INTERNATIONAL TECHNOLOGY TRANSFER WITH AN INFORMATION ASYMMETRY AND ENDOGENOUS RESEARCH AND DEVELOPMENT

by

DONALD JOHN WRIGHT

B.EC(hons.), The University of Adelaide, 1977

M.Ec., Monash University, 1980

A Thesis Submitted in Partial Fulfillment of

the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

in

The Faculty of Graduate Studies

Department of Economics

We accept this thesis as conforming

to the required standard

The University of British Columbia

February 1989

ABSRACT

This thesis developed a partial equilibrium model of international technology transfer in which the extent of technological change and the mode of technology transfer were endogenous. This endogeneity was obtained by explicitly considering the problem faced by a monopolist that was trying to lower production costs by undertaking research and development and was trying to maximise global profit by transferring technology abroad. The modes of transfer considered were (1) the export of goods, (2) production abroad in a wholly owned subsidiary, and (3) licensing a foreign producer. A fixed cost was assumed to be associated with subsidiary production while transfer via license was assumed to involve an information asymmetry. The interaction of the fixed cost, the information asymmetry, and convex cost functions at home and abroad determined which mode of transfer was optimal.

Initially it was assumed that research and development resulted in either a high or low cost technology and that license contracts were characterised by a market share restriction and a lump sum payment. Some results that emerged from the analysis of the transfer decision were that licensing always dominated the export of goods and the high cost technology was always licensed.

The welfare implications of the home country banning technology transfer via license or subsidiary were derived. In general, the welfare effects were ambiguous depending on the interaction of a profit, price, and research and development effect. The foreign country policies that were considered also had ambiguous welfare effects. Although ambiguous welfare results are disappointing, the model does highlight important welfare effects that have not been formalised in previous work.

A number of extensions to the basic model were considered. The first was increasing the number of possible technology types, and the second was including per unit royalties in license contracts. Under both extensions ambiguous welfare results were still obtained. The third and final extension involved eliminating market share restrictions from license contracts. With complete information it was shown that the owner of the new technology may license a potential competitor. The solution of the incomplete information problem is a proposed area of future research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT

I would like to thank Brian Copeland, Barbara Spencer, and John Weymark for their continous technical and moral support. As advisors for this thesis, they showed much patience and skill. I would also like to thank Carol, for without her love this thesis would never have been written.

CHAPTER I

Introduction

In recent years the international transfer of technology has become an important policy issue. Countries that export technology are concerned that technology transfer will erode their technological lead and weaken their competitive position in world trade, or result in a loss of jobs. On the other hand, technology importing countries complain of use restrictions and a general lack of control over the transferred technology [Teece (1981)].

A theoretical literature on the welfare and policy implications of technology transfer has developed; however, two restrictive assumptions are usually made. The first is that technological change is exogenously given [Rodriguez (1975), McCulloch and Yellen (1982), and Brecher (1982)], and the second is that the mode of technology transfer is exogenously given [Pugel (1982) and Feenstra and Judd (1982)]. These assumptions are inappropriate when considering the welfare effects of various policies, because the mode of technology transfer and the extent of technological change may be affected by the particular policy being considered. The thesis that follows attempts to correct this deficiency by building a model in which the mode of technology transfer and the extent of technological change are endogenously determined.

Section 2 provides a brief survey of the literature which highlights the use of the above two assumptions in existing models of technology transfer. Section 3 contains the basic model in which technological change and the mode of technology transfer are endogenous. As a starting point, this section assumes the existence of a firm that has discovered a new product over which it has global monopoly power. This firm is also assumed to have not previously transferred technology abroad via a wholly owned subsidiary. Before beginning production, this monopolist undertakes R&D

expenditure in order to reduce its production costs (this is the sense in which the extent of technological change is endogenous). The outcome of the R&D is uncertain though it is known that either a high or low cost technology will result. Once this outcome is known, the monopolist maximises global profit by transferring the technology abroad. It is assumed that a fixed cost, k, is associated with subsidiary production. This fixed cost is included to capture the assumed natural advantage possessed by local entrepreneurs in the production process. k can be interpreted as an entry fee which must be paid by a subsidiary in order to understand the workings of local factor markets and institutions.[1] For local entrepreneurs k is zero.[2] It is also assumed that an asymmetry of information exists between the owner of the technology that knows its type (high cost or low cost) and potential licensees that do not. The interaction of k with the information asymmetry determines whether the technology is transferred via a wholly owned subsidiary or via a license agreement. The importance of k and the information asymmetry in the choice between licensing or subsidiary production is highlighted by considering the optimal mode of transfer when only one of them is operative. If $k = 0$, technology is always transferred abroad via a subsidiary, because the cost associated with the information asymmetry is avoided.[3] If $k > 0$, but no information asymmetry exists, technology is always transferred via license, because the monopolist thereby avoids paying the entry fee k.

Assuming that a license contract is characterised by a lump sum payment and a market share restriction, the major result of Section 3 is that licensing is possible

[1] The fixed cost k is a natural advantage possessed in the production process not in marketing or distribution.

[2] The assumption that local entrepreneurs possess a natural advantage was used by Hymer (1960) to develop a theory of direct foreign investment.

[3] If a firm has previously transferred technology abroad via subsidiary, then it obtains information about local conditions and $k = 0$. This is why it was assumed that the firm had not previously transferred technology abroad via subsidiary, for if it had, any new technology would also be transferred via subsidiary.

in the presence of the information asymmetry. This is a new result which follows directly from the existence of the fixed cost, k. In previous work, the existence of an information asymmetry led many researchers to argue that new technological knowledge would never be licensed, rather it would be transferred internally via a wholly owned subsidiary. For example,

> *"Knowledge ... is a commodity the characteristics of which are unknown to the buyer. Consequently knowledge will be costly to exchange in the market and ... is more efficiently transferred within firms,"* [Hennart (1982)],

or similarly, the asymmetry of information causes

> *"proprietors of information to abstain from licensing and exploit the information themselves through foreign direct investment,"* [Casson (1979)].

In Section 4 the welfare and policy implications of the model developed in Section 3 are outlined. Using the sum of expected consumer surplus and expected monopoly profit as a measure of expected welfare, a ranking of various policies that have been recommended or used in practice is provided. In general, the results of this section are ambiguous. This suggests that a case by case approach to policy may be necessary.

Section 5 extends the model of Section 3 by allowing more than two types of technology. It is found that this does not alter the thrust of the arguments in Sections 3 and 4, but it does complicate the analysis greatly.

In Section 6 a per unit royalty is introduced into the license contract. It is found that this increases the likelihood of licensing being chosen as the mode of technology transfer. It is also found that the amount of R&D undertaken in a separating equilibrium increases, *ceteris paribus*, with the inclusion of a per unit royalty in the license contract.

In Section 7 the licensing decision is investigated when a market share restriction is not allowed in the license agreement. This means that when the technology is licensed the licensor is creating a competitor. With complete information it is shown that licensing may still be chosen as the mode of transfer. It is also shown that per unit royalties play an important role by restricting the competitive force of the licensee. The licensor's problem has not been solved for the case of incomplete information, though some preliminary remarks are made.

Section 8 contains some concluding comments as well as some proposed areas for future research.

CHAPTER II

Literature Survey

Technological change and technological differences have played a major role in explaining the pattern of production and trade since the time of Ricardo. However, it was not until the mid 1960's that Amano (1964) and Jones (1965) incorporated exogenous technological change into a simple general equilibrium Heckscher-Ohlin model. This led Jones (1970) to conclude that

"the analysis of exogenous changes in techniques is basically complete".

During the mid 1970's and early 1980's research expanded to consider the impact of international technology transfer on national welfare. Rodriguez (1975) developed a static general equilibrium model to derive the optimal policy for a country which owns the technology for producing a unique product. Under conditions of increasing cost, the optimal policy consisted of fully exploiting monopoly power abroad while encouraging competitive behaviour at home.[1] This policy dominated trade in goods with an optimal tariff, because it allowed a more efficient allocation of world resources.

In deriving this result Rodriguez made two crucial assumptions.[2] First, he assumed that the new technology was exogenously given, and second, he assumed that the mode of technology transfer was exogenously given and irrelevant when considering the effect of policy on national welfare. In reality both assumptions seem inappropriate.

---

1 Monopoly power was obtained abroad by either licensing the technology and charging an optimal royalty, or by establishing a foreign production facility and behaving as a monopolist in the foreign market.

2 These assumptions were also made by McCulloch and Yellen (1982) and Brecher (1982) when they analysed the welfare implications of technology transfer. Brecher was specifically concerned with the welfare of the technology receiving country, and McCulloch and Yellen examined the welfare of both countries.

Technological change is often the result of research and development expenditures which in turn respond to economic incentives; therefore, technological change should be treated as an endogenous variable. By assuming that it is exogenous Rodriguez ignores any impact policy may have on the extent of technological change, and so excludes a potentially important welfare effect.

The mode of technology transfer is also a decision variable for the owner of the new technology. The fact that one mode of transfer is preferred to another implies that policies designed to change the optimal mode of transfer will have at least an influence on the profits of the monopolist. A further welfare effect arises if changing the mode of technology transfer alters the amount of R&D undertaken.

The weakness of these two assumptions has been recognised by many researchers, and some attempts have been made to endogenise technological change and the mode of technology transfer. Some of these attempts are now surveyed.

2.1 Endogenous Technological Change

Pugel (1982), building on the work of Connolly (1973), developed a Ricardian model of complete specialisation to derive optimal policies in the face of technology transfer when technological change was endogenous. In this model costly R&D is undertaken by a perfectly competitive research sector in order to obtain new technical knowledge which lowers the cost of producing output. This knowledge has public good characteristics in that it can be used in several industries at no extra cost. It is sold to producers of output in return for royalty payments. The royalty payment is legislated by the government, and its level is determined by a Lindahl pricing scheme.

Within this model even a free transfer of technology improves home country welfare (the home country is the one that has the R&D sector, the foreign country is assumed to do no R&D), because it reduces the price of the commodity which the home country imports.[3] Introducing royalty payments leads to additional welfare increases for the home country. Another important result is that the optimal royalty rate for the foreign country need not be zero, because a positive royalty payment stimulates R&D which in turn reduces production costs and increases foreign output.

Pugel analysed the development and transfer of a new technology which reduced the cost of producing output. Feenstra and Judd (1982) develop a model in which the new technology takes the form of a new product variety. In their model new varieties arise from R&D which can be undertaken within a monopolistically competitive firm or purchased from a perfectly competitive industry. Consumers are assumed to have a utility function in which utility is increasing in variety. The number of varieties produced increases until the profits of the monopolistically competitive firms are reduced to zero. The R&D is undertaken in the country where its cost is least, and technology transfer is identified as occurring when R&D is done in one country while production of the new variety occurs in the other country.

Given this structure, Feenstra and Judd analyse the welfare implications of various policies for the home country. Only one of these policies is considered here; namely, a tariff on the export of technologies. This tariff reduces the amount of technology transfer and the number of varieties produced. In turn, this reduces home country welfare as utility is an increasing function of the number of varieties available for consumption. However, the reduction in the number of varieties produced increases the demand for the remaining varieties, increases domestic profit, and raises the number of varieties produced at home. This latter effect increases the demand for home labour and increases the home wage relative to the foreign wage. The terms of

[3] In McCulloch and Yellen a free transfer of technology can reduce home country welfare if the home country continues to export the good produced with the new technology. This difference arises because Pugel assumes complete specialisation and a new technology that can be used in more than one industry.

trade improve, and home welfare increases. Tariff revenue also raises home welfare. The net effect on home welfare can be shown to be positive. In effect, the tariff exploits the monopoly power of the home country in R&D.

Although both Pugel and Feenstra and Judd endogenised R&D in their models, both assumed this R&D was undertaken within a perfectly competitive sector. The result of this R&D was then sold to firms in competitive and monopolistically competitive industries respectively. These market structures ignore the role played by R&D in providing at least temporary monopoly power to the owner of the new technology.

Neither Pugel nor Feenstra and Judd model the mode of transfer decision. In their models the R&D sector obtains royalties which do not depend on whether the technology is transferred by license or by a wholly owned subsidiary. In practice, some technologies are transferred via license while others are transferred via a wholly owned subsidiary, the mode chosen depending on profitability. The endogeneity of this decision should not be ignored when analysing the welfare implications of technology transfer policy especially if R&D is endogenous, because the amount of R&D undertaken may vary with different policies.

The failure of Pugel and Feenstra and Judd to consider R&D as a means of developing at least temporary monopoly power has been addressed by Jensen and Thursby (1987). These authors model a Northern monopolist and a Southern social planner strategically interacting, and in the process determining how many resources are devoted to innovation and imitation. The Northern monopolist undertakes R&D to develop new products, and maximises the present value of its profit stream. The Southern social planner devotes resources to reverse engineering which results in technology transfer. A unique, locally stable, steady state Nash equilibrium is shown to exist, and in this equilibrium innovation and reverse engineering are directly related. The intuition for this result is that if the South devotes more resources to reverse engineering, then the length of time over which the monopolist has monopoly power is reduced, and this reduces the present value of profits. The best response of the monopolist is to increase the amount of resources devoted to innovation, because this increases the number of goods over which the North has monopoly power and provides an offset to the loss in monopoly power caused by reverse engineering.

The model of Jensen and Thursby is an improvement on previous product cycle models [Dollar (1986), Krugman (1979), and Vernon (1966)] in that both the rate of technological change and the rate of technology transfer are endogenous. Also, R&D is used by the Northern firm as a means of obtaining monopoly power; a feature not found in Pugel, or Feenstra and Judd. However, technology transfer does not result from an explicit decision by the monopolist regarding the optimal location of production facilities, but rather leaks abroad because of reverse engineering.[4]

In general, the literature on technology transfer in which R&D is endogenous has not considered R&D as a means of obtaining global monopoly power, nor technology transfer as a means of exploiting this power globally.[5] The importance of the world market to firms undertaking R&D is highlighted by the finding of Mansfield *et al* (1982) that between 30-40% of an R&D project's returns come from foreign sources.

2.2 The Mode Of Technology Transfer

The Eclectic Theory of direct foreign investment, developed by Dunning (1979), is useful in modelling the situation in which a monopolist owner of a new product/technology is trying to maximise global profit by the transfer of technology

[4] Pugel (1981) developed a model in which a monopolist undertook R&D to maximise global profit, but he failed to endogenise the mode of transfer decision.

[5] This is quite surprising since Vernon's initial work on the product cycle attempted to explain direct foreign investment as a consequence of a global monopolist locating production facilities around the world in order to maximise global profit.

abroad. Within this theory, three conditions are necessary for direct foreign investment to occur.

(1) The firm must possess an ownership advantage relative to firms of other countries. This ownership advantage usually takes the form of possession of some intangible asset which is specific to the firm; for example, marketing skills or technological knowledge.

(2) Given (1), it must be more beneficial for the firm to internalise this advantage by direct foreign investment rather than sell it through arm's length contracts to independent firms.

(3) Assuming (1) and (2) are satisfied, it must be more profitable for the firm to utilise its advantage by producing at least some of its output in a foreign country rather than at home (location advantage); otherwise, all production would occur at home and the world market would be served by exports.

The monopolist owner of a new technology possesses an ownership advantage. If the foreign country has no location advantage, then all production will be done at home and the world market will be served by exports. If the foreign country does have a locational advantage, then the monopolist must decide whether the technology will be transferred by a license or via a wholly owned subsidiary. This last decision depends on whether there is an advantage in internalisation.

Hirsch (1976) analysed the foreign investment decision in a manner partially consistent with the Eclectic Theory. He posited the existence of a firm–specific intangible asset that gave the firm an ownership advantage.[6] He then considered (1) differences in production costs between countries, (2) differences in the control costs of firms between countries, and (3) export marketing costs. These together

[6] This advantage may only be temporary, because other firms can devote resources to R&D, advertising, and management skills. Eventually, this may erode the initial advantage.

give the net locational advantage, and determine whether direct foreign investment or exports are chosen to exploit the ownership advantage. Hirsch did not address the internalisation issue, so his model only partially fits into the framework of the Eclectic Theory.

Two recent papers which incorporate firm specific intangible assets into a general equilibrium theory of the multinational firm also fail to explicitly model internalisation. Markusen (1984) developed a monopoly model in which firm–specific intangible assets such as R&D, advertising,marketing, and distribution could be used in more than one plant at no extra cost. By assuming that factor intensity effects dominate increasing return effects, the latter being caused by the firm–specific intangible asset, Markusen was able to model a monopolist that produces output in more than one country. However, internalisation is not modelled, it being assumed

> *"that independent firms have at best an imperfect ability to transfer intangibles among themselves".* [Markusen (1984 p.207)]

Helpman (1984) and Helpman and Krugman (1985) develop a general equilibrium theory of the multinational firm in which one sector is monopolistically competitive. Unlike Markusen, who explains horizontal integration, Helpman and Krugman explain vertical integration.[7] Once again firm–specific fixed costs play a vital role in conferring an ownership advantage. Vertical integration occurs across countries, because (1) plant specific fixed costs guarantee that some varieties of the monopolistically competitive good are produced in each country and (2) firm–specific assets can be produced in one country, but used in another at zero cost. As in Markusen and Hirsch, internalisation is not explicitly modelled, but is assumed to be supe-

[7] Horizontal integration is the acquisition of multiple plants by a single firm, where each plant produces an identical product. Vertical integration is the acquisition of plants by a single firm, where one plant produces an input into the production process of another plant.

rior to arm's length contracts.[8] This is unsatisfactory especially when one considers that arm's length contracts are potentially more profitable to the owner of intangible assets, because of the usual advantage a native entrepreneur enjoys

> *"over a foreign rival from his general accumulation of knowledge about economic, social, legal and cultural conditions in his home market and country"*, [Caves (1971), p.5].

Both Caves (1971) and Dunning (1979) emphasise that intangible ownership advantages are not easily transferred by arm's length contract. This provides some offset to the advantage possessed by local entrepreneurs.[9] This paper is specifically concerned with ownership advantages that arise from new technical knowledge. This knowledge is not easily transferred by arm's length contract (licensing), because like any other transfer of information it is subject to Arrow's Paradox of Information [Arrow (1962)].[10] Namely, for the owner of the new technology (information) to extract all the rent from the foreign firm (the licensee) it is necessary to reveal all details of the technology to the potential licensee. However, if this is done, there is no need for the licensee to purchase the technology, for the licensee already has all the relevant information. Therefore, when transferring technology by arm's length contract the licensor can not reveal all of the technical knowledge. Also, the licensee must be wary of false claims made by the licensor concerning the technology. This works against the use of arm's length contracts when technology is transferred.

[8] Helpman and Krugman provide some justification for this assumption by referring to the work of Klein, Crawford and Alchian (1978) in which the existence of specialised assets allows opportunistic individuals to appropriate quasi rents ex post. Through internalisation the owner of the specialised asset is able to appropriate all the quasi rent.

[9] In a recent paper, Horstman and Markusen (1987) explicitly consider the choice between licensing and direct foreign investment. Rather than modelling the intangible ownership advantage as technological knowledge they assume it to be a firm's reputation for quality of output. Asymmetric information about output quality works against the choice of licensing; the offset is not the natural advantage of local entrepreneurs, but economies of scope.

[10] This argument is outlined in Caves (1982).

Ethier (1986) developed a general equilibrium model of the multinational firm in which internalisation was explicitly modelled and R&D was endogenous. In his model monopolistically competitive firms undertook three activities; (1) R&D to lower production costs, (2) upstream production which determined product quality, and (3) downstream production in the form of a non–traded activity (possibly marketing and distribution). An information asymmetry arose, because only the owner of the new technology knew whether the R&D was successful in lowering the cost of production. Using this framework, Ethier derived the conditions under which arm's length contracts gave identical profits to those achieved by a multinational firm. This analysis is not directly applicable to the study of technology transfer, for it is physical inputs that are being traded between upstream and downstream firms, not technology.[11] Nevertheless, in the model developed in Section 3 below R&D is endogenised and an information asymmetry is modelled in a similar manner to Ethier.

This literature survey suggests that a model of technology transfer needs to be developed in which a monopolist owner of a new technology maximises global profit by transferring technology abroad. The new technology should arise endogenously; the result of R&D undertaken by a monopolist in order to maximise expected profit. Also, the mode of technology transfer should be endogenous and determined by the interaction of an information asymmetry with the natural advantage possessed by native entrepreneurs. This model can then be used to analyse the welfare and policy implications of technology transfer from the point of view of the transferring and transfer receiving countries. In the sections that follow such a model is built, and the welfare and policy implications that arise from it are examined.

[11] Ethier has modelled vertical integration rather than horizontal integration.

CHAPTER III

The Model

Overview

It is assumed that a firm has discovered a new product, produced with a new technology, that gives the firm monopoly power in the world market. Before beginning production or transferring the technology abroad, this monopolist can undertake R&D expenditures in order to reduce production costs. Therefore, the objective of the monopolist is to choose R&D, the mode of technology transfer, and the allocation of global production to maximise profit. In this decision process it is natural to assume that the R&D decision occurs before the choice of the mode of technology transfer and that both these decisions are made prior to the final choice of production levels at home and abroad. The structure of the decision process is as follows.

In the first stage the monopolist chooses R&D expenditure. At the time of this choice the monopolist is uncertain about the result of this R&D, but it does know that either a high or low cost technology will occur. The probability of the low cost technology occurring is increased by greater R&D expenditures. Once the R&D expenditures are made, the technology type is immediately revealed to the monopolist.

In the second stage the monopolist chooses the mode of technology transfer to maximise global profit knowing whether the technology is high or low cost. The three modes of transfer considered are; (1) exporting the final good, (2) production abroad in a wholly owned subsidiary, and (3) licensing of a foreign producer.[1] Locational advantages determine if production occurs solely at home, with exports being the

[1] A broad definition of technology transfer is used, which includes the export of goods, because this allows foreigners access to the fruits of the new technology.

mode of transfer, or whether some production occurs abroad. If the monopolist decides to undertake some production abroad, then internalisation issues determine whether this is achieved through a wholly owned subsidiary or licensing. It is assumed that a fixed cost, k, is associated with subsidiary production.

This fixed cost is included to capture the cost disadvantage faced by a subsidiary relative to a licensee. A subsidiary of a multi–national firm operates across national, cultural, social, and legal boundaries. This puts the subsidiary at a cost disadvantage relative to a licensee, for the licensee accumulates knowledge about the local environment as part of its general education. The subsidiary can obtain this knowledge, but only at a cost, and it is this cost which is captured by k.[2] It is also assumed that an asymmetry of information exists between the owner of the technology and potential licensees. Specifically, in this second stage, the owner of the technology knows whether the technology is high cost or low cost while potential licensees only have subjective probability, ρ^*, that the technology is low cost.

To simplify the exposition of the second stage, it is initially assumed that ρ^* is exogenously given though when the first stage is considered in detail this assumption is relaxed. The interaction of k with the information asymmetry determines whether foreign production is undertaken by a wholly owned subsidiary (internalised), or undertaken by a licensee.

In the third stage market shares for the home and foreign producer as well as transfer payments from subsidiaries or licensees are chosen to maximise the global profit of the monopolist, given technology type and given the mode of technology

[2] It could be argued that the multi–national firm could avoid the fixed cost, k, by taking over the potential licensee and making the previous owner of the licensee the manager of the new subsidiary. However, changing the status of the previous owner from residual claimant to manager can distort the manager's incentives sufficiently to make common ownership harmful [Grossman and Hart (1986)]. The cost of this factor can be interpreted as the fixed cost, k. Alternatively, k may be interpreted as the cost associated with the possibility of expropriation by the foreign government.

transfer.

As is typical of multi-stage maximisation problems, the monopolist's problem is solved backwards. First, Stage 3 is solved for market shares and transfer payments, this is done for each possible mode of technology transfer chosen in Stage 2 and for each possible technology type arising from the R&D decision in Stage 1. Next, Stage 2 is solved for the mode of technology transfer, this is done for each possible technology type arising from Stage 1. Finally, Stage 1 is solved for R&D expenditure. This set up guarantees that optimal choices are made after the completion of each stage.

The model outlined above concerns a one–off transfer of technology, where the only factor mitigating against licensing is the information asymmetry.[3] This is done to highlight the effect the information asymmetry has on the mode of transfer and the extent of technological change. Given this agenda, a static model seems appropriate.[4]

In order to solve the monopolist's problem it is first necessary to make some assumptions about cost and demand conditions.

Cost and Demand Conditions

Relative cost conditions determine locational advantage, and so whether any production occurs abroad. For simplicity it is assumed that there are only two countries in the world where profitable production can take place.[5] It is further assumed that one of these countries is the home country of the owner of the new

[3] Other factors which mitigate against licensing are implicitly assumed away; for example, it is implicitly assumed that the technology can be written down so it can be easily packaged and sold.

[4] Technology transfers often involve long term relationships between the transferor and the transferee in which the transferor continues to transfer new technological improvements as they are discovered [Caves (1982) p200–201]. Under these circumstances, a dynamic reputation model along the lines of Grossman (1981) and Horstman and Markusen (1987) seems appropriate. This is an area of future research.

