived agents solve a dynamic game over the choice of property rights regime. He showed that a possible equilibrium of the game involves multiple switching of regimes. Tornell allows each group's share of aggregate capital to change after a switch takes place and introduces a once-off lump sum cost at switching time. These features generate a hump-shaped pattern of growth even though the underlying technology is linear and preferences exhibit a constant elasticity of intertemporal substitution, $\sigma > 0$. Tornell allows three property rights regimes: common property, private property, and leader-follower. Under common property, both players have equal access to the aggregate capital stock. When one player incurs the once-off cost, it can convert the whole common property to its private property unless the other player is willing to incur the same cost. In the latter case, the result is the private property regime, where each player has access only to its own capital stock. On the other hand, starting from the private property regime, if both players simultaneously incur each the once-off cost, the regime will revert back to common property. If one player incurs the once-off cost while the other does not, the former becomes the leader and has exclusive access to the economy's capital stock. Thus, under the private property regime, the equation of motion of player i's capital stock is

$$\dot{S}_i = AS_i - C_i, \qquad i = 1, 2,$$

where S_i is the player's capital stock, C_i is its consumption. Under common property,

$$\dot{S} = AS - C_1 - C_2,$$

where S is the aggregate capital stock. Under the leader-follower regime, it is

$$\dot{S} = AS - C_L,$$

where the subscript L denotes the leader.

Tornell (1997) restricts the maximum number of regime switches to two. This simplifying assumption allows closed-form solutions, though it is somewhat arbitrary. A key parameter in this game is σ, the elasticity of intertemporal substitution. If $\sigma \leq 1$, the common property regime may last for ever. (Alternatively, if the economy starts with the private property regime, this institution may also last for ever.) In constrast, if $\sigma > 1$, the author shows that the economy must follow a cycle: a switch from the common property regime to the private property regime, and later on, a re-switching back to common property. There is no equilibrium which involves a switch to the leader-follower regime.

A somewhat different approach to dynamic strategic interactions is to assume that agents always have common access to capital. The focus of this type of model is on how a weak property rights regime can lead to the demise of an economy. Tornell and Velasco (1996) consider the exploitation of a public asset with a linear growth function, re-interpreting it as a model of corruption by powerful groups in a developing economy. Their model is used to explain why capital flows from poor countries to rich countries. A similar model is used by Tornell and Lane (1999) who show that the equilibrium choice of strategies leads to slow growth. They highlight the "voracity effect" : a shock, such as a terms-of-trade windfall can generate a disproportionate increase in fiscal redistribution and reduce growth. A dilution of the concentration of power would lead to faster growth and lower voracity.

Tornell and Velasco (1996) begin with a basic model. They assume a country has a public productive asset k. There are n powerful fractions that exploit this asset. Let $q_i(t)$ be the rate of exploitation by fraction i at time t. The objective function of fraction i is to maximize

$$\int_0^\infty \left(\frac{\sigma}{\sigma - 1}\right) [q_i(t)]^{(\sigma-1)/\sigma} \exp(-\delta t) dt$$

subject to

$$\dot{k}(t) = Ak(t) - q_i(t) - \sum_{j \neq i} q_j(t),\ A \geq 0$$

where $q_i = 0$ if $k = 0$.

The authors characterize an equilibrium in linear strategies. They focus on the symmetric equilibrium, i.e., all fractions choose the same strategy. The Nash equilibrium exploitation intensity is shown to be

$$\alpha^N = \frac{\sigma\delta + (1-\sigma)A}{n - \sigma(n-1)}$$

where by assumption $n - \sigma(n-1) > 0$.

Tornell and Velasco also develop a more general version of the model, where fractions can hold private wealth that yields a constant rate of return $r < A$. Each fraction i can extract $d_i(t)$ from the common property asset, and transfer it to its private asset holding. Consumption $c_i(t)$ is financed by withdrawing from the private asset.

The authors assume exogenous upper and lower bounds on $d_i(t)$:

$$\theta_L k(t) \leq d_i(t) \leq \theta_H k(t)$$

The authors show that there are three symmetric equilibria. An interior equilibrium occurs when all fractions use the exploitation strategy $d_i(t) = \beta^{int} k(t)$ where $\theta_L < \beta^{int} < \theta_H$. In the pessimistic equilibrium, everyone exploits at the maximum rate: $d_i(t) = \theta_H k(t)$. In the optimistic equilibrium, exploitation is at the lowest possible rate: $d_i(t) = \theta_L k(t)$.

This model shows that capital can flow from poor economies where the rate of return is high, to rich economies where the rate of return is lower. This is because each fraction knows that while the gross rate of return of holding asset in the form of k is A, the net rate of return is only $A - (n-1)\beta^{int}$, as the $(n-1)$ rivals appropriate part of the common return. In the pessimistic equilibrium, all fractions exploit at the maximum rate, because each believes that its rivals are extremely greedy, exploiting at the maximum rate.

Tornell and Lane (1999) observe that the interior equilibrium of this model displays what they call "the voracity effect": an increase in A will lead to an increase in β^{int}. This means that if the poor country under consideration experiences a technical progress (or perhaps a terms of trade improvement), the rivalrous fractions will exploit more, leading to a faster rate of depletion of the common asset.

In the models studied in Tornell and Velasco (1992) and Tornell and Lane (1999), the extraction from the common property asset stock is costless. Sorger (2005) and Long and Sorger (2006) argue it is important to have an explicit consideration of the costs of appropriation. Long and Sorger (2006) show that both an increase in the appropriation cost and, when appropriation costs vary across agents, an increase in the degree of heterogeneity of these costs, reduces the growth rate of the public capital stock.

Another feature of the model of Long and Sorger (2006), which is not present in Tornell and Velasco (1992) and Tornell and Lane (1999), is that the agents derive utility not only from consumption but also from wealth. Wealth is a vehicle for achieving social status, and people do care about social status. Long and Sorger show that an increase in the degree of heterogeneity of cost leads to slower growth, and under certain condition, a higher elasticity of substitution between wealth and consumption will lead to a higher intensity of extraction, and thus lower growth.

The above-mentioned models of the tragedy of the commons have a common feature: the assumption that agents care only about their absolute levels of consumption or/and wealth. This assumption has been criticized: there is strong empirical evidence that individuals care about relative consumption (or relative income) as well as absolute consumption. One then asks the following question: if agents exploiting a common asset care about their *relative* performance (consumption, income, or other indices of status), would social welfare and the growth rate of the public asset be more adversely affected compared to the case where they care only about their absolute performance? This question is dealt with in Long and Wang (2008).

An interesting extension of this type of model is to allow switching equilibria, as in Benhabib and Radner (1992), Benhabib and Rustichini (1996) and Tornell (1997). Benhabib and Radner (1992) present a continuous time model where agents have utility functions that are linear in consumption and have access to a common productive asset. They find an equilibrium where agents cooperate when the capital stock is low, and do not cooperate when the stock is high. Benhabib and Rustichini (1996) use a discrete time model with linear technology, and show that a switching equilibrium exists: the rate of exploitation switches to a lower level when the common asset reaches a certain threshold level. Thus their economy's growth rate is increasing in the capital stock. When the linear technology is replaced by the Cobb-Douglas production function, they find that the growth rate is decreasing when the common asset is at high levels.

2.3 The basic model

In this section, an overlapping generations model is assumed, where time is discrete i.e. $t = 1, 2, 3$........ Each generation lives for two periods and the economy goes on forever. In each period, there is a continuum of households, each indexed by i, where $i \in [0, 1]$. A household consists of a parent and a child. The parent is the head of the household. A child born in period t becomes the head of household in period $t + 1$. The head of a household i in period t receives a gross income $b_{it} > 0$ at the beginning of period t and pays taxes at rate τ_t. He allocates the net income, $(1 - \tau_t)b_{it}$, among three activities (following Gradstein, 2007). These are (i) household consumption in period t, which is denoted by c_{it}, (ii) investment in period t ,denoted by k_{it+1}, (because the investment becomes productive capital in the following period), and (iii) and rent seeking, denoted by r_{it+1}. The budget constraint for household i in period t is therefore

$$c_{it} + k_{it+1} + r_{it+1} \leq (1 - \tau_t) b_{it}. \tag{1}$$

The aggregate amount of capital in the economy at the beginning of period $t+1$ is therefore,

$$K_{t+1} \equiv \int_0^1 k_{jt+1} dj \tag{2}$$

Following Gradstein (2007), it is assumed that the amount of capital that household i controls at the beginning of period $t+1$ may not be equal to k_{it+1}. This is because the aggregate amount of capital in the economy, K_{t+1}, is distributed among households according to their relative power (or influence). Let z_{it+1} be a measure of the absolute power of household i at the beginning of period $t+1$. Its relative power is defined as

$$s_{it+1} \equiv \frac{z_{it+1}}{\int_0^1 z_{jt+1} dj}$$

(Thus, if all households have the same absolute power, the relative power of each household is unity.)

The actual amount of capital available to household i is denoted by κ_{it+1}. It is assumed to be determined by

$$\kappa_{it+1} = s_{it+1} K_{t+1}$$

This means that a more powerful household would have a greater share of the economy's aggregate capital stock K_{t+1} than a less powerful one.

In contrast to Gradstein (2007), it will be assumed below that the absolute power of a household depends on three factors: (i) its level of investment, k_{it+1}, (ii) its level of rent-seeking expenditures, r_{it+1}, and (iii) the degree of property right enforcement that prevails at time t, denoted by λ_t, where $0 \leq \lambda_t \leq 1$. Specifically, it is assumed that the dependence of z_{it+1} on the above three factors takes the following functional form

$$z_{it+1} = \phi(k_{it+1}, r_{it+1}, \lambda_{it}) = (k_{it+1})^{\lambda_t} (r_{it+1})^{1-\lambda_t} \tag{3}$$

Equation (3) is the fundamental departure of this model. It is in sharp constrast to Gradstein (2007), who assumes that $z_{it} = (k_{it+1})(r_{it+1})$, which implies that investment and rent-seeking are equally important in the determination of a household's absolute power. On the contrary, equation (3) indicates that rent-seeking expenditures, r_{it+1}, are relatively ineffective when λ_t is close enough to unity. In fact, as λ_t becomes arbitrarily close to unity, $z_{it+1} \longrightarrow k_{it+1}$ which in turn implies that $\kappa_{it+1} \longrightarrow k_{it+1}$, i.e., each household owns what it invests. At the other extreme, as λ_t becomes arbitrarily close to zero, a household's share of the aggregate capital stock K_{t+1} is independent of its investment k_{it+1}; it depends only on its rent-seeking expenditures r_{it+1}.

To summarize, κ_{it+1} is determined by the equation

$$\kappa_{it+1} = \frac{(k_{it+1})^{\lambda_t} (r_{it+1})^{1-\lambda_t}}{\int_0^1 z_{jt+1} dj} K_{it+1} \tag{4}$$

This equation may be called the "appropriation relationship".

What does household i do with the effective capital κ_{it+1}? It uses κ_{it+1} to generate an income according to the production function

$$b_{it+1} = F(\kappa_{it+1}, L_{it+1}) = A(\kappa_{it+1})^{\alpha} (L_{it+1})^{1-\alpha} \tag{5}$$

where L_{it+1} is the household's labour supply, which is assumed to be inelastic and normalized at unity, and b_{it+1} is the output. This output is the gross income at the disposal of the new head of the household i in period $t+1$ (who was the child in period t). Since he must pay a tax at the rate τ_{t+1}, his net income is $(1-\tau_{t+1})b_{it+1}$. This net income will be allocated among three uses, c_{it+1}, k_{it+2} and r_{it+2}.

The objective of the head of household i at time t is to maximize his "welfare", which is the sum of the utility derived by the household from consumming c_{it} and the "warm glow" derived from bequeathing to his child the after-tax income $(1-\tau_{t+1})b_{it+1}$:

$$V_{it} = \ln(c_{it} - x) + \beta \ln\left((1-\tau_{t+1})b_{it+1}\right) \tag{6}$$

Here $x > 0$ is the exogenously given minimum subsistence level of consumption, and $\beta > 0$ is a measure of the strength of his bequest motive. In what follows, it will be assumed that $b_{it} > x$. The term $\ln((1 - \tau_{t+1})b_{it+1})$, rather than being a measure of the welfare of the future generation, is only an indicator of the "warm glow" derived from bequest. This "warm glow" motive has been used in a number of models, such as Adreoni (1989, 1990) and Amegashie (2006).

The head of household i at time t maximizes to function (6) subject to the budget constraint, $(1 - \tau_t)b_{it} = c_{it} + r_{it+1} + k_{it+1}$ and taking into account the production function (5) and the "appropriation relationship" (4). He takes K_{it+1} and z_{jt+1} (where $j \neq i$) as given. Upon substituition, the optimization problem of the head of household i at time t is: choose c_{it}, r_{it+1} and k_{it+1} to maximize

$$\begin{aligned} V_{it} &= \ln\left[(1-\tau_t)\, b_{it} - r_{it+1} - k_{it+1} - x\right] \\ &\quad + \beta \ln\left\{ A\left[\frac{(k_{it+1})^{\lambda_t}(r_{it+1})^{1-\lambda_t}}{\int_0^1 z_{jt+1}dj}\,(K_{t+1})\right]^{\alpha}\right\} \end{aligned}$$

or, equivalently,

$$\begin{aligned} V_{it} &= \ln\left[(1-\tau_t)\, b_{it} - r_{it+1} - k_{it+1} - x\right] + \alpha\beta\lambda_t \ln\left[k_{it+1}\right] \\ &\quad + \alpha\beta\,(1-\lambda_t)\ln\left[r_{it+1}\right] + \beta \ln\left\{\frac{A\left[K_{t+1}\right]^{\alpha}}{\left[\int_0^1 z_{jt+1}dj\right]^{\alpha}}\right\} \end{aligned} \tag{7}$$

Taking the last term as given, for each household, the first order conditions are,

$$\frac{\partial V_{it}}{\partial k_{it+1}} = -\frac{1}{(1-\tau_t)\, b_{it} - r_{it+1} - k_{it+1} - x} + \frac{\alpha\beta\lambda_t}{k_{it+1}} = 0 \tag{8}$$

$$\frac{\partial V_{it}}{\partial r_{it+1}} = -\frac{1}{(1-\tau_t)\, b_{it} - r_{it+1} - k_{it+1} - x} + \frac{\alpha\beta\,(1-\lambda_t)}{r_{it+1}} = 0 \tag{9}$$

The two equations imply

$$r_{it+1} = \frac{(1-\lambda_t)}{\lambda_t} k_{it+1} \tag{10}$$

Equation (10) indicates that when the property right regime is perfect (i.e. when $\lambda_t = 1$), no individual would choose a positive level of rent-seeking.

Substituting equation (10) into equation (8), the following condition is obtained.

$$(1-\tau_t)\, b_{it} - x - \frac{(1-\lambda_t)}{\lambda_t} k_{it+1} - k_{it+1} = \frac{k_{it+1}}{\alpha\beta\lambda_t}$$

i.e.,

$$(1-\tau_t)\, b_{it} - x = k_{it+1} \left[\frac{1}{\lambda_t} + \frac{1}{\alpha\beta\lambda_t}\right] \equiv k_{it+1} \frac{1}{\mu_t}$$

where μ_t is defined by

$$\mu_t \equiv \left[\frac{\alpha\beta}{1+\alpha\beta}\right] \lambda_t. \tag{11}$$

Therefore, the household's investment rule is,

$$k_{it+1} = \mu_t \left[(1 - \tau_t)\, b_{it} - x \right] \tag{12}$$

and its non-consumption expenditure rule is:

$$r_{it+1} + k_{it+1} = \frac{\alpha\beta}{1 + \alpha\beta} \left[(1 - \tau_t)\, b_{it} - x \right] \tag{13}$$

Thus its influence is

$$z_{it+1} = (k_{it+1})^{\lambda_t} (r_{it+1})^{1-\lambda_t} = (k_{it+1})^{\lambda_t} \left[\frac{(1 - \lambda_t)}{\lambda_t} k_{it+1} \right]^{1-\lambda_t}$$

$$z_{it+1} = k_{it+1} \left[\frac{1 - \lambda_t}{\lambda_t} \right]^{1-\lambda_t} = \mu_t \left[(1 - \tau_t)\, b_{it} - x \right] \left[\frac{1 - \lambda_t}{\lambda_t} \right]^{1-\lambda_t}$$

Aggregate bequest at period t is defined as

$$B_t \equiv \int_0^1 b_{jt} dt \tag{14}$$

and the average influence is defined as

$$Z_{t+1} \equiv \int_0^1 z_{jt+1} dj = \mu_t \left[(1 - \tau_t)\, B_t - x \right] \left[\frac{1 - \lambda_t}{\lambda_t} \right]^{1-\lambda_t}$$

Then, using equation (12)

$$K_{t+1} = \mu_t \left[(1 - \tau_t)\, B_t - x \right]$$

The Nash equilibrium effective capital for household i,is

$$\kappa_{it+1} = \mu_t \left[(1 - \tau_t) \, b_{it} - x \right] \tag{15}$$

and its equilibrium utility from consumption in period t is

$$\ln \left[(1 - \tau_t) \, b_{it} - r_{it+1} - k_{it+1} - x \right] = \ln \left\{ \left(\frac{1}{1 + \alpha\beta} \right) \left[(1 - \tau_t) \, b_{it} - x \right] \right\}$$

The wealth acquired by this household in period $t + 1$, is

$$b_{it+1} = A \left[\kappa_{it+1} \right]^{\alpha}$$

or

$$b_{it+1} = A \left(\mu_t \right)^{\alpha} \left[(1 - \tau_t) \, b_{it} - x \right]^{\alpha} \tag{16}$$

Thus the optimized welfare of household i is,

$$V_{it}^{*}(b_{it}, \lambda_t, \tau_t) = \ln \left\{ \left(\frac{1}{1 + \alpha\beta} \right) \left[(1 - \tau_t) \, b_{it} - x \right] \right\} + \beta \ln A \left[\kappa_{it+1} \right]^{\alpha}$$

Substituting (15), the optimized objective function becomes,

$$
\begin{aligned}
V_{it}^{*}(b_{it},\lambda_t,\tau_t) &= \ln\left(\frac{1}{1+\alpha\beta}\right)+\beta\ln A+(1+\alpha\beta)\ln\left[(1-\tau_t)\,b_{it}-x\right] \\
&\quad +\alpha\beta\ln\lambda_t-\alpha\beta\ln\frac{1+\alpha\beta}{\alpha\beta} \qquad (17)
\end{aligned}
$$

It is assumed that the cost of enforcement of property rights incurred by the government is financed by tax revenue, such that the budget is balanced. The cost of achieving a degree of enforcement λ_t, in an economy of size B_t is assumed to be given by a function $G(\lambda_t, B_t)$.

Assuming a non-linear function, $G(\lambda_t, B_t) = \gamma\lambda_t^{\delta} B_t$, where $\delta > 0$, a balanced budget requiring $\tau_t B_t = \gamma\lambda_t^{\delta} B_t$ has been deduced. It follows that the income tax rate bears the following one-to-one relationship with the degree of enforcement of property rights, λ_t:

$$\tau_t = \gamma\lambda_t^{\delta} \text{ where } 0 \leq \lambda_t \leq 1.$$

Then the utility of the household is

$$
\begin{aligned}
V_{it}^{*}(b_{it},\lambda_t,) &= \ln\left(\frac{1}{1+\alpha\beta}\right)+\beta\ln A+(1+\alpha\beta)\ln\left[\left(1-\gamma\lambda_t^{\delta}\right)b_{it}-x\right] \\
&\quad +\alpha\beta\ln\lambda_t-\alpha\beta\ln\frac{1+\alpha\beta}{\alpha\beta}
\end{aligned}
$$

It will be assumed that $\left[\left(1-\gamma\lambda_t^{\delta}\right)b_{it}-x\right] > 0$.

To calculate the most preferred degree of enforcement of property rights, which is given by the choice of the most preferred tax rate, the household's objective function, $V_{it}^{*}(b_{it}, \lambda_t,)$ has been differentiated with respect to λ_t. The first order condition is,

$$\frac{(1+\alpha\beta)}{\left[\left(1-\gamma\lambda_t^{\delta}\right)b_{it}-x\right]}\left[-\delta\gamma\lambda_t^{\delta-1}b_{it}\right]+\frac{\alpha\beta}{\lambda_t}=0 \tag{18}$$

Focussing on the simplest case where $\delta = 1.$,then equation (18) can be solved for λ_t

$$\lambda_t = \frac{\alpha\beta}{\gamma(1+2\alpha\beta)}\left[1-\frac{x}{b_{it}}\right] \tag{19}$$

This equation shows that a household's most preferred tax rate τ_t increases with its wealth level b_{it}.

2.4 Homogeneous households

Consider the simple case where all households are identical. At each time period t, given their wealth $b_{it} = b_t$ (the same for all households) the households vote for the level of enforcement $\lambda_t^{*} = \lambda^{*}(b_t)$. In equation (19)

$$\begin{aligned}\lambda_t^{*} &= \frac{\alpha\beta}{\gamma(1+2\alpha\beta)}\left[1-\frac{x}{b_{it}}\right] \\ &\equiv \omega\left[1-\frac{x}{b_t}\right] \equiv \lambda^{*}(b_t),\end{aligned} \tag{20}$$

it is assumed that $\omega \leq 1$ to ensure $\lambda_t^* < 1$. given $b_t \rightarrow \infty$, $\lambda_t^* \rightarrow \omega$. This means $\gamma \geq \frac{1}{2+1/\alpha\beta}$, so γ , the unit cost of law enforcement, cannot be too small.

The dynamic evolution of the system is described by the following difference equation

$$b_{t+1} = Qb_t^{-\alpha}\left(b_t - x\right)^{2\alpha} \equiv \psi(b_t), \tag{21}$$

where

$$\begin{aligned} Q &\equiv A\left[\frac{\alpha\beta}{1+\alpha\beta}\right]^{\alpha}\omega^{\alpha}\left[1-\gamma\omega\right]^{\alpha} \\ &= A\gamma^{-\alpha}\left(\frac{\alpha\beta}{1+2\alpha\beta}\right)^{2\alpha} > 0. \end{aligned}$$

It has been noted that $\psi(b)$ is an increasing function for $b > x$, and

$$\frac{\psi(b)}{b} \rightarrow 0 \text{ as } b \rightarrow \infty,$$

indicating that, as $b \rightarrow \infty$, the curve $\psi(b)$ will lie below the 45 degree line.