[5] In other countries the marginal cost of the first unit of output is assumed to be greater than marginal revenue at the global profit maximising level of output.

product/technology.

The home firm's cost function is given by $c^i(q^i)$, $i = H, L$; where H and L signify the high and low cost technologies respectively and q^i is output. Foreign variables are represented by an asterisk, so the foreign firm's cost function is given by $c^{i*}(q^{i*})$. It is assumed that $dc^i/dq^i > 0$ and that $d^2c^i/(dq^i)^2 > 0$, so marginal cost is positive and increases with output. The foreign firm's cost function is also assumed to be characterised by increasing marginal cost. The assumption of increasing marginal cost generates the possibility of production occurring at home and abroad when global profits are maximised.[6]

The relationship between the high cost and low cost cost function is assumed to be the following

$$c^L(q^i) = \frac{1}{\gamma} \cdot c^H(q^i), \quad where\ \gamma \geq 1. \tag{3.1}$$

Demand conditions are represented by a world demand curve given by $Q_d = f(p)$, where p is the world price, Q_d is the world quantity demanded, and $f'(p) < 0$. The world inverse demand curve is given by $p = f^{-1}(Q_d)$. Consumers in all countries are assumed to have identical individual demand curves.

3.1 Stage Three

In Stage 3 market shares for the home and foreign producer as well as transfer payments for the subsidiary or licensee are chosen to maximise the global profit of the monopolist, given technology type and given the mode of technology transfer. The three modes of transfer considered are (1) the export of goods, (2) subsidiary production, and (3) a license agreement. It is assumed that the incentive structure of

[6] A recent paper by Horstmann and Markusen (1987) also makes this assumption regarding increasing marginal cost. This is also done to generate production at home and abroad. In Appendix 1 a model is presented in which the production function is characterised by constant returns to scale, yet the firm's cost function exhibits increasing marginal cost.

the firm (be it the monopoly owner of the new technology, the subsidiary, the licensor, or the licensee) is such that the new technology can be kept within the firm. That is, within the firm, individuals who gain access to the new technological knowledge have no incentive to defect outside of the firm and sell the technology in the marketplace.

The Transfer of Technology via the Export of Goods

The home firm chooses output to maximise profit, given the world inverse demand curve (a market share of one) and given its cost function. Let $\hat{Q}^i_X$ be the quantity of output that maximises this profit and let $\hat{\Pi}^i_X$ be maximised profit, where X denotes exports.

The Transfer Of Technology Via A Wholly Owned Subsidiary

The subsidiary problem is usually solved by allowing the monopolist to choose output levels at home and abroad in order to maximise global profit, given the world inverse demand curve and given the cost functions in each country.[7] Let the output levels that solve this problem be given by $\hat{q}^i_S$ and $\hat{q}^{i*}_S$. Rather than proceed by solving for $\hat{q}^i_S$ and $\hat{q}^{i*}_S$, a different formulation of the problem is used which allows a more direct comparison of the export, subsidiary, and license options.

In this different formulation the objective of the monopolist is to choose a market share for the home and foreign production facilities and a lump sum transfer payment from the subsidiary to the home facility in order to maximise global profit. With this formulation, the export option can be thought of as choosing a market share of one for the home production facility and a transfer payment of zero. The license option can be thought of as choosing a market share for the licensor (and

[7] The subsidiary problem is just the traditional multi-plant monopolist problem extended so that each plant is located in a different country. In this problem, production is allocated so that marginal cost is equated at home and abroad [Scherer *et al.* (1975)].

the foreign licensee) and a license payment that the foreign licensee must pay to the licensor. These interpretations allow a direct comparison of the export, subsidiary, and license options, and also provide a rationale for the non traditional formulation of the subsidiary problem. This is especially so as the license contracts considered under the next heading are characterised by a market share restriction and a lump sum license payment.

The structure of the decision process in Stage Three is as follows. In the first sub-stage the monopolist chooses the market share and the lump sum payment to maximise global profit. In the second sub-stage output levels are determined at home and abroad to maximise profit, given the market share arising from sub-stage one. Once again this problem is solved backwards.

Let the home firm's share of the total world demand curve be given by α, where $\alpha \in (0,1)$. The demand curve faced by the home firm is therefore given by $q_d = \alpha f(p)$. This can be rewritten as $(q_d/\alpha) = f(p)$, or $p = f^{-1}(q_d/\alpha)$, the latter being the inverse demand curve faced by the home firm.

In the second sub-stage of the problem the home firm and the subsidiary take the market share as given and choose output to maximise profit. The home firm's problem is

$$\max_{q^i} \quad \{\Pi^i(q^i,\alpha) = p(q^i/\alpha)\cdot q^i - c^i(q^i)\}, \quad i = H, L \tag{3.2}$$

with first and second order conditions respectively given by

$$\frac{\partial \Pi^i}{\partial q^i} = \frac{dp}{d(q^i/\alpha)}\cdot\frac{1}{\alpha}\cdot q^i + p(q^i/\alpha) - \frac{dc^i}{dq^i} = 0 \tag{3.3}$$

and

$$\frac{\partial^2 \Pi^i}{(\partial q^i)^2} = \frac{d^2 p}{(d(q^i/\alpha))^2}\cdot\frac{1}{\alpha^2}\cdot q^i + 2\cdot\frac{dp}{d(q^i/\alpha)}\cdot\frac{1}{\alpha} - \frac{d^2 c^i}{(dq^i)^2} < 0. \tag{3.4}$$

Assume that the second order condition for a maximum is satisfied, and let the argmax of (3.2) be given by $q^i(\alpha)$. Substituting this argmax into the objective function yields home firm maximised profit as a function solely of α; namely, $\Pi^i(\alpha)$. Solving a similar problem for the subsidiary yields $\Pi^{i*}(\alpha)$.

In the first sub–stage of the problem the monopolist chooses α and the subsidiary's lump sum payment, P, to maximise global profit subject to the constraint that the payment P is less than or equal to the subsidiary's profit net of k. This problem is written as follows

$$\max_{P,\alpha} \quad \{\Pi^i_S(P,\alpha) = \Pi^i(\alpha) + P\} \tag{3.5}$$

subject to:

$$\Pi^{i*}(\alpha) - k - P \geq 0, \tag{3.6}$$

where S denotes technology transfer via a subsidiary. As constraint (3.6) always binds it can be substituted into the objective function. The first order condition for a maximum then becomes

$$\frac{d\Pi^i_S}{d\alpha} = \frac{d\Pi^i(\alpha)}{d\alpha} + \frac{d\Pi^{i*}(\alpha)}{d\alpha} = 0, \tag{3.7}$$

or

$$\frac{d\Pi^i_S}{d\alpha} = -\frac{dp}{d(q^i/\alpha)} \cdot \frac{1}{\alpha^2} \cdot \left(q^i(\alpha)\right)^2 + \frac{dp^*}{d(q^{i*}/(1-\alpha))} \cdot \frac{1}{(1-\alpha)^2} \cdot \left(q^{i*}(\alpha)\right)^2 = 0 \tag{3.8}$$

using the envelope theorem. The second order condition for a maximum is

$$\frac{d^2\Pi^i_S}{(d\alpha)^2} = \frac{d^2\Pi^i(\alpha)}{(d\alpha)^2} + \frac{d^2\Pi^{i*}(\alpha)}{(d\alpha)^2} < 0. \tag{3.9}$$

In Appendix 2 it is shown that

$$\frac{d^2\Pi^i(\alpha)}{(d\alpha)^2} < 0 \tag{3.10}$$

for a strictly concave revenue function and a strictly convex cost function. By symmetry

$$\frac{d^2\Pi^{i*}(\alpha)}{(d\alpha)^2} < 0. \tag{3.11}$$

It is assumed that (3.10) and (3.11) are satisfied, so the second order condition for a maximum is also satisfied. Let the solution to (3.8) be given by $\hat{\alpha}^i$. This market share maximises global profit for the monopolist. Let $\hat{\Pi}^i$ represent maximised profit of the home firm and let $(\hat{\Pi}^{i*} - k)$ be maximised profit for the subsidiary after subtracting k. Given binding constraint (3.6), this latter term equals the lump sum payment made by the subsidiary. Let this be denoted by $\hat{P}^i$. An explicit solution for $\hat{\alpha}^i$ in terms of the outputs that maximise global profit is given by

$$\hat{\alpha}^i = \frac{\hat{q}_S^i}{\hat{q}_S^i + \hat{q}_S^{i*}}. \tag{3.12}$$

PROPOSITION 3.1: *If the market share for the home firm is chosen so that (3.12) holds, then allowing the home firm and the subsidiary to maximise profit with respect to their own demand curves duplicates the solution obtained when outputs are chosen to maximise global profit.*

PROOF: See Appendix 3.

This proposition establishes that the market share formulation of the subsidiary problem results in output levels and global profits which are identical to those obtained in the traditional formulation.

The solution to the monopolist's subsidiary problem can be illustrated diagramatically. Total differentiation of the objective function gives

$$d\Pi_S^i = \frac{d\Pi^i(\alpha)}{d\alpha} \cdot d\alpha + dP, \tag{3.13}$$

so that along a global iso–profit curve

$$\frac{dP}{d\alpha} = -\frac{d\Pi^i(\alpha)}{d\alpha}. \tag{3.14}$$

The objective of the monopolist is to choose P and α so that it attains the highest global iso–profit curve subject to $\Pi^{i*}(\alpha) - k \geq P$.

Assuming a strictly concave revenue function and a strictly convex cost function, it is shown in Appendix 2 that

$$\frac{d\Pi^i(\alpha)}{d\alpha} > 0 \qquad and \qquad \frac{d^2\Pi^i(\alpha)}{(d\alpha)^2} < 0. \tag{3.15}$$

Therefore, $\Pi^i(\alpha)$ is a strictly concave function of α. As a result, global iso–profit curves are convex, so

$$\frac{dP}{d\alpha} < 0 \qquad and \qquad \frac{d^2P}{(d\alpha)^2} > 0. \tag{3.16}$$

Now $\Pi^{i*}(\alpha) - k$ is strictly concave in $(1 - \alpha)$, so the constraint set is a convex set.

From (3.7) and (3.14) global profit maximisation occurs when

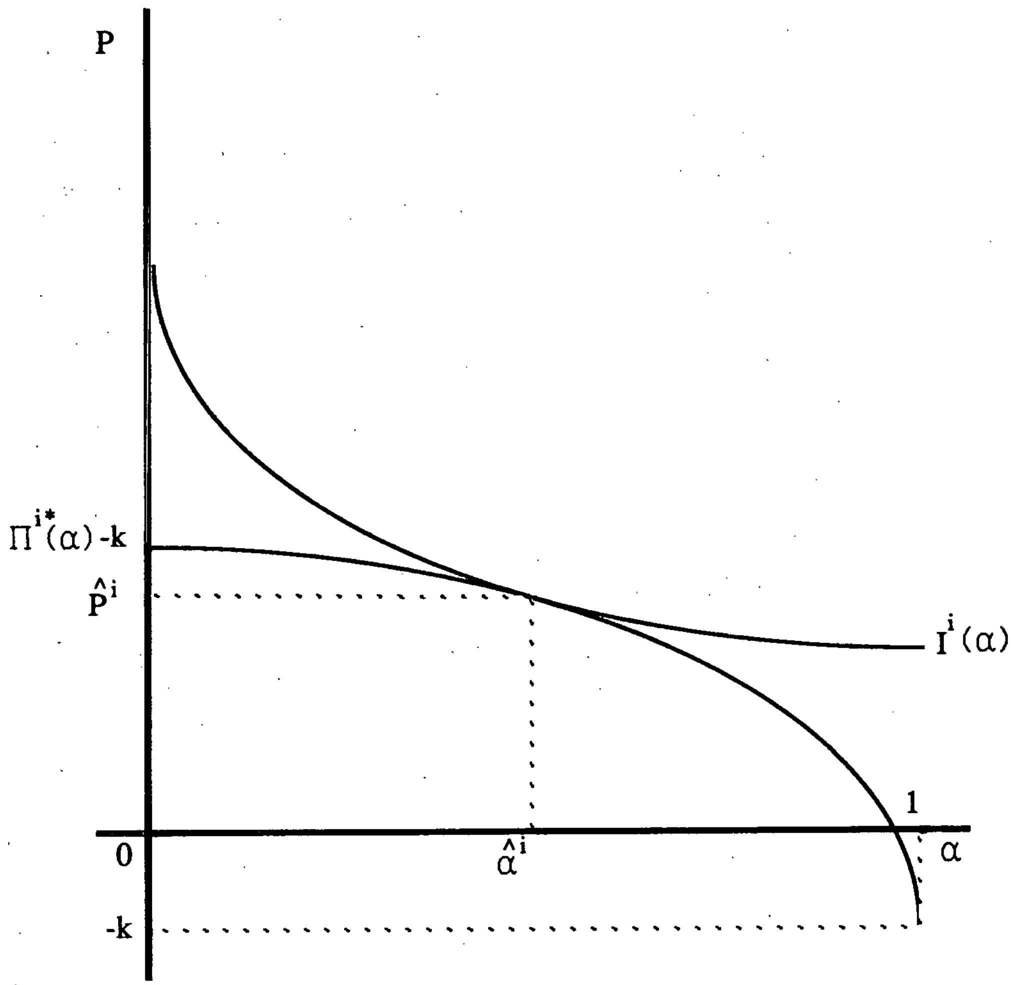
$$\frac{d\Pi^{i*}(\alpha)}{d\alpha} = -\frac{d\Pi^i(\alpha)}{d\alpha} = \frac{dP}{d\alpha}, \tag{3.17}$$

and the solution for $\hat{\alpha}^i$ and $\hat{P}^i$ is characterised in Figure 1 by the tangency of $\Pi^{i*}(\alpha)-k$ with the global iso–profit curve represented by $I^i(\alpha)$. The global profit associated with $I^i(\alpha)$ is the maximum attainable given the convex constraint set (the area bounded by $(\Pi^{i*}(\alpha) - k)$, $-k$, and $\alpha = 1$). Global iso–profit curves that are further from the origin represent higher levels of global profit.

The Transfer Of Technology Via A License Agreement

The sole concern of this thesis is with transfers of technology which suffer from what Arrow (1962) called *"The Paradox Of Information"*. Specifically, for the owner of the technology (information) to extract all the rent from the potential licensee it is necessary to reveal all aspects of the technology to the licensee. However, if this is done there is no longer any need for the licensee to purchase the technology, for the licensee already has all the relevant information. An internationally enforceable patent system

Figure 1



would overcome this problem. Nevertheless, because of imitation there are many technologies for which national patent protection is difficult, so that international patent protection is virtually impossible.[8] A further complication arises from the patenting process, for the patent itself provides information about the technology which may be used by potential licensees at zero cost. In fact, Mansfield and Romeo (1980) argue that imitation usually occurs via reverse engineering and patent information is often important in this process. In these cases it is in the interest of the monopolist to keep details of the technology secret.[9]

This information exchange problem has led many researchers to argue that new technological knowledge will never be licensed, but rather it will be transferred internally via a wholly owned subsidiary. For example,

> *"Knowledge......is a commodity the characteristics of which are unknown to the buyer. Consequently knowledge will be costly to exchange in the market and......is more efficiently transferred within firms,"* [Hennart (1982)],

or similarly, the asymmetry of information causes

> *"Proprietors of information to abstain from licensing and exploit the infor-*

8

"Multinational enterprises are among the most obvious beneficiaries of strong patent and trademark laws. But most multinational enterprises are realistic enough to know that in the conditions of modern society patent rights offer only uncertain protection anywhere, and practically no protection at all in developing countries," [Vernon (1977), p.167].

Levin (1986) on reviewing empirical research, argues that it is

"clear that patents rarely confer perfect appropriability. Many patents can be 'invented around'."

9 In a theoretical paper Horstman, MacDonald, and Slivinski (1985) develop a model in which information is not always patented, and as an extension find that

"if patenting directly reveals information that raises profits for the competitor, the equilibrium propensity to patent is reduced. This seems to be what is meant by 'trade secrecy'."

See also Kahn (1962, 318–319.)

mation themselves through foreign direct investment," [Casson (1979)].

In this section it is demonstrated that in the presence of an asymmetry of information it is still possible for the monopolist to profitably transfer technology abroad via a license agreement. This follows because of the existence of the fixed cost, k, which is associated with subsidiary production.[10]

The monopolist's problem is to design a mechanism to maximise its global profit through the international transfer of technology, given that it knows whether the technology is low cost or high cost, but given that potential licensees only have some subjective probability, ρ^*, that the technology is low cost. This problem is thus an *"informed principal problem"* [Myerson (1983,1985)] with the monopolist owner of the new technology being the informed principal.[11] Before solving this problem the following assumptions are made.

Assumptions

(1) *The new technology is licensed monopolistically to a foreign firm.*[12]

---

[10] Without this fixed cost it is true that the information asymmetry causes technology to always be transferred internally, via a subsidiary.

[11] In this problem it is natural to have the owner of the technology choosing the mechanism, because it possesses monopoly power while potential licensees possess no monopoly power.

[12] This assumption can be justified by introducing a plant specific fixed cost, F. In the presence of this fixed cost first best global monopoly profit may still require production in two locations, because marginal cost is assumed to increase with output. For production to occur at home and abroad the following condition must be satisfied

$$\hat{\Pi}^L + \hat{\Pi}^{L*} - 2F > \hat{\Pi}^L_X - F. \qquad (3.18)$$

Clearly only one plant will be established at home and only one will be established abroad. Extra plants do not increase $(\hat{\Pi}^L + \hat{\Pi}^{L*})$, but they do increase total fixed cost. Therefore, technology is licensed to a single foreign firm. A similar set up was used by Markusen (1984), where plant specific fixed costs interacted with endowments to generate production in single plants at home and abroad. In the model that follows the fixed cost, F, is not explicitly considered. This fixed cost changes the analysis of Stage 2 (the choice of mode of transfer) though in a trivial manner.

(2) *License contracts contain two elements. The first is a market share for the licensor of α.*[13] *The second is a lump sum payment of l which the licensee pays the licensor in order to obtain the new technology.*

A market share restriction is included in the license contract for a number of reasons. Firstly, it eliminates competition between the licensor and the licensee by giving each monopoly power over a certain segment of the world market. This increases the potential payoff to the licensor as monopoly profit is known to exceed the sum of two firm's non cooperative duopoly profits.[14] Competition between the licensor and the licensee could also have been eliminated by the licensor specifying output levels for itself and the licensee. However, violations of such an agreement would be hard to objectively verify, because creative accounting techniques, by either party, could easily hide true output levels. This observation leads to the second reason for including a market share restriction in the license contract; namely, so violations of the agreement can be easily and objectively identified. By dividing the world market between the licensor and the licensee on a country by country basis, import and export documentation can reveal when either party is violating the market share restriction. A typical contract may restrict the licensee to sell only in its own country, or in its global region (e.g. Europe or S.E.Asia). Dividing the world market in this manner implies that α is not a continuous variable. However, in the analysis that follows it is assumed that α can take on any value between zero and one. As there are many countries in the world and as these countries have varying market size, the assumption that α is a continuous variable seems quite reasonable to the author. Thirdly, by assuming a market share restriction, the analysis of the licensor's problem

[13] This implies a market share for the licensee of $(1-\alpha)$.

[14] A license contract is written between two firms and can specify very narrowly the conditions under which the licensee can use the new technology. Therefore, a license contract provides far more protection to the monopolist owner of a new technolgy than a patent, because a patent is a general restriction on technology use between the owner and all potential users.

is greatly simplified, so the effect of the information asymmetry is brought into sharp relief. In Section 7 below the licensor's problem is analysed when a market share restriction is not included in the license contract. Fourthly, market share restrictions are common in practice. Caves, Crookwell and Killing (1983), using survey data, found that 34% of license agreements contained a market share restriction of this form. The survey of licensees covered companies operating in Canada and the United Kingdom. For licensees located in Less Developed Countries the percentage of license agreements containing a market share restriction is much larger, for example, during 1970, in India 43% of agreements contained a market share restriction while in Chile the figure was 93%.[15]

A lump sum license payment is included in the contract rather than a per unit royalty for two reasons. Firstly, monitoring of the licensee's output, by the licensor, is assumed to be prohibitively costly.[16] Secondly, using a lump sum payment greatly simplifies the analysis of the licensor's problem. In Section 6 below the licensor's problem is analysed when a per unit royalty is included in the license contract.

(3) *Arbitrage between the market of the licensor and the licensee is costly, and its per unit cost is greater than any price differential that may exist between the markets.* This assumption is necessary, because the license contract may require the licensor to have a market share which is greater than the share that maximises first best global monopoly profit. In this case, the price in the market served by the licensor is greater than the price in the market served by the licensee.[17] The market share restriction guarantees that the licensee can not sell in the higher priced market, but nothing in the model stops a third party from buying the product in the licensee's market and

15 These figures were obtained from Casson (1979), p. 21.

16 This assumption was also made by Katz and Shapiro (1985).

17 This price differential does not arise through price discrimination, because all consumers are assumed to have identical demand curves. Rather it results from the convexity of the cost function. See Appendix 4.

selling it in the licensor's market. If this is allowed, the licensee's effective market share increases, while that of the licensor decreases. Arbitrage would continue until the price in each market was equal and the effective market shares were at their first best global profit maximising level. This implies that only the first best global profit maximising market shares can be used to solve the monopolist's problem. To overcome this difficulty costly arbitrage is assumed. A justification for costly arbitrage might be found in different product service costs for the arbitrager and the licensor, or in the existence of firm–specific warranties.

(4) *License contracts can not be renegotiated after the technology has been transferred.* That is, ex post renegotiation of license contracts is assumed away. This assumption is often made in adverse selection models, where ex post renegotiation is ruled out by assuming that agents commit themselves to the initial terms of the contract even if ex post both parties are worse off by doing so [Harris and Townsend (1985)].[18] This is particularly unsatisfactory, for if a Pareto improvement can be achieved by renegotiation, then renegotiation should be allowed. Firms can make commitments, but they can not commit to not renegotiate [Dewatripont (1988)]. Therefore, the assumption that ex post renegotiation of contracts is not allowed requires some justification which is provided by assuming that renegotiation is prohibitively costly.[19]

---

18 The assumption of no ex post renegotiation is implicit in Cooper (1984), Maskin and Riley (1984), and Weymark (1986). In fact, a general principle that has emerged from the adverse selection literature is that the self selection constraints cause distortions for all but one agent type.

In the monopoly problem (Cooper and Maskin and Riley) this distortion is manifested as an inequality between the marginal rate of substitution of the consumer and the firm. In the optimal income tax problem it is manifested as an inequality between the marginal rate of transformation in the economy and the marginal rate of substitution of the consumer/worker. Once the agent picks from the schedule of offers she reveals her type, and ex post renegotiation allows a Pareto improvement precisely because of the ex ante divergence between marginal rates of substitution. Therefore, no ex post renegotiation is an implicit assumption in models that are characterised by divergence in ex ante marginal rates of substitution.

19 In Appendix 5 these renegotiation costs are made explicit. Also, the implications of allowing ex

(5) *The licensee's subjective probability that the low cost technology has occurred,* ρ^**, is identical for all potential licensees and known by the licensor.*

(6) *Both the licensor and the potential licensees are risk neutral, so they maximise expected profit.*

(7) *There exist many potential licensees, and bidding for license contracts is competitive.* This ensures zero expected profit for the licensee.

(8) *The technology type is unable to be objectively verified.* If it could be objectively verified, then the information asymmetry could be overcome through the use of a contract which guaranteed technology of a certain type.

(9) *The first best global profit maximising share with the low cost technology is identical to the global profit maximising market share with the high cost technology. That is,* $\hat{\alpha}^H = \hat{\alpha}^L$.[20] This assumption simplifies the analysis; nevertheless, it is relaxed in a later section of this thesis.

Derivation Of The Optimal License Contract

To provide a point of reference, the licensor's problem is first solved under conditions of complete information. The licensor chooses (α^i, l^i) to maximise profit subject to the constraint that the license payment must be less than or equal to the

post renegotiation of license contracts are analysed. This Appendix is best read after finishing Section 3.1.

20 If the cost functions at home and abroad are identical, then $\hat{\alpha}^H = \hat{\alpha}^L = (1/2)$. Using the monopsony model developed in Appendix 1, the cost functions at home and abroad are identical if each country has an identical endowment of the specific factor, K, as well as identical endowments of the monopsonised factor, LS. When the endowments of the specific and monopsonised factors are not identical, at home and abroad, the relationship between $\hat{\alpha}^L$ and $\hat{\alpha}^H$ depends on the particular functional forms chosen. The relationship also depends on the particular model used to generate convex cost functions. It is not my intention to rely on any particular model or functional forms, but to keep the analysis at a more general level by assuming convex cost functions and assuming relationships between $\hat{\alpha}^L$ and $\hat{\alpha}^H$. In Appendix 6 the relationship between $\hat{\alpha}^L$ and $\hat{\alpha}^H$ is examined for some specific functional forms.

licensee's profit. This first best problem is written as follows

$$\max_{\alpha^i, l^i} \quad \{\Pi(\alpha^i, l^i) = \Pi^i(\alpha^i) + l^i \quad ; i = H, L\} \tag{3.19}$$

subject to:

$$\Pi^{i*}(\alpha^i) \geq l^i, \tag{3.20}$$

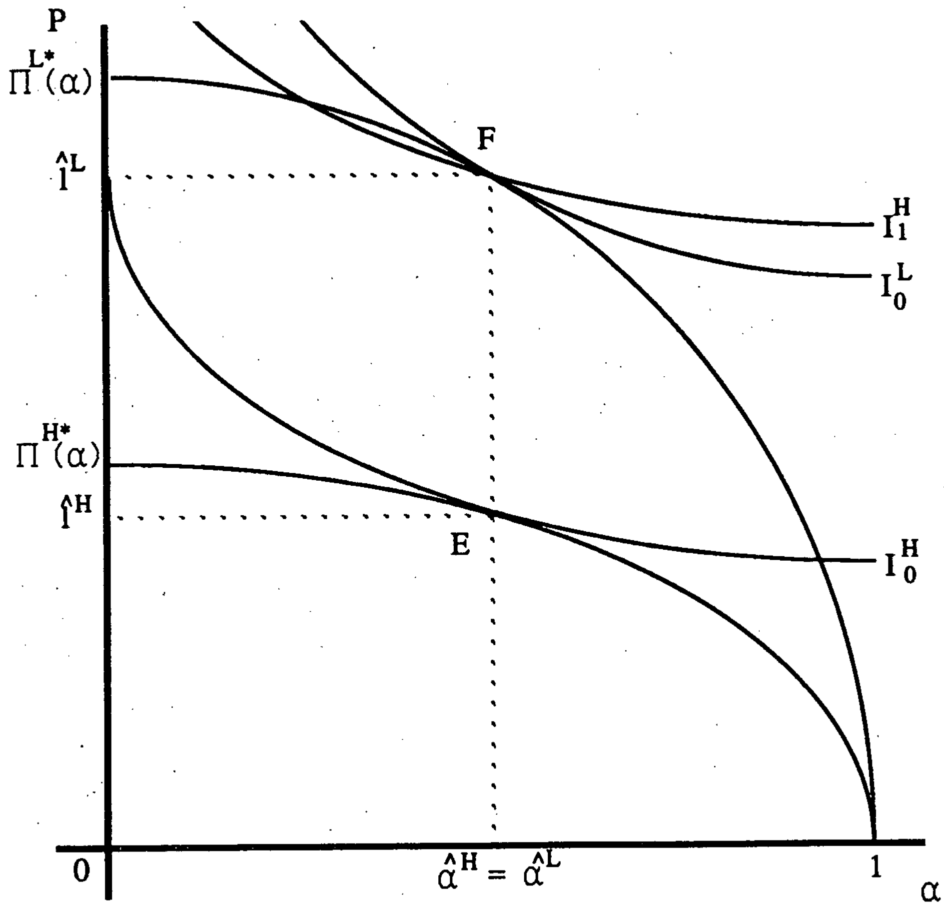
and is essentially the same as that faced by the monopolist when transferring technology via a subsidiary except now $k = 0$.

Competitive bidding for the license contract ensures that constraint (3.20) always binds; therefore, this constraint can be substituted into (3.19). Solving this problem for α^i gives $\hat{\alpha}^i$ as the licensor's market share, where this market share is identical to that of the home production facility in the subsidiary problem. Let the licensor's first best maximised profit be given by $\hat{\Pi}^i(\hat{\alpha}^i) + \hat{l}^i$, where $\hat{l}^i = \hat{\Pi}^{i*}(\hat{\alpha}^i)$.

The solutions $(\hat{\alpha}^H, \hat{l}^H)$ and $(\hat{\alpha}^L, \hat{l}^L)$ are illustrated in Figure 2. In this diagram point E represents the first best solution if the high cost technology has occurred. The global profit associated with global iso profit curve I_0^H is the maximum feasible, given the convex constraint set (the area bounded by $\Pi^{H*}(\alpha)$, 0, and 1.) Similarly, point F represents the first best solution if the low cost technology had occurred. The global profit associated with I_0^L is the maximum feasible, given the convex constraint set (the area bounded by $\Pi^{L*}(\alpha)$, 0, and 1.) For all α, the absolute value of the slope of $\Pi^{L*}(\alpha)$ and I^L is greater that the absolute value of the slope of $\Pi^{H*}(\alpha)$ and I^H. This result is proved in Appendix 9.

Figure 2 also makes it clear that in the presence of an information asymmetry the first best outcome is not implementable. If the high cost technology occurs, the licensor obtains more profit if it offers the contract $(\hat{\alpha}^L, \hat{l}^L)$ than if it offers $(\hat{\alpha}^H, \hat{l}^H)$, because I_1^H (the global iso-profit curve associated with contract $(\hat{\alpha}^L, \hat{l}^L)$ given that the high cost technology has occurred) represents a higher global iso-profit curve than

Figure 2


P
$\Pi^{L*}(\alpha)$
$\hat{I}^{L}$
F
I_1^H
I_0^L
$\Pi^{H*}(\alpha)$
$\hat{I}^{H}$
E
I_0^H
0
$\hat{\alpha}^H = \hat{\alpha}^L$
1
α

I_0^H.[21] Since the licensee has some positive probability that the technology type is high cost, the licensee makes a loss in expected value terms if it accepts the licensor's contract offer of $(\hat{\alpha}^L, \hat{l}^L)$. Therefore, the licensee refuses such a contract offer. That is, the first best is not implementable.

To solve the licensor's problem under conditions of incomplete information the Revelation Principle is invoked.

The Revelation Principle

The Revelation Principle states that

"any equilibrium allocation of any mechanism can be achieved by a truthful, direct mechanism," [Harris and Townsend (1985), p.384].[22]

To show that this is true for the licensor's problem assume that the licensor has designed an indirect game (mechanism), played between the licensor and the licensee, which has an equilibrium that yields the licensor maximum profit. Let the strategies available to the licensee be given by $(x_1, x_2, ...x_n)$ and let the strategies available to the licensor be given by $(y_1, y_2, y_3, y_4, ...y_m)$. Also, let the outcome of each party playing a particular strategy be a license contract (α, l). This indirect mechanism is illustrated in Table 1.

A Bayesian Equilibrium of this mechanism is a set of strategies for the licensor and the licensee which depend on their type such that the expected profit of the licensee is greater than or equal to zero. By construction the licensee has only one type while the licensor can be a high cost or low cost technology transferor. The licensee has subjective probability, ρ^*, that the licensor has a low cost technology to

21 For all α, I_1^H involves a larger license payment, l, than I_0^H, so I_1^H yields more global profit than I_0^H.

22 For other statements and uses of the Revelation Principle see Myerson (1979, 1982, 1983).

transfer.

Let the Bayesian Equilibrium of this game be characterised by the following strategies

$$\sigma(H) = y_4, \quad \sigma(L) = y_2, \quad and \quad \phi = x_1 \tag{3.21}$$

where $\sigma(i)$, $i = H, L$ denotes the equilibrium strategy of the licensor, and ϕ denotes the equilibrium strategy of the licensee. This equilibrium is identical to the equilibrium of the direct mechanism shown in Table 2 in which the licensor truthfully announces technology type.

The Revelation Principle greatly simplifies the licensor's problem as it allows the search for a mechanism which maximises the licensor's profit, to be restricted to truthful, direct mechanisms. On applying the Revelation Principle the licensor's problem can be written as a maximisation problem, where (α^H, l^H) and (α^L, l^L) are chosen to maximise profit subject to certain self selection (truth telling) constraints, and where an announcement by the licensor concerning technology type determines which contract is used.[23]

Two general solutions to the licensor's problem are possible. The first is a separating solution in which a different contract arises for each technology type and the contract used is contingent on the truthful announcement of technology type by the licensor. In practice one does not observe contracts between licensees and licensors which are contingent on the announcement of a technology type by the licensor.[24]

[23] In this licensor–licensee problem, where the licensor could be one of two possible types, but the licensee is only one type, use of a direct mechanism does not add extra equilibria to those that are truthful. For cases in which extra equilibria are added see Repullo (1986).

[24] In Appendix 7 it is shown that contingent contracts of this form are characterised by $l^H > \Pi^{H*}(\alpha^H)$. Therefore, if the high cost technology occurs, the licensee is guaranteed of making a loss if it pays l^H for the technology. In such cases the licensee will renege on the contingent contract unless of course the contingent contract can be enforced through the legal system. One might surmise that the lack of such enforcement is why contingent contracts are not seen in practise.

Table 1

LICENSOR \ LICENSEE	x_1	x_2		x_n
y_1	α_{11}, l_{11}	$\cdots$	$\cdots$	α_{1n}, l_{1n}
y_2	α_{21}, l_{21}			$\vdots$
y_3	α_{31}, l_{31}			$\vdots$
y_4	α_{41}, l_{41}			$\vdots$
				$\vdots$
y_m	α_{m1}, l_{m1}	$\cdots$	$\cdots$	α_{mn}, l_{mn}

Table 2

LICENSOR \ LICENSEE	1
HIGH	α_{41}, l_{41}
LOW	α_{21}, l_{21}

Rather, a contract is offered by the licensor and it is accepted or rejected by the licensee. With this set up, in a separating solution the licensor announces its type through the contract offered, and feasibility requires

$$l^i \leq \Pi^{i*}(\alpha^i). \tag{3.22}$$

As (3.22) would also be a requirement for feasibility in any indirect game the Revelation Principle is still applicable.[25]

The second solution is a pooling solution in which the same contract is offered regardless of technology type. This solution does not require that (3.22) be satisfied, because the contract offered by the licensor does not reveal the technology type.[26]

In the separating solution and the pooling solution only one contract is ever offered. Nevertheless, the licensee knows whether it is being offered the pooling solution or a contract from the separating solution, because it knows all the details of the licensor's problem (except technology type) and so can calculate the exact form of the three possible contract offers.

The Separating Solution

Assume that the high cost technology has occurred. In a separating equilibrium the licensor announces its type through the contract offered; therefore, $l^H \leq \Pi^{H*}(\alpha^H)$. Given this constraint, the license contract which maximises global profit is given by

$$(\hat{\alpha}^H, \hat{l}^H = \hat{\Pi}^{H*}(\hat{\alpha}^H)). \tag{3.23}$$

[25] This can be seen by referring to the indirect mechanism in Table 1. If the Bayesian Equilibrium of this mechanism is a separating equilibrium, then the contracts (α^i, l^i) must satisfy (3.22) to be feasible. This equilibrium can be achieved by a direct, truthful mechanism similar to that in Table 2. That is, the Revelation Principle still applies.

[26] In Appendix 7 the licensing decision is analysed when contingent contracts are allowed. In this case it is shown that a pooling solution is never optimal, because it is always dominated by the separating solution.

If contract (3.23) is offered to the licensee, the licensee accepts the offer, because regardless of technology type the licensee's profit is greater than or equal to zero. This is seen from Figure 2, where point E yields zero profit if the high cost technology has occurred and positive profit if the low cost technology has occurred.

Now assume that the low cost technology has occurred. Using Figure 2 it was shown above that the global profit maximising contract, given by $(\hat{\alpha}^L, \hat{l}^L)$, was not implementable. To obtain the license contract which maximises global profit and is also implementable, the following problem is solved.

Problem 1:

$$\max_{\alpha^L, l^L} \quad \{\Pi(L) = \Pi^L(\alpha^L) + l^L\} \tag{3.24}$$

subject to:

$$\hat{\Pi}^H(\hat{\alpha}^H) + \hat{l}^H \geq \Pi^{HL}(\alpha^L) + l^L \tag{3.25}$$

$$\Pi^L(\alpha^L) + l^L \geq \Pi^{LH}(\hat{\alpha}^H) + \hat{l}^H \tag{3.26}$$

$$\Pi^{L*}(\alpha^L) \geq l^L. \tag{3.27}$$

(3.24) represents the objective function which is maximised by choice of (α^L, l^L). Constraint (3.25) ensures that the contract that solves Problem 1 is only offered when the low cost technology has actually occurred.[27] $\Pi^{HL}(\alpha^L)$ represents maximised home firm profit if the high cost technology occurred, but the licensor offers α^L in the license contract. $\Pi^{HL}(\alpha^L)$ is defined as follows

$$\Pi^{HL}(\alpha^L) = p(q^{HL}(\alpha^L)/\alpha^L) \cdot q^{HL}(\alpha^L) - c^H(q^{HL}(\alpha^L)), \tag{3.28}$$

[27] The contract $(\hat{\alpha}^L, \hat{l}^L)$ does not satisfy this constraint, because $\hat{\Pi}^H(\hat{\alpha}^H) = \hat{\Pi}^L(\hat{\alpha}^L)$ while $\hat{l}^H < \hat{l}^L$.

where $q^{HL}(\alpha^L)$ is the argmax of the following problem

$$\max_{q^{HL}} \quad \{\Pi^{HL} = p(q^{HL}/\alpha^L) \cdot q^{HL} - c^H(q^{HL})\}. \tag{3.29}$$

In words, $q^{HL}(\alpha^L)$ maximises profit of the home firm, given its market share is α^L and given the high cost technology has occurred.

Constraint (3.26) ensures that the contract that solves Problem 1 yields more profit than contract $(\hat{\alpha}^H, \hat{l}^H)$. If this constraint was not satisfied, then the licensor would offer contract $(\hat{\alpha}^H, \hat{l}^H)$ when the low cost technology occurs. $\Pi^{LH}(\hat{\alpha}^H)$ is defined in a similar manner to $\Pi^{HL}(\alpha^L)$. Constraints (3.25) and (3.26) are known in the literature as self selection constraints.

Finally, constraint (3.27) is needed for the licensee to participate and accept the contract offer. This requires the license payment to be less than or equal to the licensee's profit.

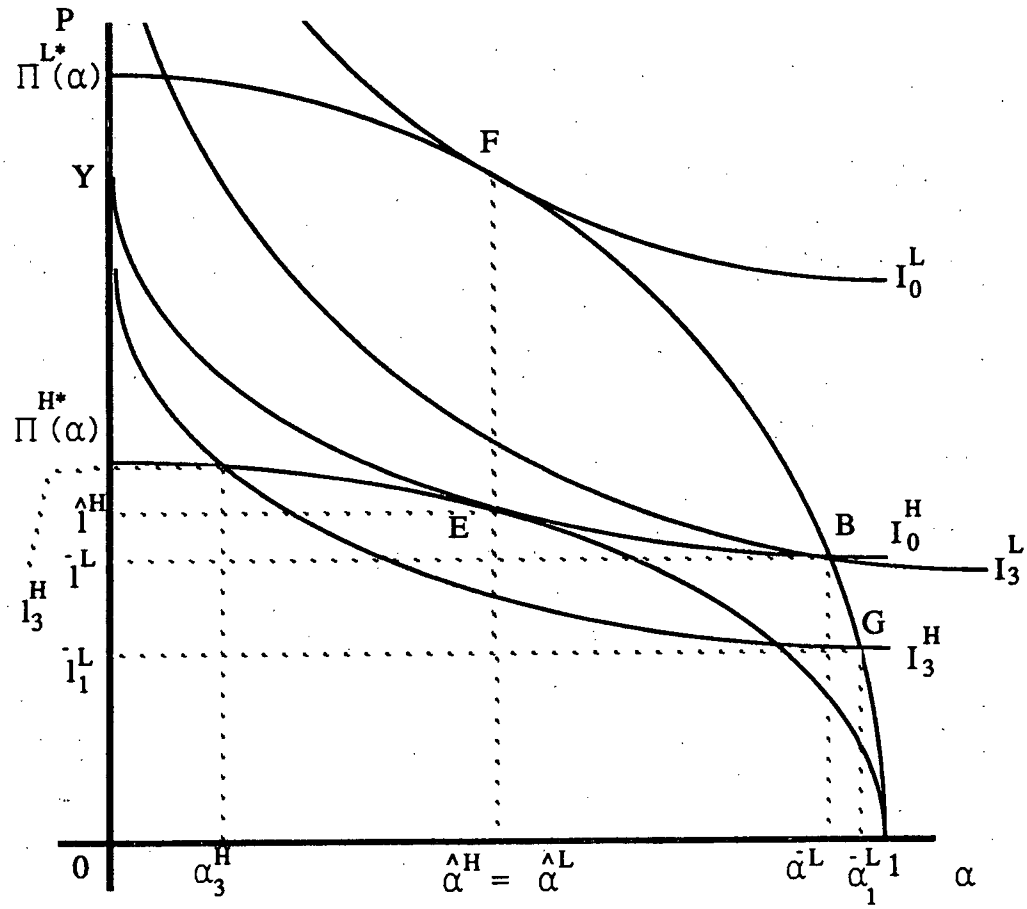
The solution to Problem 1 is shown in Figure 3, and is represented by the license contract

$$(\bar{\alpha}^L, \bar{l}^L), \tag{3.30}$$

where $\bar{\alpha}^L > \hat{\alpha}^L$ and $\bar{l}^L = \bar{\Pi}^{L*}(\bar{\alpha}^L) < \hat{l}^L$. In Figure 3 points E and F represent the first best solutions. Given $(\hat{\alpha}^H, \hat{l}^H)$, self selection constraint (3.25) is represented by I_0^H. To be feasible (α^L, l^L) must lie on or below this line. For example, the (α^L, l^L) combination associated with point G satisfies (3.25), because, given the high cost technology has occurred, point G is on a lower global iso–profit curve than point E. Constraint (3.27) is represented by $\Pi^{L*}(\alpha)$. To be feasible (α^L, l^L) must lie on or below this line. In order to satisfy constraints (3.25) and (3.27) (α^L, l^L) must lie on or below the line $YEBG1$.

Given the low cost technology has occurred and given $YEBG1$, the global profit associated with global iso–profit curve I_3^L is the maximum attainable and is achieved

Figure 3



P
$\Pi^{L*}(\alpha)$
F
Y
I_0^L
$\Pi^{H*}(\alpha)$
$\hat{l}^H$
E
B
I_0^H
$\bar{l}^L$
I_3^L
l_3^H
G
$\bar{l}_1^L$
I_3^H
0
α_3^H
$\hat{\alpha}^H = \hat{\alpha}^L$
$\bar{\alpha}^L$
$\bar{\alpha}_1^L$
1
α

with contract $(\bar{\alpha}^L, \bar{l}^L)$ at point B.[28] At this solution constraints (3.25) and (3.27) bind; however, constraint (3.26) does not bind, because point E is on a lower global iso–profit curve than point B.

Combining (3.23) and (3.30) yields the following separating solution

$$(\hat{\alpha}^H, \hat{l}^H) \quad ; \quad (\bar{\alpha}^L, \bar{l}^L). \tag{3.31}$$

If the high cost technology occurs, then license contract $(\hat{\alpha}^H, \hat{l}^H)$ is offered. If the low cost technology occurs, then license contract $(\bar{\alpha}^L, \bar{l}^L)$ is offered.[29]

The intuition for mechanism (3.31) is as follows. If the high cost technology occurs, the licensor is able to obtain first best global monopoly profit, because the licensee is prepared to accept contract $(\hat{\alpha}^H, \hat{l}^H)$ regardless of technology type. However, if the low cost technology occurs, then first best global monopoly profit is not attainable, because the licensee only accepts the contract offer if it is certain that the low cost technology has occurred. To convince the licensee that the low cost technology has occurred, the licensor distorts its contract offer away from the first best solution. Given the assumptions of the model, this involves a contract offer of $(\bar{\alpha}^L, \bar{l}^L)$. The information asymmetry imposes a cost on the licensor which is given by the difference between global profit with contract $(\hat{\alpha}^L, \hat{l}^L)$ and contract $(\bar{\alpha}^L, \bar{l}^L)$.

28 This follows because $\frac{d\Pi^L}{d\alpha^L} > \frac{d\Pi^H}{d\alpha^H}$ for all α. The result that $\frac{d\Pi^L}{d\alpha^L} > \frac{d\Pi^H}{d\alpha^H}$ for all α is known in the literature as the single crossing property. A strength of the model developed in this section is that the single crossing property, quasi–linearity of the monopolist's objective function, and convexity of the monopolist's upper level sets arise from standard assumptions regarding revenue and cost functions. In other papers these conditions are imposed [Cooper (1984), Hayes (1984), and Maskin and Riley (1984)].

29 Any feasible separating solution other than (3.31) yields less profit to the licensor in each technological state. For example, in Figure 3 the separating solution

$$(\alpha_3^H, l_3^H) \quad ; \quad (\bar{\alpha}_1^L, \bar{l}_1^L) \tag{3.32}$$

satisfies all the participation and self selection constraints; however, (α_3^H, l_3^H) yields less profit than $(\hat{\alpha}^H, \hat{l}^H)$ and $(\bar{\alpha}_1^L, \bar{l}_1^L)$ yields less profit than $(\bar{\alpha}^L, \bar{l}^L)$.

In Figure 3 this cost is represented by the vertical distance between global iso–profit curves I_0^L and I_3^L.[30]

In the separating solution, the licensee's subjective probability, ρ^*, does not influence the design of the optimal separating mechanism. This is not so in the pooling solution.

The Pooling Solution

In the pooling solution the same contract is offered regardless of technology type, so

$$l^H = l^L = l \qquad and \qquad \alpha^H = \alpha^L = \alpha. \tag{3.33}$$

As a result, the contract offer does not reveal which technology type has occurred. In turn, this implies that the licensee will participate and accept the contract offer only if

$$l \leq \rho^* \cdot \Pi^{L*}(\alpha) + (1 - \rho^*) \cdot \Pi^{H*}(\alpha). \tag{3.34}$$

Assume the low cost technology has occurred. The licensor's problem is

Problem 2:

$$\max_{\alpha, l} \quad \{\Pi(L) = \Pi^L(\alpha) + l\} \tag{3.35}$$

subject to:

$$\Pi^{E*} = \rho^* \cdot \Pi^{L*}(\alpha) + (1 - \rho^*) \cdot \Pi^{H*}(\alpha) \geq l. \tag{3.36}$$

30 In many adverse selection models (e.g. Cooper (1984) and Maskin and Riley (1984)) private information has value and its holder is rewarded for this information. However, in the model of technology transfer developed above, the existence of private information imposes a cost on the holder of this information. These two results can be reconciled once it is realised that in most adverse selection models the agent possesses the private information while in the technology transfer model the principal possesses the private information.

At the solution to this problem (3.36) always binds; otherwise, it would be possible to increase l while continuing to satisfy (3.36), yet increase the value of the objective function. Substituting binding constraint (3.36) into the objective function of Problem 2 yields the following problem

$$\max_{\alpha} \quad \{\Pi(L) = \Pi^{L}(\alpha) + \rho^{*} \cdot \Pi^{L*}(\alpha) + (1-\rho^{*}) \cdot \Pi^{H*}(\alpha)\}. \tag{3.37}$$

The first order condition for a maximum is

$$\frac{d\Pi^{L}}{d\alpha} = -(1-\rho^{*}) \cdot \frac{d\Pi^{H*}}{d\alpha} - \rho^{*} \cdot \frac{d\Pi^{L*}}{d\alpha} \tag{3.38}$$

which is solved for $\check{\alpha}^{L}$. The second order condition for a maximum is

$$\frac{d^{2}\Pi^{L}}{(d\alpha)^{2}} + (1-\rho^{*}) \cdot \frac{d^{2}\Pi^{H*}}{(d\alpha)^{2}} + \rho^{*} \cdot \frac{d^{2}\Pi^{L*}}{(d\alpha)^{2}} < 0 \tag{3.39}$$

which is satisfied for all α. Now, at $\hat{\alpha}^{L}$

$$\frac{d\Pi^{L}}{d\alpha} > -(1-\rho^{*}) \cdot \frac{d\Pi^{H*}}{d\alpha} - \rho^{*} \cdot \frac{d\Pi^{L*}}{d\alpha}, \tag{3.40}$$

because

$$\frac{d\Pi^{H*}}{d\alpha} > \frac{d\Pi^{L*}}{d\alpha} \tag{3.41}$$

and

$$\frac{d\Pi^{L}}{d\alpha^{L}} = \frac{d\Pi^{L*}}{d\alpha^{L}}. \tag{3.42}$$

Together, (3.40) and (3.39) imply that $\check{\alpha}^{L} > \hat{\alpha}^{L}$.

In Figure 4 the area below $l(\alpha)$ represents constraint (3.36). The licensor tries to get on the highest global iso-profit curve, given the low cost technology has occurred and given constraint (3.36). This occurs at point H with global iso-profit curve I_{4}^{L}. The solution to (3.38) is, therefore, given by the license contract

$$(\check{\alpha}^{L}, \check{l}^{L}), \tag{3.43}$$

where

$$\check{\Pi}^{H*}(\check{\alpha}^L) < \check{l}^L < \check{\Pi}^{L*}(\check{\alpha}^L). \tag{3.44}$$

Unlike the separating solution, in the pooling solution the licensee participates in mechanism (3.43) even though the license payment is greater than the licensee's profit when the high cost technology has occurred. This follows, because at the time the lump sum payment is made the licensee is uncertain of the technology type in the pooling solution while the licensee knows the technology type in the separating solution.