A steady-state is a fixed point b^* such that

$$b^* = \psi(b^*).$$

Then b^* is a solution of

$$b^* = Q(b^*)^{-\alpha}(b^* - x)^{2\alpha}, \tag{22}$$

Hence

$$(b^*)^{1+\alpha} = Q(b^* - x)^{2\alpha}$$

or

$$b^* = Q^{1/(1+\alpha)} [b^* - x]^{2\alpha/(1+\alpha)} . \tag{23}$$

Now $\alpha < 1$ implies $2\alpha/(1+\alpha) < 1$. Hence the left hand-side of (23) is a linear function of b^* and the right-hand side is a concave curve for $b^* > x$. So there are two intersections, b_L^* and b_H^* where $x < b_L^* < b_H^*$. It is observed that b_H^* is a stable equilibrium, and b_L^* is unstable.

The evolution of the property rights regime is as follows. If $b_0 \in (b_L^*, b_H^*)$, both b_t and λ_t will be increasing with time, converging to b_H^* and λ_H^* where

$$\lambda_H^* \equiv \omega \left(1 - \frac{x}{b_H^*}\right) < 1.$$

If $b_0 \in (x, b_L^*)$, then b_t falls steadily toward x and λ_t falls steadily to zero.

Thus, in a non-decaying economy, both the level of income and the level of property rights enforcement increase over time. This shows a parallel evolution of growth in income and a decrease in illegal activities.

2.5 Extension

Now, consider the case where $\delta = 2$. The optimal degree of enforcement of property rights, $\lambda_t^* = \lambda_t^* (b_t)$, is given by

$$\lambda_t^* = \sqrt{\left(\frac{b_t - x}{2\gamma b_t}\right)\left(\frac{2\alpha\beta}{3\alpha\beta + 2}\right)} \tag{24}$$

The dynamic evolution of the system is given by

$$\begin{aligned} b_{t+1} &= A\left(\frac{\alpha\beta}{1+\alpha\beta}\right)^{\alpha}\left(\sqrt{\left(\frac{b_t - x}{2\gamma b_t}\right)\left(\frac{2\alpha\beta}{3\alpha\beta + 2}\right)}\right)^{\alpha} \\ &\quad \left[\left\{1 - \gamma\left\{\left(\frac{b_t - x}{2\gamma b_t}\right)\left(\frac{2\alpha\beta}{3\alpha\beta + 2}\right)\right\}\right\} b_t - x\right]^{\alpha} \end{aligned}$$

$$b_{t+1} = A\left(\frac{2}{\sqrt{\gamma}}\right)^{\alpha}\left(\frac{\alpha\beta}{3\alpha\beta + 2}\right)^{\frac{3\alpha}{2}}\left(1 - \frac{x}{b_t}\right)^{\frac{\alpha}{2}}(b_t - x)^{\alpha}$$

$$b_{t+1} = Q\left(1 - \frac{x}{b_t}\right)^{\frac{\alpha}{2}}(b_t - x)^{\alpha} \equiv Q\Omega(b_t) \tag{25}$$

where $Q = A\left(\frac{2}{\sqrt{\gamma}}\right)^{\alpha}\left(\frac{\alpha\beta}{2+3\alpha\beta}\right)^{\frac{3\alpha}{2}}$.

Notice that $\Omega(b)$ is an increasing function for $b > x$ and $\Omega(b) = 0$ when $b = x$.

A steady-state is a a fixed point, b^*, that solves

$$b^* = Q\left(1 - \frac{x}{b^*}\right)^{\frac{\alpha}{2}}(b^* - x)^{\alpha} = Q\left[\frac{b^* - x}{b^*}\right]^{\frac{\alpha}{2}}(b^* - x)^{\frac{2\alpha}{2}} \tag{26}$$

Then

$$(b^*)^{1+\frac{\alpha}{2}} = Q(b^* - x)^{\frac{3a}{2}}$$

or

$$b^* = Q^{\frac{2}{2+\alpha}}(b^* - x)^{\frac{3a}{2+\alpha}} \tag{27}$$

Notice that $\alpha < 1$ implies $2\alpha/(1+\alpha) < 1$. Hence the left hand-side of (27) is a linear function of b^* and the right-hand side is a concave curve for $b^* > x$. So there are two intersections, b_L^* and b_H^* where $x < b_L^* < b_H^*$., where b_H^* is a stable equilibrium, and b_L^* is unstable.

2.6 Conclusion

The model presented above showed how property rights regime may evolve along paths of capital accumulation. On approaching a steady state, the degree of enforcement increases as the stock of capital is accumulated. The intuition is that, as households become richer, they become more committed to property rights protection. Although the model makes several specific assumptions by necessity, it does highlight the influence on the transmission of wealth of law-enforcement activities and their financing.

Various extensions of our analysis may be worthwhile. First, technological shocks can result in a change in property rights regime. Second, the opening of an economy to international trade and investment can make households re-evaluate their opportunities and this may result in their collective decisions about property rights enforcement. A third possible extension is to consider households with different characteristics, for example, different levels of x. Then one may be able to show that, in a democratic but heterogenous ruthless society, political power may shift from one group to another. A discrete shift in power may be called a “revolution”. It results in a new regime with a different commitment to property rights protection.

Chapter 3
Optimal Enforcement of Property Rights Protection and Technology Transfer in a Joint Venture

3.1 Introduction

The transfer of technological know-how is one of the key benefits of joint ventures between multinational corporations and local firms. The role of technological advancement for growth has long been recognized in both the theoretical and the empirical literature. Acknowledging the importance of technology transfer, governments of many emerging economies require joint ventures instead of foreign-owned subsidiaries as the form of foreign investment in some key sectors of industrial production in order that the host country may benefit from derived technological knowledge. An example is the regulation by the Government of China that requires foreign car manufacturers to mandatorily form joint ventures with local firms. In fact, even as early as the mid-nineties, many host countries required foreign firms to establish joint ventures as a condition of entry into the home market. Restrictions were economy specific. In China, for example, a foreign partner in a joint-venture was required to invest at least 25% of the registered capital of a joint venture while in India the upper limit of foreign ownership was 40% of an Industrial Investment Company[1]. This limit has now been increased to 74% foreign equity approved under the automatic appproval scheme in 37 high priority areas in the industrial sector as outlined by the Government of India.[2]

A multinational may approach a local firm for a joint venture agreement for reasons such as the following. First, the production capacities of the multinational in other regions may have reached full capacity and the multinational may therefore be looking for additional capacity in this new economy[3]. Second, affiliation with the local firm which has adequate knowledge about the market conditions may ensure a smooth entry of the multinational into the home market. This has been noted in Roy Chowdhury and Roy Chowdhury (2001). On the other hand, the multinational provides incentives like a transfer of technical knowledge to the local firm, greater levels of employment in the economy due to higher production capacity resulting from the foreign investment, higher state tax revenues owing to higher incomes as a result of higher investment, to the government, etc[3].

This mutually beneficial set up is not without potential problems. In particular the local firm may break away from the joint venture after having acquired sufficient technological knowledge from the multinational. Such break-ups, as observed by Long, Soubeyran and Soubeyran (2009), are seen

[1] Laura B. Pincus and James A. Belohlav, (1996, page 53-54)
[2] http://madaan.com/jointventure.html
[3] Djordjija Petkoski (1997, page 5-6)

to be a common phenomenon in many emerging economies. Kogut (1988) similarly finds that approximately half out of the 92 joint ventures studied by him, had broken-up by the sixth year. While the break-away local firm may ensure maximum benefits having gained sufficient technological knowledge, and having acquired sufficient market power thereafter, the risk of such an opportunistic behavior is surely taken into account by the multinational.

In such a scenario, a multinational firm, while proposing a joint venture agreement, must guard against potential break-up. In the absence of a legally binding contract to maintain the partnership, the only tool in the hands of the multinational is the control of the flow of technological knowledge to the local firm, such that the local firm no longer finds it profitable to defect from the partnership. This chapter provides a principle on which such a control could be based. Inspired by Long, Soubeyran and Soubeyran (2009), this chapter differs in several respects, in particular, on its focus on profit shares during the life-time of the joint venture.

This chapter studies the properties of a joint-venture between a multinational firm and a local firm, where the former has superior technological knowledge. The local firm is a recipient of this technological knowledge during the time-interval of the joint-venture. The relationship is modelled as a two-period, principal-agent model where the the local firm behaves as the agent. This local firm can choose to quit the partnership at any point and start earning monopoly profits. It is assumed that the multinational must leave the country (earn zero profits) at the point at which the local chooses to defect, since no foreign firm is allowed to produce and sell in the domestic country without collaborating with a local firm. The multinational, however, is assumed not to initiate defection, for the sake of credibility in other countries where it might undertake future collaborations. Given this, the multinational designs a scheme to control the amount of technological knowledge it is willing to transfer to the local firm while anticipating the incentive of defection by the local firm in the second period. If there were extremely severe penalty for defection (e.g. 100% of the local firm's profit must be used as compensation payment for the joint-venture's loss of profits) the local firm would definitely choose not to quit. Thus in this "first-best" case the multinational would choose to transfer a level of technology which is optimal in the sense of joint-profit maximization. Without the 100% penalty, the local firm has an incentive to quit the partnership on sufficient accumulation of technological knowledge in order to earn monopoly profits thereafter. The multinational, in this case, must design a contract choosing a second-best level of technology transfer, in order to pre-empt the local firm from defecting. This chapter tries to determine how the profit shares of the multinational and the local firms affect the optimal levels of output in the two periods and the multinational's optimal level of technology transferred under partial enforcement of property rights protection. It also finds the optimal level of property rights protection from the point of view of the host country. It is found that this level depends on whether the output of the joint-venture is totally exported to a third market, or is consumed by the citizens of the host country, and, in the latter case, it depends on the relative weights attached to consumers' surplus and the local producer's surplus.

The rest of the chapter is structured as follows. In section 2, the related literature has been reviewed. In Section 3, the basic model has been introduced. Section 4 studies the optimal degree of technology transfer in the first best scenario as the benchmark. Section 5 explores the case of partial enforcement of property rights, and characterizes the incentive compatible solution (with the second-best degree of technological transfer). Section 6 determines, from the point of view of the host country, the optimal degree of enforcement of property rights, both in a case where the goods are produced for a third market and in a case where goods are produced for the home market. Section 7 concludes the discussion.

3.2 Related literature

This chapter uses a two-period model. In this respect, it bears some similarity with a number of papers on partnerships between multinational and local agents that use a two period model. In a two-stage game, D'Aspremont and Jacquemin (1988) consider two types of scenarios that bring together two potential competitors on grounds of research cooperation. The first scenario involves R&D cooperation at a "pre-competitive stage" and competition in the market. In the second scenario, the collusion between partners extend upto the production stage, so that partners who have achieved successful

R&D together, also control processes and products, thereby avoiding potential problems arising from rivalry. They analyze three different games. In the first game, firms are non-cooperative in both periods. In the second game, cooperation occurs for R&D in the first period, and non-cooperation prevails in the second period. In the third game, the firms cooperate in both the periods to form a single identity. Their welfare analysis show that in general one cannot conclude that one type of behavior is superior to another. The paper shows that more cooperation could lead to higher profits but lower consumer surplus, while less production due to monopoly could be compensated by more R&D. It concludes that cooperative behaviour can play a positive role in industries having a few firms and characterized by R&D activities generating spillover effects. Similar to this chapter in its use of a two stage model, the paper analyzes a theory of formation of a partnership as opposed to a theory that encourages an existing partnership to continue.

Ethier and Markusen (1996), in a two-period set up, model the choice of a multinational between costly exports and the possible dissipation of knowledge by producing abroad. They study the choice between exporting, licensing, and acquiring a subsidiary on the basis of the cost and technology parameters, in complete absence of IPR (intellectual property rights) protection in the host country. Their paper presents five possible equilibrium outcomes. First, the foreign firm exports in both periods; second the foreign firm owns a subsidiary but appropriates all the rents; third, a subsidiary arrangement exists, in which the rents are shared; fourth, there is exporting in period one and a one period licencing in the second and fifth, there are two one-period licences with different firms in the host country. The paper also provides some insight as to why most investment occurs between similar economies.

Markusen (2001) uses a two-period model to study a case of double sided moral hazard. He assumes that the length of a product cycle is two periods. The multinational enterprise hires a local agent in the host country. This local agent gains technological knowledge in the first period, and can choose to defect in the second period. The multinational enterprise can dismiss the local firm at the beginning of the second period and hire a new agent. Property rights protection is modelled as a cost imposed on the defecting party. A key result of this paper is that the multinational finds it profitable to shift from the mode of exporting to the host country, to the mode of hiring a local agent as a subsidiary in the presence of contract enforcement. The latter implies welfare gains for both parties. But if a subsidiary was chosen to begin with, then, contract enforcement leads to either no change or to a fall in host-country welfare. Another important result of this paper is that binding both the MNE (multinational enterprise) and the agent through a contract is worse for the agent and better for the MNE than binding the agent alone. This is because a contract enforceability constraint on the MNE allows it to credibly offer a lower licensing fee in the second period. The optimal policy for a developing country is to set the level of contract enforcement just high enough to ensure entry. This chapter differs from Markusen's model in its consideration of a joint venture, instead of a foreign-owned subsidiary, its focus on the one-sided incentive of the local to defect, and in the fact that the local firm becomes a monopolist post-defection, rather than a rival.

The above-mentioned papers, along with others like, Bardhan (1982), Choi (1993), and Marjit (1991), either question the benefits of formation of a partnership or try to determine which kind of partnership might be superior to the others. The joint paper by Roy Chowdhury and Roy Chowdhury (2001) differs from all of the above in its effort to explain why an existing partnership, in the form of a joint venture, may breakdown. In a dynamic two-period model of the life cycle of a joint venture, the paper demonstrates that the outcome of a joint venture may be any one of the following scenarios: a stable joint venture formation when the level of demand is very high, a joint venture breakdown at intermediate demand levels or a Cournot competition for low levels of demand. Their model is based on three building blocks. First, synergy that arises out of complementary grounds of competency of the two firms (e.g., superior technical knowledge of the foreign firm and superior knowledge of local conditions of the local firm); second, organizational learning, so that one of the partners in the joint venture may learn form the competencies of the other; third, moral hazard, because the input levels offered by each participant firm are non-verifiable and thus non-contractible, so that each firm has a tendency to free-ride on the other. The intuition for the breakdown of a joint venture, as a consequence, has been explained as the following. In period one, the joint venture forms in order to take advantage of the cost savings from synergy. After formation, organisational learning occurs. Thus, in period two, both firms become more efficient, whereby the cost savings from synergy becomes zero, and the moral hazard costs of maintaining the joint venture outweighs the benefits from synergy, leading to a breakdown. The paper, apart from considering a dynamic model, derives conditions for joint venture breakdown. This chapter on the contrary, finds the multinational's optimal level of technology transfer given the degree of enforcement of property rights such that it deters such a potential breakdown.

The need to prevent the breakdown of a joint venture, as has already been explained, arises more out the needs of the multinational than that of the local firm. The reasons, as explained by Long, Soubeyran and Soubeyran (2009), are the following. The transfer of technology, is costly. Apart from the "absorptive capacity costs"[4], there are transfer costs such that given an amount of technology transfer, a faster pace of transfer gives rise to higher transfer costs. The second factor is the time factor. The sooner the local firm breaks away, the longer is the stand-alone profit earning phase for the local, but the shorter the profit earning phase for the multinational. Therefore it is in the interest of the multinational to lengthen the duration of the partnership. The third factor is the cumulative amount of technology transfer. The

[4] "...the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilitites. We label this capability a firm's absorptive capacity and suggest that it is largely a function of the firm's level of prior related knowledge." - Cohen and Levinthal (1990)

larger the amount of technology transfer, the larger is the joint profit earned during the partnership but the greater is the stand-alone profit of the local firm after the break-up, which encourages it to defect. Such defection implies loss of profits for the multinational. Therefore, the multinational wishes to retain the partnership. While the second and third factors are intrinsic to the analysis in this chapter, the first relates more to the pace of technology transfer rather than the total amount of technology transferred. Furthermore, this chapter focuses on the optimization decision of the host country regarding the extent of compensation that a defecting local firm must pay to the foreign partner.

Finally there are a number of papers that explain the kind of technology transferred, given the policies of the host country, and that evaluate the importance of some of the above-mentioned concepts, expecially the costs of technology transfer.

Coughlin (1982) examines the relationship between foreign ownership and technology transfer. He argues that, MNE's produce both product and process technology. New product technology is not easily transferred by way of markets because the determination of its value is difficult. Hence transfer tends to take place internally by way of wholly owned subsidiaries. In contrast, the determination of the value of process technology is easier because it has at least one alternative older technology. Accordingly, he tests and finds support for the hypotheses that technology transferred to countries that deter wholly owned foreign direct investment will be a process, rather than product technology, and any product technology transferred will tend to be old.

Cohan and Levinthal (1990) argue that the absorptive capacity of an organization is history dependant and thus the lack of investment in any area of expertise may shut off future development of technical capacity in that area. They formulate a model of firm investment in R&D such that R&D contributes to the firm's absorptive capacity. They suggest that rather than treating absorptive capacity as a mere by-product of R&D, it is in the best interests of the firm to invest in it in order to enhance learning capacities and the ability to exploit learning in future.

Given the low absorptive capacity of a local firm, the transfer of technology may be costly whereby the multinational expects to cover this cost of transfer through profits in the product market. Therefore the long-term maintenance of the partnership becomes especially important if the multinational is barred from selling in the host country after the breakdown of the joint venture as has been assumed in this chapter. In keeping with this argument of costly technology transfer, Teece (1977) argues that such costs, which includes both transmission and absorption costs, may be high particularly if the technology is complex and the recipient firm has low absorption capabilities. He categorizes the costs related to transfer of technology into several groups - the costs of pre-engineering technological exchanges, costs of transferring and absortion, costs of the process or product design, R&D costs of adapting or modifying technology, and training costs..

In view of all the above arguments, the following model has been built, where (i) the multinational chooses to transfer an amount of technology that deters the incentive of the local firm to defect, given the existing degree of enforcement of property rights and (ii) the government of the host country, anticipating the response of the multinational to the behavior of the local, chooses the optimal level of property rights enforcement (in the form of the extent of compensation it requires a local firm to make after a defection), such that the welfare of the host country is maximized despite the individual non-cooperative profit-maximizing motives of both the local and the multinational.

3.3 The basic model

The main elements of the model are as follows. First, a multinational firm, M, can produce in the host country (a developing country) if and only if it signs a contract with a local firm, L, for joint profit maximization. Second, the time horizon consist of two periods, where there is technology transfer only in period 1. Third, the production cost of the joint venture, c_t, is a decreasing function of the level of technology transferred T, such that $c_t = \bar{c} - T$ (where it is assumed that $0 \leq T \leq \bar{c}$). Fourth, the transfer of technology involves an 'absorption cost' of γT^2 for any level of technology $T \leq \bar{c}$. Fifth, if the local firm defects in period 2, it can retain only a part, $\lambda < 1$, of the technology, whereby cost of production for the local firm, post-defection, is $c_t = \bar{c} - \lambda T$.

Given all of the above, four possible cases are specified below.

Case 1: M and L maximize the joint profit. Each has a constant share in profits, α_{L1} and α_{L2} being the shares for L, and, $(1-\alpha_{L1})$ and $(1-\alpha_{L2})$ being those for M in periods 1 and 2 respectively.

Case 2: M and L maximize joint profits in period 1, but L defects in period 2, without having to pay a compensation to M.

Case 3: M and L maximize joint profits in period 1. L defects in period 2, but has to pay a compensation equal to θ times its profit in the second period $(0 < \theta < 1)$.

Case 4: M and L maximize joint profits in period 1. If L defects in period 2, the required compensation factor is $\theta = 1$. In this case L loses by defecting and thus chooses not to defect. This case therefore, becomes identical to Case 1.

Cases 1, 2 and 3 will be analysed below. Further, since Case 2 implies $\theta = 0$, cases 2 and 3, can be combined together and analysed allowing $0 \leq \theta < 1$

3.4 A joint venture

This section deals with the benchmark case of joint profit maximization of two firms engaged in a joint venture. Since one of these firms is a multinational, and is assumed to be technologically superior to the local, there is a simultaneous transfer of technological know-how from the former to the latter along with production within the duration of the partnership. This section tries to determine the optimal level of technology transfer, on the basis of the following assumptions. Let c_t denote the unit cost of production in period t, where $t = 1, 2$. Assume constant costs $c_1 = c_2 = \bar{c} - T$ if $0 \leq T \leq \bar{c}$, and $c_1 = c_2 = 0$ if $\bar{c} \leq T$. Assume constant shares of profits $\alpha_{L1} = \alpha_{L2}$, and an inverse demand function $P_t = a - bQ_t$, where Q_t is the output level, and P_t is the price. Assume $a > 0$ and $b > 0$.

The discounted profit to be maximized by the joint venture is given by,

$$V = \left(\pi_1 - \gamma T^2\right) + \beta\pi_2, \qquad 0 < \beta < 1. \tag{1}$$

where π_t is the gross profit (i.e. before subtracting absorption costs γT^2) in period t, where $t = 1, 2$. The discount factor is β.

The problem can be solved backwards. Starting from period 2, where the technology transfer level T has been carried out in period 1, the second period profit of the joint venture is maximized with respect to the total second period output, Q_2.

In period 1, for any given $T \in [0, \bar{c}]$, the profit-maximizing output is determined by choosing Q_1 to solve the problem

$$\max(a - bQ_1)Q_1 - (\bar{c} - T)\,Q_1$$

Then

$$Q_1^* = \frac{a - \overline{c} + T}{2b}$$

and

$$\pi_1^* = \frac{1}{b}\left[\frac{a - \overline{c} + T}{2}\right]^2$$

Substituting optimal values of first and second period profits in the discounted profit as given in (1), the value of the firm, V, is then a function of the technology transfer level T:

$$V = \left(\frac{1}{b}\ \left[\frac{a - \overline{c} + T}{2}\right]^2 - \gamma T^2\right) + \beta\frac{1}{b}\left[\frac{a - \overline{c} + T}{2}\right]^2$$

Maximizing V respect to level of technology transfer T, the first order condition, is $(1 + \beta)(a - \overline{c}) = [4\gamma b - (1 + \beta)]\, T$. Hence, the optimal level of technological transfer, is

$$T^* = \frac{(a - \overline{c})(1 + \beta)}{4\gamma b - (1 + \beta)}. \tag{2}$$

The second order condition is satisfied if and only if the following assumption is satisfied:

Assumption A:

$$(1+\beta) - 4\gamma b < 0 \tag{3}$$

This condition is assumed to hold throughout this chapter. The optimal values of output and optimal amount of technology transfer, are

$$Q_1^* = Q_2^* = \frac{a - \overline{c} + T^*}{2b}$$

$$T^* = \frac{(a - \overline{c})(1+\beta)}{4\gamma b - (1+\beta)}.$$

The "first-best" level of technology transfer (from the point of view of the joint venture) is T^*.