If the high cost technology had occurred a different pooling solution would arise. The licensor's problem would be

Problem 2a:

$$\max_{\alpha} \quad \{\Pi(H) = \Pi^H(\alpha) + \rho^* \cdot \Pi^{L*}(\alpha) + (1 - \rho^*) \cdot \Pi^{H*}(\alpha). \tag{3.45}$$

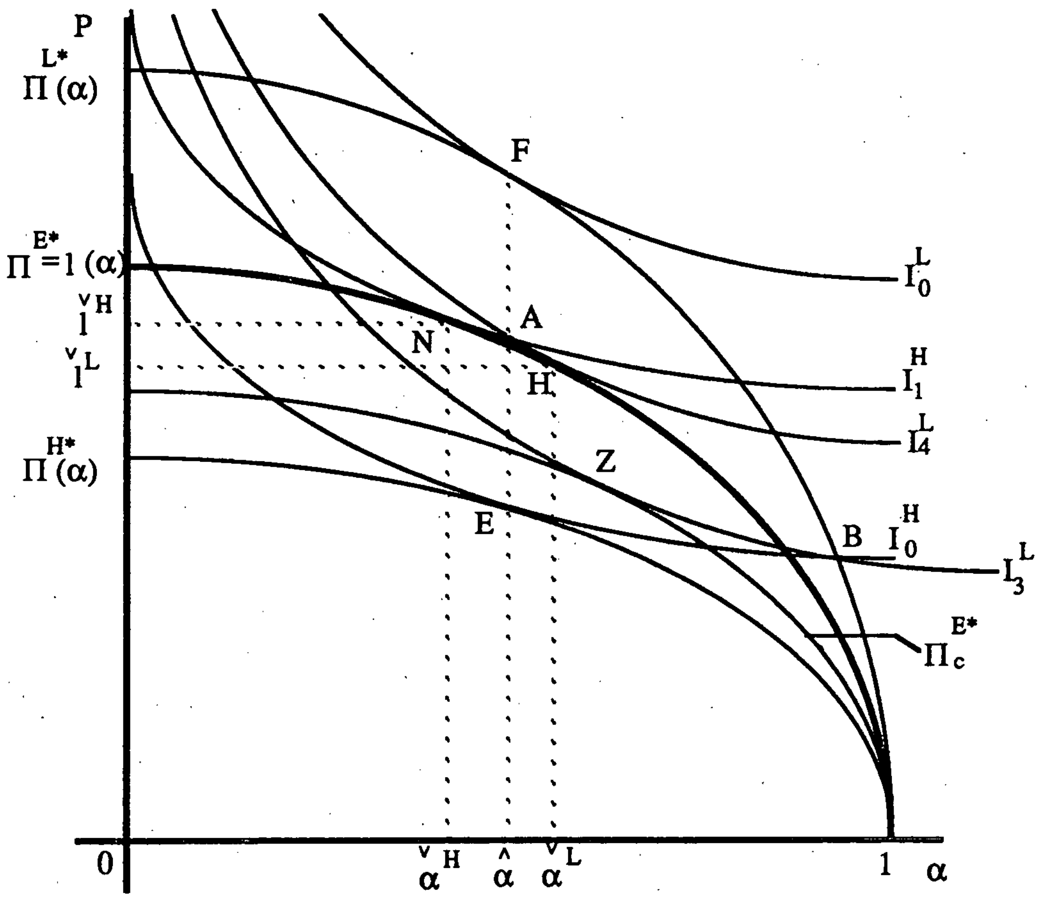
In effect the licensor tries to get on the highest global iso–profit curve, given the high cost technology has occurred and given $l(\alpha) = \rho^* \cdot \Pi^{L*}(\alpha) + (1 - \rho^*) \cdot \Pi^{H*}(\alpha)$. The solution to this problem occurs at point N in Figure 4, and is given by the following mechanism

$$(\check{\alpha}^H, \check{l}^H). \tag{3.46}$$

At this solution, $\check{\alpha}^H < \hat{\alpha}^H$ and $\check{\Pi}^{H*}(\check{\alpha}^H) < \check{l}^H$.

The above analysis suggests that the licensor's offer of mechanism (3.43) or (3.46) depends on the technology type that actually occurs. However, this is not the case. If the licensor offers mechanism (3.46), the licensee must infer that the high cost technology has occurred; otherwise, mechanism (3.43) would have been offered. But if the licensee infers that the high cost technology has occurred it will not participate

Figure 4



in mechanism (3.46), because $\check{\Pi}^{H*}(\check{\alpha}^H) < \check{l}^H$. Therefore, mechanism (3.46) is never offered in practice.

On the other hand, if the licensor offers mechanism (3.43), the licensee may infer that the low cost technology has occurred, or the licensee may leave its subjective probability of the low cost technology occurring unchanged. In either case, the licensee participates in the mechanism, because $\check{\Pi}^{L*}(\check{\alpha}^L) > \check{l}^L$ and $\check{l}^L = \rho^* \cdot \check{\Pi}^{L*}(\check{\alpha}^L) + (1-\rho^*) \cdot \check{\Pi}^{H*}(\check{\alpha}^L)$. Using the terminology of Myerson (1983), mechanism (3.43) is a pooling core mechanism, it being the only pooling mechanism that is incentive compatible in practice, given the inferences that the licensee may make about the technology type from the licensor's optimal mechanism offer. Therefore, the pooling solution involves a license contract offer of $(\check{\alpha}^L, \check{l}^L)$ regardless of the technology type that actually occurs.

We have seen that two general solutions to the licensor's problem exist; namely, a separating solution and a pooling solution. What determines which solution is chosen by the licensor?

PROPOSITION 3.2: *Let ρ_c^* be the critical ρ^* at which the licensor is indifferent between the pooling or the separating solution. For $\rho^* > \rho_c^*$ the pooling solution is chosen while for $\rho^* < \rho_c^*$ the separating solution is chosen.*

PROOF: Π^{E*} is a convex combination of $\Pi^{L*}(\alpha)$ and $\Pi^{H*}(\alpha)$ with weights being respectively given by ρ^* and $(1-\rho^*)$. Therefore, there exists some $0 < \rho_c^* < 1$ which gives a pooling solution that yields the licensor identical profit in the low cost state to the profit obtained in the separating solution. In Figure 4 the licensee's participation constraint that is associated with ρ_c^* is given by Π_c^{E*}. The pooling solution associated with ρ_c^* is represented by point Z. Let the probability $\rho^* > \rho_c^*$ be such that point H in Figure 4 represents the pooling solution. In this case the pooling solution (mechanism

(3.43)) will be chosen, because the licensor makes more profit in both states compared to the separating solution. Now consider a $\rho^* < \rho_c^*$ so that the pooling solution is given by point J in Figure 4. In this case if the pooling solution is offered by the licensor, then the licensee infers that the high cost technology has occurred, because if the low cost technology had occurred the licensor would be better off with the separating solution given by point B. However, if the licensee infers that the high cost technology has occurred, then the mechanism associated with point J is not a core mechanism, because the licensee will not participate in this mechanism as the license payment is greater than the licensee's profit. Therefore, with this smaller ρ^* the separating solution must be chosen by the licensor. **(Q.E.D.)**

The separating solution is what Myerson (1983) termed a safe mechanism. A safe mechanism is one in which the licensee participates even if it knows the technology type. In fact, with ρ^* being such that the separating solution is chosen by the licensor, the separating solution is undominated (for the pooling solution yields more profit if the high cost technology occurs, but less if the low cost technology occurs) and is what Myerson (1983) termed a strong solution.

3.2 Stage Two

In Stage Two the monopolist chooses the mode of technology transfer to maximise global profit, given technology type. If the low cost technology has occurred, this choice is made by comparing

$$\hat{\Pi}_X^L, \quad (\hat{\Pi}^L(\hat{\alpha}^L) + \hat{\Pi}^{L*}(\hat{\alpha}^L) - k), \quad (\bar{\Pi}^L(\bar{\alpha}^L) + \bar{l}^L), \quad (\check{\Pi}^L(\check{\alpha}^L) + \check{l}^L). \tag{3.47}$$

If the high cost technology occurred

$$\hat{\Pi}_X^H, \quad (\hat{\Pi}^H(\hat{\alpha}^H) + \hat{\Pi}^{H*}(\hat{\alpha}^H) - k), \quad (\hat{\Pi}^H + \hat{\Pi}^{H*}), \quad (\check{\Pi}^H(\check{\alpha}^L) + \check{l}^L) \tag{3.48}$$

are compared with the proviso that $\left(\check{\Pi}^H(\check{\alpha}^L)+\check{l}^L\right)$ only be considered if $\left(\check{\Pi}^L(\check{\alpha}^L)+\check{l}^L\right)$ yields the most profit of the choices in (3.47). This proviso is necessary, because if license contract $(\check{\alpha}^L, \check{l}^L)$ does not yield the most profit of the choices in (3.47), then on seeing $(\check{\alpha}^L, \check{l}^L)$ the licensee will infer that the high cost technology has occurred. In this case, $(\check{\alpha}^L, \check{l}^L)$ is not feasible.

PROPOSITION 3.3: *If first best global profit maximisation involves output being produced at home and abroad* $(\hat{\Pi}^i_X < \hat{\Pi}^i + \hat{\Pi}^{i*})$*, then the monopolist never transfers technology via the export of goods, because this option is dominated by licensing.*

PROOF: In the separating solution the licensor obtains $\hat{\Pi}^H + \hat{\Pi}^{H*}$ if the high cost technology occurs and $\bar{\Pi}^L + \bar{\Pi}^{L*}$ if the low cost technology occurs. By assumption $\hat{\Pi}^H_X < \hat{\Pi}^H + \hat{\Pi}^{H*}$. It is also true that $\hat{\Pi}^L_X < \bar{\Pi}^L + \bar{\Pi}^{L*}$ as production is allocated more efficiently between countries when licensing with a separating solution is chosen by the monopolist as the mode of technology transfer rather than the export of goods. This follows because marginal cost is increasing in output at home and abroad and the divergence marginal cost at home and abroad is less under the separating solution, where $0 < \bar{\alpha}^L < 1$, than under exports, where $\alpha = 1 \quad or \quad 0$.

As licensing with the separating mechanism is always an option available to the monopolist, a profit maximising monopolist never chooses exports as the optimal mode of technology transfer. **(Q.E.D.)**

PROPOSITION 3.4: *The high cost technology is always licensed. The contract is given by* $(\check{\alpha}^L, \check{l}^L)$ *if the pooling solution is optimal and* $(\hat{\alpha}^H, \hat{l}^H)$ *otherwise.*

PROOF: If ρ^* is such that the pooling solution is chosen by the licensor, then in Figure 4 the pooling solution must lie above I^L_3, but below $\Pi^{L*}(\alpha)$. This implies that $\left(\check{\Pi}^H(\check{\alpha}^L) + \check{l}^L\right) > \left(\hat{\Pi}^H + \hat{\Pi}^{H*}\right)$. Therefore, the high cost technology is licensed with contract $(\check{\alpha}^L, \check{l}^L)$.

If ρ^* is such that the separating solution is chosen by the licensor and the high cost technology has occurred, then mechanism (3.31) requires contract $(\hat{\alpha}^H, \hat{l}^H)$. This contract yields the licensor total profit of $\left(\hat{\Pi}^H(\hat{\alpha}^H)+\hat{\Pi}^{H*}(\hat{\alpha}^H)\right)$ which is greater than the profit obtained from subsidiary production.

If ρ^* is such that

$$(\check{\Pi}^L + \check{l}^L) < (\hat{\Pi}^L + \hat{\Pi}^{L*} - k), \tag{3.49}$$

and if

$$(\bar{\Pi}^L + \bar{l}^L) < (\hat{\Pi}^L + \hat{\Pi}^{L*} - k), \tag{3.50}$$

then the low cost technology (if it occurs) is transferred via subsidiary. Under these circumstances, if the high cost technology occurs, then it is transferred via license with a contract offer of

$$(\hat{\alpha}^H, \hat{l}^H). \tag{3.51}$$

This contract is accepted by the licensee, for regardless of technology type it yields the licensee profits which are greater than or equal to zero. **(Q.E.D.)**

PROPOSITION 3.5: *The likelihood of the low cost technology being transferred by license rather than subsidiary increases, ceteris paribus, (1) the greater is k and (2) for $\rho^* > \rho^*_c$ the greater is ρ^*.*

PROOF: (1) The low cost technology is licensed rather than transferred by subsidiary when

$$\check{\Pi}^L(\check{\alpha}^L) + \check{l}^L \geq \hat{\Pi}^L + \hat{\Pi}^{L*} - k, \tag{3.52}$$

or

$$\bar{\Pi}^L(\bar{\alpha}^L) + \bar{l}^L \geq \hat{\Pi}^L + \hat{\Pi}^{L*} - k. \tag{3.53}$$

Clearly, conditions (3.52) and (3.53) are more likely to be satisfied the larger is k.

(2) Proposition 3.2 established that the pooling solution was optimal for $\rho^* > \rho_c^*$. For $\rho^* > \rho_c^*$ the higher is ρ^* the greater is $\left(\check{\Pi}^L(\check{\alpha}^L) + \check{l}^L\right)$, because the constraint locus $l(\alpha)$ shifts further from the origin. For a given k, the larger is $\left(\check{\Pi}^L(\check{\alpha}^L) + \check{l}^L\right)$ the more likely will condition (3.52) be satisfied. **(Q.E.D.)**

Apart from k and ρ^*, γ is another parameter of the model which may affect the likelihood of licensing the low cost technology. For the moment assume that ρ^* is such that the separating solution yields more profit to the licensor than the pooling solution. If

$$\hat{\Pi}^L + \hat{\Pi}^{L*} - k > \bar{\Pi}^L + \bar{l}^L, \tag{3.54}$$

then a subsidiary will be chosen as the mode of technology transfer. Therefore, given k, if the difference $\left((\hat{\Pi}^L + \hat{\Pi}^{L*}) - (\bar{\Pi}^L + \bar{l}^L)\right)$ increases with increases in γ, then subsidiary production is more likely. On the other hand, if this difference decreases with increases in γ, then licensing is more likely. As a result, when γ is increased the sign of

$$\frac{d((\hat{\Pi}^L + \hat{\Pi}^{L*}) - (\bar{\Pi}^L + \bar{l}^L))}{d\gamma} \tag{3.55}$$

gives an indication of whether the likelihood of licensing increases or decreases with increases in γ. If (3.55) is > 0, then subsidiary production is more likely. If (3.55) is < 0, then licensing is more likely.

In Appendix 10 it is shown that maximised profit is a function of γ and $\alpha(\gamma)$ when γ is explicitly considered in the monopolist's subsidiary and licensing problems of Stage Three. It is also shown that

$$\begin{aligned} \frac{d((\hat{\Pi}^L + \hat{\Pi}^{L*}) - (\bar{\Pi}^L + \bar{l}^L))}{d\gamma} &= \frac{1}{\gamma^2} \cdot \left(\hat{c}^L(\cdot) + \hat{c}^{L*}(\cdot)\right) \\ &\quad - \frac{1}{\gamma^2} \cdot \left(\bar{c}^L(\cdot) + \lambda^L \cdot \bar{c}^{L*}(\cdot)\right), \end{aligned} \tag{3.56}$$

where λ^L is the Lagrange multiplier attached to constraint (3.27) in Problem 1. This constraint is rewritten here for convenience, $\Pi^{L*}(\alpha^L) \geq l^L$.

The first and second terms on the right hand side of (3.56) are the direct cost saving associated with the change in γ if respectively a subsidiary and license agreement were used to transfer technology. The second term is made up of the direct cost saving on the licensor's home production plus a fraction of the direct cost saving on the licensee's production. This fraction is given by λ^L which represents the marginal increase in the maximised value of $(\bar{\Pi}^L + \bar{l}^L)$ when constraint (3.27) is relaxed by a small amount.[31] Appendix 10 demonstrates that $0 < \lambda^L < 1$. Therefore, the sign of (3.55) depends on the relative size of the first and second terms on the right hand side of (3.56).

PROPOSITION 3.6: *Given $c^L(q) = \frac{1}{\gamma} \cdot c^H(q)$, the sign of $\frac{d\left((\hat{\Pi}^L+\hat{\Pi}^{L*})-(\bar{\Pi}^L+\bar{l}^L)\right)}{d\gamma}$ is ambiguous as it depends on the initial value of γ.*

PROOF: To establish this proposition it is only necessary to consider a specific example. Let the world inverse demand curve be given by

$$p = 50 - Q \quad so \quad that \quad p = 50 - \frac{q}{\alpha}. \tag{3.57}$$

Let $c^H(q) = q^2$ and $c^{H*}(q^*) = q^{*2}$, so that $c^L(q) = \frac{1}{\gamma} \cdot q^2$ and $c^{L*}(q^*) = \frac{1}{\gamma} q^{*2}$. Solving the monopolist's subsidiary and licensing problems for different values of γ yields Table 3. The high cost technology is represented by $\gamma = 1$. Table 3 demonstrates that as γ is increased the equilibrium value of $\bar{\alpha}^L$ also increases. This would be expected from an examinination of Figure 3.

31 The process by which $(\bar{\Pi}^L + \bar{l}^L)$ is increased when constraint (3.27) is relaxed is as follows. Relaxation of constraint (3.27) allows $\bar{\alpha}^L$ to be increased. In turn, this increases $\bar{\Pi}^L$, but also increases Π^{HL}. This latter increase requires a fall in $\bar{l}^L$, for self selection constraint (3.25) to be satisfied. In turn, this allows a further increase in $\bar{\alpha}^L$ as (3.27) no longer holds. λ^L is the marginal increase in $(\bar{\Pi}^L + \bar{l}^L)$ which results from the above process when (3.27) is relaxed by a small amount.

The row of immediate interest is row 16 which gives the sign of (3.55). For small γ, this shows that an increase in γ makes subsidiary production more likely while for large γ, an increase in γ makes licensing more likely. **(Q.E.D.)**[32]

The intuition for this result is as follows. Comparing rows 3 and 4 to row 1 establishes that total output is less under licensing than under subsidiary production.[33] Yet total cost is greater under licensing than subsidiary production from rows 7 and 8. Therefore, in this example the inefficient allocation of production between home and abroad that occurs under licensing ($\bar{\alpha}^L > \hat{\alpha}^L$) increases total cost to such an extent that total cost under licensing is greater than under subsidiary production. This is so even though more output is produced under subsidiary production than under licensing. At first sight the potential for cost savings under licensing seem larger than those under subsidiary production for all γ. However, under licensing all the cost saving of the licensee does not add to the license payment only λ^L of it does. This follows because self selection constraint (3.25) must be satisfied.

In Appendix 10 it is shown that

$$\lambda^L = \left(\frac{\partial\Pi^L}{\partial\alpha^L} - \frac{\partial\Pi^{HL}}{\partial\alpha^L}\right) \Big/ \left(-\frac{\partial\Pi^{L*}}{\partial\alpha^L} - \frac{\partial\Pi^{HL}}{\partial\alpha^L}\right), \tag{3.58}$$

where the derivatives are calculated at $\bar{\alpha}^L$. In Table 3, for small γ, the calculated value of λ^L is small, therefore, $\lambda^L \cdot \bar{c}^{L*}$ is small and (3.55) is > 0. For large γ (e.g. $\gamma = 8$), $\bar{c}^L > \hat{c}^L + \hat{c}^{L*}$, so regardless of $\bar{c}^{L*}$ (3.55) is < 0.[34]

[32] The sign of (3.55) may also depend on the other parameters in the model. However, for my purposes, concentrating on γ is sufficient as it reveals the ambiguity in the sign of (3.55).

[33] This is true for all convex cost functions for which $c^{L'''}(q) > 0$. For a proof see Appendix 11.

[34] For small γ, at $\bar{\alpha}^L$, $\left(\frac{\partial\Pi^L}{\partial\alpha^L} - \frac{\partial\Pi^{HL}}{\partial\alpha^L}\right)$ is small while $\left(-\frac{\partial\Pi^{L*}}{\partial\alpha^L} - \frac{\partial\Pi^{HL}}{\partial\alpha^L}\right)$ is relatively large. This follows because $-\frac{\partial\Pi^{L*}}{\partial\alpha^L}$ is significantly greater than $\frac{\partial\Pi^L}{\partial\alpha^L}$. Therefore, λ^L is small. However, as γ becomes large although $\left(\frac{\partial\Pi^L}{\partial\alpha^L} - \frac{\partial\Pi^{HL}}{\partial\alpha^L}\right)$ becomes large, $\frac{\partial\Pi^L}{\partial\alpha^L}$ and $-\frac{\partial\Pi^{L*}}{\partial\alpha^L}$ move closer together. This implies that $\lambda^L \to 1$.

Table 3

	γ	1	1.2	1.5	2	4	8
1	$\hat{q}=\hat{q}^H$	8.3	8.8	9.4	10	11.1	11.8
2	$\bar{\alpha}^L$		.64	.685	.714	.745	.757
3	$\bar{q}^L$		10.4	11.7	13.1	15.7	17.3
4	$\bar{q}^{L*}$		6.9	6.5	6.3	6.0	5.9
5	$\bar{C}^L$		90.6	92.2	86.5	61.8	37.4
6	$\bar{C}^{L*}$		39.6	28.2	19.6	9	4.4
7	$\bar{C}^L+\bar{C}^{L*}$		130.6	120.5	106.1	70.8	41.7
8	$\hat{C}^L+\hat{C}^{L*}$	138.8	129.7	117.2	100	61.7	34.6
9	$\bar{\Pi}^L$		260.9	293.9	328.8	392.5	432.3
10	$\bar{\Pi}^{L*}$		173	162.7	156.4	149.8	147.4
11	$\bar{\Pi}^L+\bar{\Pi}^{L*}$		433.9	456.6	485.2	542.3	579.7
12	$\hat{\Pi}^L+\hat{\Pi}^{L*}$	416.7	441.2	468.7	500	555.6	588.2
13	$\hat{\Pi}^L+\hat{\Pi}^{L*}$ $-\bar{\Pi}^L+\bar{\Pi}^{L*}$		7.3	12.1	14.8	13.3	8.5
14	λ^L		.243		.477		.83
15	$\bar{C}^L+\lambda^L\bar{C}^{L*}$		100.3		95.85		41.1
16	$\hat{C}^L+\hat{C}^{L*}$ $-\bar{C}^L+\lambda^L\bar{C}^{L*}$		29.4		4.1		-6.5
17	$\hat{\Pi}^L_X$	312.5	340	375	417.5	500	555
18	$\hat{\Pi}^L+\hat{\Pi}^{L*}$ $-\hat{\Pi}^L_X$	104.2	100.3	93.7	83.3	55.6	32.7

The ambiguity regarding the sign of (3.55) can be seen directly from Table 3 by examining row 13. For small γ, the difference between subsidiary and license profits is relatively small. Initially, as γ increases this difference increases, but as γ becomes relatively large the difference begins to fall. This follows because of the specification of the technology difference.

An increase in γ has two effects; (1) q and q^* diverge further from their first best levels ($\hat{q} = \hat{q^*}$) and (2) the low cost technology's marginal cost curve becomes flatter. The first effect tends to increase the difference between $(\hat{\Pi}^L + \hat{\Pi}^{L*})$ and $(\bar{\Pi}^L + \bar{l}^L)$, because, given $\bar{\alpha}^L$, an increase in γ under licensing causes production to be allocated more inefficiently between home and abroad. The second effect tends to decrease the difference between $(\hat{\Pi}^L + \hat{l}^L)$ and $(\bar{\Pi}^L + \bar{l}^L)$, because the cost of the inefficient allocation of world production is reduced as a result of the flatter marginal cost curve reducing the divergence between marginal cost at home and abroad. For small γ, the first effect dominates the second, so increases in γ increase the likelihood of technology transfer via subsidiary. On the other hand, for large γ, the second effect dominates the first, so increases in γ increase the likelihood of technology transfer via license. Therefore, without knowledge of the level of γ it is not possible to sign (3.55) when the technology difference is given by $c^L(q) = \frac{1}{\gamma} \cdot c^H(q)$.[35]

The above analysis concerning the relationship between the size of γ and the likelihood of licensing was carried on under the assumption that the separating solution was optimal for the licensor. However, the choice between licensing under the pooling or separating solution may itself depend on the size of the technology difference. Given ρ^*, Figure 5 suggests that for large γ the separating solution is more likely to be the optimal choice of the licensor. For a relatively small technology

[35] In Appendix 12 a model is outlined in which the technology difference takes a different form. In this model the greater is the technology difference the more likely is technology transferred via subsidiary.

difference represented by $(\Pi^{L*}(\alpha)_0)$, the pooling solution given by point H yields more profit than the separating solution given by point B. For a larger technology difference represented by $(\Pi^{L*}(\alpha)_1)$, the pooling solution given by point Q yields less profit than the separating solution given by point N.

This result has also been obtained in numerical examples. The intuition for this result is that as γ gets large the separating solution yields profit which is very close to the first best level. On the other hand, the pooling solution yields a license payment which is only a weighted average of the licensee's high and low cost profits. Therefore, for large γ, the separating solution is more likely to be the optimal choice of the licensor. A mathematical proof of this hypothesis has not been derived though Figure 5 strongly suggests that the result is true, *ceteris paribus.*

To date it has been assumed that $\hat{\alpha}^L = \hat{\alpha}^H$. Now consider the case where $\hat{\alpha}^L \geq \bar{\alpha}^L > \hat{\alpha}^H$.[36]

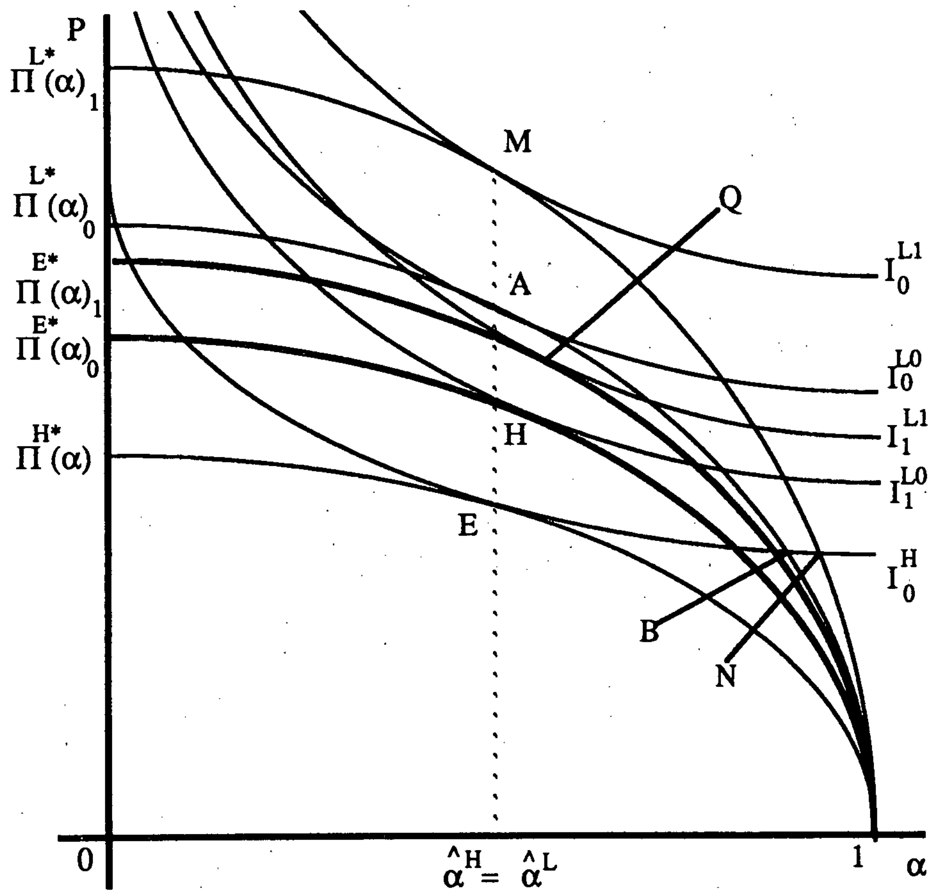
PROPOSITION 3.7: *If $\hat{\alpha}^L \geq \bar{\alpha}^L > \hat{\alpha}^H$, then both the high cost and low cost technologies are licensed and the licensor obtains first best global monopoly profit with each technology.*

PROOF: Consider Figure 6. $\bar{\alpha}^L$ is obtained from the intersection of I_0^H and $\Pi^{L*}(\alpha)$. Initially assume that there is complete information. If the high cost technology occurred, the monopolist would maximise profit by licensing with contract $(\hat{\alpha}^H, \hat{l}^H)$. If the low cost technology occurred, the licensor would maximise profit by licensing with contract $(\hat{\alpha}^L, \hat{l}^L)$.

Now consider the case of asymmetric information. If the high cost technology occurred, the licensor makes more profit from contract $(\hat{\alpha}^H, \hat{l}^H)$ than from contract

[36] Clearly there are many other cases which could be considered. However, this seems to be the most interesting.

Figure 5



P
$\Pi^{L*}(\alpha)_1$
$\Pi^{L*}(\alpha)_0$
$\Pi^{E*}(\alpha)_1$
$\Pi^{E*}(\alpha)_0$
$\Pi^{H*}(\alpha)$
M
Q
A
H
E
B
N
I_0^{L1}
I_0^{L0}
I_1^{L1}
I_1^{L0}
I_0^{H}
0
$\hat{\alpha}^H = \hat{\alpha}^L$
1
α

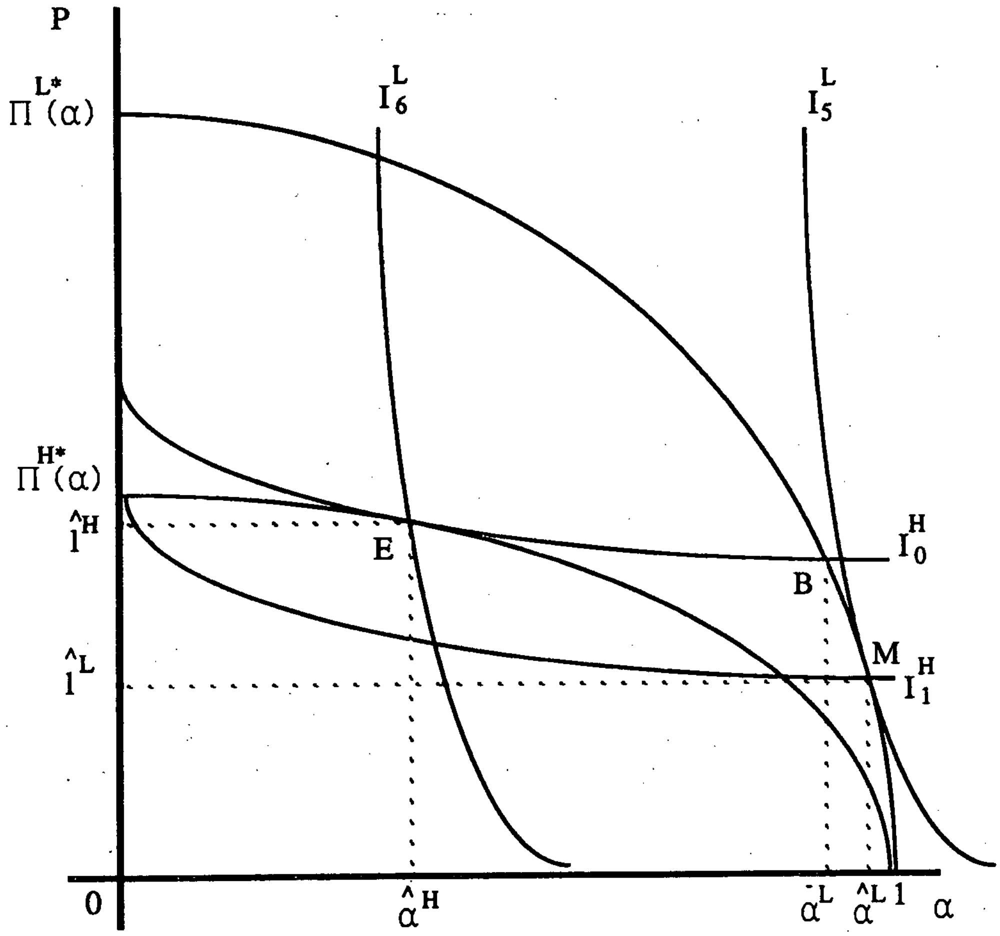
$(\hat{\alpha}^L, \hat{l}^L)$, because I_0^H is further from the origin than I_1^H. Therefore, if the high cost technology occurs, then contract $(\hat{\alpha}^H, \hat{l}^H)$ is offered by the licensor and accepted by the licensee. This allows the licensor to make first best (complete information) global monopoly profit. A similar argument applies if the low cost technology occurred. **(Q.E.D.)**

Empirical Support

The model developed above is a formal model with specific testable hypotheses regarding the choice between modes of technology transfer. However, it is difficult to use the large amount of empirical work previuosly directed to technology transfer, because it was not undertaken with the above model in mind. Therefore, the following discussion must be viewed with caution.

Davidson and McFetridge (1984, p.259) found for the U.S. that the international transfer of technology via subsidiary was more likely to Canada than Western Europe and more likely to Western Europe than the rest of the world. A similar finding was also obtained by Kravis and Lipsey (1982, p.205). As the natural advantage possessed by Canadian entrepreneurs over U.S. entrepreneurs is likely to be small, these results provide some support for Proposition 3.5 which implied that the smaller was k the more likely was technology transfer via subsidiary. Davidson and McFetridge (p.259) provide further support for Proposition 3.5 by finding that if a multinational already has an affiliate in the receiving country, then it is more likely that transfer will occur via a subsidiary. Presumably, with an existing affiliate knowledge of local institutions is quite extensive in which case k would be very small. Caves, Crookwell, and Killing (1983, p.261–262) found that most license agreements occurred between firms in different nations rather than between firms in the same nation. Their justification for this result was that there was less of a threat of future competition from a

Figure 6



P
$\Pi^{L*}(\alpha)$
I_6^L
I_5^L
$\Pi^{H*}(\alpha)$
$\hat{l}^H$
E
I_0^H
B
$\hat{l}^L$
M
I_1^H
0
$\hat{\alpha}^H$
$\bar{\alpha}^L$
$\hat{\alpha}^L$
1
α

foreign producer compared to a domestic producer. However, another possibilty is that for transfers between nations k is larger than for transfers within nations. The existence of an alternative hypothesis which is also supported by the data highlights the inadequacy of *ad hoc* hypothesis formulation. The model outlined above also suggests that the technologies transferred via subsidiary are low cost, unless $k = 0$. However, existing empirical findings are not able to confirm this.

Another empirical finding that gains much support is that newer technologies are more likely to be transferred internally (via a subsidiary) while older technologies are more likely to be transferred via a license. This was found by Davidson and McFetridge (p.259) and also by Mansfield and Romeo (1980, p.738–739). The model developed above is a static model in which new technologies are transferred as soon as they are obtained. However, amending the model by allowing the foreign country's cost curve to move down over time (maybe because of endowment changes) in such a way that production abroad becomes profitable allows a possible explanation of this finding. If the technology is not immediately transferred abroad via subsidiary or license, then potential licensees have time in which to obtain information about the true technology type. Thus, over time, ρ^* approaches zero or one. If ρ^* approaches zero, then $\rho^* < \rho_c^*$ and the technology is transferred via license as a high cost technology. If ρ^* approaches one, then $\rho^* > \rho_c^*$ and the pooling solution is chosen. Once again the technology is again transferred via license. Therefore, if older technologies are associated with subjective probabilities, ρ^*, that are close to zero or one, then Propositions 3.4 and 3.5 suggest that these technologies are always transferred via license.

Davidson and McFetridge (p.259) also found that more radical technologies were more likely to be transferred internally. In a survey article Cheng (1984, p.182) also observed from his reading of the empirical literature that

"Very profitable technologies were mostly reserved for subsidiaries, whereas marginal or older technologies (more than 5 years after commercialisation) were often made available to foreign firms via license."

More radical or very profitable can be interpreted as low cost technologies. This finding provides support for Proposition 3.4 which established that high cost technologies (marginal or not radical) are always licensed while low cost technologies may be transferred via a subsidiary.

More radical or very profitable could also be interpreted as referring to technologies in which γ was large. With this interpretation, the empirical finding implies that the larger is γ the more likely is technology transferred via subsidiary. As Proposition 3.6 established an ambiguous link between the size of γ and the likelihood of licensing, the empirical finding supports the theoretical model only if γ, although large, is not so large that $\frac{d\left((\hat{\Pi}^L+\hat{\Pi}^{L*})-(\bar{\Pi}^L+\bar{l}^L)\right)}{d\gamma} < 0$.[37]

Finally, bearing on the next section in which R&D is endogenous; Mansfield, Romeo, and Wagner (1980, p.51–52) found that when the 30 firms in their sample were asked by how much their R&D expenditure would fall if they were not able to transfer technology abroad via subsidiary or license, the reply was on average between 15% and 25%. As this was an average, some firms would have cut their R&D by more while others would have cut R&D by less. What is of interest is what determines by how much R&D is cut if it is cut at all. This requires a formal model of technology transfer in which R&D is endogenous.

In conclusion it must be re–emphasised that existing empirical evidence provides only weak support for the propositions established in this section, because existing empirical work has not attempted to test specific formal models regarding interna-

[37] If the plant location model outlined in Appendix 12 was used, then this model would be consistent with the empirical result, because Proposition A.12.1 established that the likelihood of licensing decreases as γ increases.

tional technology transfer. This does not mean that the model developed in this section is not a good description of technology transfer in the face of asymmetric information, but only that existing empirical evidence was not obtained in order to explicitly test this model.

The analysis of Stage Two has demonstrated conditions under which technology transfer occurs via a license agreement in the presence of an information asymmetry. This is an improvement on the traditional approach to technology transfer which assumes, because of the "Paradox of Information" that technology is transferred via a wholly owned subsidiary. The role played by the fixed cost, k, is crucial in allowing licensing to occur.

Before analysing Stage One of the monopolist's problem, it must be pointed out that in many situations the monopolist's problem only consists of Stage Two and Stage Three. This occurs if the R&D stage was completed in the past when transferring technology abroad was unprofitable, but due to changing circumstances, it is profitable now.[38] In this situation, the monopolist's problem is only a two stage problem, and the subjective probability, ρ^*, is exogenously given. This is precisely the circumstance under which Propositions 3.2–3.7 were derived.

However, this thesis is chiefly concerned with those circumstances in which the amount of R&D undertaken is determined by explicitly considering how the technology is to be transferred internationally. It will be seen that under these circumstances ρ^* may be endogenously determined.

3.3 Stage One

In Stage One the monopolist undertakes R&D to lower its production costs.

[38] These changing circumstances may be changes in endowments which allow profitable production abroad.

The result of this R&D is uncertain though it is known that either a high or low cost technology results. The probability of the low cost technology occurring is increased by greater R&D expenditure. Given this information, the monopolist chooses R&D to maximise its expected profit.

Let $\rho(R)$ be the probability of the low cost technology occurring if R units of R&D are done, where $\rho'(R) > 0$ and $\rho''(R) < 0$.[39] For the moment, continue to assume that ρ^* is exogenously given.[40]

ρ^* *EXOGENOUS*

The monopolist's problem in Stage One is

Problem 3:

$$\max_R \quad \{\Pi^E = \rho(R) \cdot \pi^L + \big(1 - \rho(R)\big) \cdot \pi^H - \omega R\}, \tag{3.59}$$

where π^i=total profit of the monopolist in state i and ω is the unit cost of R&D. This is a general formulation which at present does not distinguish between the differing modes of technology transfer. The first order condition for this problem is

$$\rho'(R) \cdot (\pi^L - \pi^H) + \rho(R) \cdot \frac{d\pi^L}{dR} + \big(1 - \rho(R)\big) \cdot \frac{d\pi^H}{dR} - \omega \tag{3.60}$$

which reduces to

$$\rho'(R) = \frac{\omega}{(\pi^L - \pi^H)} \tag{3.61}$$

39 The high cost technology can be thought of as the technology associated with the new product at the time of its discovery.

40 ρ^* is the licensee's subjective probability, at the time of transfer, that the low cost technology has occurred. $\rho(R)$ is the licensor's subjective probability that the low cost technology will occur at the end of Stage One and is a function of the amount of R&D undertaken in Stage One.

when ρ^* is exogenous, as π^L and π^H depend only on exogenous given parameters, not R. The second order condition for a maximum is satisfied, because of the concavity of $\rho(R)$.

It is assumed that an interior solution exists. Solving (3.61) for the optimal R, substituting into (3.61), and totally differentiating yields

$$\rho''(R)dR = -\frac{\omega}{(\pi^L - \pi^H)^2} \cdot d(\pi^L - \pi^H). \tag{3.62}$$

Rearranging (3.62) gives

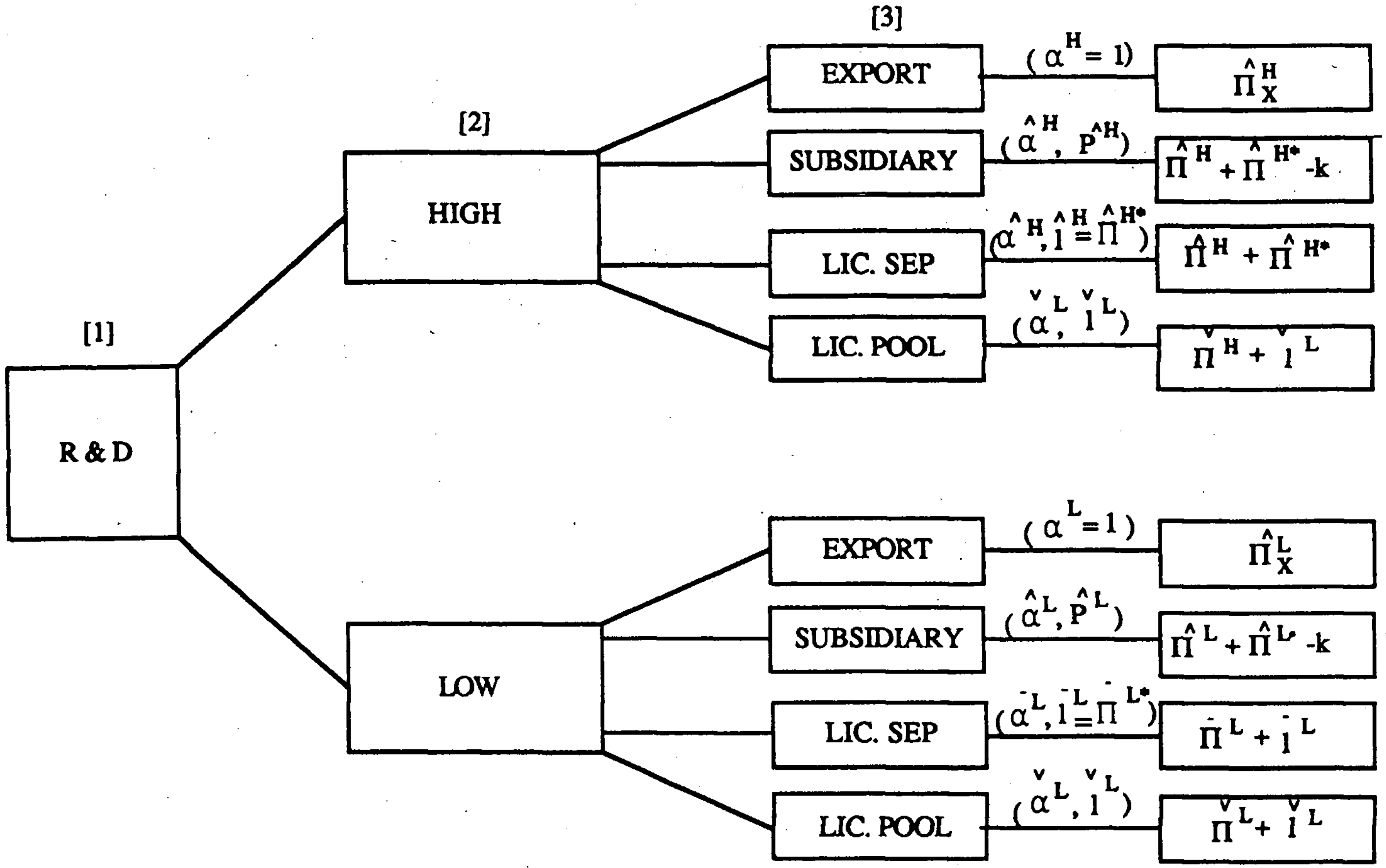
$$\frac{dR}{d(\pi^L - \pi^H)} = -\frac{\omega}{(\pi^L - \pi^H)^2} \cdot \frac{1}{\rho''(R)} > 0 \tag{3.63}$$

from the concavity of $\rho(R)$. In words, the greater is the difference between the monopolist's total profits in each state the greater is the amount of R&D undertaken.

At this point, it seems appropriate to clearly set out the decision process of the monopolist on a tree diagram. This is done in Figure 7. In Stage One the monopolist chooses R&D to maximise expected profit, as in (3.59), looking forward to the result of Stage Two and Stage Three. For example, assume in Stage Three that $(\hat{\Pi}^L + \hat{\Pi}^{L*} - k)$ is the largest of the payoffs if the low cost technology occurs while $(\hat{\Pi}^H + \hat{\Pi}^{H*})$ is the largest of the payoffs if the high cost technology occurs.[41] Stage Two thus results in the low cost technology being transferred via subsidiary and the high cost technology being transferred via license. In Stage One R&D expenditure is determined by substituting $(\hat{\Pi}^L + \hat{\Pi}^{L*} - k)$ for π^L and $(\hat{\Pi}^H + \hat{\Pi}^{H*})$ for π^H in (3.61). In Stage Two and Stage Three the licensor knows the technology type, but the licensee does not.

Although the R&D stage occurs before Stages 2 and 3, the choice of mode of transfer and the choice of $(\alpha, l\ or\ P)$ are independent of the amount of R&D

[41] $(\check{\Pi}^H + \check{l}^L)$ can only be achieved if $(\check{\Pi}^L + \check{l}^L)$ is the largest of the payoffs associated with the low cost technology.



[1]
R & D
[2]
HIGH
LOW
[3]
EXPORT
SUBSIDIARY
LIC. SEP
LIC. POOL
EXPORT
SUBSIDIARY
LIC. SEP
LIC. POOL
$(\alpha^H = 1)$
$(\hat{\alpha}^H, \hat{P}^H)$
$(\hat{\alpha}^H, \hat{l}^H = \hat{\Pi}^{H*})$
$(\check{\alpha}^L, \check{l}^L)$
$(\alpha^L = 1)$
$(\hat{\alpha}^L, \hat{P}^L)$
$(\bar{\alpha}^L, \bar{l}^L = \bar{\Pi}^{L*})$
$(\check{\alpha}^L, \check{l}^L)$
$\hat{\Pi}^H_X$
$\hat{\Pi}^H + \hat{\Pi}^{H*} - k$
$\hat{\Pi}^H + \hat{\Pi}^{H*}$
$\check{\Pi}^H + \check{l}^L$
$\hat{\Pi}^L_X$
$\hat{\Pi}^L + \hat{\Pi}^{L*} - k$
$\bar{\Pi}^L + \bar{l}^L$
$\check{\Pi}^L + \check{l}^L$

Figure 7

undertaken in Stage 1. This independence arises from the uncertainty surrounding the outcome of R&D expenditures. In particular, all that is known before the R&D is undertaken is that a high or low cost technology will result with some probability dependent on R. When the monopolist transfers the technology it knows the technology type, but this type did not arise in a deterministic manner from the R&D expenditure. Therefore, the mode of transfer and $(\alpha, l \text{ or } P)$ do not depend on R, but rather depend on technology type. Referring once again to Figure 7, the dollar values of the eight terminal nodes do not depend on R, and so neither does the mode of transfer.

On the other hand, the amount of R&D undertaken in Stage 1 does depend on the anticipated outcome of Stages 2 and 3, because the monopolist is forward looking. In turn, the outcome of Stages 2 and 3 depends on the parameters of the revenue and cost functions. From (3.38), the optimal pooling solution under licensing depends not only on the parameters of the revenue and cost functions, but also on the exogenously given ρ^*. This is not the case for technology transfer via the export of goods, subsidiary production, or licensing in a separating equilibrium.

In the pooling solution the effect of changes in ρ^* on $\breve{\alpha}^L$ is obtained by totally differentiating first order condition (3.38). This gives

$$\begin{aligned}\left(\frac{d^2\Pi^L}{(d\alpha)^2} + \rho^* \cdot \frac{d^2\Pi^{L*}}{(d\alpha)^2} + (1-\rho^*) \cdot \frac{d^2\Pi^{H*}}{(d\alpha)^2}\right) \cdot d\alpha \\ + \left(\frac{d\Pi^{L*}}{d\alpha} - \frac{d\Pi^{H*}}{d\alpha}\right) \cdot d\rho^* = 0.\end{aligned} \tag{3.64}$$

The first bracketed term in (3.64) is second order condition (3.39) which is less than zero. The second bracketed term is also less than zero.[42] Together, these results imply that

$$\frac{d\breve{\alpha}^L}{d\rho^*} < 0. \tag{3.65}$$

[42] The proof of this result is shown in Appendix 9.