3.5 A joint venture in a scenario of partial enforcement of property rights.

With enforcement of property rights in the economy, the multinational receives a compensation in the event of defection by the local firm. Assume that if the local firm breaks away in period 2 and earns a monopoly profit, then a fraction θ of this profit must be paid to the multinational as a compensation. The parameter θ will be referred to as the extent to which the property rights protection θ is enforced.

This section determines the optimal level of technological transfer from the multinational to the local while within the joint venture, given that the local may defect in the second period, thereby having to compensate the multinational at the rate θ.

In period 2, the local firm earns a monopoly profit on defection. Its cost function, post-defection, is, $c_2 = \overline{c} - \lambda T$. Therefore, if the local firm breaks away from the joint-venture relationship, it earns a monopoly profit of $(a - bQ_2)Q_2 - (\overline{c} - \lambda T)\, Q_2$. From this, a fraction θ must be paid as compensation to the multinational.

The local firm, after defection, chooses Q_2 to maximize the retained monopoly profits $(1 - \theta)\left[(a - bQ_2)Q_2 - (\overline{c} - \lambda T)\, Q_2\right]$. Its optimal output is

$$Q_2^* = \frac{a - \overline{c} + \lambda T}{2b}$$

and its profit is

$$\pi_2^* = (1 - \theta)\, \frac{1}{b} \left[\frac{a - \overline{c} + \lambda T}{2}\right]^2$$

The local firm defects if its share of profits in the second period while in the joint venture is less than its retained monopoly profit. The sufficient condition for defection, therefore is:

$$\frac{\alpha_{L2}}{4b} \left[a - \overline{c} + T\right]^2 < \frac{1 - \theta}{4b} \left[a - \overline{c} + \lambda T\right]^2$$

viz.,

$$\frac{\alpha_{L2}}{1-\theta} < \left[\frac{a-\bar{c}+\lambda T}{a-\bar{c}+T}\right]^2$$

It follows that the first-best level of technology transfer obtained in Case 1 would be implemented if and only if the magnitude of α_{L2} or θ are great enough to satisfy the following condition

$$\frac{\alpha_{L2}}{1-\theta} \geq \left[\frac{a-\bar{c}+\lambda T^*}{a-\bar{c}+T^*}\right]^2 \tag{4}$$

If condition (4) is not satisfied, the multinational firm will have no incentive to provide the first-best level of technology transfer, T^*.

Defining μ by

$$\mu \equiv \frac{\alpha_{L2}}{1-\theta}$$

then incentive-compatibility constraint is binding, for any given $T < \bar{c}$, if the value of μ is equal to $\widetilde{\mu}(T)$ where

$$\widetilde{\mu}(T) \equiv \left[\frac{a-\bar{c}+\lambda T}{a-\bar{c}+T}\right]^2 \tag{5}$$

It may be noted that $\frac{\partial}{\partial T}\left[\frac{a-\bar{c}+\lambda T}{a-\bar{c}+T}\right] = \frac{(a-\bar{c})(\lambda-1)}{(a-\bar{c}+T)^2} < 0$. Therefore, the graph on the incentive-compatibility constraint, in the space (T, μ) where T is measured along the horizontal axis and μ is measured along the vertical axis, is a downward-sloping curve. At $T = 0, \widetilde{\mu}(T) = 1$ and as $T \to \bar{c}$, $\widetilde{\mu}(T) \to [a - (1-\lambda)\bar{c}]^2 / a^2 < 1$. The following Proposition has been obtained from these observations.

Proposition 1: *Let T^* denote the first-best level of technology transfer as given in (2).*
(i) If $\mu \geq \widetilde{\mu}(T^*)$ then there is no incentive for the local firm to defect
(ii) If $\mu < \widetilde{\mu}(T^*)$ then the multinational will not implement T^*.

The optimal incentive scheme of the multinational can now be investigated. The multinational must determine the profit share $\alpha_{L2} \geq 0$ and a technology transfer level $T \geq 0$ such that the local firm has no incentive to defect in period 2. The incentive-compatibility constraint is thus,

$$\alpha_{L2} \geq (1-\theta)\left[\frac{a - \bar{c} + \lambda T}{a - \bar{c} + T}\right]^2 \equiv \alpha(T) \tag{6}$$

The maximization problem of the multinational is

$$\max_{\alpha_{L1}, \alpha_{L2}, T} (1-\alpha_{L1})\left[\frac{1}{b}\left(\frac{a - \bar{c} + T}{2}\right)^2 - \gamma T^2\right] + \beta(1-\alpha_{L2})\frac{1}{b}\left(\frac{a - \bar{c} + T}{2}\right)^2 \tag{7}$$

subject to $\alpha_{L1} \geq 0$, and the incentive-compatibility constraint (6). It has been assumed that at the optimal, the profit is positive in each period. Therefore, by inspecting the objective function (7), it is evident that the optimal

α_{L1} is zero, and the optimal α_{L2} is equal to $\alpha(T)$. It follows that

$$1-\alpha_{L2}=1-(1-\theta)\left[\frac{a-\overline{c}+\lambda T}{a-\overline{c}+T}\right]^2=$$

$$=\frac{(a-\overline{c}+T)^2-(1-\theta)(a-\overline{c}+\lambda T)^2}{(a-\overline{c}+T)^2} \tag{8}$$

Substituting (8) into the objective function (7), the optimization problem of the multinational firm becomes

$$\max_T \left[\frac{1}{b}\left(\frac{a-\overline{c}+T}{2}\right)^2-\gamma T^2\right]+\frac{\beta}{4b}\left[(a-\overline{c}+T)^2-(1-\theta)(a-\overline{c}+\lambda T)^2\right]$$

The first order condition, is

$$\frac{1}{2b}(a-\overline{c}+T)-2\gamma T+\frac{\beta}{2b}\left[a-\overline{c}+T-\lambda(1-\theta)(a-\overline{c}+\lambda T)\right]=0$$

The second order condition, is satisfied if and only if

$$4\gamma b-(1+\beta)+\beta(1-\theta)\lambda^2>0$$

This condition is satisfied under Assumption A (see equation (3). Thus, the optimal incentive-compatible T, denoted by $\widehat{T}$, is given by

$$\widehat{T}=\frac{(a-\overline{c})\left[(1+\beta)-\beta\lambda(1-\theta)\right]}{4\gamma b-(1+\beta)+\beta(1-\theta)\lambda^2} \tag{9}$$

To compare $\widehat{T}$ with the first-best T^*, observe that, as long as $(1-\theta)>0$, the following inequality holds

$$\widehat{T} < T^* \tag{10}$$

The optimal incentive-compatible level of technological transfer $\widehat{T}$ is the "second-best" level of technology transfer (from the point of view of the joint venture). From equations (9) and (10), the following Proposition is obtained:

Proposition 2: *Given that the local firm is not required to fully compensate the multinational in the event of defection (i.e., given that $\theta < 1$), the multinational firm will lower the level of technology transfer (relative to the first-best level T^*). Furthermore,*
(i) the second-best level of technology transfer, $\widehat{T}$, is an increasing function of the index of property rights protection θ,
(ii) $\widehat{T}$ is a decreasing function of λ for all $\lambda \in (0, 1)$.

Proof: It is verified, herewith, that $\widehat{T} < T^*$. Proposition 2(i), is proved by differentiating (9) to obtain,

$$\frac{d\widehat{T}}{d\theta} = \frac{\beta\lambda(a - \overline{c})\left[4\gamma b - (1 + \beta)(1 - \lambda)\right]}{\left[4\gamma b - (1 + \beta) + \beta(1 - \theta)\lambda^2\right]^2} > 0 \tag{11}$$

Similarly,

$$\frac{d\widehat{T}}{d\lambda} < 0$$

3.6 Optimal level of property rights protection

In the preceding section, the degree of enforcement of property rights protection in the economy has been taken as given. This section determines the optimal degree of enforcement of property rights protection, θ^* from the point of view of the host country, by maximizing the objective function of its government with respect to θ. It is assumes that the government wishes to maximize the welfare of its citizens. The welfare depends on whether the goods are goods produced for an export market or for the home market.

3.6.1 Optimal level of property rights protection when goods are produced for an export market

When goods are produced for export to a third market (i.e. the consumers are not citizens of the exporting country), the only surplus retained within the host country is the profit of the local firm. In the case of the relevant two-period model, the welfare function of the home government is equal to the discounted sum of profits of the local firm.

$$W = \alpha_{L1}\left[\frac{1}{b}\left(\frac{a-\overline{c}+T}{2}\right)^2 - \gamma T^2\right] + \beta\alpha_{L2}\frac{1}{b}\left(\frac{a-\overline{c}+T}{2}\right)^2$$

Given that the multinational sets $\alpha_{L1} = 0$ and $\alpha_{L2} = (1-\theta)\left[\frac{a-\bar{c}+\lambda T}{a-\bar{c}+T}\right]^2$ as shown above, the welfare function reduces to

$$W = \beta(1-\theta)\left[\frac{a-\bar{c}+\lambda T}{a-\bar{c}+T}\right]^2 \left[\frac{1}{b}\left(\frac{a-\bar{c}+T}{2}\right)^2\right]$$

$$= \frac{(1-\theta)\beta}{4b}\left[a-\bar{c}+\lambda T\right]^2 \tag{12}$$

where T is chosen by the multinational to be

$$T = \widehat{T}(\theta) = \frac{(a-\bar{c})\left[1+\beta-\beta\lambda(1-\theta)\right]}{4\gamma b-(1+\beta)+\beta(1-\theta)\lambda^2}$$

The home country thus chooses $\theta \in [0,1]$ to maximize welfare. The first order condition for an interior maximum is

$$\frac{dW}{d\theta} = -\frac{\beta}{4b}\left[a-\bar{c}+\lambda\widehat{T}(\theta)\right]^2 + 2\beta\left(\frac{1-\theta}{4b}\right)\left[a-\bar{c}+\lambda\widehat{T}(\theta)\right]\lambda\frac{d\widehat{T}(\theta)}{d\theta} = 0$$

or,

$$\frac{d\widehat{T}(\theta)}{d\theta} - \frac{1}{2\lambda(1-\theta)}\left[a-\bar{c}+\lambda\widehat{T}(\theta)\right] = 0 \tag{13}$$

This equation determines the optimal degree of property rights protection. Using (13) and (11) it can be seen that the optimal θ is

$$\theta^* = \min\left\{0, 1-\frac{4b\gamma-(1+\beta}{\beta\lambda^2}\right\}$$

Note that if $\lambda^2 \leq (4b\gamma - (1+\beta))/\beta$ then the optimal θ^* is a corner solution, $\theta^* = 0$. From this, the following conclusions emerge:

(i) If $(4b\gamma - (1+\beta))/\beta \geq 1$ then the optimal θ^* is at the corner $\theta^* = 0$, regardless of λ (as long as $0 < \lambda \leq 1$)

(ii) If $(4b\gamma - (1+\beta))/\beta < 1$ then the optimal θ^* is positive if λ is large enough, and is zero if λ is small enough. The threshold value of λ is

$$\lambda_P = \sqrt{\frac{(4b\gamma - (1+\beta))}{\beta}}$$

Proposition 3: *If the goods produced are for an export market, then the optimal degree of property rights protection, θ^*, is strictly less than 1. In particular,*
(i) If $(4b\gamma - (1+\beta))/\beta \geq 1$ then the optimal θ^* is at the corner $\theta^* = 0$
(ii) If $(4b\gamma - (1+\beta))/\beta < 1$ and $\lambda \in [0, \lambda_P]$, then the optimal θ^* is zero
(iii) If $(4b\gamma - (1+\beta))/\beta < 1$ and $\lambda \in (\lambda_P, 1)$, then the optimal θ^* is positive. It is increasing in λ.

3.6.2 Optimal level of property rights protection when goods are produced for the home market

In a situation where goods are produced solely for the home market, the government's objective function to be maximized is taken to be a weighted sum of the consumer's surplus and the profits of the local firm. The optimal degree of property rights protection, θ^*, to be enforced on the economy has been determined by maximizing the welfare function with respect to θ.

The case of equal weights to the local firm's profit and the consumers surplus.

Consumers surplus is the difference between the total amount the consumers are willing to pay and the prevailing market price. For period t, it is equal to the area of the triangle with height $a - P_t$ and base Q_t, such that,

$$CS_t = (a - P_t)\,\frac{Q_t}{2} = (a - (a - bQ_t))\frac{Q_t}{2} = \frac{bQ_t^2}{2}$$

where,

$$Q_t = \left(\frac{a - \overline{c} + T}{2b}\right)$$

Therefore, the consumers surplus is equal to

$$CS_t = \frac{(a - \overline{c} + T)^2}{8b} \tag{14}$$

The resulting welfare function, using (12) and (14), is

$$W = \frac{(1-\theta)\beta}{4b}\left[a - \overline{c} + \lambda T\right]^2 + (1+\beta)\frac{(a - \overline{c} + T)^2}{8b}$$

where $T = \widehat{T}(\theta)$.

The first order condition for maximizing W is

$$-\beta\left[a-\overline{c}+\lambda\widehat{T}(\theta)\right]+\left[2\beta\lambda\left(1-\theta\right)+\left(1+\beta\right)\left[\frac{a-\overline{c}+\widehat{T}(\theta)}{a-\overline{c}+\lambda\widehat{T}(\theta)}\right]\right]\frac{d\widehat{T}(\theta)}{d\theta}=0$$

Substituting values from (13) and (11) the following equation is obtained:

$$(1-\theta)=\frac{\left[4\gamma b-(1+\beta)\right]^{2}-\lambda\left(1+\beta\right)^{2}}{2\beta\lambda^{2}\left[2\gamma b-(1+\beta)\left(1-\lambda\right)\right]}$$

Therefore the value of the optimal degree of enforcement of property rights is

$$\theta^{*}_{Home}=1-\left[\frac{\left[4\gamma b-(1+\beta)\right]^{2}-\lambda\left(1+\beta\right)^{2}}{2\beta\lambda^{2}\left[2\gamma b-(1+\beta)\left(1-\lambda\right)\right]}\right]$$

$$\theta^{*}_{Home}=1-\left[\frac{\left[4\gamma b-(1+\beta)\right]^{2}}{2\beta\lambda^{2}\left[2\gamma b-(1+\beta)\left(1-\lambda\right)\right]}-\frac{\left(1+\beta\right)^{2}}{2\beta\lambda\left[2\gamma b-(1+\beta)\left(1-\lambda\right)\right]}\right]$$

Proposition 4: *If the goods are produced for the home market, then the optimal degree of property rights protection, θ^{*}, is strictly greater than 0. In* *particular,*

(i) If $\lambda \geqslant \left[\frac{4\gamma b}{(1+\beta)} - 1\right]^2$, *then* $\theta^*_{Home} = 1$

(ii) If $\lambda < \left[\frac{4\gamma b}{(1+\beta)} - 1\right]^2$, *then* θ^*_{Home} *is positive.*

The case of unequal weights to the local firm's profit and the consumers surplus

Imposing weights, $(1-\tau)$ on the profit and τ on consumers' surplus, the welfare function becomes the following weighted average.

$$W = (1-\tau)\,\frac{(1-\theta)\beta}{4b}\left[a-\overline{c}+\lambda T\right]^2 + (\tau)\,(1+\beta)\frac{(a-\overline{c}+T)^2}{8b}$$

The first order condition with respect to θ,yields the following.

$$(1-\theta) = \frac{(1-\tau)\left[4\gamma b-(1+\beta)(1-\lambda)\right]\left[(1+\beta)-4\gamma b\right]+(1+\beta)\,\lambda\,(\tau)\,(4\gamma b)}{-\beta\lambda^2\,(1-\tau)\left[4\gamma b-(1+\beta)(1-\lambda)\right]+(\tau)\,(1+\beta)\,\beta\lambda^2\,(1-\lambda)}$$

$$\begin{aligned}\theta^*_{Home\ weighted} &= 1- \\ &\frac{(1-\tau)\left[4\gamma b-(1+\beta)(1-\lambda)\right]\left[(1+\beta)-4\gamma b\right]+(\tau)\,(1+\beta)\,\lambda\,(4\gamma b)}{\beta\lambda^2\left[(1+\beta)(1-\lambda)-(1-\tau)\,4\gamma b\right]}\end{aligned} \tag{15}$$

Rearranging (15),the optimal degree of property rights protection can be re-written as,

$$\theta^{*}_{Home\ weighted} = 1 - \left[\begin{array}{c} \frac{(1+\beta)[(2\tau-1)(4\gamma b)+(1-\tau)(1+\beta)]}{\beta\lambda[(1+\beta)(1-\lambda)-(1-\tau)4\gamma b]} - \\ \frac{(1-\tau)[4\gamma b-(1+\beta)]^2}{\beta\lambda^2[(1+\beta)(1-\lambda)-(1-\tau)4\gamma b]} \end{array} \right]$$

If $\tau \leqslant \frac{4\gamma b-(1+\beta)}{2(4\gamma b)-(1+\beta)}$ then, $\theta^{*}_{Home\ weighted} = 1$ regardless of λ (as long as $0 < \lambda \leq 1$)

If $\tau > \frac{4\gamma b-(1+\beta)}{2(4\gamma b)-(1+\beta)}$ then, $\theta^{*}_{Home\ weighted} = 1$ whenever,

$$\lambda \leqslant \frac{(1-\tau)\left[4\gamma b-(1+\beta)\right]^2}{(1+\beta)\left[(\tau)(4\gamma b)-(1-\tau)\left[4\gamma b-(1+\beta)\right]\right]}$$

and $\theta^{*}_{Home\ weighted} > 0$ whenever,

$$\lambda > \frac{(1-\tau)\left[4\gamma b-(1+\beta)\right]^2}{(1+\beta)\left[(\tau)(4\gamma b)-(1-\tau)\left[4\gamma b-(1+\beta)\right]\right]}$$

Notice that, with a zero-weight on the consumers' surplus, the optimal degree of property rights protection, $\theta^{*}_{Home\ weighted}$ converges to its value θ^{*} i.e. the optimal degree of property rights protection where the goods were produced for the export market. In other words, if $\tau = 0$, then the optimal degree of property rights protection is,

$$\theta^*_{Home\ weighted} = 1 - \left[\frac{4\gamma b - (1+\beta)}{\beta\lambda^2}\right]$$

Rearranging (15) once more, the following expession for the optimal degree of enforcement of property rights protection, is obtained.

$$\theta^*_{Home\ weighted} = 1 - \left[\begin{array}{c} \frac{(4\gamma b)}{\beta\lambda^2} + \frac{(1+\beta)^2(1-\lambda)+(4\gamma b)(1+\beta)}{\beta\lambda^2[(1+\beta)(1-\lambda)-(1-\tau)4\gamma b]} - \\ \frac{\tau(1+\beta)(1-\lambda)[(1+\beta)+(4\gamma b)]}{\beta\lambda^2[(1+\beta)(1-\lambda)-(1-\tau)4\gamma b]} \end{array}\right]$$

Differentiating with respect to τ,the following is derived.

$$\frac{\delta\theta^*_{Home\ weighted}}{\delta\tau} = \begin{array}{c} \frac{4\gamma b\,(1+\beta)\,[(1+\beta)\,(1-\lambda)+(4\gamma b)]}{\beta\lambda^2\,[(1+\beta)\,(1-\lambda)-(1-\tau)\,4\gamma b]^2} + \\ \frac{(1+\beta)\,(1-\lambda)\,[(1+\beta)+(4\gamma b)]\,[(1+\beta)\,(1-\lambda)-4\gamma b]}{\beta\lambda^2\,[(1+\beta)\,(1-\lambda)-(1-\tau)\,4\gamma b]^2} \end{array}$$

It is evident, that $\frac{\delta\theta^*_{Home\ weighted}}{\delta\tau} > 0$, since $|4\gamma b\,[(1+\beta)\,(1-\lambda)+4\gamma b]| > |(1-\lambda)\,[(1+\beta)+4\gamma b]\,[(1+\beta)\,(1-\lambda)-4\gamma b]|$ by piece-wise comparison where, $[(1+\beta)\,(1-\lambda)-4\gamma b] < 0$, from Assumption A. The above results are summarized in the following proposition.

Proposition 5: *If the goods produced are for the home market, where the* *welfare function is a weighted average of the profits of the local firm and the consumers' surplus, then*

(i)The optimal degree of property rights protection, $\theta^*_{Home\ weighted}$ *is strictly positive and a decreasing function of* λ *as long as* $\tau > \frac{4\gamma b-(1+\beta)}{2(4\gamma b)-(1+\beta)}$. *In particular,*

(a) $\theta^*_{Home\ weighted} = 1$ *whenever* $\lambda \leqslant \frac{(1-\tau)[4\gamma b-(1+\beta)]^2}{(1+\beta)[(\tau)(4\gamma b)-(1-\tau)[4\gamma b-(1+\beta)]]}$

(b) $\theta^*_{Home\ weighted}$ *is positive whenever* $\lambda > \frac{(1-\tau)[4\gamma b-(1+\beta)]^2}{(1+\beta)[(\tau)(4\gamma b)-(1-\tau)[4\gamma b-(1+\beta)]]}$

(ii) The optimal degree of property rights protection, $\theta^*_{Home\ weighted}$ *is an increasing function of the weight* τ*,on consumers' surplus. In particular, when* $\tau = 0$, $\theta^*_{Home\ weighted}$ *reduces to the optimal degree of property rights protection,* θ^*, *in the case where goods are for the export market.*

3.7 Conclusion

It has been shown that the incentive-compatible level of technology transfer from the multinational to the local firm is lower than the first-best. This suggests that given that a lower level of technology transferred, the profitability of the local firm as a monopolist is reduced, whereby the latter loses the incentive to defect from the collaboration in the second period. The partnership, as a result, survives both periods. The multinational on the other hand has been shown to choose the incentive-compatible level of technology transfer, such that the local, firm, using this level of technology, may earn no more profits from a monopoly than it does from its share in the joint venture. This principle, used to determine the optimal level of technology transfer, ensures no defection by the local and thus no loss of profits for the multinational.