The intuition for this result is that as ρ^* is increased the monopolist can move (α, l) closer to the first best level associated with the low cost technology. This is so even if the high cost technology has occurred.[43]

Given ρ^* and given the pooling solution

$$\pi^L - \pi^H = \left(\check{\Pi}^L(\check{\alpha}^L(\rho^*)) + \check{l}^L\right) - \left(\check{\Pi}^H(\check{\alpha}^L(\rho^*)) + \check{l}^L\right). \tag{3.66}$$

Substituting (3.66) into (3.61) and totally differentiating yields

$$\begin{aligned} &\rho''(R) \cdot \left(\check{\Pi}^L(\check{\alpha}^L(\rho^*)) - \check{\Pi}^H(\check{\alpha}^L(\rho^*))\right) \cdot dR \\ &+ \rho'(R) \cdot \left(\frac{d\check{\Pi}^L}{d\check{\alpha}^L} - \frac{d\check{\Pi}^H}{d\check{\alpha}^L}\right) \cdot \frac{d\check{\alpha}^L}{d\rho^*} \cdot d\rho^* = 0. \end{aligned} \tag{3.67}$$

Rearranging (3.67) gives

$$\frac{dR}{d\rho^*} = -\frac{\rho'(R) \cdot \left(\frac{d\check{\Pi}^L}{d\check{\alpha}^L} - \frac{d\check{\Pi}^H}{d\check{\alpha}^L}\right) \cdot \frac{d\check{\alpha}^L}{d\rho^*}}{\rho''(R) \cdot \left(\check{\Pi}^L(\check{\alpha}^L(\rho^*)) - \check{\Pi}^H(\check{\alpha}^L(\rho^*))\right)}. \tag{3.68}$$

Now

$$\rho'(R) > 0, \tag{3.69}$$

$$\rho''(R) < 0, \tag{3.70}$$

$$\frac{d\check{\alpha}^L}{d\rho^*} < 0, \tag{3.71}$$

$$\left(\frac{d\check{\Pi}^L}{d\check{\alpha}^L} - \frac{d\check{\Pi}^H}{d\check{\alpha}^L}\right) > 0, \tag{3.72}$$

and

$$\check{\Pi}^L > \check{\Pi}^H, \tag{3.73}$$

so

$$\frac{dR}{d\rho^*} < 0. \tag{3.74}$$

43 $\check{\alpha}^L$ is bounded from below by $\hat{\alpha}^L$ when $\rho^* = 1$, and bounded from above by an α less than $\bar{\alpha}^L$.

That is, as ρ^* is increased, $(\pi^L - \pi^H)$ falls. From (3.63) this implies that R&D expenditure falls.

ρ^* ENDOGENOUS

To date it has been assumed that ρ^* is exogenously given. This assumption is now relaxed so that ρ^* becomes an endogenous variable. This endogeneity is obtained by assuming that the licensee (1) knows the function $\rho(R)$ and (2) can observe R.[44] Therefore,

$$\rho^* = \rho(R) = \rho^*(R). \tag{3.75}$$

As mentioned above, the only final nodes of Figure 7 that are influenced by ρ^* are the two associated with the pooling solution. Therefore, only those nodes are affected when ρ^* becomes endogenous. The monopolist's Stage Three pooling problem is now written as

Problem $2^{'}$:

$$\max_{\alpha} \quad \{\Pi(L) = \Pi^L(\alpha) + \rho^*(R) \cdot \Pi^{L*}(\alpha) + \big(1 - \rho^*(R)\big) \cdot \Pi^{H*}(\alpha)\}, \tag{3.76}$$

where

$$l(\alpha, R) = \rho^*(R) \cdot \Pi^{L*}(\alpha) + \big(1 - \rho^*(R)\big) \cdot \Pi^{H*}(\alpha) \tag{3.77}$$

is the state independent license payment.[45] The first order condition for this problem is

$$\frac{d\Pi(L)}{d\alpha} = \frac{d\Pi^L}{d\alpha} + \rho^*(R) \cdot \frac{d\Pi^{L*}}{d\alpha} + \big(1 - \rho^*(R)\big) \cdot \frac{d\Pi^{H*}}{d\alpha} = 0. \tag{3.78}$$

---

[44] R might be observable, because the licensee can observe (1) the size of the R&D department of the monopolist, or (2) accounting reports of the monopolist which specify R&D expenditure.

[45] This is just Problem 2, of Stage Three above, with the subjective probability being a function of R. See (3.37).

The second order condition for a maximum is

$$\frac{d^2\Pi^L}{(d\alpha)^2} + \big(1-\rho^*(R)\big)\cdot\frac{d^2\Pi^{H*}}{(d\alpha)^2} + \rho^*(R)\cdot\frac{d^2\Pi^{L*}}{(d\alpha)^2} < 0 \tag{3.79}$$

which is satisfied for all α. Solving (3.78) gives

$$\breve{\alpha}^L(R). \tag{3.80}$$

Substituting (3.80) into (3.78) and totally differentiating yields

$$\begin{aligned}&\left(\frac{d^2\Pi^L}{(d\alpha)^2} + \rho^*(R)\cdot\frac{d^2\Pi^{L*}}{(d\alpha)^2} + \big(1-\rho^*(R)\big)\cdot\frac{d^2\Pi^{H*}}{(d\alpha)^2}\right)\cdot d\breve{\alpha}^L\\ &\quad + \rho^{*'}(R)\cdot\left(\frac{d\Pi^{L*}}{d\alpha} - \frac{d\Pi^{H*}}{d\alpha}\right)\cdot dR = 0.\end{aligned} \tag{3.81}$$

Rearranging (3.81) gives

$$\frac{d\breve{\alpha}^L}{dR} = -\frac{\rho^{*'}(R)\cdot(\frac{d\Pi^{L*}}{d\alpha} - \frac{d\Pi^{H*}}{d\alpha})}{(S.O.C.(3.79))} < 0. \tag{3.82}$$

Therefore, the greater is the amount of R&D undertaken the smaller is $\breve{\alpha}^L$. However, as long as $\rho^*(R) < 1$ it is also true that $\breve{\alpha}^L > \hat{\alpha}^L$. This latter statement is clear from Figure 4.

By assumption ρ^* is a function of R and from (3.80) above the market share in the pooling equilibrium is also a function of R. Therefore, the dollar values of the nodes in Figure 7 which are associated with the pooling solution are also functions of R. To calculate the values of these nodes the licensor solves Problem $3'$ for the optimal value of R, where ρ, ρ^*, $\breve{\alpha}^L$, and $\breve{l}^L$ are all functions of R.

Problem $3'$:

$$\begin{aligned}\max_R \quad \{\Pi^E &= \rho(R)\Big(\breve{\Pi}^L(\breve{\alpha}^L(R)) + \breve{l}^L\Big) + \big(1-\rho(R)\big)\cdot\Big(\breve{\Pi}^H(\breve{\alpha}^L(R)) + \breve{l}^L\Big) - \omega R\\ &= \rho(R)\cdot\breve{\Pi}^L(\breve{\alpha}^L(R)) + \big(1-\rho(R)\big)\cdot\breve{\Pi}^H(\breve{\alpha}^L(R))\\ &\quad + \rho^*(R)\cdot\breve{\Pi}^{L*}(\breve{\alpha}^L(R)) + \big(1-\rho^*(R)\big)\cdot\breve{\Pi}^{H*}(\breve{\alpha}^L(R)) - \omega R\}.\end{aligned} \tag{3.83}$$

Assuming that $\rho(R) = \rho^*(R)$ the first order condition for this problem is

$$\frac{d\Pi^E}{dR} = \rho'(R) \cdot (\check{\Pi}^L - \check{\Pi}^H) + \rho'(R) \cdot (\check{\Pi}^{L*} - \check{\Pi}^{H*})$$
$$+ \left(\rho(R) \cdot \left(\frac{d\check{\Pi}^L}{d\check{\alpha}^L} + \frac{d\check{\Pi}^{L*}}{d\check{\alpha}^L} \right) + (1 - \rho(R)) \cdot \left(\frac{d\check{\Pi}^H}{d\check{\alpha}^L} + \frac{d\check{\Pi}^{H*}}{d\check{\alpha}^L} \right) \right) \cdot \frac{d\check{\alpha}^L}{dR}$$
$$- \omega = 0. \tag{3.84}$$

The second order condition for a maximum is

$$\frac{d^2\Pi^E}{(dR)^2} = \rho''(R) \cdot ((\check{\Pi}^L + \check{\Pi}^{L*}) - (\check{\Pi}^H + \check{\Pi}^{H*}))$$
$$+ 2\rho'(R) \cdot \left(\left(\frac{d\check{\Pi}^L}{d\check{\alpha}^L} + \frac{d\check{\Pi}^{L*}}{d\check{\alpha}^L} \right) - \left(\frac{d\check{\Pi}^H}{d\check{\alpha}^L} + \frac{d\check{\Pi}^{H*}}{d\check{\alpha}^L} \right) \right) \cdot \frac{d\check{\alpha}^L}{dR}$$
$$+ \left(\rho(R) \cdot \left(\frac{d^2\check{\Pi}^L}{(d\check{\alpha}^L)^2} + \frac{d^2\check{\Pi}^{L*}}{(d\check{\alpha}^L)^2} \right) + (1 - \rho(R)) \cdot \left(\frac{d^2\check{\Pi}^H}{(d\check{\alpha}^L)^2} + \frac{d^2\check{\Pi}^{H*}}{(d\check{\alpha}^L)^2} \right) \right) \cdot \frac{d\check{\alpha}^L}{dR}$$
$$+ \left(\rho(R) \cdot \left(\frac{d\check{\Pi}^L}{d\check{\alpha}^L} + \frac{d\check{\Pi}^{L*}}{d\check{\alpha}^L} \right) + (1 - \rho(R)) \cdot \left(\frac{d\check{\Pi}^H}{d\check{\alpha}^L} + \frac{d\check{\Pi}^{H*}}{d\check{\alpha}^L} \right) \right) \cdot \frac{d^2\check{\alpha}^L}{(dR)^2} < 0. \tag{3.85}$$

Unfortunately, it is not clear that the S.O.C. for a maximum is satisfied.[46] However, it is assumed that ω and the function $\rho(R)$ are such that an interior solution exists and the second order condition for a maximum is satisfied. Let the solution of (3.84) be given by $\check{R}$. This implies a license contract of

$$\left(\check{\alpha}^L(\check{R}), \check{l}^L(\check{\alpha}^L(\check{R})) \right) \tag{3.86}$$

in Stage Three and hence dollar values for the nodes associated with the pooling solution in Figure 7. Given these dollar values, the mode of technology transfer can be chosen for each technology type, and the amount of R&D undertaken in Stage 1

[46] The first term of (3.85) is negative, the second term has ambiguous sign, the third term is positive, and the last term has ambiguous sign.

follows directly from (3.61) if the mode chosen is subsidiary production or licensing with a separating equilibrium while the amount of R&D undertaken follows from (3.84) if the mode chosen is licensing with a pooling equilibrium.

In the pooling solution compared to the situation in which the licensee could not observe R, when the licensee can observe R more R&D is undertaken by the licensor. This follows from F.O.C. (3.84) and S.O.C. (3.85). Substituting (3.66) into (3.61), and comparing this to (3.84) reveals that (3.84) involves two extra terms which have positive sign.[47] Therefore, at the solution of (3.61), F.O.C. (3.84) does not hold as $\frac{d\Pi^E}{dR} > 0$. Given that the S.O.C. is satisfied, an increase in R is necessary to make (3.84) hold with equality. By (3.86), this also implies that $\breve{\alpha}^L$ is less and $\breve{l}^L$ is more when R is observed compared to where it is not. The increase in R also increases the probability that the low cost technology will result.

PROPOSITION 3.8: *Let $\rho_c(R)$ be a distribution which leaves the licensor indifferent between the pooling or separating solution. If $\underline{\rho(R)}$ is a transformation of $\rho_c(R)$ such that*

$$\underline{\rho(R)} > \rho_c(R) \quad \forall\ R \neq 0 \tag{3.87}$$

and

$$\underline{\rho'(R)} > \rho_c'(R) \quad at\ \underline{\rho} = \rho, \tag{3.88}$$

then with distribution $\underline{\rho(R)}$ the licensor prefers the pooling solution to the separating solution.

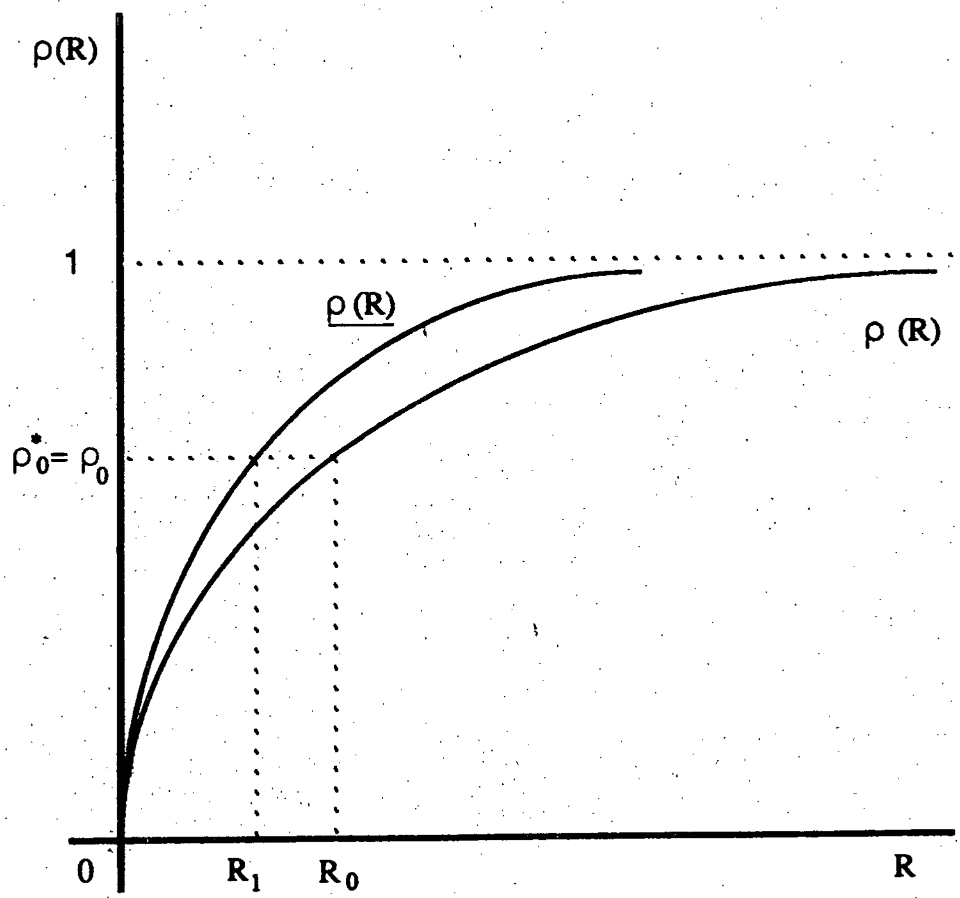
PROOF: Two distributions which satisfy (3.87) and (3.88) are drawn in Figure 8. Let the monopolist's optimal choice of R with distribution $\rho_c(R)$ be given by R_0. Let the probability associated with R_0 be given by $\rho_0 = \rho_0^*$. Using distribution $\underline{\rho(R)}$, let

[47] The second term in (3.84) is positive, because $\breve{\Pi}^{L*} > \breve{\Pi}^{H*}$. The third term is positive, because $\frac{d\breve{\alpha}^L}{dR} < 0$ and $\frac{d\breve{\Pi}^i}{d\breve{\alpha}^L} < \left|\frac{d\breve{\Pi}^{i*}}{d\breve{\alpha}^L}\right|$ at $\alpha^L > \hat{\alpha}^L$.

the amount of R&D necessary for $\underline{\rho_0^*} = \rho_0^*$ be given by R_1. If R&D expenditure of R_1 is undertaken by the monopolist, then $\frac{d\Pi^E}{dR} > 0$, because $\underline{\rho'(R_1)} > \rho_c'(R_0)$. S.O.C. (3.85) implies that optimality with distribution $\underline{\rho(R)}$ requires an increase in R above R_1. An increase in R above R_1 increases $\underline{\rho^*}$ above ρ_0^*, and increases the value of the objective function of Problem $2'$. The pooling solution now yields more profit than the separating solution and so is preferred to the separating solution. **(Q.E.D.)**

This proposition is just the analogue of Proposition 3.2 extended to the case where ρ^* is a function of R.

Figure 8



CHAPTER IV

Welfare and Policy

In this section the welfare and policy implications of the model developed above are analysed. This is done from the point of view of both the home and foreign countries, but it is assumed that each country's policy is determined independently of the other country's policy. Although this is unrealistic, it is an assumption often made in the policy literature [Rodriguez (1975), Bardhan (1982), Brecher (1982), and Pugel (1982)], for without it, home and foreign policy makers would be involved in a game and policy analysis would be substantially complicated.

4.1 Home Country Welfare and Policy

Unlike Rodriguez (1975), who derived the optimal policy concerning technology transfer, this section only provides a welfare ranking of various policies, given a monopoly market structure at home and abroad.[1] With complete information and exogenous technological change, Rodriguez found the optimal policy to be promotion of competitive behaviour at home and the full exploitation of monopoly power abroad. Competitive behaviour at home was obtained through a domestic consumption subsidy. However, if there is incomplete information, in that the policy maker (regulator) does not know the monopolist's costs, the optimal policy at home is not a simple consumption subsidy nor is it the simple forcing of marginal cost pricing. Incomplete information is precisely the situation analysed in the model of Section 3, because only the monopolist knows whether the technology is high cost or low cost.

Under conditions of incomplete information, Baron and Myerson (1982) derived the optimal policy for a monopoly regulator. For the author, imbedding similar

[1] Feenstra and Judd (1982), also, only provide a welfare ranking of different policies.

analysis into the technology transfer problem of Stage Three would be prohibitively complicated. This complication would be further exacerbated by the need for the regulator to overcome the distortion caused when R&D is undertaken by a monopolist in Stage One. This distortion arises because the monopolist chooses R&D to maximise expected profit not expected welfare.

Rather than proceed by deriving the optimal policy in the face of incomplete information, let us proceed by providing a welfare ranking of various policies which are often recommended or enacted in practice. The measure of welfare which is used in this ranking is the sum of expected monopoly profit and expected consumer surplus.

A Ban On The Transfer Of Technology Via License Or Subsidiary

This policy is often advocated in technology exporting countries in order to protect employment and living standards, or to protect a technological lead.[2] However, banning the transfer of technology via license or subsidiary leaves the export of goods as the only option available to a global profit maximising monopolist. The ban has three effects on expected welfare; (1) a profit effect, (2) a price effect, and (3) an R&D effect. The latter is important as more R&D expenditure increases the probability of the low cost technology occurring, and so tends to increase expected profit and expected consumer surplus. The welfare effects also depend on the modes of transfer that were originally optimal for the monopolist. There are three cases to consider.

(1) *Low cost technology transferred by subsidiary - High cost technology transferred by license.*

If this scheme of transfer was optimal for the monopolist, then k must be such that $\hat{\Pi}^L + \hat{\Pi}^{L*} - k > \hat{\Pi}^L_X$. It must also be true that $\hat{\Pi}^H + \hat{\Pi}^{H*} > \hat{\Pi}^H_X$. Together,

[2] Feenstra and Judd (1982) argue that their model provides insight into organised labour's desire to restrict technology transfer. See also Teece (1981).

these inequalities imply that

$$\Pi^{E}_{XX} < \Pi^{E}_{SL}, \tag{4.1}$$

where E denotes an expected value and subscripts S, L, and X respectively denote technology transfer via subsidiary, license and exports (the first subscript refers to the low cost technology, the second to the high cost technology). Therefore, banning the transfer of technology via license or subsidiary causes expected monopoly profit to fall.

The impact on expected consumer surplus is ambiguous, because of a price and an R&D effect. First, the shift to exports increases the price of output for home consumers, because marginal cost increases in output. This implies that $CS^{L}_{X} < CS^{L}_{S}$ and $CS^{H}_{X} < CS^{H}_{L}$, where CS denotes consumer surplus of home consumers. This effect unambiguously reduces expected consumer surplus. Secondly, in Section 3 it was seen that the amount of R&D undertaken in Stage One depended on $(\pi^{L} - \pi^{H})$. Therefore,

$$R_{SL} > R_{XX} \quad if \quad (\hat{\Pi}^{L} + \hat{\Pi}^{L*} - k) - (\hat{\Pi}^{H} + \hat{\Pi}^{H*}) > (\hat{\Pi}^{L}_{X} - \hat{\Pi}^{H}_{X}). \tag{4.2}$$

If $R_{SL} > R_{XX}$, then the ban on technology transfer via license or subsidiary reduces the likelihood that the low cost technology will occur. In turn, this tends to reduce expected profit and expected consumer surplus.

The second inequality in (4.2) can be rearranged to yield

$$\hat{\Pi}^{L} + \hat{\Pi}^{L*} - k - \hat{\Pi}^{L}_{X} > \hat{\Pi}^{H} + \hat{\Pi}^{H*} - \hat{\Pi}^{H}_{X}. \tag{4.3}$$

A necessary condition for (4.3) to be satisfied is that

$$\hat{\Pi}^{L} + \hat{\Pi}^{L*} - \hat{\Pi}^{L}_{X} > \hat{\Pi}^{H} + \hat{\Pi}^{H*} - \hat{\Pi}^{H}_{X}. \tag{4.4}$$

To date, general conditions under which (4.4) holds have not been obtained. However, assuming linear demand and linear marginal cost, the following proposition has been established.

PROPOSITION 4.1: *If the home production facility's demand curve is given by*

$$p = a - b\frac{q}{\alpha}, \quad \textit{where} \quad \frac{q}{\alpha} = Q \tag{4.5}$$

its cost function is given by

$$c^L = \frac{d}{\gamma}q^2 \quad \forall\, \gamma \geq 1, \tag{4.6}$$

and

$$c^L = c^{L*}, \tag{4.7}$$

then the necessary condition for $R_{SL} > R_{XX}$ (condition (4.4)) is satisfied if

$$\gamma < \frac{1}{2}\left(\frac{d}{b}\right)^2. \tag{4.8}$$

PROOF: See Appendix 13.

For specific functional forms, Proposition 4.1 establishes that necessary condition (4.4) is more likely to be satisfied the smaller is γ and the larger is $\left(\frac{d}{b}\right)$. The intuition regarding the size of γ is clear. As γ increases, the low cost technology's marginal cost curve becomes flatter. In turn, this reduces the benefits obtained from locating production abroad. In fact, as γ becomes very large the marginal cost curve approaches the horizontal and $\hat{\Pi}^L + \hat{\Pi}^{L*}$ approaches $\hat{\Pi}^L_X$. Clearly, for large γ (4.4) is less likely to hold.

The intuition regarding $\frac{d}{b}$ is obtained by considering Figures 9 and 10. In Figure 9 the marginal revenue and marginal cost curves are drawn so that $\frac{d}{b}$ is relatively

Figure 9

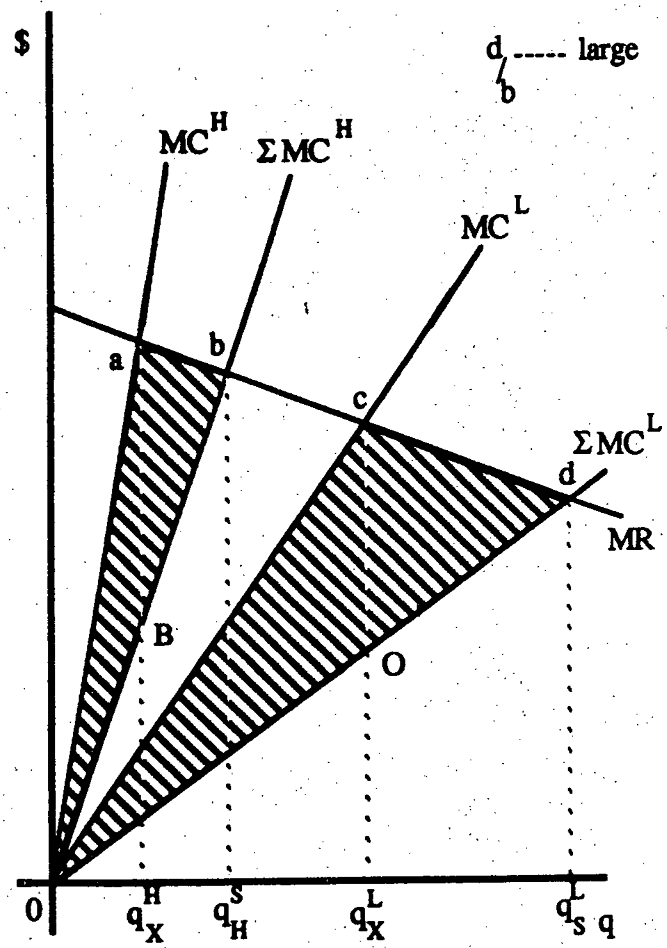
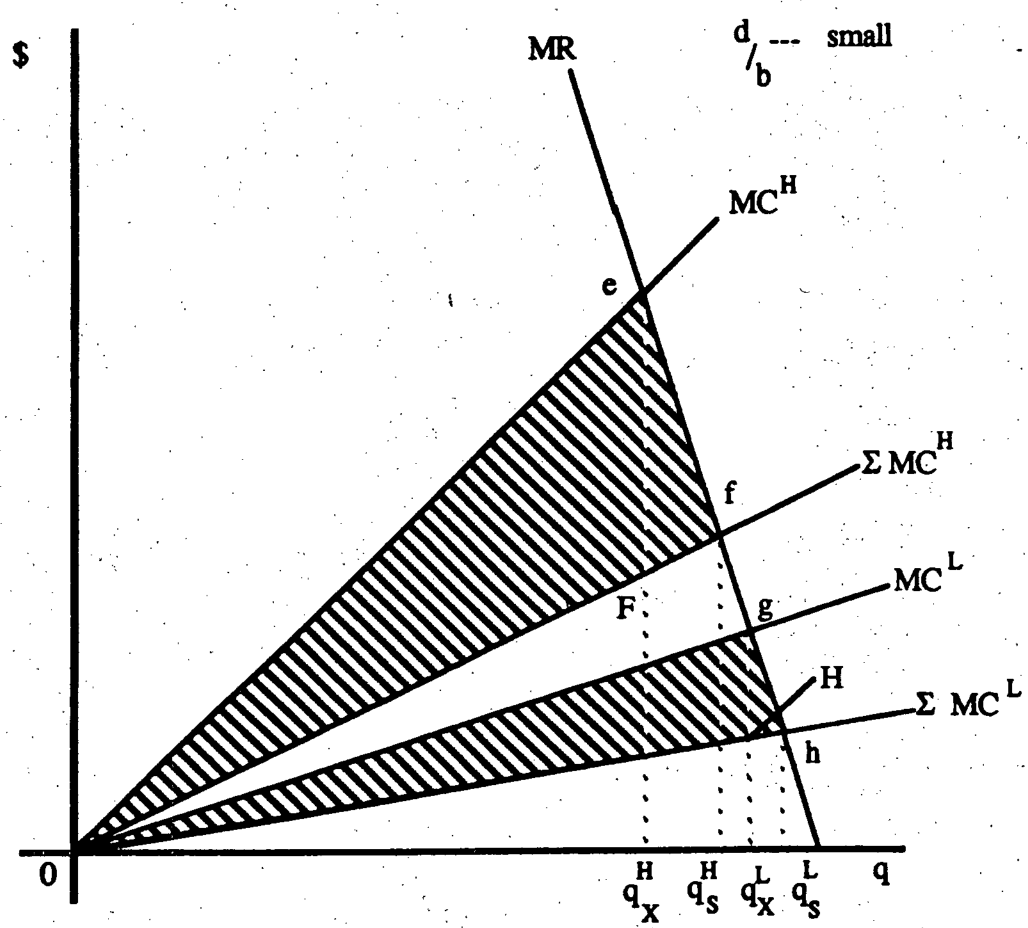


Figure 10



large. In this diagram

$$(\hat{\Pi}^H + \hat{\Pi}^{H*}) - \hat{\Pi}_X^H = oab \tag{4.9}$$

and

$$(\hat{\Pi}^L + \hat{\Pi}^{L*}) - \hat{\Pi}_X^L = ocd. \tag{4.10}$$

Clearly,

$$ocd > oab \tag{4.11}$$

which implies that condition (4.4) holds. Area oab can fruitfully be divided into two regions. oaB represents the cost saving that subsidiary production provides on world export output, while abB represents extra profits that accrue from subsidiary production as a result of the expansion in world output.

In Figure 10 $\frac{d}{b}$ is relatively small. In this diagram

$$(\hat{\Pi}^H + \hat{\Pi}^{H*}) - \hat{\Pi}_X^H = oef \tag{4.12}$$

and

$$(\hat{\Pi}^L + \hat{\Pi}^{L*}) - \hat{\Pi}_X^L = ogh. \tag{4.13}$$

Clearly,

$$oef > ogh \tag{4.14}$$

which implies that condition (4.4) does not hold.

The major difference between Figures 9 and 10 is that when $\frac{d}{b}$ is large the difference between q_X^L and q_X^H and $(q_S^L - q_X^L)$ and $(q_S^H - q_X^H)$ is much greater than when $\frac{d}{b}$ is small. This provides the intuition. The much larger output, q_X^L, allows the cost saving of subsidiary production to accrue over more output. As well, the large expansion in world output allows further increases in profit to accrue from subsidiary production.

Although Proposition 4.1 was obtained by assuming linear demand and linear marginal cost, Figures 9 and 10 suggest that the size of γ and the ratio $\frac{d}{b}$ will be important in determining if (4.4) holds under less restrictive conditions. A simple relation like (4.8) is not expected, but as the output response to the low cost technology is crucial, some relation between $\frac{d}{b}$ and γ which is qualitatively similar to (4.8) will determine if (4.4) holds.

Condition (4.4) is only a necessary condition for (4.3) to hold.[3] However, if (4.4) is not satisfied, then clearly $R_{SL} < R_{XX}$. In this case, the ban on technology transfer via license or subsidiary increases the probability of the low cost technology occurring which in turn tends to increase expected consumer surplus. It is assumed that the policy maker knows the cost and demand conditions faced by the monopolist as well as the function $\rho(R)$ though at no stage does it know the technology type. This knowledge enables the policy maker to infer the R&D effect of its policy, and so infer the effect on expected consumer surplus.

Combining the price and R&D response implies that the total effect on expected consumer surplus is ambiguous when (4.4) is not satisfied. Therefore, the impact on expected welfare is also ambiguous.

If (4.4) is satisfied and (4.3) is also satisfied, expected consumer surplus unambiguously falls as a result of the ban as both the price and R&D response affect expected consumer surplus in the same direction. In this case, banning technology

[3] Using (4.3) to obtain conditions on γ, b, d, and k does not yield a simple relationship like (4.8).

transfer via license or subsidiary causes an unambiguous decline in expected welfare.[4]

(2) *Both technologies transferred by license - Separating solution optimal*

If this scheme of transfer was optimal for the monopolist, then $\bar{\Pi}^L + \bar{\Pi}^{L*} > \hat{\Pi}^L_X$, so

$$\Pi^E_{XX} < \bar{\Pi}^E_{LL}. \tag{4.16}$$

Once again the impact on expected consumer surplus is ambiguous. The ban causes the home price to rise under both technology types, because $\hat{\alpha}^H < 1$ and $\bar{\alpha}^L < 1$.[5] Therefore, $CS^L_X < \bar{C}S^L_L$ and $CS^H_X < \hat{C}S^H_L$. This tends to reduce expected consumer surplus.

From Section 3 it is clear that

$$\bar{R}_{LL} > R_{XX} \quad if \quad (\bar{\Pi}^L + \bar{\Pi}^{L*}) - (\hat{\Pi}^H + \hat{\Pi}^{H*}) > (\hat{\Pi}^L_X - \hat{\Pi}^H_X). \tag{4.17}$$

(4.4) is a necessary condition for (4.17) to hold as $(\hat{\Pi}^L + \hat{\Pi}^{L*}) > (\bar{\Pi}^L + \bar{\Pi}^{L*})$. If (4.4) does not hold, then $\bar{R}_{LL} < R_{XX}$, and expected consumer surplus tends to increase as a result of the ban. In this case, combining the price and R&D response leads to an ambiguous impact on expected consumer surplus and expected welfare.

However, if (4.4) is satisfied and (4.17) is also satisfied, then $\bar{R}_{LL} > R_{XX}$, and the ban on technology transfer via license or subsidiary unambiguously reduces expected consumer surplus and expected welfare.

---

4 If the technology difference takes the form assumed in Appendix 12, that is,

$$C^L(q) = c(q) + (a - \gamma)q, \tag{4.15}$$

then Appendix 14 demonstrates that condition (4.4) holds for all γ. In this case, the effect on R&D of the ban on technology transfer via license or subsidiary depends solely on the size of k.

5 Price is an increasing function of the market share from Appendix 4. In equilibrium it is assumed that the market share is such that home and foreign consumers are served by local production.

(3) *Both technologies transferred by license - Pooling equilibrium optimal*

(i) ρ^* EXOGENOUS

If this scheme of transfer was optimal for the monopolist, then

$$\Pi_{XX}^{E} < \check{\Pi}_{LL}^{E} \tag{4.18}$$

Once again the impact on expected consumer surplus is ambiguous. The ban causes the home price to rise under both technology types as $\check{\alpha}^L < 1$. Therefore, $CS_X^L < \check{C}S_L^L$ and $CS_X^H < \check{C}S_L^H$ which tends to reduce expected consumer surplus.

In Section 3, where ρ^* was exogenously given, it was seen that in a pooling equilibrium the amount of R&D undertaken depended solely on the difference between home profits in each state. Now $(\Pi^L(\alpha) - \Pi^H(\alpha))$ is an increasing function of α and $\check{\alpha}^L < 1$.[6] Therefore,

$$(\check{\Pi}^L - \check{\Pi}^H) < (\hat{\Pi}_X^L - \hat{\Pi}_X^H) \tag{4.19}$$

and

$$\check{R}_{LL} < R_{XX} \qquad \forall\, \gamma. \tag{4.20}$$

Combining the price and R&D response leads to an ambiguous impact on expected consumer surplus and expected welfare.

(ii) $\rho^*(R)$ ENDOGENOUS

The price and expected profit effects are qualitatively the same as when ρ^* was exogenous. However, the R&D effect differs. The appropriate F.O.C. to consider is (3.84) which includes terms other than the difference between home profits in each

[6] $(\Pi^L(\alpha) - \Pi^H(\alpha))$ is an increasing function of α, because $\frac{d\Pi^L}{d\alpha} > \frac{d\Pi^H}{d\alpha}$.

state. In Section 3, when ρ^* was endogenous and given by $\rho^*(R)$, it was shown that more R&D was undertaken than when ρ^* was exogenous. Therefore, it is no longer clear that (4.20) holds. If the extra R&D undertaken in the pooling solution is such that $\check{R}_{LL} > R_{XX}$, then there is an unambiguous decline in expected welfare as a result of the ban.

The ambiguity regarding the effect on R&D of a ban on technology transfer via subsidiary or license calls into question a point made by Mansfield, Romeo, and Wagner (1979, p.51)

> *"that, if American firms could not establish foreign subsidiaries (or transfer technology abroad in other ways), they would not carry out as much research and development,"*

In the model developed above this statement is true if condition (4.3) is satisfied; however, if (4.3) is not satisfied, then $R_{SL} < R_{XX}$ and the statement of Mansfield *et al.* is not true.

A policy that bans technology transfer via license or subsidiary usually arises from concerns over employment, living standards, or the loss of a technological lead. The above analysis suggests that there are cases in which this policy has costs in the form of reduced expected profit or reduced expected consumer surplus. These costs must be weighed against any supposed gains. Overall the ambiguity in the above analysis also may suggest that a case by case approach to policy is better than blanket bans or blanket acceptance of all technology transfer via license or subsidiary. Using this case by case approach, the policy maker would need to consider the scheme of transfer that was initially optimal for the monopolist as well as whether the relevant condition (4.3) or (4.17) is satisfied. These circumstances need to be determined before the monopolist does any R&D, and requires the policy maker to have knowledge regarding cost and demand conditions for all potential technology transfers. This is a major information requirement, and operates against the use of a case by case approach. In practise, all that may be possible is blanket bans or blanket acceptance of all technology transfers via license or subsidiary knowing that in some cases expected welfare is lowered by the policy. This may seem an unsatisfactory way to end a section on welfare and policy. However, at least these results were obtained from a formal model and highlight welfare effects that have previously been ignored or specified incorrectly.

4.2 Foreign Country Welfare And Policy.

When technology is transferred by license or subsidiary the foreign country receives no monopoly profit, because competitive bidding for licenses and wholly owned subsidiaries have been assumed.[7] Therefore, the welfare effects of technology transfer on the foreign country are completely reflected in expected consumer surplus. As in the previous section, the optimal policy is not derived; only a welfare ranking of policies that are often recommended or used in practise is provided.

Banning Direct Foreign Investment

This policy is usually advocated to foster national independence, or because some externality is thought to arise if technology is transferred via license rather than subsidiary.[8] Using the model developed in Section 3, the welfare implications of this policy are now investigated. To make the ban binding, it is assumed that prior to the ban it was optimal for the monopolist to transfer the low cost technology via

[7] Even in these circumstances the foreign country can obtain some of the monopoly profit through taxation. This will be considered later.

[8] This externality could be the development of indigenous entrepreneurial or managerial skills, or other learning by doing benefits [Bardhan (1982)].

a subsidiary. After the ban, it is optimal for both technologies to be transferred via license.[9]

Transfer via License in a Separating Solution

The impact on expected consumer surplus is ambiguous. Once again there is a price and an R&D effect to consider. The price faced by the foreign country's consumers falls as a result of the ban, because $\bar{\alpha}^L > \hat{\alpha}^L$.[10] Therefore, $\bar{CS}^{L*} > \hat{CS}^{L*}$ and expected consumer surplus tends to rise.[11]

The effect on R&D depends on the difference $\pi^L - \pi^H$. If before the ban it was optimal for the monopolist to transfer the low cost technology by subsidiary, then

$$\pi^L = \hat{\Pi}^L + \hat{\Pi}^{L*} - k > (\bar{\Pi}^L + \bar{l}^L). \tag{4.21}$$

In a separating solution the high cost technology is transferred by license with

$$\pi^H = \hat{\Pi}^H + \hat{\Pi}^{H*}, \tag{4.22}$$

[9] In Section 3 it was established that licensing always dominated the export of goods as a mode of technology transfer when first best global profit maximisation required some production to be located abroad.

[10] A larger market share for the licensor implies a smaller market share for the licensee. As price is positively related to the market share (Appendix 4), the price faced by consumers in the foreign country falls.

[11] This result is a little unsatisfactory, because the assumption on which it is based, namely, that local consumers are served by local production, generates a price discontinuity. Specifically, as $\alpha \rightarrow 1$ the price faced by foreign consumers falls, while at $\alpha = 1$ the price suddenly rises as foreign consumers are now solely served by exports.

In reality there is some $\underline{\alpha} < 1$, determined by the size of the foreign countries local market, above which the foreign country must be served by some exports. The foreign country's consumers can not be served by the licensor and the licensee, because export and import data can not be used to observe violations of the market share agreement. In this case, the foreign country's consumers must be served solely by exports, and any production that occurs in the foreign country must be exported to some third market. A price discontinuity still occurs at $\alpha = \underline{\alpha}$, though it is not as large as that which occurs at $\alpha = 1$.

For $\alpha > \underline{\alpha}$, the foreign country is unambiguously worse off as a result of the ban on subsidiary production, because the price faced by foreign consumers rises when the low cost technology occurs and less R&D is undertaken.

In Section 6 a per unit royalty is introduced into the analysis. This raises the price faced by foreign consumers under licensing and lessens the extent of the price discontinuity.

Combining (4.21) and (4.22) with (3.61) gives

$$R_{SL} > \bar{R}_{LL}. \tag{4.23}$$

Therefore, the ban on technology transfer via subsidiary reduces the amount of R&D undertaken. This in turn reduces expected consumer surplus of foreign country consumers. Combining the price and R&D effects leads to an ambiguous effect on expected consumer surplus.

Transfer via License with a Pooling Solution

(i) ρ^* *EXOGENOUS*

The price faced by the foreign country's consumers falls as a result of the ban, because $\check{\alpha}^L > \hat{\alpha}^L$. Therefore, $\check{C}S^{L*} > \hat{C}S^{L*}$ and expected consumer surplus tends to rise. The effect on R&D depends on the difference $\pi^L - \pi^H$. If before the ban it was optimal for the monopolist to transfer the low cost technology by subsidiary, then

$$\pi^L = \hat{\Pi}^L + \hat{\Pi}^{L*} - k > \check{\Pi}^L + \check{l}^L. \tag{4.24}$$

In a pooling solution

$$\hat{\Pi}^H + \hat{\Pi}^{H*} < \check{\Pi}^H(\check{\alpha}^L) + \check{l}^L. \tag{4.25}$$

Combining (4.24) and (4.25) with (3.61) gives

$$R_{SL} > \check{R}_{LL}. \tag{4.26}$$

Combining the price and the R&D effects leads to an ambiguous effect on expected consumer surplus.

(ii) $\rho^*(R)$ *ENDOGENOUS*

The price effect is qualitatively the same as when ρ^* was exogenous. However, the R&D effect differs. Once again it is not clear that (4.26) holds, because more

R&D is undertaken when ρ^* is a function of R than when ρ^* is exogenous. If the extra R&D undertaken in this pooling solution is such that $R_{SL} < \check{R}_{LL}$, then there is an unambiguous increase in expected welfare as a result of the ban. However, overall the welfare effect of the ban is ambiguous.

Rather than banning technology transfer via subsidiary, foreign country welfare may be increased if technology transfer via a subsidiary is encouraged. In this case, both technologies would be transferred via a subsidiary. Although the price response reduces expected consumer surplus, the R&D response may offset this reduction as

$$R_{SS} > R_{SL} > \bar{R}_{LL} \quad and \quad \check{R}_{LL}. \tag{4.27}$$

(4.27) follows, because

$$(\hat{\Pi}^L + \hat{\Pi}^{L*} - k) - (\hat{\Pi}^H + \hat{\Pi}^{H*} - k) > (\hat{\Pi}^L + \hat{\Pi}^{L*} - k) - (\hat{\Pi}^H + \hat{\Pi}^{H*}), \tag{4.28}$$

where the LHS of (4.28) is the difference in the monopolist's total profits when both technologies are transferred via subsidiary and the RHS of (4.28) is the same difference when the low cost technology is transferred via subsidiary and the high cost technology is transferred via license. Once again the above analysis suggests a case by case approach to policy may be necessary, rather than a blanket ban on all direct foreign investment. The same proviso concerning the information requirements of such a policy that was made when considering home country welfare is also in force here.

Taxing The Income Of Subsidiaries Or Licensees

Income taxation provides a method whereby the foreign country is able to obtain some of the global monopoly profit and, therefore, increase its welfare.[12] It is assumed

[12] Income taxation allows the foreign country to shift profit from the home country to itself. A number of recent articles on trade policy, under imperfect competition, also stress the welfare effects of shifting profit, although in different contexts [Brander and Spencer (1983), and (1985)].

that tax is paid in the country where income is earned. Therefore, subsidiaries and licensees are taxed on Π^{i*}.

After the technology is transferred, the foreign policy maker faces an information asymmetry, because it does not know the technology type whereas both the monopolist/licensor and the subsidiary/licensee do. Rather than deriving the optimal tax policy in the presence of this information asymmetry, this section outlines the welfare implications of changing the tax rate which applies to subsidiaries and licensees away from that rate which applies to all other firms. The foreign country's expected welfare is assumed to be given by the sum of expected consumer surplus and expected tax revenue.

The initial home and foreign income tax rates are respectively given by τ and τ^*. It is assumed that $\tau = \tau^*$.[13] The introduction of income taxation alters the monopolist's problem in the following way.

Stage Three

Technology Transfer Via Exports

Maximised profit is now given by $(1-\tau)\cdot\hat{\Pi}^i_X$.

Technology Transfer Via a Wholly Owned Subsidiary

The monopolist's problem is[14]

$$\max_{\alpha,P} \quad \{\Pi^i_S = (1-\tau)\cdot\Pi^i(\alpha) + P\} \tag{4.29}$$

subject to:

$$(1-\tau^*)\cdot\left(\Pi^{i*}(\alpha) - k\right) \geq P. \tag{4.30}$$

[13] The initial values of τ and τ^* are exogenously given and apply to all firms operating in the home and foreign countries.

[14] As income is taxed in the country where it is earned, the transfer payment P is not taxed in the home country. Tax has already been paid on Π^{i*} in the foreign country.

The first order condition for a maximum is

$$\frac{\partial \Pi_S^i}{\partial \alpha} = (1-\tau) \cdot \frac{\partial \Pi^i(\alpha)}{\partial \alpha} + (1-\tau^*) \cdot \frac{\partial \Pi^{i*}(\alpha)}{\partial \alpha} = 0. \tag{4.31}$$

Let the solution of (4.31) be given by $\hat{\alpha}_T^i(\tau, \tau^*)$. If $\tau = \tau^*$, then (4.31) reduces to (3.7), and

$$\hat{\alpha}_T^i = \hat{\alpha}^i \tag{4.32}$$

and

$$\hat{P}_T^i = (1-\tau^*)\hat{P}^i. \tag{4.33}$$

That is, when $\tau = \tau^*$, the global profit maximising market share is unchanged when income taxation is introduced into the analysis. Global profit, however, is reduced.

Technology Transfer Via a License Agreement

SEPARATING SOLUTION:

Problem 1 of Section 3 becomes[15]

$$\max_{\alpha^L, l^L} \quad \{\Pi_T(L) = (1-\tau) \cdot \Pi^L(\alpha^L) + l^L\} \tag{4.34}$$

subject to:

$$(1-\tau) \cdot \Pi^H(\hat{\alpha}_T^H) + \hat{l}_T^H \geq (1-\tau)\Pi^{HL}(\alpha^L) + l^L \qquad ; \mu^H, \tag{4.35}$$

$$(1-\tau^*) \cdot \Pi^{L*}(\alpha^L) \geq l^L \qquad ; \lambda^L, \tag{4.36}$$

[15] It is assumed that the lump sum license payment is not taxed in the home country. It is also assumed that the lump sum license payment is not a deduction from income in the foreign country. These two assumptions are made so that the tax system treats subsidiaries and licensees in identical fashion. If the lump sum license payment was a deduction from income, then no tax would be paid in the foreign country by the licensee. This defeats the purpose of the policy considered in this section.

where μ^H and λ^L are Lagrange multipliers. Let the solution to this problem be given by

$$\left(\bar{\alpha}_T^L(\tau,\tau^*), \bar{l}_T^L\right). \tag{4.37}$$

Therefore, the separating solution is given by

$$\left(\hat{\alpha}_T^H(\tau,\tau^*), \hat{l}_T^H\right) \quad ; \quad \left(\bar{\alpha}_T^L(\tau,\tau^*), \bar{l}_T^L\right). \tag{4.38}$$

If $\tau = \tau^*$, then

$$\hat{\alpha}_T^H = \hat{\alpha}^H, \tag{4.39}$$

$$\hat{l}_T^H = (1-\tau^*)\cdot \hat{l}^H, \tag{4.40}$$

$$\bar{\alpha}_T^L = \bar{\alpha}^L, \tag{4.41}$$

and

$$\bar{l}_T^L = (1-\tau^*)\cdot \bar{l}^L. \tag{4.42}$$

That is, when $\tau = \tau^*$, the market shares in the separating solution are unchanged when income taxation is introduced into the analysis. Global profit, however, is reduced.[16]

POOLING SOLUTION:[17]

Problem 2 of Section 3 becomes

$$\max_{\alpha} \quad \{\Pi_T(L) = (1-\tau)\cdot\Pi^L(\alpha) + (1-\tau^*)\cdot\left(\rho^*\cdot\Pi^{L*}(\alpha) + (1-\rho^*)\cdot\Pi^{H*}(\alpha)\right)\}. \tag{4.43}$$

The first order condition for a maximum is

$$(1-\tau)\cdot\frac{\partial\Pi^L}{\partial\alpha} = (1-\tau^*)\cdot\left(-\rho^*\cdot\frac{\partial\Pi^{L*}}{\partial\alpha} - (1-\rho^*)\cdot\frac{\partial\Pi^{L*}}{\partial\alpha}\right). \tag{4.44}$$

16 If $\tau = \tau^*$, then the introduction of income taxation into the problem involves multiplying all the constraints and the objective function by $(1-\tau)$ which leaves the solution of the optimal market share unchanged.

17 In this section and also in the remaining sections of this thesis, it is assumed that ρ^* is exogenously given. For the case where ρ^* is a function of R, the analysis must be amended as outlined in Section 3.

Let the solution to (4.44) be given by $\check{\alpha}_T^L(\tau, \tau^*)$. If $\tau = \tau^*$, then (4.44) reduces to (3.38), and

$$\check{\alpha}_T^L = \check{\alpha}^L \tag{4.45}$$

and

$$\check{l}_T^L = (1 - \tau^*) \cdot \check{l}^L. \tag{4.46}$$

That is, when $\tau = \tau^*$, the market shares in the pooling solution are unchanged when income taxation is introduced into the analysis. Global profit, however, is reduced.

Stage Two

Assuming that the low cost technology has occurred the monopolist chooses the mode of transfer by comparing:

$$\begin{aligned} &(1 - \tau) \cdot \hat{\Pi}_X^L; \quad ((1 - \tau) \cdot \hat{\Pi}^L + (1 - \tau^*) \cdot (\hat{\Pi}^{L*} - k)); \\ &\qquad\qquad ((1 - \tau) \cdot \bar{\Pi}_T^L + \bar{l}_T^L); \quad ((1 - \tau)\check{\Pi}_T^L + \check{l}_T^L). \end{aligned} \tag{4.47}$$

A similar comparison is made if the high cost technology has occurred. If $\tau = \tau^*$, then the optimal mode of transfer after the introduction of taxation is the same mode of transfer that was optimal before the introduction of taxation.

Stage One

Let π_T^i = total profit of the monopolist in state i when income tax rates are given by (τ, τ^*). The monopolist's optimal choice of R&D expenditure is obtained by solving the following first order condition

$$\rho'(R) = \frac{\omega}{(\pi_T^L - \pi_T^H)}. \tag{4.48}$$

If $\tau = \tau^*$, this reduces to

$$\rho'(R) = \frac{\omega}{(1 - \tau) \cdot (\pi^L - \pi^H)} \tag{4.49}$$

which implies that the introduction of taxation reduces the amount of R&D undertaken. Income taxation reduces the difference between total global profit in each state, and so reduces the amount of R&D undertaken.