The actual value of the incentive-compatible level of technology transfer has been shown to depend on the degree of enforcement of property rights in the economy. Specifically, the greater the degree of enforcement of property rights protection, the greater the level of technology transfer. Intuitively, the greater the degree of enforcement, the greater is the amount of compensation for defection that the local must pay to the multinational out of its monopoly profits. Thus the retained monopoly profit is lower. So, given a high degree of enforcement of property rights protection, even a relatively higher total profit owing to a high level of technology transfer will reduce to a low enough retained monopoly profit, post-compensation. The incentive for defection by the local is the retained monopoly profit in the presence of property right protection. Thus, it finds no incentive to defect despite a higher technology acquired, as long as the compensation payment is high enough.

The degree of enforcement of property rights which determines the optimal level of technology transfer, has on the other hand been shown to be determined by maximizing the welfare function of the economy. When goods are produced solely for the export market, what pertains to the welfare of the home country is the share of profits of the local firm. In this case the optimal degree of enforcement of property rights has been shown to be positively related to the rate of retention of technological knowledge acquired by the local firm. The higher the rate of retention, the higher the monopoly profits and therefore the higher the requirement for property rights protection. When goods are produced for the home market, the welfare function for the home country includes both the profits of the local firm and the consumers surplus. The optimal degree of enforcement of property rights protection has been determined by maximizing the welfare function which is a weighted sum of the two. While the optimal degree of enforcement has been shown to be zero or positive is the in first case, the same is either positive or one in the second. In an overall analysis therefore, the optimal degree of property rights protection is higher, with higher total surplus earned within the economy. In other words, the higher the accumulation of surplus, the greater the need for formal protection and greater the formal protection of property rights, the higher the possibility of growth enhancing technogical transfer.

Chapter 4
A North South Model of Optimal Enforcement of Property Rights in the Pharmaceutical Industry

4.1 Introduction

Non-rival goods, or goods that are capable of being used by multiple users at the same time, need to be protected in use, by intellectual property rights. This is mainly to preserve monopolies, over distribution and use of these non-rival goods, such that incentives for further innovation is retained. However, the resulting monopoly price, which is the most basic of the ills of monopoly power, works against the interests of large sections of the society, especially in developing economies. Intellectual property rights, must therefore aim to balance the interest of the society for new works on one hand and problems of monopoly power on the other. In keeping with this requirement, the TRIPS agreement allows countries, a considerable degree of freedom in the implementation of their patent laws, subject to meeting the minimum standards outlined in TRIPS. Since the benefits and costs of patents are unevenly distributed across countries, they are allowed to devise their patent systems to seek the best balance, in their own circumstances, between benefits and costs. [1]

While copyrights and patents are both forms of IPR, the one relevant to a research-intensive industry, is 'patents' - a measure of protection guaranteed by the government of an economy to the inventor of some idea, process, innovation etc in exchange for public disclosure. This chapter, builds a case for the basis of determination of optimal enforcement of property rights in the form of patents in the pharmaceutical industry. The latter, for the following reasons. Danzon, Nicholson and Pereira (2005) in an empirical study to estimate the phase-specific success rate of a pharmaceutical R&D of a firm, point out that pharmaceutical firms invest a relatively greater percentage of sales in R&D [2]. R&D in the pharmaceutical industry has further been pointed out as especially risky and time consuming owing to the various stages of testing and re-examination that have to be survived. Protection by patents, thus assume greater relative importance. DiMasi et.al. (1991) in another empirical study to estimate the pre-tax, average R&D costs, have utilized a list of randomly selected NCE's[3] obtained from a survey of U.S.-owned pharmaceutical firms. A cost analysis of research according to them is relevant, since it has a direct bearing on the calculation of returns on

[1] "Public health, innovation and intellectual property rights" - Report of the commission on Intellectual Property Rights, Innovation and Public Health, WHO

[2] "R&D accounted for 15.6% of global sales in 2000 for the US research-based pharmaceutical industry. compared to 10.5% for computer software, 8.4% for electrical and electronics firms and 3.9% for U.S. companies overall, excluding drugs and medicines" - Danzon et al.(2005)

[3] "Although other forms of pharmaceutical innovation exist, new chemical entity (NCE) development is, on the whole, the most therappeutically and economically significant" - DiMasi, Hansen, Grabowski, Lasagna (1991)

the R&D investment, a bearing on the international resource allocation and competitiveness, and in policy making involving measures for regulations and economic performance of this industry. The relationship between risks and cost of R&D, expected returns on R&D investment and the required protection of property rights, enforced as a policy measure, therefore seems relatively stronger in the pharmaceutical industry. Yin (2008), analyzes the impact of tax incentives on pharmaceutical R&D by studying the impact of the Orphan Drug Act, 1983 on rare disease drug development. Based on the dataset published by NORD[4], he uses a difference-in-differences approach, which compares clinical trials for rare to non-rare disease drugs, before and after passage of the ODA. He finds that on average, the ODA led to a 69% increase in the annual flow of new clinical trials for traditional rare diseases, concluding therefore, that tax credits can generate R&D through a direct impact on the cost margins. Mosel (2010) on the other hand, provides a theoretical foundation to the considerations that influence a sector-specific patent regime. He finds that patent protection of a sector ought to be weaker the more intense the product market competition and the more its research acitivity and the more effort intensive the imitation process.

In the context of international trade, concerns have been expressed that TRIPS would result in higher prices of drugs for people in less developed

[4] "National Organization for Rare Disorders, a not-for-profit agency established in 1983 to serve as a clearinghouse to medical, policy and patient groups for information on uncommon diseases and conditions. They publish a database of 1177 uncommon diseases." - Yin (2008)

countries (Danzon, 2002, Lanjouw, 2003). In response, the Doha Declaration on Trips and Public Health has extended the deadline for the implementation patent protection for drugs in 49 poor countries from 2006 to 2012. Chadha and Blomqvist (2005) argued that exclusive marketing rights granted by patents on drugs can adversely affect the poor countries, and possibly result in welfare losses. While in industrial organisation theory, there is a literature on generic drugs versus brand-name drugs (Frank and Salkever, 1997, Ellison and Ellison, 2007). There is however a lack of formal modeling of the dynamic issues involved in world trade in pharmaceutical products and the related R&D decisions.

This paper lays a theoretical foundation to the mechanism by which an imitating country may decide an optimal "effective" patent length within its geographical boundary. Its real world relevance comes from the fact that individual countries have been allowed flexibilities like "compulsory liscences" (generalized as the competitive fringe in the paper) in order to ensure that patent protection for pharmaceutical products does not prevent people in poor countries from having access to medicines, at the same time maintaining the patent system's role in providing incentives for research and development into new medicines. The issue was further clarified in the Doha round of the WTO in 2001 (ref: appendix).

This chapter determines the optimal enforcement of property rights in the pharmaceutical industry, using a North South model. A North South model aimed at examining the impact of strong property rights in the South on

R&D investment, technology transfer and skill accumulation has been built by Parello (2008). Constructing a quality-ladder endogenous growth model, he finds that protection has a temporary positive impact on the innovation rate and negative impact on the long run imitation rate. This paper differs both in the use of a simple microeconomic model and in the determination of the optimal patent length as opposed to the impact of such protection on future innovation.

Following the literature, R&D is assumed to be undertaken in the technologically advanced North. The South undertakes reverse engineering and has the potential to produce and sell the drug at a lower price than that offered by the Northern monopolist. However, in case the South is allowed to seize market power entirely from the North, rendering production and sales by the North unprofitable, the incentive of the North to undertake R&D is lost. In other words, unless the North is assured of profits from the sales of the drug in whose R&D it has invested, there remains no economic incentive for the firm to undertake such R&D. An optimal enforcement of property rights in this scenario, therefore, refers to a mechanism which allows reverse engineering and sale of the drug by the South at a lower price, while retaining enough profitability for the North to sustain the incentive to invest in R&D. Such property rights have been considered equivalent to the patent length of the drug viz., the period of time over which the North is allowed to retain a monopoly or, the time period beyond which the South is allowed to reverse engineer. This paper therefore aims to determine the optimal patent length from the point of view of the South.

The rest of the paper is structured as follows. In section 2, the basic model has been intoduced and the cases of a Northern monopoly and a Northern limit pricing response to production by the Southern competitive fringe have been analyzed. Section 3 compares the social welfare gains in case of the monopoly and those in case of the limit pricing response. Section 4 determines the optimal patent length, taking into account the R&D. Section 5 determines the optimal research effort when the rate of discount is positive. Section 6, extends the analysis to a case where the effectiveness of drugs diminishes over time. and determines the optimal rotation period for new drugs in case of a monopoly and a price limiting response and calculates the optimal patent length for these drugs with diminishing effectiveness, while section 7 concludes the discussion.

4.2 The model

A North South model of competition has been considered, to illustrate the market for a medical product, an antibiotic (or drug, for short), to fight against bacteria. The technologically advanced Northern country (North), is considered capable of undertaking research aimed at continual improvements in the effectiveness of the drug, The Southern country (South), is assumed not to be able to undertake independant research, but rather to undertake reverse engineering in order to reproduce its own replica of the drug. The

South has also been assumed to be able to produce and sell the drug at a lower price than the North even though it is not allowed to enter the Northern market. The entire analysis therefore, concerns the Southern market and the time period upto which the Northern firm is allowed to retain its monopoly in the South. Accordingly, the following have been assumed. First, there exists a single firm in the North and a competitive fringe in the South. Second, the cost of production of the South, c_s is lower than the monopoly price, p^m, of the Northern firm, and higher than its cost of production c such that $c_s = (1+\gamma)c; \gamma > 0$. Third, effectiveness of a drug, $a(R)$, is linearly dependant on the research effort, R,such that $a(R) = a_0 + R$. Fourth, the cost of R&D,$\phi(R)$, is a non-linear function of research effort R, such that $\phi(R) = \frac{\lambda R^2}{2}$.Fifth, the time horizon for the Northern firm is fixed at some given number, T, where time, $t \in [0, T]$ is a continuous variable. Finally, the rate for discounting profits over the time period $t \in [0, T]$, has been assumed to be zero.

The population of the South, has been represented by the unit interval $[0, 1]$ that is uniformly distributed. θ has been assumed to be the index of natural resistance to infection. A person of type $\theta = 0$, then is the person who needs the drug most. A person of type $\theta = 1$ is the most healthy one, his need for the drug is lowest. Consumption of the drug has been modelled as a “zero-one” demand. An individual either consumes one unit, or none. The gross benefit to a person of type θ when he consumes one unit of the drug has been formulated as $a - b\theta$. It has been assumed that $a - b > 0$. This implies that even the most healthy person would benefit from consuming the drug. The price of the drug is p,such that,. $p > 0$. The net benefit of consuming a drug, for a person of type θ, has therefore been formulated as

$$v(\theta, p) = a - b\theta - p.$$

The above suggests that if $p \leq a - b$ then, the whole population of South will demand the drug. Conversely, if $p > a - b$ then only a fraction of the population will buy the drug. In this case, the "pivot consumer" has been defined as the person of type θ^* such that

$$a - b\theta^* - p = 0$$

i.e.

$$\theta^* = \frac{a - p}{b} \equiv x(p) \text{ for } a > p > a - b$$

Individuals to the left of θ^*, thus consume a unit of drug each, while individuals to the right of θ^* do not purchase the drug.

4.3 The Firms

The North consists of a single firm while the South consists of a competitive fringe. There can therefore, be two cases concerning the interaction of the Northern firm with the Southern firms in the Southern market. Either, the Northern firm, protected by the patent, acts as a monopolist, sets a monopoly price, p^m and earns a monopoly profit, π^m.Or the Northern firm faces competition from the Southern firms in which case it responds with the limit pricing behaviour whereby it sets a price p_L which is arbitarily close to the cost of production c_s, of the Southern firms and earns a profit π_L. The two cases have been analyzed in this section.

4.3.1 Monopoly

Suppose that the drug is supplied by a Northern firm, who has monopoly power. Assume the Southern market is separate from the Northern market, so that the firm can charge different prices in different markets. A polar case of interest is that there is no demand in the North for the drug (e.g. some bacteria and virus thrive only in the South; like malaria and dengue fever).

Let c be the unit production cost (not including R&D cost). Assume $c < a$. The monopolist's pricing decision is to choose p to maximize profit

$$\max_p (p-c)x(p)$$

This is equivalent to

$$\max_x (a-bx-c)x$$

Assume an interior solution for simplicity. Then the monopolist optimal output for the South is

$$x^m = \frac{a-c}{2b}$$

Since the maximum market size has been normalized at unity, it will be assumed that the following restriction holds:

Assumption A.0: *The parameters are such that the monopoly does not serve the entire market:*

$$0 < \frac{a-c}{2b} < 1 \tag{1}$$

The monopoly price is

$$p^m = \frac{a+c}{2}$$

And the monopoly profit is

$$\pi^m = (p^m - c)x^m = \frac{(a-c)^2}{4b}$$

4.3.2 Limit Pricing

The case where a competitive fringe of Southern firms, by reverse engineering, has been considered in this section. These Southern firms have been assumed to produce the same drug, but at a higher marginal cost, such that,

$$c_s > c$$

where the subscript s refers to the Southern firms. Suppose that c_s is smaller than the monopoly price.

$$c_s < p^m \equiv \frac{a+c}{2} \tag{2}$$

Then, if the Northern firm charges the monopoly price p^m, the Southern firms enter the Southern market, to capture the entire market, by charging the competitive price that equals the marginal cost c_s. The Southern firms have been assumed not to be allowed entry to the Northern market.

Without loss of generality, the Cost of production of the Southern firms can be written as,

$$c_s = (1+\gamma)c,\ \gamma > 0$$

Then, to satisfy (2) the following must be assumed.

Assumption A1

$$a > (1+2\gamma)c \tag{3}$$

The Northern firm's response is to charge a price p_L just below the marginal cost c_s of the Southern firm, according to the limit pricing behaviour. The Northern firm then captures the entire market. Since p_L is arbitrarily close to c_s, the demand for the Northern firm's product is abitrarily close to

$$x_L \equiv x(c_s) = \frac{a-c_s}{b} = \frac{a-(1+\gamma)c}{b}$$

The profit of the Northern firm under limit pricing is arbitrarily close to

$$\pi_L \equiv (c_s - c)x(c_s)$$

where

$$(c_s - c) = \gamma c$$

Thus the Northern firm's profit under limit pricing is approximately

$$\pi_L = \frac{\gamma c}{b}\left[a - (1+\gamma)c\right]$$

4.4 Social Welfare in a static model

The social welfare defined as the aggregate of the total surplus earned and retained within the economy is the sum of the consumer's and producer's surplus. In this case however, the producer's surplus earned by the Northern firm is irrelevant to the social welfare of the South. The social welfare of South, therefore, is the aggregate consumer surplus, i.e. the area under the net benefit curve $v(p, \theta)$ upto the pivot consumer $x(p)$:

$$W \equiv \int_0^{x(p)} v(p,\theta)d\theta = ax - \frac{b}{2}x^2 - px = \frac{bx^2}{2}$$

Under monopoly,

$$x = x^m = \frac{a-c}{2b}$$

Under limit pricing

$$x = x_L = \frac{a - (1+\gamma)c}{b} = \frac{(a-c) + (a-c-2\gamma c)}{2b}$$

where

$$x_L > x^m$$

This has been derived from **Assumption A1,** whereby**,**

$$(1+\gamma)c < \frac{a+c}{2}$$

Remark: Since the limit pricing output cannot be greater than the market size, the following restriction must be imposed.

Assumption A.1.b: *Under limit pricing, the healthiest person does not purchase the drug:*

$$\frac{a - (1+\gamma)c}{b} \leq 1 \tag{4}$$

Thus, under Northern monopoly, the Southern welfare is

$$W^m = \frac{(a-c)^2}{8b}$$

Under limit pricing, the Southern welfare has been derived as,

$$W_L = \frac{(a-c+a-c-2\gamma c)^2}{8b} > W^m$$

or

$$W_L = \frac{(2a - 2(1+\gamma)c)^2}{8b}$$

Therefore, in a static model without R&D, the South would prefer the limit pricing regime, i.e. it would allow Southern firms to threaten entry.

4.5 Endogenising R&D effort

In the previous sections, the parameter a has been treated as constant. The interpretation of α has now been modifed to imply the quality of the drug viz., its effectiveness in fighting the bacteria. The Northern firm can increase a by investing in R&D. The time horizon of the Northern firm has been assumed to be fixed number, T. At time zero, the Northern firm chooses its *R&D* effort level, denoted by R. The higher is R, the higher is the quality of the drug:

$$a = a(R), \text{with } a'(R) > 0.$$

The cost of achieving R is written as $\phi(R)$, where,

$$\phi(R) = \frac{\lambda R^2}{2}, \lambda > 0.$$

In deciding on its *R&D* effort level R, the firm must compute the expected returns from this investment. If the perfectly competitive Southern firms are allowed to market the substitutes (called the generic drugs) as soon as the Northern firm introduces its drug, the incentive for its *R&D* is low. It is assumed that reverse engineering takes no time, and thus the Southern firms can imitate the Northern firm's product as soon as it is available.

The government of South therefore faces a trade off: if the generic drugs are allowed to be produced soon after the Northern firm's introduction of the drug, the consumers will benefit from the Northern firm's "limit pricing" price which is lower than the monopoly price, but then this lower profitability will dull the Northern firm's incentive to invest in $R\&D$. The tension between these two forces suggests that the Southern government must balance the two objectives (lower price versus higher quality) by determining an optimal patent length for the Northern product. Let time be a continuous variable. Assume that T is the time horizon of the South's social planner as well as the time horizon of the Northern firm. Let ℓ denote the patent's length determined by the Southern government. Assume that the government can credibly commit not to change the patent length.

Assume also that the rate of discount is zero for simplicity. Then the Northern monopolist knows that if it introduces the drug of quality $a(R)$ at time zero, it profit stream will consist of two phases. In Phase 1, which is the time interval $[0, \ell]$, it is a monopolist, and therefore can charge the monopoly price

$$p^m(t) = \frac{a(R) + c}{2} \text{ for all } t \in [0, \ell]$$

and earn a monopoly profit at $t \in [0, \ell]$ of,

$$\pi^m(t) = \frac{1}{4b}\left[a(R) + c\right]^2$$

And Phase 2, which is the time interval $(\ell, T]$, the Northern firm faces the Southern competitive fringe, and must charge the limit pricing price

$$p_L(t) = (1+\gamma)c = c_s$$

such that its profit is

$$\pi_L(t) = (1+\gamma)c\left[\frac{a(R) - (1+\gamma)c}{b}\right]$$

The northern firm's total profit over the time horizon T, the discount rate being zero, is,

$$\Pi = \ell\frac{1}{4b}\left[a(R) + c\right]^2 + (T-\ell)(1+\gamma)c\left[\frac{a(R) - (1+\gamma)c}{b}\right] - \frac{\lambda R^2}{2}$$

The following assumtions have been made.

Assumption A.2: *The quality of the drug is linear in R&D effort:*

$$a(R) = a_0 + R$$

Assumption A.3: *The R&D cost parameter λ is sufficiently great, such* *that*

$$\lambda > \frac{T}{2b}$$

Remark: Assumption A.3 ensures that the FOC corresponds to a maximum.

4.5.1 The firm's choice of R&D effort

Maximizing Π with respect to R gives the first order condition,

$$\frac{2\ell}{4b}\left[a_0 + R + c\right] + \frac{1}{b}(T-\ell)(1+\gamma)c - \lambda R = 0 \tag{5}$$

The SOC, namely,

$$\frac{\ell}{2b} - \lambda < 0$$

is satisfied because of **Assumption A.3** and the fact that $\ell \leq T$.

The firm's optimal choice of R is then

$$R^* = \frac{2}{2b\lambda - \ell}\left[\frac{\ell}{2}(a_0 + c) + (T-\ell)(1+\gamma)c\right] \tag{6}$$

It can be noticed that R^* is a function of ℓ, T, γ and other parameters such as λ, b, c and a_0.We now determine the response of R^* to various parameter values. This can be done by differentiating equation (6) directly, or by applying the implicit function theorem to the FOC (5).

Optimal R&D is calculated as,

$$R^*(\ell, T, \gamma, \lambda) \equiv \frac{\ell(a_0 + c) + 2(T - \ell)(1 + \gamma)c}{2b\lambda - \ell} \tag{7}$$

Observe that R^* increases with the effective patent length ℓ for all $\ell \in [0, T]$:

$$\frac{\partial R^*(\ell, T, \gamma, \lambda)}{\partial \ell} =$$

$$\frac{(2b\lambda - \ell)\,(a_0 - (1 + 2\gamma)c) + [\ell(a_0 + c) + 2(T - \ell)(1 + \gamma)c]}{(2b\lambda - \ell)^2} > 0 \tag{8}$$

where the strict inequality follows from **Assumption A.1**. Notice also that,

$$R^*(T, T, \gamma, \lambda) = \frac{(a_0 + c)T}{2b\lambda - T} > R^*(0, T, \gamma) = \frac{Tc(1 + \gamma)}{b\lambda}.$$

and

$$\frac{\partial^2 R^*(\ell, T, \gamma, \lambda)}{\partial \ell^2} = \frac{2R^*}{(2b\lambda - \ell)^2} > 0$$

Thus R^* is strictly convex in ℓ. *As the effective patent length inreases, the research effort will increase at an increasing rate.*

Similarly,

$$\frac{\partial R^*(\ell, T, \gamma, \lambda)}{\partial T} = \frac{2(1 + \gamma)c}{2b\lambda - \ell} > 0$$

$$\frac{\partial R^*(\ell, T, \gamma, \lambda)}{\partial \gamma} = \frac{2c(T - \ell)}{2b\lambda - \ell} \geq 0$$

$$\frac{\partial R^*(\ell, T, \gamma, \lambda)}{\partial \lambda} = -\frac{2b\,[\ell(a_0 + c) + 2(T - \ell)(1 + \gamma)c]}{(2b\lambda - \ell)^2} < 0$$

Alternatively, the response of R^* to parameter changes can be derived by applying the implicit function theorem, To this end, define

$$G(\ell, T, \gamma, \lambda, R) = \frac{\ell}{2b}\left[a_0 + R + c\right] + \frac{1}{b}(T - \ell)(1 + \gamma)c - \lambda R$$

The F.O.C. can then be written as

$$G(\ell, T, \gamma, \lambda, R^*) = 0$$

and the S.O.C. is

$$\frac{\partial G}{\partial R^*} = \frac{\ell}{2b} - \lambda < 0$$

The comparative static results are as follows.

Proposition 1: *The Northern firm's R&D effort is*

(a) increasing in the length ℓ *of the patent,*

(b) increasing in the time horizon T*,*

(c) increasing in the cost disadvantage parameter γ *of the Southern firm.*

(d) decreasing in the difficulty of research, λ*.*

(Proof: See the appendix)

4.6 The Southern Government's choice of patent length

Now, knowing that $R = R(\ell, T, \gamma, \lambda)$, the Southern government must choose ℓ to maximize the country's total welfare, V, over the time horizon $[0, T]$.

$$
\begin{aligned}
V(\ell; T, \gamma, \lambda) &\equiv \ell W^m + (T-\ell) W_L \\
&= \frac{\ell}{8b}\left(a_0 + R^*(\ell, T, \gamma, \lambda) - c\right)^2 \\
&\quad + \frac{4(T-\ell)}{8b}\left(a_0 + R^*(\ell, T, \gamma, \lambda) - (1+\gamma)c\right)^2 \qquad (9)
\end{aligned}
$$

Considering the comparison of welfare under the polar policies, namely $\ell = T$ (i.e., do not allow the entry of domestic generic firms at any point of time), versus $\ell = 0$ (i.e., setting the effective patent length equal to zero), which policy is better depends on parameter values. Substituting for $R^*(\ell, T, \gamma, \lambda)$ and evaluating at $\ell = T$, we obtain the welfare level with no entry of domestic firms, denoted by $V(T; T, \gamma, \lambda)$,

$$
V(T; T, \gamma, \lambda) = \frac{T}{8b}\left[\frac{(a_0 - c)(2b\lambda - T) + T(a_0 + c)}{2b\lambda - T}\right]^2 = \frac{4T}{8b}\left[\frac{Tc + b\lambda(a_0 - c)}{2b\lambda - T}\right]^2
$$

and the welfare level with immediate entry of domestic firms, denoted by $V(0; T, \gamma, \lambda)$:

$$
V(0; T, \gamma, \lambda) = \frac{4T}{8b}\left[\frac{(a_0 - (1+\gamma)c)) + Tc(1+\gamma)}{b\lambda}\right]^2
$$

Recall that by **Assumption A.3**, $2b\lambda - T > 0$. It follows that $V(0; T, \gamma, \lambda) > V(T; T, \gamma, \lambda)$ if and only if

$$
\frac{(a_0 - (1+\gamma)c) + Tc(1+\gamma)}{b\lambda} > \frac{Tc + b\lambda(a_0 - c)}{2b\lambda - T}
$$

i.e., if and only if

$$\frac{(1+\gamma)cT^2}{b\lambda} < (b\lambda - T)\left(a_0 - (1+2\gamma)c\right) \tag{10}$$

Hence the following result is obtained:

Proposition 2: *Assume* $a_0 - (1+2\gamma)c > 0$. *Then*

(i) If $T \geq b\lambda$ *then the immediate entry of generic firms yields lower welfare than the prohibition of their entry.*

(ii) If $T < b\lambda$ *then the immediate entry of generic firms is better than the prohibition of their entry provided that the cost disadvantage of the domestic firms, the parameter* γ*, is small enough and* $a_0 - c$ *is large enough.*

(Proof: see the appendix)

The intuition behind the above proposition is as follows. If T is great, then the Northern firm will invest a lot in $R\&D$, given that entry of the local firms is prohibited. Such investment is beneficial to both parties. If T is small, the Northern firm does not invest a lot. Then if the cost disadvantage of the local firms are small, the gain from forcing the Northern firm to use limit pricing is greater than the loss that results from a reduced $R\&D$.

The South's optimal choice of ℓ now needs to be determined. At the onset, the derivative of the welfare function (9) with respect to ℓ has been evaluated at $\ell = 0$ and at $\ell = T$ respectively. Ignoring the term $8b$ and rewriting the objective function as follows,

$$\begin{aligned}\Omega(\ell;T,\gamma,\lambda) &= 8bV = \ell\left[a_0+R^*-c\right]^2 \\ &\quad +(T-\ell)\left[(a_0+R^*-c)+(a_0+R^*-(1+2\gamma)c)\right]^2\end{aligned}$$

And writing

$$A \equiv a_0 + R^* - c > 0$$

$$B \equiv a_0 + R^* - (1+2\gamma)c > 0$$

The following is obtained.

$$\frac{\partial\Omega(\ell;T,\gamma,\lambda)}{\partial\ell} = A^2 - (A+B)^2 + \left\{\left[2\ell A + 4(T-\ell)(A+B)\right]\frac{\partial R}{\partial \ell}\right\} \quad (11)$$

It is evident that the derivative $\partial\Omega/\partial\ell$ consists of two terms. The first term, $A^2-(A+B)^2$, is the *direct effect* of an increase in the patent length ℓ. It is negative, because, keeping $R\&D$ level R^* constant, an increase in ℓ lengthens the monopoly phase and shortens the limit pricing phase, thus reducing welfare. The second term (the term inside the second bracket) is positive. It represents the *indirect effect* of an increase in ℓ: the Northern firm invests more in $R\&D$ when the monopoly phase ℓ is lengthened. This investment is in the interest of the Northern firm, but also is beneficial to the consumers. It is the tension between these two opposite forces that determines the optimal policy.

The sign of the derivative $\partial\Omega(\ell;T,\gamma,\lambda)/\partial\ell$ is determined at the two polar values, $\ell = 0$ and $\ell = T$ respectively. Evaluating $\partial\Omega(\ell; T, \gamma, \lambda)/\partial\ell$ at $\ell = 0$.

$$\frac{\partial\Omega(0; T, \gamma, \lambda)}{\partial\ell} = -B(B + 2A) + \left\{4T(A + B)\frac{\partial R}{\partial\ell}\right\}$$

$$= -(a_0 + R^0 - (1 + 2\gamma)c)(3a_0 + 3R^0 - (3 + 2\gamma)c) +$$

$$8T\left(a_0 + R^0 - (1 + \gamma)c\right)\left[\frac{(2b\lambda)(a_0 - (1 + 2\gamma)c) + 2Tc(1 + \gamma)}{(2b\lambda)^2}\right] \tag{12}$$

where

$$R^0 \equiv R^*(0, T, \gamma) = \frac{Tc(1 + \gamma)}{b\lambda} \tag{13}$$

Substitution (13) into (12) the following can be obtained.

$$\begin{aligned}
\frac{\partial\Omega(0; T, \gamma, \lambda)}{\partial\ell} \quad = \quad & -\left[a_0 + \frac{Tc(1 + \gamma)}{b\lambda} - (1 + 2\gamma)c\right] \times \\
& \left[3a_0 + \frac{3Tc(1 + \gamma)}{b\lambda} - (3 + 2\gamma)c\right] \\
& +8T\left[a_0 + \frac{Tc(1 + \gamma)}{b\lambda} - (1 + \gamma)c\right] \times \\
& \left[\frac{(2b\lambda)(a_0 - (1 + 2\gamma)c) + 2Tc(1 + \gamma)}{(2b\lambda)^2}\right]
\end{aligned}$$

The first term on the right-hand side of equation (**??**) is negative while the second term is positive. If T is small enough (i.e., as $T \to 0$), the first term dominates, and thus $\partial\Omega(0; T, \gamma, \lambda)/\partial\ell < 0$. Conversely, if $T \to \infty$, the second term dominates, and $\partial\Omega(0; T, \gamma, \lambda)/\partial\ell > 0$. Thus the following proposition can be stated:

Proposition 3: *Starting from an initial situation with zero patent length, a* *marginal increase in patent length will improve welfare if the time horizon T is sufficiently large.*

Next, evaluate $\partial\Omega(\ell;T,\gamma,\lambda)/\partial\ell$ at $\ell = T$.

$$\frac{\partial\Omega(T;T,\gamma,\lambda)}{\partial\ell} = -(a_0 + R^T - (1+2\gamma)c)(3a_0 + 3R^T - (3+2\gamma)c)+$$

$$2T\left(a_0 + R^T - c\right)\left[\frac{(2b\lambda - T)(a_0 - (1+2\gamma)c) + T(a_0+c)}{(2b\lambda - T)^2}\right] \tag{14}$$

The first term on the right-hand side of equation (14) is negative while the second term is positive. If T is small enough (i.e., as $T \to 0$), the first term dominates, and thus $\partial\Omega(T;T,\gamma,\lambda)/\partial\ell < 0$. Conversely, if $T \to \infty$, the second term dominates, and $\partial\Omega(T;T,\gamma,\lambda)/\partial\ell > 0$. The following proposition can be stated accordingly.

Proposition 4: *Starting from an initial situation with patent length equal to T, a marginal decrease in patent length will improve welfare if the time horizon T is sufficiently small, and will worsen welfare if T is sufficiently large.*

Consider the case where the optimal patent length ℓ^* is an interior solution, the FOC which determines the optimal ℓ for the Southern government is

$$\frac{\partial\Omega(\ell;T,\gamma,\lambda)}{\partial\ell} = -B(B+2A) + \left\{[2\ell^* A + 4(T-\ell^*)(A+B)]\,\frac{\partial R}{\partial\ell}\right\} = 0$$

i.e.,

$$\left(\frac{\partial R^*}{\partial \ell}\right)[2\ell^*(a_0 + R^* - c) + 8(T - \ell^*)(a_0 + R^* - (1+\gamma)c)] = 0 \qquad (15)$$

where R^* denotes the function $R^*(\ell, T, \gamma)$. The SOC. is

$$(8\gamma c - 6(a_0 + R^* - c))\left(\frac{\partial R^*}{\partial \ell}\right) + (8T - 6\ell)\left(\frac{\partial R^*}{\partial \ell}\right)^2 +$$

$$[2\ell(a_0 + R^* - c) + 8(T - \ell)(a_0 + R^* - (1+\gamma)c]\left(\frac{\partial^2 R^*}{\partial \ell^2}\right) < 0 \qquad (16)$$

Defining,

$$\begin{aligned} F(\ell, T, \gamma) \equiv \; & (a_0 + R^* - c)^2 - 4(a_0 + R^* - (1+\gamma)c)^2 + \\ & \left(\frac{\partial R^*}{\partial \ell}\right)[2\ell(a_0 + R^* - c) + 4(T - \ell)(2a_0 + 2R^* - 2(1+\gamma)c] \end{aligned}$$

The comparative statics on the Southern government's optimal ℓ are given by

$$\frac{\partial \ell^*}{\partial T} = -\frac{\partial F/\partial T}{\partial F/\partial \ell}$$

$$\frac{\partial \ell^*}{\partial \gamma} = -\frac{\partial F/\partial \gamma}{\partial F/\partial \ell}$$

Since $\partial F/\partial \ell < 0$ by the SOC, *sign* $(\partial \ell^*/\partial T) =$ *sign* $(\partial F/\partial T)$. From $\partial R^*/\partial \ell > 0$, $\partial R^*/\partial T > 0$ and (3) the sign of $\partial F/\partial T$ seems ambiguous because the term inside the second bracket seems ambiguous.

$$
\begin{aligned}
\frac{\partial F}{\partial T} &= 2\left(\frac{\partial R^*}{\partial T}\right)\{(a_0+R^*-c)-4(a_0+R^*-(1+\gamma)c)\} \\
&\quad +\left(\frac{\partial R^*}{\partial \ell}\right)\left[[2\ell+8(T-\ell)]\left(\frac{\partial R^*}{\partial T}\right)+4\left(2a_0+2R^*-2(1+\gamma)c\right)\right]
\end{aligned}
$$

Similarly, $sign\ (\partial\ell^*/\partial\gamma) = sign\ (\partial F/\partial\gamma)$. From ,$\frac{\partial R^*}{\partial\gamma}>0$, $\frac{\partial R^*}{\partial\ell}>0$ the sign of $\partial F/\partial\gamma$ also seems ambiguous as according to the following.

$$
\begin{aligned}
\frac{\partial F}{\partial \gamma} &= 2(a_0+R^*-c)\left(\frac{\partial R^*}{\partial \gamma}\right)-8\left[\frac{\partial R^*}{\partial \gamma}-c\right](a_0+R^*-(1+\gamma)c)+ \\
&\quad 2\left(\frac{\partial R^*}{\delta\gamma\partial\ell}\right)[\ell(a_0+R^*-c)+4(T-\ell)(a_0+R^*-(1+\gamma)c]+ \\
&\quad 2\left(\frac{\partial R^*}{\partial \ell}\right)\left[\ell\left(\frac{\partial R^*}{\partial \gamma}\right)+4(T-\ell)\left[\left(\frac{\partial R^*}{\partial \gamma}\right)-c\right]\right]
\end{aligned}
$$

Therefore the optimal patent length ℓ^* and the change in ℓ^* for given changes in γ, λ and T are numerically determined as follows. In each of the three tables below, presenting the change in ℓ^* in response to changes in γ, λ and T, the base line scenario, with values $T=20$, $a_0=5, b=0.7, c=4, \lambda=30, \gamma=0.2$ has been highlighted. Substituting these numerical values in (15) ,the optimal patent length has been calculated as,

$$\ell^* = 11.052.$$

To see how the optimal patent length ℓ^* depends on the the value taken by the cost disadvantage parameter γ, the parameter values $T = 20$, $a_0 = 5, b = 0.7, c = 4, \lambda = 30$, have been substituted in the first order condition(15). The results have been tabulated as follows, where $\mathbf{V}^{\ell^*}, \mathbf{V}^0, \mathbf{V}^T$ are the values of the welfare at ℓ^*, $\ell = 0$ and $\ell = T$.

γ	ℓ^*	R^*	V^{ℓ^*}	V^0	V^T
0.12	11.178	5.8285	347.04	263.09	301.09
0.15	11.133	5.888 9	344.84	276.57	301.09
0.18	11.085	5.949 3	342.69	290.39	301.09
0.2	**11.052**	**5.9897**	**341.29**	**299.79**	**301.09**
0.22	11.017	6.0300	339.91	309.34	301.09

The values of optimal patent length, ℓ^* have been observed to vary inversely with the values of the cost disadvantage parameter, γ. Given any patent length, the lower is the domestic cost disadvantage, the weaker is the incentive for the Northern firm engage in R&D. In order to offset this dampening effect, the Southern government extends the patent length as the domestic cost disadvantage falls.

To make an observation, about changes in the patent length in response to changes in the R&D cost parameter, λ, the values $T = 20$, $a_0 = 5, b = 0.7, c = 4, \gamma = 0.2$ have been substituted in (15) and the value of λ varied. The results have been tabulated in the following table.

λ	ℓ^*	R^*	V^{ℓ^*}	V^0	V^T
25	18.801	11.156	606.59	461.81	603.57
27	15.781	8.2897	460.41	398.16	441.01
30	**11.052**	**5.989 7**	**341.29**	**299.79**	**301.09**
34	4.366	4.3803	256.86	256.04	202.06
35	2.623	4.106	242.36	242.29	185.50

The values of optimal patent length, ℓ^* have been observed to vary inversely with the values of λ. The higher is the research cost λ, the lower is the optimal R&D undertaken. Since a lower R^* has a relatively greater diminishing effect on welfare from price limiting, W^m, than the welfare from W_L, given, $V \equiv \ell W^m + (T - \ell)W_L$, a lower ℓ^* becomes welfare maximizing by putting a lesser weight on the greater welfare loss. Therefore it is welfare maximizing to put greater importance on cheaper availability of antibiotics by allowing reverse engineering and limit pricing response to begin sooner.

The impact of a change in the time horizon, T, on optimal patent length, ℓ^*, has been observed, by substituting values, $a_0 = 5, b = 0.7, c = 4, \lambda = 30, \gamma = 0.2$ in (15). The value of T has been varied and the results have been tabulated as follows:

T	ℓ^*	R^*	V^{ℓ^*}	V^0	V^T
17	0.785	3.9483	202.74	184.24	153.89
18	4.368	4.5222	240.91	218.65	193.06
20	**11.052**	**5.9897**	**341.30**	**299.79**	**301.09**
22	16.954	8.0263	490.57	398.87	466.75
25	25.329	13.485	904.99	585.04	904.65

The optimal patent length, ℓ^* has been observed to vary positively as the time horizon T, Given the parameter values, it has been noticed, that $\ell^* \simeq 0$, around $T^* = 17$, and that $\ell^* \simeq T$ around $T^* = 25$. This must imply that when the time horizon is short enough, the cost of enforcing patent rights is higher than the gains from monopoly preservation whereby $\ell^* \simeq 0$. The numerical value of $\ell^* > T$ at $T = 25$, has been retained solely for illustration of the case where $\ell^* \simeq T$. The following proposition has accordingly been stated.

Proposition 5: *The patent length, ℓ, of the Northern firm is*

(a) decreasing in the cost disadvantage parameter, γ.

(b) decreasing in the R&D cost parameter, λ.

(c) incr*easing in time period T, given the parameter values.*

4.7 The effect of discounting

If the discount rate is positive, the present value of the Northern firm's profit is

$$\Pi = \int_0^{\ell} \exp(-\rho t)\pi_m(t)dt + \int_{\ell}^{T} \exp(-\rho t)\pi_L(t)dt - \phi(R)$$
$$= \pi^m \left[\frac{1-e^{-\rho\ell}}{\rho}\right] + \pi_L \left[\frac{e^{-\rho\ell}-e^{-\rho T}}{\rho}\right] - \frac{\lambda}{2}R^2$$

The FOC. is

$$\frac{d\Pi}{dR} = \frac{\left(1-e^{-\rho\ell}\right)}{2b\rho}\left[a_0+R+c\right] + \frac{1}{b\rho}\left(e^{-\rho\ell}-e^{-\rho T}\right)(1+\gamma)c - \lambda R = 0$$

or,

$$\left(1-e^{-\rho\ell}\right)\left[a_0+R+c\right] + 2\left(e^{-\rho\ell}-e^{-\rho T}\right)(1+\gamma)c = \lambda b\rho R$$

The SOC. is

$$\frac{d^2\Pi}{dR^2} = \frac{\left(1-e^{-\rho\ell}\right)}{2b\rho} - \lambda < 0$$

Thus

$$R^{**}(\rho,\ell,T,\gamma) = \frac{\left(1-e^{-\rho\ell}\right)\left[a_0+c\right] + 2\left(e^{-\rho\ell}-e^{-\rho T}\right)(1+\gamma)c}{\lambda b\rho - (1-e^{-\rho\ell})}$$

Assumption A.4

$$\lambda > \frac{\left(1-e^{-\rho T}\right)}{2b\rho}$$

This assumption ensures that the SOC is satisfied. Define

$$\psi(\ell, R, \gamma, T) = \frac{\left(1 - e^{-\rho\ell}\right)}{2b\rho}\left[a_0 + R + c\right] + \frac{1}{b\rho}\left(e^{-\rho\ell} - e^{-\rho T}\right)(1+\gamma)c - \lambda R$$

Proposition 6: *In the case of positive discounting,*

(a) a longer time horizon will lead to more R&D,

(b) a longer patent length will lead to more R&D.

(c) a higher discount rate will lead to lower R&D level.

(Proof: see the appendix.)

4.8 Bacteria Resistance and the Introduction of new drugs

In the previous sections, the effectiveness of a drug has been assumed to remain unchanged. However it is commonly known, that bacteria develop resistance to drug, so that the effectiveness of a drug declines over time. Therefore, at some point, a new drug needs to be invented to replace the ineffective old. It has been assumed that the decline in effectiveness of a drug, is a function of time, such that, the effectiveness at time t of a drug invented at time $\tau < t$ is a linear and decreasing function of the distance $t - \tau$. This diminishing effectiveness has been denoted by $a(t - \tau)$.

Setting $\tau = 0$, the demand for the drug at time t is $\theta^*(t) = \frac{a(t)-p(t)}{b}$. The following function has been defined for effectiveness,

$$a(t) = a_0 - \beta t, \text{ where } \beta > 0.$$

where a_0 is the effectiveness of a drug that has not been exposed to resistance. Then the demand function is

$$x(t) = \frac{a_0 - \beta t - p(t)}{b}$$

4.8.1 Monopoly of Northern firm for drugs subject to bacteria resistance

Similar to the pattern of analysis in section 3, the North has been assumed to have an initial monopoly over the market, now in a situation where the effectiveness of the drug reduces over time. A drug invented at time $\tau = 0$, has been considered, for which a replacement has not yet been found. Profit maximization by the Northern firm requires,

$$\max_p \, [p(t) - c] \left[\frac{a_0 - \beta t - p(t)}{b} \right]$$

Thus its monopoly price at time t is

$$p^m(t) = \frac{a_0 - \beta t + c}{2}$$

A monopolist by definition, must earn positive profits, and, the profit is non-negative if and only if $p^m(t) \geq c$, i.e.

$$\frac{a_0 - \beta t + c}{2} \geq c$$

i.e.,

$$t \leq \frac{a_0 - c}{\beta} \tag{17}$$

The quantity produced is then

$$q^m(t) = \frac{1}{2b}(a_0 - \beta t - c) \text{ for } t \leq \frac{a_0 - c}{\beta}$$

and the profit at time t is

$$\pi^m(t) = \frac{(a_0 - \beta t - c)^2}{4b} \text{ for } t \leq \frac{a_0 - c}{\beta}$$

It is assumed that a new drug, with effectiveness level a_0, can be introduced at any time, as soon as a one-time R&D cost I is incurred. The monopolist would invent a new drug, according to the following problem which is similar to the Faustmann's forest rotation problem, set in continuous time with an infinite horizon. Suppose new drug is invented at time $t = 0$. Then, the optimal date of replacement, given that the firm's horizon is infinite, is determined as follows. Let z denote the "rotation period". Let

α denote the vector of parameters:

$$\alpha \equiv (a_0, c, \beta, b, \rho) \tag{18}$$

The monopoly's present value of the stream of profits from a given drug is a function of the choice variable z and the vector of parameters denoted by α

$$V_m(z;\alpha) = \int_0^z e^{-\rho t}\frac{(a_0 - \beta t - c)^2}{4b}dt \text{ for } z \leq \frac{a_0 - c}{\beta} \tag{19}$$

Note that $V_m(z;\alpha)$ is increasing and concave in z, and is decreasing in β:

$$\frac{\partial V_m}{\partial z} = e^{-\rho z}\frac{(a_0 - \beta z - c)^2}{4b} > 0 \tag{20}$$

$$\begin{aligned} \frac{\partial^2 V_m}{\partial z^2} &= -\rho e^{-\rho z}\frac{(a_0 - \beta z - c)^2}{4b} - 2\beta e^{-\rho z}\frac{(a_0 - \beta z - c)}{4b} \\ &= -\rho V_m' - 2\beta e^{-\rho z}\frac{(a_0 - \beta z - c)}{4b} \end{aligned} \tag{21}$$

The monopoly's stream of profit from a sequence of drugs, each invented z periods after the preceding one, is

$$\Pi = (1 + e^{-\rho z} + e^{-2\rho z} + ... + e^{-n\rho z} + ...)(V_m(z;\alpha) - I) \tag{22}$$

Using the formula for the summation of a series with geometric progression,

Π can be re-written as follows

$$\Pi = \frac{V_m(z;\alpha) - I}{1 - e^{-\rho z}} \tag{23}$$

The Northern firm's optimization problem is

$$\Pi^* \equiv \max_z \frac{V_m(z;\alpha) - I}{1 - e^{-\rho z}} \tag{24}$$

For notational convenience, denote

$$V_m'(z;\alpha) \equiv \frac{\partial V_m}{\partial z}$$

The FOC is

$$\frac{1}{\left(1 - e^{-\rho z}\right)^2} \left\{ \left(1 - e^{-\rho z}\right) V_m'(z;\alpha) - \left[V_m(z;\alpha) - I\right] \rho e^{-\rho z} \right\} = 0 \tag{25}$$

i.e.,

$$\frac{V_m(z;\alpha) - I}{V_m'} = \frac{1 - e^{-\rho z}}{\rho e^{-\rho z}} \tag{26}$$

It can be shown that whenever the the FOC is satisfied, the SOC is also satisfied. (See Appendix 1).

Welfare when consuming a drug with effectiveness $a(t) = a_0 - \beta t$ is calculated as follows. Under Northern monopoly, the social welfare of South is the aggregate consumer surplus, i.e. the area under the net benefit curve

$v(p, \theta, t)$ upto the pivot consumer $x(p, t)$:

$$W(t) \equiv \int_0^{x(p(t))} v(p, \theta, t) d\theta = a(t)x(t) - \frac{b}{2}x(t)^2 - p(t)x = \frac{bx(t)^2}{2}$$

where

$$x(t) = \frac{a_0 - \beta t - p(t)}{b}$$

Under monopoly,

$$p(t) = \frac{a_0 - \beta t + c}{2}$$

So,

$$x_m(t) = \frac{a - \beta t - c}{2b}$$

So

$$W_M(t) = \frac{(a - \beta t - c)^2}{8b}$$

Some comparative statics results have been stated below.

Proposition 7: *An increase in β always decreases the present value of the monopoly's profit stream. That is,*

$$\frac{\partial \Pi^*}{\partial \beta} < 0$$

(Proof: see the appendix.)

Proposition 8: *The effect of an increase in the speed of bacteria resistance* *(i.e., an increase in β), on the optimal rotation period is ambiguous.*

(Proof: see the appendix.)

Because of this ambiguity, a numerical solution is required. First, $V_m(z;\alpha)$ has been calculated explicitly. After some manipulation (see Appendix 2), $V_m(z;\alpha)$ becomes,

$$V_m(z;\alpha) = \frac{(a_0-c)^2}{4b\rho}\left(1-e^{-\rho z}\right) + \frac{2\beta^2}{4b\rho^3}\left[1-e^{-\rho z}-\rho z e^{-\rho z}-\frac{1}{2}(\rho z)^2 e^{-\rho z}\right]$$

$$-\frac{2\,(a_0-c)\,\beta}{4b\rho^2}\left[1-e^{-\rho z}-\rho z e^{-\rho z}\right] \tag{27}$$

and

$$V_m'(z;\alpha) = \frac{e^{-\rho z}}{4b}\left[a_0-c-z\beta\right]^2 \tag{28}$$

Note that

$$V_m''(z;\alpha) = -\frac{\rho e^{-\rho z}}{4b}\left[a_0-c-z\beta\right]^2 - \frac{\beta e^{-\rho z}}{2b}\left[a_0-c-z\beta\right] < 0. \tag{29}$$

Using the explicit expression for $V(m;\alpha)$, equation (27), the FOC can be rewritten as (see Appendix 3)

$$(\beta z)^2 - 2\beta(a_0-c)z - \frac{2\beta^2}{\rho^2} + \frac{2(a_0-c)\beta}{\rho} -$$

$$e^{-\rho z}\left[-\frac{2\beta^2}{\rho^2}+\frac{2(a_0-c)\,[\boldsymbol{\beta}]}{\rho}+z\left(-\frac{2\beta^2}{\rho}\right)\right]=-4b\rho I \tag{30}$$

Substituting values, $c = 4, \beta = 0.2, \rho = 0.1, a_0 = 8, b = 4,\ I = 2.5,$ the optimal rotation period is,

$$z^* = 10$$

The SOC, (39), is satisfied at $z^* = 10$.

Then, at $z^* = 10$, profit at period z (i.e. when the existing drug is about to be replaced) is

$$\pi^m(z^*) = \frac{(a_0 - c - \beta z)^2}{4b} = 0.25$$

And the price is

$$p^m(z^*) = \frac{a_0 - \beta z + c}{2} = 5$$

and the quantity demanded is

$$x(z^*) = \frac{a_0 - \beta z - p^m(z)}{b} = 0.25$$

Compare with the price of a new drug, i.e.,

$$p^m(0) = \frac{a_0 - \beta(0) + c}{2} = 6$$

and quantity

$$x(0) = \frac{a_0 - \beta(0) - p^m(0)}{b} = 0.5$$

The cumulative profit $V_m(z)$ upto $z^* = 10$, substituting values, $c = 4, \beta = 0.2, \rho = 0.1, a_0 = 8, b = 4$ and $z^* = 10$ in (27), is,

$$V_m(10) = 4.0803$$

The profits over an infinite horizon is calculated as,

$$\Pi = \frac{V_m(z) - I}{1 - e^{-\rho z}} = 2.5$$

4.8.2 Effects of an increase in β

Now suppose $\beta = 0.3$

Substituting values, $c = 4, \beta = 0.3, \rho = 0.1, a_0 = 8, b = 4,\ I = 2.5,$ the optimal rotation period has been solved as,

$$z^* = 8.66$$

The SOC, (39), is satisfied at $z^* = 8.66$.

At $z^* = 8.66$, profit at period z (i.e. when the existing drug is about to be replaced) is

$$\pi^m(8.66) = \frac{(a_0 - c - \beta z)^2}{4b} = 0.12285$$

And the price is

$$p^m(8.66) = \frac{a_0 - \beta z + c}{2} = 4.701$$

and the quantity demanded is

$$x(8.66) = \frac{a_0 - \beta z - p^m(z)}{b} = 0.17525$$

The cumulative profit $V_m(z)$ upto period $z^* = 8.66$, substituting values $c = 4, \beta = 0.3, \rho = 0.1, a_0 = 8, b = 4$ in (27), is,

$$V_m(8.66) = 3.2126$$

The profits over an infinite horizon, is calculated as,

$$\Pi(8.66) = \frac{V_m(z) - I}{1 - e^{-\rho z}} = 1.23$$

Under Northern monopoly, welfare of South over the period $[0, z]$ is

$$J(z) \equiv \int_0^z e^{-\rho t} W_M(t) dt = \int_0^z e^{-\rho t} \frac{(a - \beta t - c)^2}{8b} dt = \frac{1}{2} V_m(z)$$

$$J(8.66) = 1.6063$$

Welfare of South over the infinite horizon under Northern monopoly is thus

$$\psi(z) = (1 + e^{-\rho z} + e^{-2\rho z} + ... + e^{-n\rho z} + ...)J(z) = \frac{J(z)}{1 - e^{-\rho z}} = \frac{V_m(z)}{2(1 - e^{-\rho z})}$$

Or,

$$\psi(8.66) = 2.7725$$

The two cases i.e., when $\beta = 0.2$, and $\beta = 0.3$, have been compared in the table below.

	$\beta = 0.2$	$\beta = 0.3$
Optimal Rotation period, z^*	10	8.66
Profits over period $[0, \mathbf{z}^*]$, $V_m(\mathbf{z}^*)$	4.08	3.21
Profits over an infinite period, Π	2.5	1.23
Welfare over period $[0, \mathbf{z}^*]$, $J(\mathbf{z}^*)$	2.04	1.61
Welfare over an infinite period, ψ	3.23	2.77

Therefore, we state the following proposition.

Proposition 9: *An increase in* β,*from* $\beta = 0.2$ *to* $\beta = 0.3$ *which is equivalent to a decrease in* z^*, *from* $z^* = 10$ *to* $z^* = 8.66$,*suggests that,*

i) Cumulative profits upto period z^* *are s.t.* $V_m(10) > V_m(8.66)$

ii) Profits over an infinite horizon are s.t. $\Pi(10) > \Pi(8.66)$

iii) Welfare of the South over a time horizon $[0, z^*]$ *is s.t.* $J(10) > J(8.66)$,*and,* *iv) Welfare of South over an infinite horizon is s.t.* $\psi(10) > \psi(8.66)$

So welfare over a longer time horizon is greater. And over an infinite horizon, welfare is smaller whenever β is larger, since this implies that per period profit, $\pi^m(z)$.must be smaller, the effectiveness, of the drug, $a(t) = a_0 - \beta t$, reducing faster with time.

4.8.3 Effects of an increase in ρ

Now suppose $\rho = 0.2$

Substituting values, $c = 4, \beta = 0.2, \rho = 0.2, a_0 = 8, b = 4,\ I = 2.5$,the optimal rotation period has been derived as,

$$z^* = 12.81$$

The SOC, (39), is also satisfied at $z^* = 12.81$.

Then, at $z^* = 4.3593$, profit at period z (i.e. when the existing drug is about to be replaced) is

$$\pi^m(z) = \frac{(a_0 - c - \beta z)^2}{4b} = 0.12924$$

And the price is

$$p^m(z) = \frac{a_0 - \beta z + c}{2} = 4.719$$

and the quantity demanded is

$$x(z) = \frac{a_0 - \beta z - p^m(z)}{b} = 0.17975$$

The cumulative profit $V_m(z)$ upto period $z^* = 12.81$, substituting values in (27), is,

$$V_m(12.81) = 3.0963$$

The profits over an infinite horizon, is calculated as,

$$\Pi(12.81) = \frac{V_m(z) - I}{1 - e^{-\rho z}} = 0.64615$$

Then, welfare of the South over the period $[0, z^*]$, i.e., $[0, 12.81]$ is.

$$J(12.81) = 1.5482$$

and welfare of the South over an infinite horizon, is,

$$\psi\,(12.81) = 1.6776$$

Comparing the two cases i.e. when $\rho = 0.1$ and $\rho = 0.2$, it can be observed that,

	$\rho = 0.1$	$\rho = 0.2$
Optimal Rotation period, z^*	10	12.81
Profits over period $[0, \mathbf{z}^*]$, $V_m(\mathbf{z}^*)$	4.08	3.10
Profits over an infinite period, Π	2.5	0.65
Welfare over period $[0, \mathbf{z}^*]$, $J(\mathbf{z}^*)$	2.04	1.55
Welfare over an infinite period, ψ	3.23	1.68

Therefore, the following proposition can be stated.

Proposition 10: *An increase in* ρ, *from* $\rho = 0.1$ *to* $\rho = 0.2$ *which is equivalent to an increase in* z^*, *from* $z^* = 10$ *to* $z^* = 12.81$,*suggests that,*

i) Cumulative profits upto period z^* *are s.t.* $V_m(10) > V_m(12.81)$,

ii) Profits over an infinite horizon, are s.t. $\Pi(10) > \Pi(12.81)$

iii) Welfare of the South over a time horizon $[0, z^*]$ *is s.t.* $J(10) > J(12.81)$,*and,*

iv) Welfare of South over an infinite horizon is s.t. $\psi(10) > \psi(12.81)$

4.9 Limit pricing northern firm for drugs subject to bacteria resistance

Consider now the other extreme: as soon as a new drug is introduced by the Northern firm, if faces Southern firms that can imitate and produce a perfect substitute generic drug at a higher cost $(1 + \gamma)c$. Then, under limit pricing, the Northern firm's profit at t for a product invented at time zero is

$$\pi_L(t) = \frac{\gamma c}{b}\left[a_0 - \beta t - (1+\gamma)c\right] \text{ for } t \leq \frac{a_0 - (1+\gamma)c}{\beta}$$

while z denotes the "rotation period". The limit-pricing Northern firm's present value of the stream of profits from a given drug is

$$V_L(z) = \int_0^z e^{-\rho t} \frac{(a_0 - \beta t - (1+\gamma)c)\gamma c}{b} dt \text{ for } z \leq \frac{a_0 - (1+\gamma)c}{\beta}$$

where,

$$\frac{\partial V_L}{\partial z} = e^{-\rho z} \frac{(a_0 - \beta z - (1+\gamma)c)\gamma c}{b} > 0$$

$$\frac{\partial V_L}{\partial \beta} = -\int_0^z e^{-\rho t} \frac{\beta(a_0 - \beta t - (1+\gamma)c)\gamma c}{b} dt < 0$$

The monopoly's stream of profit from a sequence of drugs, each invented z periods after the preceding one, is

$$\Pi = (1 + e^{-\rho z} + e^{-2\rho z} + ... + e^{-n\rho z} + ...)(V_L(z) - I)$$

which being a geometric series as in the case of the monopoly, on summation, becomes,

$$\Pi = \frac{V_L(z) - I}{1 - e^{-\rho z}}$$

The Northern firm's optimal z is determined by

$$\max_z \frac{V_L(z) - I}{1 - e^{-\rho z}}$$

The first order condition being,

$$\frac{1}{(1 - e^{-\rho z})^2} \left\{ \left(1 - e^{-\rho z}\right) V_L'(z) - [V_L(z) - I]\, \rho e^{-\rho z} \right\} = 0$$

which as before, becomes,

$$\frac{V_L'(z)}{V_L(z) - I} = \frac{\rho e^{-\rho z}}{(1 - e^{-\rho z})} \tag{31}$$

The stream of profits, becomes

$$V_L(z) = \left[\frac{a_0 - (1+\gamma)c)\gamma c}{b}\right] \int_0^z e^{-\rho t} dt - \frac{\beta}{b} \int_0^z t e^{-\rho t} dt$$

To compute,

$$\int_0^z t e^{-\rho t} dt$$

(**??**) has been used whereby the integral becomes,

$$V_L(z) = \frac{\rho \left(1 - e^{-\rho z}\right) [a_0 - (1+\gamma)c)\gamma c] - \beta \left[1 - e^{-\rho z} - \rho z e^{-\rho z}\right]}{b\rho^2} \tag{32}$$

From the first order condition, $\frac{\partial V_L}{\partial z}$, the following has been written.

$$V_L'(z) = e^{-\rho z}\frac{(a_0 - \beta z - (1+\gamma)c)\gamma c}{b} \tag{33}$$

Rearranging (31), simplifying, (see Appendix 4), and substituting values, $c = 4, \beta = 0.2, \gamma = 0.7, \rho = 0.1, a_0 = 8, b = 4,\ I = 2.5$, the optimal z is,

$$z^* = 5.235$$

So, profits, at time, $z^* = 5.235$, is calculated as,

$$\pi_L(z^*) = \frac{\gamma c}{b}\left[a_0 - \beta z^* - (1+\gamma)c\right] = 0.107\,1$$

Quantity sold,

$$x_L \equiv x(c_s) = \frac{a_0 - \beta z^* - c_s}{b} = 0.03825$$

Price is

$$p_L(t) = (1+\gamma)c = c_s = 6.8$$

At time $t = 0$

$$\pi_L(0) = \frac{\gamma c}{b}\left[a_0 - \beta\,(0) - (1+\gamma)c\right] = 0.84$$

$$x_L \equiv x(c_s) = \frac{a_0 - \beta\,(0) - c_s}{b} = 0.3$$

Cumulative profit at $z^* = 5.235$, is calculated by substituting the value of z^*

in (32) .Substituting values, $c = 4$, $\beta = 0.2$, $\gamma = 0.7$, $\rho = 0.1$, $a_0 = 8$, $b = 4$, $I = 2.5$, cumulative profit is calculated as,

$$V_L(5.235) = 2.936\,4$$

The profits over an infinite horizon, is calculated as,

$$\Pi = \frac{V_L(z) - I}{1 - e^{-\rho z}} = 1.0708$$

Welfare of the South, under price limiting response, is

$$W \equiv \int_0^{x(p)} v(p,\theta)d\theta = ax - \frac{b}{2}x^2 - px = \frac{bx^2}{2}$$

where,

$$x_L \equiv x(c_s) = \frac{a_0 - \beta t - c_s}{b}$$

So,

$$W_L\left(t\right) \equiv \frac{1}{2b}\left(c_s - a_0 + t\beta\right)^2$$

Welfare upto period z, is,

$$2bJ(z) \equiv \int_0^z e^{-\rho t} W_L(t)dt = \int_0^z e^{-\rho t}\left((1+\gamma)c - a_0 + t\beta\right)^2 dt$$

Substituting values, $c = 4$, $\beta = 0.2$, $\gamma = 0.7$, $\rho = 0.1$, $a_0 = 8$, $b = 4$, $I = 2.5$

and using, (40) and (41), the welfare of the South over a time horizon $[0, z]$, is,

$$J(5.235) = 3.385$$

Welfare of South over an infinite horizon under Northern monopoly is thus

$$\psi(z) = (1 + e^{-\rho z} + e^{-2\rho z} + ... + e^{-n\rho z} + ...)J(z) = \frac{J(z)}{1 - e^{-\rho z}}$$

So, the welfare over an infinite horizon, at $z^* = 5.235$ is,

$$\psi(5.235) = 8.3056$$

The results for monopoly and limit pricing, substituting values, $c = 4$, $\beta = 0.2$, $\gamma = 0.7$, $\rho = 0.1$, $a_0 = 8$, $b = 4$, $I = 2.5$, are tabulated below for comparison.

	Monopoly	*Limit Pricing*$(\gamma = 0.7)$
Optimal Rotation period, z^*	10	5.24
Profits over period $[0, \mathbf{z}^*]$, $V(\mathbf{z}^*)$	4.08	2.94
Profits over an infinite period, Π	2.5	1.07
Welfare over period $[0, \mathbf{z}^*]$, $J(\mathbf{z}^*)$	2.04	3.39
Welfare over an infinite period, ψ	3.23	8.31

Values of profits are seen to smaller and values of welfare, greater in case of the limit pricing response as compared to monopoly.

4.10 The choice of the rotation period given a fixed patent length

It has now been assumed that for each new drug, the patent length is ℓ. If the rotation period is $z > \ell$, the Northern firm will earn, for each drug, a phase of monopoly profit from period 0 to ℓ and a phase of limit-pricing profit.from period ℓ to z.

The monopoly profit phase yields,

$$V_m(\ell) = \int_0^{\ell} e^{-\rho t} \frac{(a_0 - \beta t - c)^2}{4b} dt \text{ for } \ell \leq z \leq \frac{a_0 - c}{\beta}$$

The limit pricing profit phase yields,

$$V_L(\ell, z) = \int_{\ell}^{z} e^{-\rho t} \frac{(a_0 - \beta t - (1+\gamma)c)\gamma c}{b} dt \text{ for } z \leq \frac{a_0 - (1+\gamma)c}{\beta}$$

The stream of profit s earned by the Northern firm, from a sequence of drugs, each invented z periods after the preceding one, where $z > \ell$, is

$$\Pi = (1 + e^{-\rho z} + e^{-2\rho z} + ... + e^{-n\rho z} + ...)(V_m(\ell) + V_L(\ell, z) - I)$$

The Northen firm seeks to determine the optimal rotation period z. Suppose the optimal choice is such that $z > \ell$. Then z must solve:

$$\max_z \frac{V_m(\ell) + V_L(\ell, z) - I}{1 - e^{-\rho z}}$$

The first order condition yields,

$$\frac{\frac{dV_L(\ell,z)}{dz}}{V_m(\ell) + V_L(\ell, z) - I} = \frac{\rho e^{-\rho z}}{(1 - e^{-\rho z})} \tag{34}$$

Or,

$$\frac{dV_L(\ell, z)}{dz}\left(1 - e^{-\rho z}\right) = \left(V_m(\ell) + V_L(\ell, z) - I\right)\rho e^{-\rho z}$$

From (33),

$$\frac{dV_L(\ell, z)}{dz} = e^{-\rho z}\frac{(a_0 - \beta z - (1 + \gamma)c)\gamma c}{b}$$

The integrals $V_m(\ell)$ and $V_L(\ell, z)$ have been evaluated in Appendix 5, as

$$\begin{aligned} V_m(\ell) &= \frac{(a_0 - c)^2}{4b}\left(1 - e^{-\rho\ell}\right) \\ &\quad + \frac{2\beta^2}{4b\rho^3}\left[1 - e^{-\rho\ell} - \rho\ell e^{-\rho\ell} - \frac{1}{2}(\rho\ell)^2 e^{-\rho\ell}\right] \\ &\quad - \frac{2\,(a_0 - c)\,\beta}{4b\rho^2}\left[1 - e^{-\rho\ell} - \rho\ell e^{-\rho\ell}\right] \end{aligned} \tag{35}$$

and

$$V_L(\ell, z) = \left(\frac{a_0 - (1+\gamma)c)\gamma c}{b}\right)\left[\frac{1}{\rho}\left(e^{-\rho\ell} - e^{-\rho z}\right)\right] -$$

$$\frac{\beta}{b}\left(\frac{1}{\rho}\left(e^{-\rho\ell}\ell - e^{-\rho z}z\right) + \frac{1}{\rho^2}\left(e^{-\rho\ell} - e^{-\rho z}\right)\right) \tag{36}$$

From (34), using the reduced form as derived in Appendix 6**,** and substituting values, $c = 4$, $\beta = 0.2$, $\gamma = 0.7$, $\rho = 0.1$, $a_0 = 8$, $b = 4$, $I = 2.5$, the FOC reduces to,

$$1.2e^{-0.1z} + 2.8\left(e^{-0.1z} - 1\right)(0.2z - 1.2) = 2.8e^{-0.1\ell} - 0.1\ell e^{-0.1\ell}(0.1\ell - 2.0) - 2.6$$

The change in optimal values of the rotation period, i.e., z^*, with ℓ have been calculated and illustrated as follows:

ℓ	1	2	3	5	7	8	9	10
z^*	7.545	7.84	8.16	8.86	9.52	9.87	10.17	10.46

It can be noticed, that z^* is increasing in ℓ, at a decreasing rate, given the parameter values. Since the second integral pre-supposes $z^* \geq \ell$**.** only those results that satisfy $z^* \geq \ell$,.have been retained.

4.11 Southern Welfare under different values of ℓ

Welfare, of the South, over a period $[0, z]$, under different values of ℓ can be calculated from

$$W_M(t) = \frac{(a_0 - \beta t - c)^2}{8b}$$

and

$$W_L(t) = \frac{1}{2b}(c_s - a_0 + t\beta)^2$$

as the following.

$$W = \int_0^\ell e^{-\rho t} W_M(t)dt + \int_\ell^z e^{-\rho t} W_L(t)dt$$

Substituting values, this becomes,

$$W = \frac{1}{8b}\int_0^\ell e^{-\rho t}(a_0 - \beta t - c)^2 dt + \frac{1}{2b}\int_\ell^z e^{-\rho t}(c_s - a_0 + t\beta)^2 dt \tag{37}$$

And, welfare over an infinite horizon, is,

$$\Omega_W = (1 + e^{-\rho z} + e^{-2\rho z} + ... + e^{-n\rho z} + ...)W = \frac{W}{1 - e^{-\rho z}}$$

Welfare from (37) is derived as shown in Appendix 7. Solving numerically, by substituting values $c = 4, \beta = 0.2, \gamma = 0.7, \rho = 0.1, a_0 = 8, b = 4$ the following is obtained.

$$\begin{aligned} W &= 2.2e^{-0.1\ell} - 4.7e^{-0.1z} + 0.05\ell^2 e^{-0.1\ell} \\ &\quad -0.15ze^{-0.1z} + 0.4\ell e^{-0.1\ell} - 0.0625z^2 e^{-0.1z} + 2.5 \end{aligned}$$

The results for given values of ℓ have been tabulated as follows.

Patent length, ℓ	1	2	3	5
Optimal Rotation period, z^*	7.55	7.84	8.16	8.86
Welfare over $[0, \mathbf{z}^*]$, W	0.48	0.68	0.89	1.29
Welfare over infinite period, Ω_W	0.91	1.26	1.59	2.21

Patent length, ℓ	7	8	9	10
Optimal Rotation period, z^*	9.52	9.87	10.17	10.46
Welfare over $[0, \mathbf{z}^*]$, W	1.65	1.79	1.91	2.01
Welfare over infinite period, Ω_W	2.68	2.86	3.00	3.11

Accordingly, the following proposition has been stated.

Proposition 11: *The level of welfare over an infinite horizon increases with patent length, with associated increases in rotation periods. Welfare over* *comparable values of rotation periods, are lower as compared to the case of limit pricing.*

4.12 Conclusion

In this paper, the optimal patent length has been determined for an antibiotic produced in the North and imitated in the South. The impact of changes in several parameters has been analyzed, on the patent length, profits of the Northern firm, and welfare of the Southern country. In general, welfare has been seen to increase with an increase in the patent length. In a static model, without R&D, the South prefers the limit pricing regime, and thus, allows Southern firms to threaten entry into the market. Taking into account R&D, the optimal patent length, is decreasing in the cost disadvantage parameter, γ and research cost parameter, λ and increasing in the time period, T. From an initial situation with $\ell = 0$, a marginal increase in ℓ, improves Southern welfare if the time horizon T, is sufficiently large and starting from an initial situation with $\ell = T$, a marginal decrease in ℓ will improve welfare if the time horizon is sufficiently small.

Similarly, the optimal rotation period of the drug, profts of the Northern firm and levels of welfare have been calculated under considerations of bacteria resistance. An increase in the speed of bacteria resistance has been seen to always decrease the present value of the monopoly's profit stream while, its effect on the optimal rotation period is ambiguous. In the case of a fixed patent length, the optimal rotation period increases with an increase in the patent length while the levels of welfare over $[0, z^*]$, and over an infinite period, increase with longer rotation periods though at a decreasing rate.

It can be concluded that even though the regular patent length of twenty years must be adhered to by all member countries of the WTO, under TRIPS, the flexibility outlined at the Doha round, with regard to public health, might imply that the effective patent length of pharmaceutical products, given that reverse engineering is still a common practice in many developing countries, may be determined by the welfare maximizing policy of the government in question. This effective patent length may refer to the extent to which the patent of a foreign drug is respected within the geographical boundary of the developing economy (the South) whenever the pharmaceutical product in question is imported. In view of the flexibility allowed at the Doha round, this paper has outlined a possible theoretical foundation on which, policy making for the pharmaceutical industry in a developing economy may rely.

APPENDICES

APPENDIX 1: SOC for the monopolist's optimal choice of z

Let

$$A \equiv \frac{1}{\left(1 - e^{-\rho z}\right)^2}$$

and

$$B \equiv \left(1 - e^{-\rho z}\right) V_m'(z) - \left[V_m(z) - I\right] \rho e^{-\rho z}$$

The FOC implies $B = 0$. The SOC is

$$B \frac{\partial A}{\partial z} + A \frac{\partial B}{\partial z} < 0$$

which is satisfied iff

$$\frac{\partial B}{\partial z} < 0$$

Thus the SOC is equivalent to

$$\rho e^{-\rho t} V_m'(z) + \left(1 - e^{-\rho z}\right) V_m''(z) - V_m'(z) \rho e^{-\rho z} + \rho^2 e^{-\rho z} \left[V_m(z) - I\right] < 0$$

i.e.

$$\left(1 - e^{-\rho z}\right) V_m''(z) + \rho^2 e^{-\rho z} \left(\frac{1 - e^{-\rho z}}{\rho e^{-\rho z}}\right) V_m'(z) < 0$$

i.e.

$$V_m''(z) + \rho V_m'(z) < 0 \tag{38}$$

This condition is satisfied iff

$$V_m''(z) + \rho V_m'(z) = -2\beta e^{-\rho z}\frac{(a_0 - \beta z - c)}{4b} < 0$$

which requires that

$$\beta z + c - a_0 < 0 \tag{39}$$

The SOC can then be expressed as the rate of growth at profit should be lower than the interest rate:

$$-\frac{1}{V_m'(z)}\frac{dV_m'(z)}{dz} < \rho$$

APPENDIX 2: Explicit expression for $V_m(z;\alpha)$

Recall that

$$(a_0 - \beta t - c)^2 = (a_0 - c)^2 + \beta^2 t^2 - 2\left(a_0 - c\right)\beta t$$

Then we must first compute

$$\int_0^z te^{-\rho t}dt$$

and

$$\int_0^z t^2 e^{-\rho t}dt$$

To evaluate the first integral, define

$$F(t) = t \text{ so that } F'(t) = 1$$

$$G(t) = -\frac{e^{-\rho t}}{\rho} \text{ so that } G'(t) = e^{-\rho t}$$

Then

$$\begin{aligned}
\int_0^z te^{-\rho t}dt &= \int_0^z F(t)G'(t)dt \\
&= [F(z)G(z) - F(0)G(0)] - \int_0^z F'(t)G(t)dt \\
&= -\frac{ze^{-\rho z}}{\rho} + \frac{1}{\rho^2}\left[1 - e^{-\rho z}\right] \\
&= \frac{1}{\rho^2}\left[1 - e^{-\rho z} - \rho z e^{-\rho z}\right] > 0
\end{aligned} \tag{40}$$

To evaluate the second integral, we define

$$U(t) = t^2 \text{ so that } U'(t) = 2t$$

$$G(t) = -\frac{e^{-\rho t}}{\rho} \text{ so that } G'(t) = e^{-\rho t}$$

Then

$$\begin{aligned}
\int_0^z t^2 e^{-\rho t} dt &= \int_0^z U(t) G'(t) dt \\
&= [U(z)G(z) - U(0)G(0)] - \int_0^z U'(t)G(t)dt \\
&= -\frac{z^2 e^{-\rho z}}{\rho} + \frac{2}{\rho}\int_0^z te^{-\rho t}dt \\
&= -\frac{z^2 e^{-\rho z}}{\rho} + \frac{2}{\rho^3}\left[1 - e^{-\rho z} - \rho z e^{-\rho z}\right] \\
&= \frac{2}{\rho^3}\left[1 - e^{-\rho z} - \rho z e^{-\rho z} - \frac{1}{2}(\rho z)^2 e^{-\rho z}\right] > 0 \qquad (41)
\end{aligned}$$

Then

$$V_m(z) = \frac{(a_0 - c)^2}{4b}\int_0^z e^{-\rho t}dt + \frac{\beta^2}{4b}\int_0^z t^2 e^{-\rho t}dt - \frac{2\,(a_0 - c)\,\beta}{4b}\int_0^z te^{-\rho t}dt$$

becomes,

$$V_m(z;\alpha) = \frac{(a_0 - c)^2}{4b\rho}\left(1 - e^{-\rho z}\right) + \frac{2\beta^2}{4b\rho^3}\left[1 - e^{-\rho z} - \rho z e^{-\rho z} - \frac{1}{2}(\rho z)^2 e^{-\rho z}\right]$$

$$-\frac{2\,(a_0 - c)\,\beta}{4b\rho^2}\left[1 - e^{-\rho z} - \rho z e^{-\rho z}\right]$$

APPENDIX 3: Reduced form FOC for the monopoly's optimal z

Substituting (27) and (28) into the F.O.C. (26) we get an equation that determines the optimal z^* which is dependent on parameters such as β, a_0,

ρ and I. Substitute,(28)

$$V_m'(z) = \frac{e^{-\rho z}}{4b}\left[a_0 - c - z\beta\right]^2$$

and(27)

$$\begin{aligned} V_m(z) &= \frac{1}{4b\rho}\left[(a_0-c)^2 + \frac{2\beta^2}{\rho^2} - \frac{2\left(a_0-c\right)\beta}{\rho}\right] \\ &\quad - \left[\begin{array}{c} (a_0-c)^2 + \frac{2\beta^2}{\rho^2}\left(1+\rho z+\frac{1}{2}(\rho z)^2\right) \\ -\frac{2(a_0-c)\beta}{\rho}\left(1+\rho z\right) \end{array}\right]\frac{e^{-\rho z}}{4b\rho} \end{aligned}$$

into (26),

$$V_m'(z)\left(1-e^{-\rho z}\right) = V_m(z)\rho e^{-\rho z} - I\rho e^{-\rho z}$$

Then, L.H.S. becomes,

$$V_m'(z)\left(1-e^{-\rho z}\right) = \frac{e^{-\rho z}}{4b}\left[a_0 - c - z\beta\right]^2\left(1-e^{-\rho z}\right)$$

and R.H.S. becomes,

$$\left[\begin{array}{c} \frac{1}{4b\rho}\left[(a_0-c)^2 + \frac{2\beta^2}{\rho^2} - \frac{2(a_0-c)\beta}{\rho}\right] - \\ \left[(a_0-c)^2 + \frac{2\beta^2}{\rho^2}\left(1+\rho z+\frac{1}{2}(\rho z)^2\right) - \frac{2(a_0-c)\beta}{\rho}\left(1+\rho z\right)\right]\frac{e^{-\rho z}}{4b\rho} - I \end{array}\right]\left[\rho e^{-\rho z}\right]$$

With L.H.S. = R.H.S.

$$\frac{e^{-\rho z}}{4b}\left[a_0 - c - z\beta\right]^2\left(1 - e^{-\rho z}\right)$$

$$= \left[\begin{array}{c} \frac{(a_0-c)^2}{4b\rho}\left(1 - e^{-\rho z}\right) + \frac{2\beta^2}{4b\rho^3}\left[1 - e^{-\rho z} - \rho z e^{-\rho z} - \frac{1}{2}(\rho z)^2 e^{-\rho z}\right] \\ -\frac{2(a_0-c)\beta}{4b\rho^2}\left[1 - e^{-\rho z} - \rho z e^{-\rho z}\right] - I \end{array}\right]\rho e^{-\rho z}$$

or,

$$\begin{aligned} \left[a_0 - c - z\beta\right]^2\left(1 - e^{-\rho z}\right) &= (a_0 - c)^2\left(1 - e^{-\rho z}\right) \\ &+\frac{2\beta^2}{\rho^2}\left[1 - e^{-\rho z} - \rho z e^{-\rho z} - \frac{1}{2}(\rho z)^2 e^{-\rho z}\right] \\ &-\frac{2\left(a_0 - c\right)\beta}{\rho}\left[1 - e^{-\rho z} - \rho z e^{-\rho z}\right] - 4b\rho I \end{aligned}$$

Hence, the FOC is,

$$\left(1 - e^{-\rho z}\right)\left[(a_0 - c - z\beta)^2 - (a_0 - c)^2 - \frac{2\beta^2}{\rho^2} + \frac{2\left(a_0 - c\right)\beta}{\rho}\right]$$

$$= e^{-\rho z}\left[-\frac{2\rho z\beta^2}{\rho^2} - \frac{\beta^2\rho^2 z^2}{\rho^2} + \frac{2\left(a_0 - c\right)\beta\rho z}{\rho}\right] - 4b\rho I$$

Note that,

$$(a_0 - c - z\beta)^2 - (a_0 - c)^2 = (\beta z)^2 - 2\beta(a_0 - c)z$$

Hence,

$$\begin{aligned}
& (\beta z)^2 - 2\beta(a_0 - c)z - \frac{2\beta^2}{\rho^2} + \frac{2(a_0 - c)\beta}{\rho} \\
& -e^{-\rho z} \left(\begin{array}{c} (\beta z)^2 - 2\beta(a_0 - c)z \\ -\frac{2\beta^2}{\rho^2} + \frac{2(a_0-c)\beta}{\rho} - \frac{2z\beta^2}{\rho} - \beta^2 z^2 + 2\left(a_0 - c\right)\beta z \end{array} \right) \\
= \; & -4b\rho I
\end{aligned}$$

and,

$$\begin{aligned}
& (\beta z)^2 - 2\beta(a_0 - c)z - \frac{2\beta^2}{\rho^2} + \frac{2(a_0 - c)\left(\beta\right)}{\rho} - \\
& \frac{2z\beta^2}{\rho} - \beta^2 z^2 + 2\left(a_0 - c\right)\beta z \\
= \; & -\frac{2\beta^2}{\rho^2} + \frac{2(a_9 - c)\beta}{\rho} + z\left(-\frac{2\beta^2}{\rho}\right)
\end{aligned}$$

The FOC becomes,

$$(\beta z)^2 - 2\beta(a_0 - c)z - \frac{2\beta^2}{\rho^2} + \frac{2(a_0 - c)\beta}{\rho} -$$

$$e^{-\rho z}\left[-\frac{2\beta^2}{\rho^2} + \frac{2(a_0 - c)\beta}{\rho} + z\left(-\frac{2\beta^2}{\rho}\right)\right] = -4b\rho I$$

APPENDIX 4 : Reduced form FOC for the optimal z in case of

Rearranging (31) ,

$$\left(1-e^{-\rho z}\right)V_L'(z)=\rho e^{-\rho z}\left(V_L(z)-I\right)$$

L.H.S. has been re-written from (33) as

$$\left(1-e^{-\rho z}\right)e^{-\rho z}\frac{(a_0-\beta z-(1+\gamma)c)\gamma c}{b}$$

R.H.S. has been re-written from (32) as

$$\rho e^{-\rho z}\left[\frac{\rho\left(1-e^{-\rho z}\right)\left[\left(a_0-(1+\gamma)c\right)\gamma c\right]-\beta\left[1-e^{-\rho z}-\rho z e^{-\rho z}\right]}{b\rho^2}-I\right]$$

Writing L.H.S.= R.H.S.

$$\begin{aligned}&\frac{e^{-\rho z}}{b}(a_0-\beta z-(1+\gamma)c)\gamma c\left(1-e^{-\rho z}\right)\\ =\ &\rho e^{-\rho z}\left[\frac{\rho\left(1-e^{-\rho z}\right)\left[\left(a_0-(1+\gamma)c\right)\gamma c\right]-\beta\left[1-e^{-\rho z}-\rho z e^{-\rho z}\right]}{b\rho^2}-I\right]\end{aligned}$$

Or,

$$
\begin{aligned}
& (a_0 - \beta z - (1+\gamma)c)\gamma c \left(1 - e^{-\rho z}\right) \\
= \ & \frac{\rho\left(1 - e^{-\rho z}\right)\left[\left(a_0 - (1+\gamma)c\right)\gamma c\right] - \beta\left[1 - e^{-\rho z} - \rho z e^{-\rho z}\right]}{\rho} - b\rho I
\end{aligned}
$$

APPENDIX 5: Solution of integrals for monopoly phase profit $V_m(\ell)$ and the profits during the limit pricing $V_L(\ell, z)$

1) The monopoly phase profit, i.e.,

$$V_m(\ell) = \frac{1}{4b}\int_0^{\ell} e^{-\rho t}(a_0 - \beta t - c)^2 dt$$

using (40) and (41) ,(ref : Appendix 2) becomes,

$$
\begin{aligned}
V_m(\ell) \ = \ & \frac{(a_0 - c)^2}{4b}\left(1 - e^{-\rho\ell}\right) \\
& + \frac{2\beta^2}{4b\rho^3}\left[1 - e^{-\rho\ell} - \rho\ell e^{-\rho\ell} - \frac{1}{2}(\rho\ell)^2 e^{-\rho\ell}\right] \\
& - \frac{2\left(a_0 - c\right)\beta}{4b\rho^2}\left[1 - e^{-\rho\ell} - \rho\ell e^{-\rho\ell}\right]
\end{aligned}
$$

2) The profits during the limit pricing response, i.e,

$$V_L(\ell, z) = \int_{\ell}^{z} e^{-\rho t}\frac{(a_0 - \beta t - (1+\gamma)c)\gamma c}{b} dt \text{ for } z \leq \frac{a_0 - (1+\gamma)c}{\beta}$$

rearranging as,

$$V_L(z) = \left[\frac{(a_0 - (1+\gamma)c)\gamma c}{b}\right] \int_\ell^z e^{-\rho t} dt - \frac{\beta}{b} \int_\ell^z t e^{-\rho t} dt$$

and substituting,

$$F(t) = t \text{ so that } F'(t) = 1$$

$$G(t) = -\frac{e^{-\rho t}}{\rho} \text{ so that } G'(t) = e^{-\rho t}$$

whereby,

$$\begin{aligned}
\int_\ell^z t e^{-\rho t} dt &= \int_\ell^z F(t) G'(t) dt \\
&= [F(z)G(z) - F(\ell)G(\ell)] - \int_\ell^z F'(t) G(t) dt \\
&= \left[-\frac{e^{-\rho z}}{\rho} z + \frac{e^{-\rho \ell}}{\rho} \ell\right] + \frac{1}{\rho} e^{-\rho t} dt \\
&= \frac{1}{\rho}\left[e^{-\rho \ell}\ell - e^{-\rho z} z\right] + \frac{1}{\rho}\left[-\frac{1}{\rho} e^{-\rho t}\right]_\ell^z \\
&= \frac{1}{\rho}\left[e^{-\rho \ell}\ell - e^{-\rho z} z\right] + \frac{1}{\rho}\left[-\frac{1}{\rho} e^{-\rho z} + \frac{1}{\rho} e^{-\rho \ell}\right] \\
&= \frac{1}{\rho}\left(e^{-\rho \ell}\ell - e^{-\rho z} z\right) + \frac{1}{\rho^2}\left(e^{-\rho \ell} - e^{-\rho z}\right) \qquad (42)
\end{aligned}$$

becomes,

$$
\begin{aligned}
V_L(\ell, z) \quad &= \quad \left(\frac{a_0 - (1+\gamma)c)\gamma c}{b}\right)\left[\frac{1}{\rho}\left(e^{-\rho\ell} - e^{-\rho z}\right)\right] - \\
&\frac{\beta}{b}\left(\frac{1}{\rho}\left(e^{-\rho\ell}\ell - e^{-\rho z}z\right) + \frac{1}{\rho^2}\left(e^{-\rho\ell} - e^{-\rho z}\right)\right)
\end{aligned}
$$

APPENDIX 6: Reduced form FOC for optimal z in the case of fixed patent length

From (34), we have,

$$
\frac{dV_L(\ell, z)}{dz}\left(1 - e^{-\rho z}\right) = \left[V_m(\ell) + V_L(\ell, z) - I\right]\rho e^{-\rho z}
$$

L.H.S. becomes,

$$
e^{-\rho z}\frac{(a_0 - \beta z - (1+\gamma)c)\gamma c}{b}\left(1 - e^{-\rho z}\right)
$$

R.H.S. becomes

$$
\begin{aligned}
& \left[V_m(\ell)+V_L(\ell,z)-I\right]\rho e^{-\rho z} \\
= \; & \rho e^{-\rho z}\left[\begin{array}{c} \frac{(a_0-c)^2}{4b}\left(1-e^{-\rho\ell}\right)+\frac{2\beta^2}{4b\rho^3}\left[1-e^{-\rho\ell}-\rho\ell e^{-\rho\ell}-\frac{1}{2}(\rho\ell)^2 e^{-\rho\ell}\right] \\ -\frac{2(a_0-c)\beta}{4b\rho^2}\left[1-e^{-\rho\ell}-\rho\ell e^{-\rho\ell}\right] \end{array}\right] \\
& +\rho e^{-\rho z}\left[\begin{array}{c} \frac{1}{\rho}\left(\frac{a_0-(1+\gamma)c)\gamma c}{b}\right)\left(e^{-\rho\ell}-e^{-\rho z}\right) \\ -\frac{\beta}{b}\frac{1}{\rho}\left(e^{-\rho\ell}\ell-e^{-\rho z}z\right)-\frac{\beta}{b}\frac{1}{\rho^2}\left(e^{-\rho\ell}-e^{-\rho z}\right) \end{array}\right]-I\rho e^{-\rho z}
\end{aligned}
$$

Or,

$$
\begin{aligned}
& \left[V_m(\ell)+V_L(\ell,z)-I\right]\rho e^{-\rho z} \\
= \; & e^{-\rho z}\left[\begin{array}{c} \left(\frac{\rho(a_0-c)^2}{4b}+\frac{2\beta^2}{4b\rho^2}-\frac{2(a_0-c)\beta}{4b\rho}\right)\left(1-e^{-\rho\ell}\right) \\ -\left(\frac{\beta^2}{2b\rho^2}+\frac{\beta^2\rho\ell}{4b\rho^2}-\frac{(a_0-c)\beta}{2b\rho}\right)\left(\rho\ell e^{-\rho\ell}\right) \end{array}\right] \\
& +e^{-\rho z}\left[\begin{array}{c} \left(\frac{a_0-(1+\gamma)c)\gamma c}{b}-\frac{\beta}{\rho b}-\ell\frac{\beta}{b}\right)e^{-\rho\ell} \\ -\left(\frac{a_0-(1+\gamma)c)\gamma c}{b}-\frac{\beta}{\rho b}-z\frac{\beta}{b}\right)e^{-\rho z} \end{array}\right]-I\rho e^{-\rho z}
\end{aligned}
$$

L.H.S. = R.H.S.

$$
\begin{aligned}
&\frac{(a_0 - \beta z - (1+\gamma)c)\gamma c}{b}\left(1-e^{-\rho z}\right) \\
= \;&\frac{1}{b}\left[\begin{array}{c} \left(\frac{\rho(a_0-c)^2}{4}+\frac{2\beta^2}{4\rho^2}-\frac{2(a_0-c)\beta}{4\rho}\right)\left(1-e^{-\rho\ell}\right) \\ -\left(\frac{\beta^2}{2\rho^2}+\frac{\beta^2\rho\ell}{4\rho^2}-\frac{(a_0-c)\beta}{2\rho}\right)\left(\rho\ell e^{-\rho\ell}\right) \end{array}\right] \\
&+\frac{1}{b}\left[\begin{array}{c} \left(a_0-(1+\gamma)c)\gamma c-\frac{\beta}{\rho}-\ell\beta\right)e^{-\rho\ell} \\ -\left(a_0-(1+\gamma)c)\gamma c-\frac{\beta}{\rho}-z\beta\right)e^{-\rho z} \end{array}\right]-I\rho
\end{aligned}
$$

Or,

$$
\begin{aligned}
&(a_0 - \beta z - (1+\gamma)c)\gamma c\left(1-e^{-\rho z}\right) \\
&+\left(a_0-(1+\gamma)c)\gamma c-\frac{\beta}{\rho}-z\beta\right)e^{-\rho z} \\
= \;&\left(\frac{\rho(a_0-c)^2}{4}+\frac{2\beta^2}{4\rho^2}-\frac{2\left(a_0-c\right)\beta}{4\rho}\right)\left(1-e^{-\rho\ell}\right) \\
&-\left(\frac{\beta^2}{2\rho^2}+\frac{\beta^2\rho\ell}{4\rho^2}-\frac{\left(a_0-c\right)\beta}{2\rho}\right)\left(\rho\ell e^{-\rho\ell}\right) \\
&+\left(a_0-(1+\gamma)c)\gamma c-\frac{\beta}{\rho}-\ell\beta\right)e^{-\rho\ell}-Ib\rho
\end{aligned}
$$

APPENDIX 7: Explicit expression for welfare, $W = W\left(W_M(t), W_L(t)dt\right)$, in the case of fixed patent length

$$W=\frac{1}{8b}\int_0^{\ell}e^{-\rho t}\left(a_0-\beta t-c\right)^2dt+\frac{1}{2b}\int_{\ell}^{z}e^{-\rho t}\left(c_s-a_0+t\beta\right)^2dt$$

Given that,

$(a_0-\beta t-c)^2=(a_0-c)^2+(c-a_0)\,2t\beta+t^2\beta^2$

$(c_s-a_0+t\beta)^2=(a_0-c_s)^2+(c_s-a_0)\,2t\beta+t^2\beta^2$

Welfare becomes,

$$\begin{aligned} W &= \frac{1}{8b}\left[\begin{array}{c} (a_0-c)^2\int_0^{\ell}e^{-\rho t}dt \\ +(c-a_0)\,2\beta\int_0^{\ell}te^{-\rho t}dt+\beta^2\int_0^{\ell}t^2e^{-\rho t}dt \end{array}\right] \\ & \quad +\frac{1}{2b}\left[\begin{array}{c} (a_0-c_s)^2\int_{\ell}^{z}e^{-\rho t}dt \\ +(c_s-a_0)\,2\beta\int_{\ell}^{z}te^{-\rho t}dt+\beta^2\int_{\ell}^{z}t^2e^{-\rho t}dt \end{array}\right] \end{aligned}$$

We make the following substitutions.

From (40) and (41), we have,

(1)

$$\int_0^z te^{-\rho t}dt=\frac{1}{\rho^2}\left[1-e^{-\rho z}-\rho ze^{-\rho z}\right]$$

(2)

$$\int_0^z t^2e^{-\rho t}dt=\frac{2}{\rho^3}\left[1-e^{-\rho z}-\rho ze^{-\rho z}-\frac{1}{2}(\rho z)^2e^{-\rho z}\right]$$

(3) From (42)

$$\int_{\ell}^{z} te^{-\rho t}dt = \frac{1}{\rho}\left(e^{-\rho\ell}\ell - e^{-\rho z}z\right) + \frac{1}{\rho^2}\left(e^{-\rho\ell} - e^{-\rho z}\right)$$

(4) To evaluate $\int_{z}^{\ell} t^2 e^{-\rho t}dt$, we define,

$$U(t) = t^2 \text{ so that } U'(t) = 2t$$

$$G(t) = -\frac{e^{-\rho t}}{\rho} \text{ so that } G'(t) = e^{-\rho t}$$

Then,

$$\begin{aligned}
\int_{\ell}^{z} t^2 e^{-\rho t}dt &= \int_{\ell}^{z} U(t)G'(t)dt \\
&= \left[\ell^2\left(\frac{e^{-\rho\ell}}{\rho}\right) - z^2\left(\frac{e^{-\rho z}}{\rho}\right)\right] \\
&\quad + \frac{2}{\rho}\int_{\ell}^{z} te^{-\rho t}\ dt \\
&= \ell^2\left(\frac{e^{-\rho\ell}}{\rho}\right) - z^2\left(\frac{e^{-\rho z}}{\rho}\right) \\
&\quad + \frac{2}{\rho}\left[\frac{1}{\rho}\left(e^{-\rho\ell}\ell - e^{-\rho z}z\right) + \frac{1}{\rho^2}\left(e^{-\rho\ell} - e^{-\rho z}\right)\right] \\
&= \ell^2\left(\frac{e^{-\rho\ell}}{\rho}\right) - z^2\left(\frac{e^{-\rho z}}{\rho}\right) \\
&\quad + \frac{2}{\rho^2}\left(e^{-\rho\ell}\ell - e^{-\rho z}z\right) + \frac{2}{\rho^3}\left(e^{-\rho\ell} - e^{-\rho z}\right)
\end{aligned}$$

Substituting values, welfare can be written as,

$$W = \frac{1}{8b}\left[\begin{array}{c} (a_0 - c)^2 \frac{1}{\rho}\left[1 - e^{-\rho z}\right] \\ +(c - a_0)\, 2\beta \frac{1}{\rho^2}\left[1 - e^{-\rho z} - \rho z e^{-\rho z}\right] \\ +\beta^2 \frac{2}{\rho^3}\left[1 - e^{-\rho z} - \rho z e^{-\rho z} - \frac{1}{2}(\rho z)^2 e^{-\rho z}\right] \end{array}\right]$$

$$+\frac{1}{2b}\left[\begin{array}{c} (a_0 - c_s)^2 \frac{1}{\rho}\left[e^{-\rho z} - e^{-\rho \ell}\right] \\ +(c_s - a_0)\, 2\beta\left[\frac{1}{\rho}\left(e^{-\rho \ell}\ell - e^{-\rho z} z\right) + \frac{1}{\rho^2}\left(e^{-\rho \ell} - e^{-\rho z}\right)\right] \\ +\beta^2 \left[\begin{array}{c} \ell^2\left(\frac{e^{-\rho \ell}}{\rho}\right) - z^2\left(\frac{e^{-\rho z}}{\rho}\right) \\ +\frac{2}{\rho^2}\left(e^{-\rho \ell}\ell - e^{-\rho z} z\right) + \frac{2}{\rho^3}\left(e^{-\rho \ell} - e^{-\rho z}\right) \end{array}\right] \end{array}\right]$$

Proof of Proposition 1

To prove part (a), note that

$$\frac{\partial R^*}{\partial \ell} = -\frac{\partial G/\partial \ell}{\partial G/\partial R} = \frac{(a_0 + R + c) - 2(1+\gamma)c}{2b\lambda - \ell} > 0 \tag{43}$$

where the inequality follows from **Assumption A.1** and the SOC.

To prove part (b),

$$\frac{\partial R^*}{\partial T} = -\frac{\partial G/\partial T}{\partial G/\partial R} = \frac{2(1+\gamma)c}{2b\lambda - \ell} > 0 \tag{44}$$

To prove part (c),

$$\frac{\partial R^*}{\partial \gamma} = -\frac{\partial G/\partial \gamma}{\partial G/\partial R} = \frac{2(T-\ell)c}{2b\lambda - \ell} > 0 \tag{45}$$

For part (d),

$$\frac{\partial R^*}{\partial \lambda} = -\frac{\partial G/\partial \lambda}{\partial G/\partial R} < 0 \tag{46}$$

This completes the proof.■

Proof of Proposition 2

(i) If $T \geq b\lambda$ then the right hand side of (10) is negative (or zero) and thus the inequality (10) cannot be satisfied, given that $T > 0$.

(ii) If $T < b\lambda$ then the right hand side of (10) is strictly positive, and so is the left-hand side. When $\gamma = 0$ then the inequality (10) is satisfied provided that

$$a_0 - c > \frac{cT^2}{b\lambda(b\lambda - T)} \tag{47}$$

It follows that if γ is close enough to zero, and (47) holds, then the inequality (10) is satisfied. This completes the proof.■

Proof of Proposition 6

The F.O.C. is

$$\psi(\ell, R, \gamma, T) = 0$$

and the S.O.C. is

$$\frac{\partial \psi(\ell, R, \gamma, T)}{\partial R} < 0$$

(a) Given,

$$\frac{\partial R^{**}}{\partial T} = -\frac{\partial \psi / \partial T}{\partial \psi / \partial R}$$

we know,

$$\text{sign}\frac{\partial R^{**}}{\partial T} = \text{sign}\frac{\partial \psi(\ell, R, \gamma, T)}{\partial T}$$

where,

$$\frac{\partial \psi(\ell, R, \gamma, T)}{\partial T} = \frac{(1+\gamma)\, c}{b} e^{-\rho T} > 0$$

Therefore,

$$\frac{\partial R^{**}}{\partial T} > 0$$

(b) Given,

$$\frac{\partial R^{**}}{\partial \ell} = -\frac{\partial \psi / \partial \ell}{\partial \psi / \partial R}$$

we know,

$$\text{sign}\frac{\partial R^{**}}{\partial \ell} = \text{sign}\frac{\partial \psi(\ell, R, \gamma, T)}{\partial \ell}$$

where,

$$\frac{\partial \psi(\ell, R, \gamma, T)}{\partial \ell} = e^{-\rho \ell}\left[\frac{[a_0 + R + c] - 2(1+\gamma)c}{2b}\right] > 0$$

(c) We need to show,

$$\frac{\partial \psi(\ell, R, \gamma, T)}{\partial \rho} < 0$$

Since,

$$\text{sign}\frac{\partial R^{**}}{\partial \rho} = \text{sign}\frac{\partial \psi(\ell, R, \gamma, T)}{\partial \rho}$$

Now,

$$\frac{d}{d\rho}\left[\frac{\left(1 - e^{-\rho\ell}\right)}{\rho}\right] = \frac{\rho\ell e^{-\rho\ell} - 1 + e^{-\rho\ell}}{\rho^2}$$

and

$$\rho\ell e^{-\rho\ell} - 1 + e^{-\rho\ell} < 0 \tag{48}$$

(recall that the function $f(x) \equiv e^{-x\ell}$ is a strictly convex function, which implies that $f(x) - f(y) < f'(x)(x - y)$ for all $y \neq x$. Setting $x = \rho$ and $y = 0$ proves the inequality (48).

Similarly,

$$\frac{d}{d\rho}\left[\frac{1}{\rho}\left(e^{-\rho\ell} - e^{-\rho T}\right)\right] = \frac{d}{d\rho}\left[\int_{\ell}^{T} e^{-\rho t}dt\right] = -\left[\int_{\ell}^{T} te^{-\rho t}dt\right] < 0$$

Therefore,

$$\frac{\partial \psi(\ell, R, \gamma, T)}{\partial \rho} < 0$$

has been proved.

Proof of Propostition 7

Applying the envelope theorem to (24).

$$\frac{\partial \Pi^*}{\partial \beta} = \frac{1}{1-e^{-\rho z}} \frac{\partial}{\partial \beta}\left[V_m(z;\alpha)\right] = \frac{1}{1-e^{-\rho z}} \int_0^z e^{-\rho t} \frac{\frac{\partial}{\partial \beta}(a_0 - \beta t - c)^2}{4b} dt$$

$$= \frac{1}{1-e^{-\rho z}} \int_0^z e^{-\rho t} \frac{\frac{\partial}{\partial \beta}(a_0 - \beta t - c)^2}{4b} dt$$

$$= \frac{1}{1-e^{-\rho z}} \int_0^z \frac{e^{-\rho t}}{4b} \left[-2t(a_0 - \beta t - c)\right] dt < 0 \text{ because } a_0 - \beta t - c > 0 \blacksquare$$

proved.

Proof of Proposition 8

Proof: The FOC (25) define an implicit relationship between the optimal z^* and the parameter vector $\alpha \equiv (a_0, c, \beta, b, \rho)$.

$$F(z^*;\alpha) \equiv \left(1 - e^{-\rho z^*}\right) V_m'(z^*;\alpha) - \left[V_m(z^*;\alpha) - I\right] \rho e^{-\rho z^*} = 0$$

Implicit differentiation of the above equation with respect to the parameter β gives

$$\frac{\partial F}{\partial z^*}\frac{\partial z^*}{\partial \beta} + \frac{\partial F}{\partial \beta} = 0$$

Thus

$$\frac{\partial z^*}{\partial \beta} = -\frac{\frac{\partial F}{\partial \beta}}{\frac{\partial F}{\partial z^*}}$$

Since $\frac{\partial F}{\partial z^*} < 0$ by the SOC, it follows that

$$sign\left[\frac{\partial z^*}{\partial \beta}\right] = sign\left[\frac{\partial F}{\partial \beta}\right]$$

Now

$$\frac{\partial F}{\partial \beta} = \left(1 - e^{-\rho z^*}\right)\frac{\partial V_m^2}{\partial \beta \partial z} - \rho e^{-\rho z^*}\frac{\partial V_m}{\partial \beta}$$

Where, from (19)

$$\frac{\partial V_m}{\partial \beta} = \int_0^z e^{-\rho t}\frac{\frac{\partial}{\partial \beta}(a_0 - \beta t - c)^2}{4b}dt = \int_0^z e^{-\rho t}\left[\frac{-2(a_0 - \beta t - c)t}{4b}\right]dt < 0$$

where $(a_0 - \beta t - c) > 0$ because of (17). And, from (20)

$$\frac{\partial^2 V_m}{\partial \beta \partial z} = e^{-\rho t}\left[\frac{-2z(a_0 - \beta z - c)}{4b}\right] = -e^{-\rho t} z q_m(z) < 0$$

Therefore the sign of $\frac{\partial F}{\partial \beta}$ is ambiguous.(Proved) ■

Appendix : Declaration on TRIPS agreement at the Doha Round

Declaration on the TRIPS agreement and public health

Adopted on 14 November 2001

1. We recognize the gravity of the public health problems afflicting many developing and least-developed countries, especially those resulting from HIV/AIDS, tuberculosis, malaria and other epidemics.

2. We stress the need for the WTO Agreement on Trade-Related Aspects

of Intellectual Property Rights (TRIPS Agreement) to be part of the wider national and international action to address these problems.

3. We recognize that intellectual property protection is important for the development of new medicines. We also recognize the concerns about its effects on prices.

4. We agree that the TRIPS Agreement does not and should not prevent members from taking measures to protect public health. Accordingly, while reiterating our commitment to the TRIPS Agreement, we affirm that the Agreement can and should be interpreted and implemented in a manner supportive of WTO members' right to protect public health and, in particular, to promote access to medicines for all. In this connection, we reaffirm the right of WTO members to use, to the full, the provisions in the TRIPS Agreement, which provide flexibility for this purpose.

5. Accordingly and in the light of paragraph 4 above, while maintaining our commitments in the TRIPS Agreement, we recognize that these flexibilities include:

a. In applying the customary rules of interpretation of public international law, each provision of the TRIPS Agreement shall be read in the light of the object and purpose of the Agreement as expressed, in particular, in its objectives and principles.

b. Each member has the right to grant compulsory licences and the freedom to determine the grounds upon which such licences are granted.

c. Each member has the right to determine what constitutes a national emergency or other circumstances of extreme urgency, it being understood that public health crises, including those relating to HIV/AIDS, tuberculosis, malaria and other epidemics, can represent a national emergency or other circumstances of extreme urgency.

d. The effect of the provisions in the TRIPS Agreement that are relevant to the exhaustion of intellectual property rights is to leave each member free to establish its own regime for such exhaustion without challenge, subject to the MFN and national treatment provisions of Articles 3 and 4.

6. We recognize that WTO members with insufficient or no manufacturing capacities in the pharmaceutical sector could face difficulties in making effective use of compulsory licensing under the TRIPS Agreement. We instruct the Council for TRIPS to find an expeditious solution to this problem and to report to the General Council before the end of 2002.

7. We reaffirm the commitment of developed-country members to provide incentives to their enterprises and institutions to promote and encourage technology transfer to least-developed country members pursuant to Article 66.2. We also agree that the least-developed country members will not be obliged, with respect to pharmaceutical products, to implement or apply Sections 5 and 7 of Part II of the TRIPS Agreement or to enforce rights provided for under these Sections until 1 January 2016, without prejudice to the right of least-developed country members to seek other extensions of the transition periods as provided for in Article 66.1 of the TRIPS Agreement. We instruct the Council for TRIPS to take the necessary action to give effect

to this pursuant to Article 66.1 of the TRIPS Agreement.

http://www.wto.org/english/thewto_e/minist_e/min01_e/mindecl_trips_e.htm

Conclusion

This dissertation consists of a survey chapter on the economic literature on property rights and three original models dealing with various aspects of property rights in different economic contexts. The main aims are to provide microenomic insight into why a property right regime may change, and to show how the optimal enforcement of property rights may depend on the various trade-offs in any given context. The first chapter presents a selective survey of the literature on the evolution of the concept of property and rights to property. The first section begins from the Physiocratic regime between the eighteenth to the beginning of the nineteenth century, and continues through the regime of the Utopian Socialists, the Liberalists, the Dissenters and the Anarchists. The second section surveys the more recent views of the Austrian School and the school of New Institutional Economics and continues to study different aspects of imperfect property rights. The importance of property as an economic institution has been seen to have its ups and downs in the mind of various generations of economists, until the views of the New Institutional Economics whereby property rights as a component of economic institutions were formally introduced into economic modelling.

The second chapter illustrates the movement of an economy, from a regime of partially secure propery rights to a regime where property rights are fully secure, along paths of capital accumulation. The choice of the optimal property rights regime has been given by the maximization of a welfare function of a representative household. It has been noticed that on approaching a steady state the degree of enforcement increases as the stock of capital is accumulated, since the households become more committed to property rights protection as they become richer.

The third chapter provides a theoretical basis on which the optimal enforcement of property rights could be based, in a situation of joint venture between a multinational and a local firm, where the local firm earns profit share and gains technological knowledge from the multinational firm, over the duration of the joint venture. The extent of control of technology transfer is given by the degree of enforcement of property rights in the host country while the degree of enforcement of property rights is determined by maximizing the social welfare. It has been shown that the incentive-compatible level of technology transfer from the multinational to the local firm is lower than the first-best. The multinational has been shown to choose the incentive-compatible level of technology transfer, such that the local firm, using this level of technology, may earn no more profits from a monopoly than it does from its share in the joint venture. The actual value of the incentive-compatible level of technology transfer has been shown to depend on the degree of enforcement of property rights in the economy. The greater the degree of enforcement of property rights protection, the greater the level of technology transfer.

The fourth chapter explores the mechanism for an enforcement of property rights for the protection for research activities in the pharmaceutical industry. The optimal enforcement of property rights in this case is a restriction which on the one hand retains the incentive for R&D investment and on the other hand prevents the formation of monopoly prices in the market. The optimal patent length has been determined for an antibiotic produced in the North and imitated in the South. The impact of changes in several parameters has been analyzed, on the patent length, profits of the Northern firm, and welfare of the Southern country. Welfare has been seen to increase with an increase in the patent length. Taking into account R&D, the optimal patent length has been seen to be decreasing in the cost disadvantage parameter, and research cost parameter, and increasing in the time horizon. The optimal rotation period of the drug, profits of the Northern firm and levels of welfare have been calculated under considerations of bacteria resistance. An increase in the speed of bacteria resistance has been seen to decrease the present value of the monopoly's profit stream while its effect on the optimal rotation period is ambiguous. It has been concluded that even though the regular patent length of twenty years must be adhered to by all member countries of the WTO, the flexibility outlined in the TRIPS implies that the effective patent length of pharmaceutical products may be determined by the welfare maximizing policy of the government in question.

The main message that this thesis conveys is that while property rights protection is important, policy makers should clearly identify the trade-offs involving the interests of consumers and producers, and short-run versus long-run gains or losses. These trade-offs are context-dependent. And in any real world applications, it is important to formulate an appropriate framework for analysis as well as to obtain good estimates of parameter values.

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