Having amended the model of Section 3 to allow for income taxation at home and abroad, it is now possible to analyse the welfare implications, for the foreign country, of changes in the tax rate which apply to subsidiaries and licensees. Assume that initially $\tau = \tau^*$. What are the welfare implications for the foreign country of changing τ^*? Before answering this question, it is first necessary to derive the positive effects of a change in τ^* on the subsidiary and license decisions.

SUBSIDIARY

Totally differentiating (4.31) and using the second order condition for a maximum gives

$$\frac{\partial \hat{\alpha}_T^i}{\partial \tau^*} > 0. \tag{4.50}$$

That is, the monopolist responds to the higher tax rate abroad by reducing the market share and the income of the subsidiary. Substituting $\hat{\alpha}_T^i(\tau, \tau^*)$ into the objective function, (4.29), differentiating with respect to τ^*, and applying the envelope theorem gives

$$\frac{\partial \hat{\Pi}_S^i}{\partial \tau^*} = -(\hat{\Pi}_T^{i*} - k) < 0. \tag{4.51}$$

That is, a small increase in τ^* causes the monopolist's profit to fall.

LICENSE–Separating Solution

By symmetry with the subsidiary problem,

$$\frac{\partial \hat{\alpha}_T^H}{\partial \tau^*} > 0 \tag{4.52}$$

and

$$\frac{\partial(\hat{\Pi}_T^H + \hat{l}_T^H)}{\partial \tau^*} = -\hat{\Pi}_T^{H*} < 0. \tag{4.53}$$

Therefore, when the high cost technology has occurred, the licensor offers a smaller market share to the licensee and receives less profit when the foreign country increases τ^*.

From the first order conditions of Problem (4.34) to (4.36), Appendix 15 shows that

$$\frac{\partial \bar{\alpha}_T^L}{\partial \tau^*} > 0. \tag{4.54}$$

Substituting $\bar{\alpha}_T^L$ into problem (4.34)–(4.36), differentiating with respect to τ^*, and applying the envelope theorem gives

$$\frac{\partial(\bar{\Pi}_T^L + \bar{l}_T^L)}{\partial \tau^*} = -(\mu^H \cdot \hat{\Pi}_T^{H*} + \lambda^L \cdot \bar{\Pi}_T^{L*}) < 0. \tag{4.55}$$

Therefore, when the low cost technology has occurred, the licensor offers a smaller market share to the licensee and receives less profit when the foreign country increases τ^*.

LICENSE–Pooling Solution

Totally differentiating (4.44) and using the second order condition for a maximum gives

$$\frac{\partial \check{\alpha}_T^L}{\partial \tau^*} > 0. \tag{4.56}$$

Substituting $\check{\alpha}_T^L(\tau, \tau^*)$ into the objective function, differentiating with respect to τ^*, and applying the envelope theorem gives

$$\frac{\partial(\check{\Pi}_T^L + \check{l}_T^L)}{\partial \tau^*} = -(\rho^* \cdot \check{\Pi}_T^{L*} + (1 - \rho^*) \cdot \check{\Pi}_T^{H*}) < 0. \tag{4.57}$$

Therefore, under the pooling solution, the licensor offers a smaller market share to the licensee and receives less profit when the foreign country increases τ^*.

To see that the optimal mode of transfer can change with changes in τ^*, assume that the low cost technology has occurred and assume that initially the monopolist is indifferent between each mode of transfer. This indifference is shown in Figure 11 in which the subsidiary solution, point S, the license pooling solution , point C, and the license separating solution, point B, all lie on global iso–profit curve I_1^L. In Figure 11 it is clear that

$$(\hat{\Pi}_T^{L*} - k) > \left(\rho^* \cdot \check{\Pi}_T^{L*} + (1 - \rho^*) \cdot \check{\Pi}_T^{H*}\right) = \check{l}_T^L > (\mu^H \cdot \hat{\Pi}_T^{H*} + \lambda^L \cdot \bar{l}_T^L). \qquad (4.58)$$

Combining (4.58) with (4.51), (4.57), and (4.55) implies that licensing with the separating solution is now preferred to licensing with the pooling solution which is preferred to subsidiary production.[18] That is, the optimal mode of transfer depends on τ and τ^*.

To analyse the welfare implications of an increase in τ^* it is assumed that before and after the increase the subsidiary/license option is optimal for the monopolist.[19]

Low Cost Technology Transferred Via Subsidiary–High Cost Technology Transferred Via License

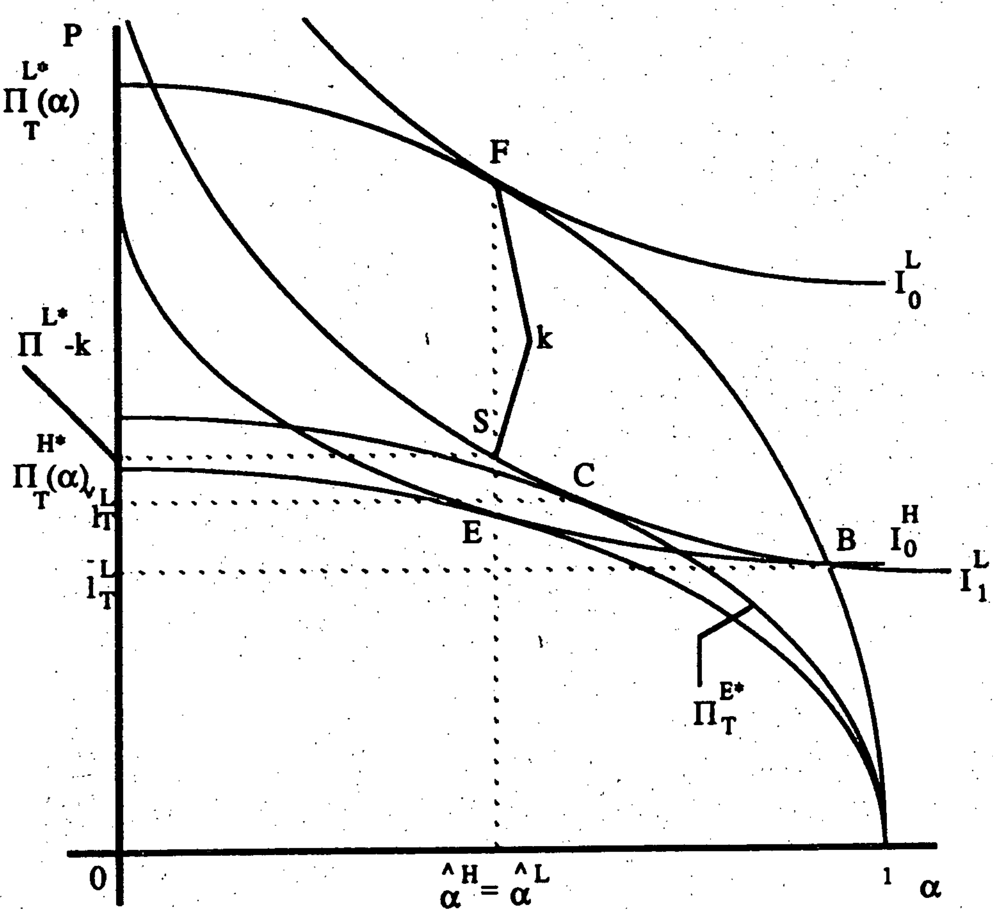
(1) Consumer Surplus:

Assume that the low cost technology has occurred. From (4.50), an increase in τ^* causes the licensee's market share to fall. In turn, this causes the price faced by foreign consumers to fall and increases consumer surplus. Assume that the high cost technology has occurred. (4.52) implies that the price faced by foreign consumers falls when τ^* is increased, which subsequently increases consumer surplus. Therefore, regardless of technology type, an increase in τ^* increases consumer surplus abroad.

[18] It is also possible that the export of goods becomes the preferred mode of tranfer. This was not possible when taxation was not in the model.

[19] This assumption is made for expositional purposes.

Figure 11


P
$\Pi_T^{L*}(\alpha)$
F
I_0^L
Π^{L*}-k
k
S
$\Pi_T^{H*}(\alpha)$
$\check{\Pi}^L$
C
E
B
I_0^H
$\bar{I}_T^L$
I_1^L
Π_T^{E*}
0
$\hat{\alpha}^H = \hat{\alpha}^L$
1
α

(2) Research and Development:

Given ω and $\rho(R)$, the amount of R&D undertaken depends on the difference $(\pi_T^L - \pi_T^H)$. From (4.51) and (4.53)

$$\frac{\partial\Big((\hat{\Pi}_T^L + (\hat{\Pi}_T^{L*} - k)) - (\hat{\Pi}_T^H + \hat{l}_T^H)\Big)}{\partial \tau^*} = \hat{\Pi}_T^{H*} - (\hat{\Pi}_T^{L*} - k) < 0. \tag{4.59}$$

So from (4.48) the increase in τ^* causes the amount of R&D undertaken to fall. The increase in τ^* reduces the difference between the monopolist's global profit in each state, and so reduces the amount of R&D undertaken.

(3) Tax Revenue:

Assume the low cost technology has occurred. The government receives tax revenue of

$$T^L = \tau^* \cdot (\hat{\Pi}_T^{L*} - k) \tag{4.60}$$

before the increase in τ^*. Differentiating T^L with respect to τ^* gives

$$\frac{\partial T^L}{\partial \tau^*} = (\hat{\Pi}_T^{L*} - k) + \tau^* \cdot \frac{\partial \hat{\Pi}_T^{L*}}{\partial \hat{\alpha}_T^L} \cdot \frac{\partial \hat{\alpha}_T^L}{\partial \tau^*}. \tag{4.61}$$

The sign of $\frac{\partial T^L}{\partial \tau^*}$ is ambiguous as the first term on the R.H.S. of (4.61) is positive, while the second term is negative. The first term is the tax base, while the second term represents the loss in tax revenue that results from the reduction in the tax base caused by the increase in $\hat{\alpha}_T^L$. The sign of $\frac{\partial T^H}{\partial \tau^*}$ is similarly ambiguous.

Combining (1) and (2) implies that the change in expected consumer surplus is ambiguous, and combining (2) and (3) implies that the change in expected tax revenue is ambiguous.[20] Therefore, whether an increase in τ^* increases or decreases

[20] It is assumed that the policy maker knows the cost and demand conditions as well as $\rho(R)$; therefore, it can calculate how its policy changes R and changes the probability of the low cost technology occurring.

expected welfare is ambiguous, the actual result depending on the parameters of the model. This ambiguous result also holds for changes in τ^* when both technologies are licensed. To derive the optimal tax rate specific demand and cost conditions are needed. Therefore, a case by case approach to tax policy may be needed. Once again the usual proviso concerning the information requirement of such a policy is made.

CHAPTER V

The Model with more than Two Technology Types

To date, R&D was assumed to result in either a low cost or high cost technology. In this section this assumption is relaxed by allowing more than two types of technology. For simplicity, rather than allowing there to be n discrete technology types; only the case of three technologies is considered, namely, a low cost, a medium cost, and a high cost technology.[1]

Stage Three

When three technologies are allowed, the analysis of technology transfer via subsidiary or exports is identical to that of Section 3. However, when licensing is considered this is no longer true. As well as a separating solution, in which all three technology types are associated with different license contracts and a pooling solution, in which all technology types are associated with the same license contract, other possibilities now arise. For example, the high cost and medium cost technologies may be associated with the same contract (pooled) while the low cost technology is associated with a different contract (separated). Similarly, the medium and low cost technologies may be associated with the same license contract while the high cost technology is associated with a different contract.

The first possibility, where all three technologies are associated with different license contracts, is obtained by solving two problems. First, given $(\hat{\alpha}^H, \hat{l}^H)$, Problem 4a is solved.

[1] The arguments that follow carry over to the case of n discrete technology types though the analysis is more complicated.

Problem 4a:

$$\max_{\alpha^M, l^M} \quad \{\Pi(M) = \Pi^M(\alpha^M) + l^M\} \tag{5.1}$$

subject to:

$$\Pi^H(\hat{\alpha}^H) + \hat{l}^H \geq \Pi^{HM}(\alpha^M) + l^M, \tag{5.2}$$

$$\Pi^{M*}(\alpha^M) \geq l^M. \tag{5.3}$$

where superscript M denotes the medium cost technology and all other variables and constraints are interpreted as in Problem 1 in Section 3 above. Let the solution to Problem 4a be given by

$$(\bar{\alpha}^M, \bar{l}^M). \tag{5.4}$$

Second, given $(\bar{\alpha}^M, \bar{l}^M)$, Problem 4b is solved.[2]

Problem 4b:

$$\max_{\alpha^L, l^L} \quad \{\Pi(L) = \Pi^L(\alpha^L) + l^L\} \tag{5.5}$$

subject to :

$$\Pi^M(\bar{\alpha}^M) + \bar{l}^M \geq \Pi^{ML}(\alpha^L) + l^L \tag{5.6}$$

$$\Pi^{L*}(\alpha^L) \geq l^L, \tag{5.7}$$

Let the solution to Problem 4b be given by

$$(\bar{\alpha}^L, \bar{l}^L). \tag{5.8}$$

Combining $(\hat{\alpha}^H, \hat{l}^H)$, (5.4), and (5.8) results in the following separating solution

$$(\hat{\alpha}^H, \hat{l}^H) \quad ; \quad (\bar{\alpha}^M, \bar{l}^M) \quad ; \quad (\bar{\alpha}^L, \bar{l}^L). \tag{5.9}$$

[2] Only the binding constraints are listed in Problems 4a and 4b. Similar arguments to those used in Section 3 make it clear that these are the only constraints that do bind.

This solution is shown in Figure 12. Figure 12 is identical to Figure 3 except for the addition of the medium cost technology.

Without going into detail, the second possibility, where all three technologies are associated with the same license contract is shown on Figure 13 in which $\Pi^{E*} = \rho^{*L}\Pi^{L*} + \rho^{*M}\Pi^{M*} + \rho^{*H}\Pi^{H*}$.[3] The pooling mechanism is given by

$$(\breve{\alpha}^L, \breve{l}^L). \tag{5.10}$$

Figure 13 is identical to Figure 4 except Π^{E*} now takes account of the medium cost technology.

The third possibility, where the high cost and medium cost technologies are associated with the same license contract while the low cost technology is associated with a different contract is shown on Figure 14. Π^{E*}_{HM} represents the expected value of the high and medium cost technology, given a separate contract is associated with the low cost technology. It is calculated as follows

$$\Pi^{E*}_{HM} = \left(\frac{\rho^{*H}}{\rho^{*H} + \rho^{*M}}\right) \cdot \Pi^{H*} + \left(\frac{\rho^{*M}}{\rho^{*H} + \rho^{*M}}\right) \cdot \Pi^{M*}. \tag{5.11}$$

The solution is given by

$$(\breve{\alpha}^{HM}, \breve{l}^{HM}) \quad ; \quad (\bar{\alpha}^L_{HM}, \bar{l}^L_{HM}). \tag{5.12}$$

Finally, the fourth possibility, where the medium and low cost technologies are associated with the same license contract while a different contract is associated with the high cost technology is shown in Figure 15. Π^{E*}_{ML} is obtained in a similar fashion to Π^{E*}_{HM}. The solution is given by

$$(\hat{\alpha}^H, \hat{l}^H) \quad ; \quad (\breve{\alpha}^{ML}, \breve{l}^{ML}). \tag{5.13}$$

[3] As drawn, $\Pi^{E*} > \Pi^{M*}$. With different subjective probabilities it is possible that $\Pi^{E*} < \Pi^{M*}$.

Of these four possible licensing mechanisms, which is chosen by the licensor? To answer this question the analysis and terminology of Section 3 is used once again. For mechanism (5.10) to be chosen it must be true that $\check{\Pi}^L + \check{l}^L > \bar{\Pi}^L + \bar{l}^L$; otherwise, the licensee would infer that the high or medium cost technology has occurred and not participate in the mechanism. That is, if $\check{\Pi}^L + \check{l}^L < \bar{\Pi}^L + \bar{l}^L$, then (5.10) is not a core mechanism. Similarly, mechanism (5.12) is a core mechanism only when $\check{\Pi}^{HM} + \check{l}^{HM} > \bar{\Pi}^M + \bar{l}^M$, and (5.13) is a core mechanism only when $\Pi^{\check{M}L} + \check{l}^{ML} > \bar{\Pi}^L + \bar{l}^L$. Which mechanism is actually chosen, therefore, depends on the technology type that has occurred and on the relationship between ρ^{*L}, ρ^{*M}, and ρ^{*H}.

If more than three technology types are considered, then the number of potential mechanisms for the licensor to choose from increases dramatically, and it for this reason that the analysis of this section has been limited to just three technology types. Nevertheless, it seems clear that the analysis of Stage Three in this section is basically the same as that in Section 3.

Stage Two

Given technology type, the monopolist chooses among the modes of transfer to maximise profit. Assume that the high cost technology has occurred. A comparison of

$$\check{\Pi}^H + \check{l}^L, \quad \check{\Pi}^{HM} + \check{l}^{HM}, \quad \hat{\Pi}^H + \hat{\Pi}^{H*}, \quad \hat{\Pi}^H + \hat{\Pi}^{H*} - k, \quad \textit{and} \quad \hat{\Pi}^H_X \tag{5.14}$$

determines how the technology is transferred, with the proviso that $(\check{\Pi}^H + \check{l}^L)$ and $(\check{\Pi}^{HM} + \check{l}^{HM})$ only be considered if they are associated with core mechanisms.

PROPOSITION 5.1: *The high cost technology is always transferred via a license agreement.*

Figure 12

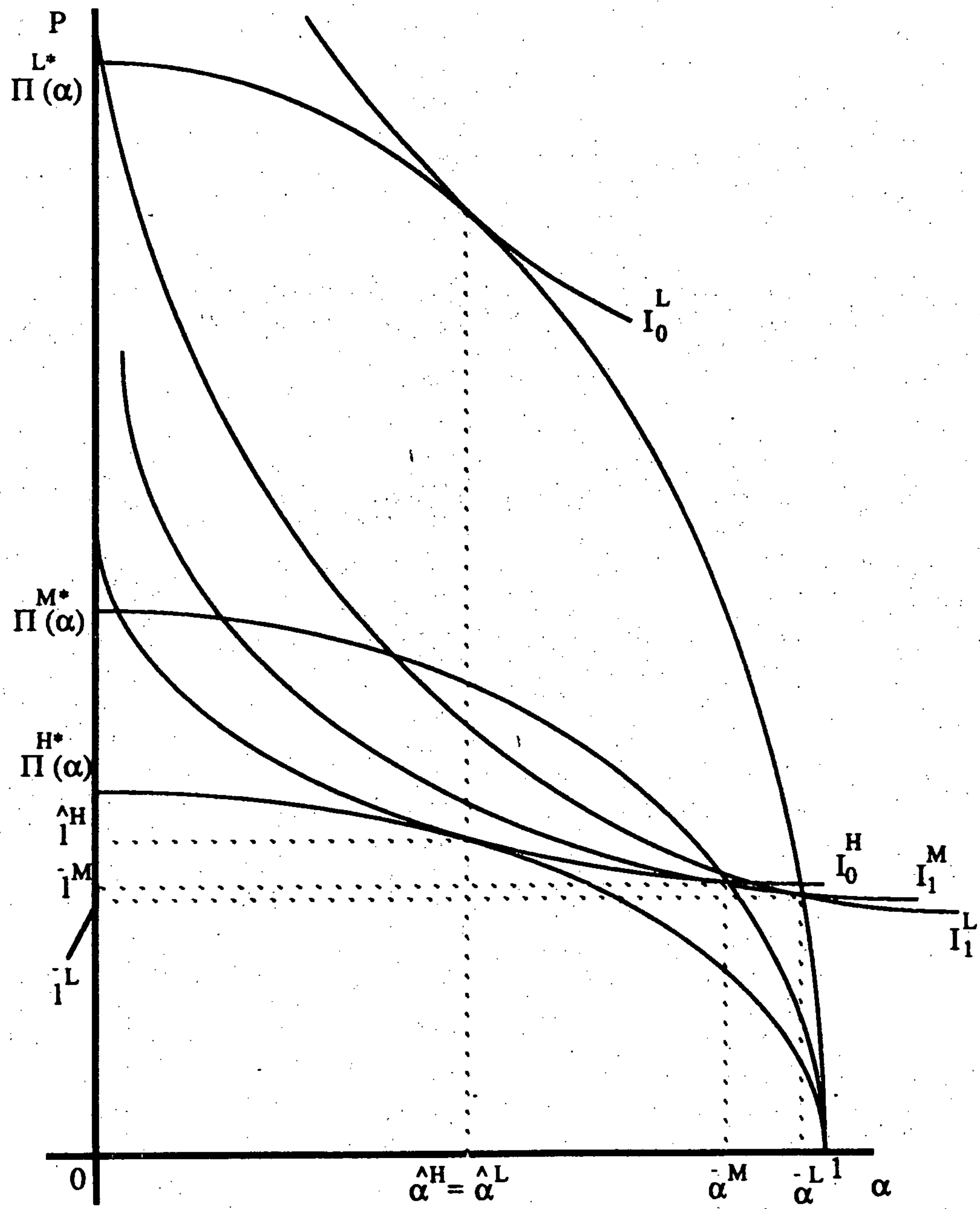

P
$\Pi^{L*}(\alpha)$
I_0^L
$\Pi^{M*}(\alpha)$
$\Pi^{H*}(\alpha)$
$\hat{l}^H$
$\bar{l}^M$
$\bar{l}^L$
I_0^H
I_1^M
I_1^L
0
$\hat{\alpha}^H = \hat{\alpha}^L$
$\bar{\alpha}^M$
$\bar{\alpha}^L$
1
α

Figure 13

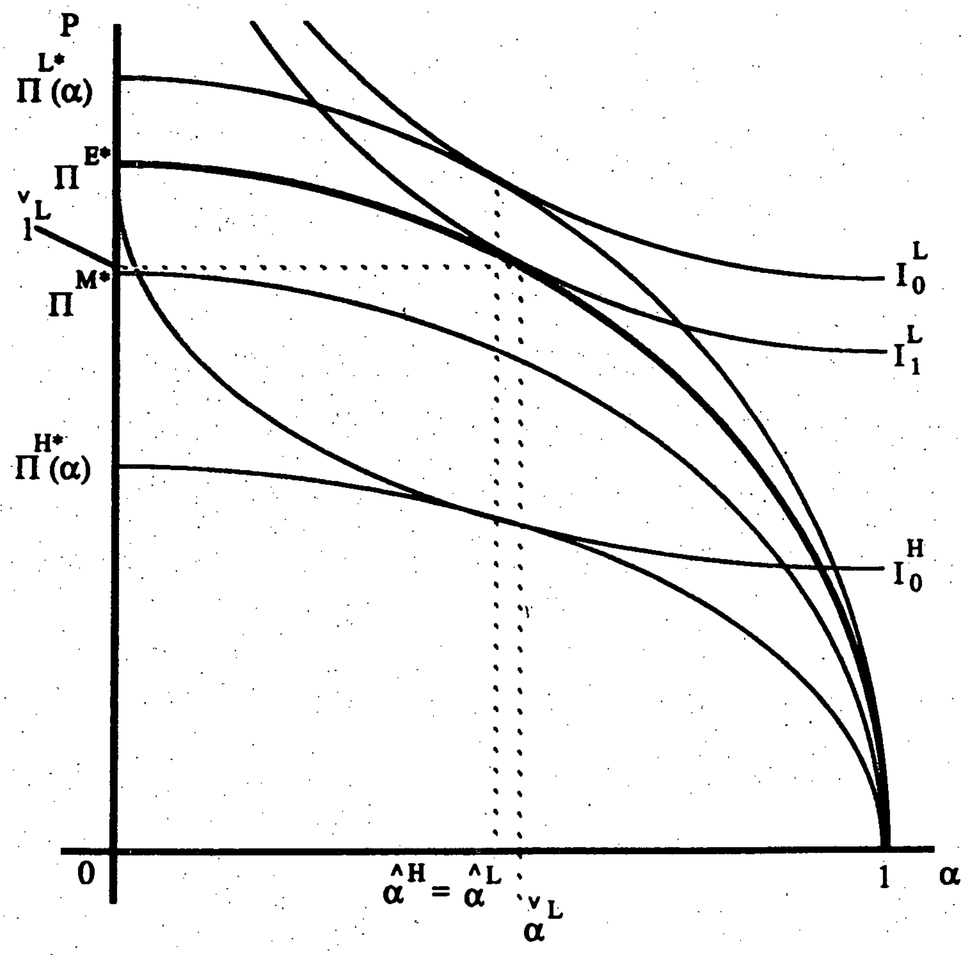

P
$\Pi^{L*}(\alpha)$
Π^{E*}
$\check{I}^{L}$
Π^{M*}
$\Pi^{H*}(\alpha)$
I_0^L
I_1^L
I_0^H
0
$\hat{\alpha}^H = \hat{\alpha}^L$
$\check{\alpha}^L$
1
α

Figure 14

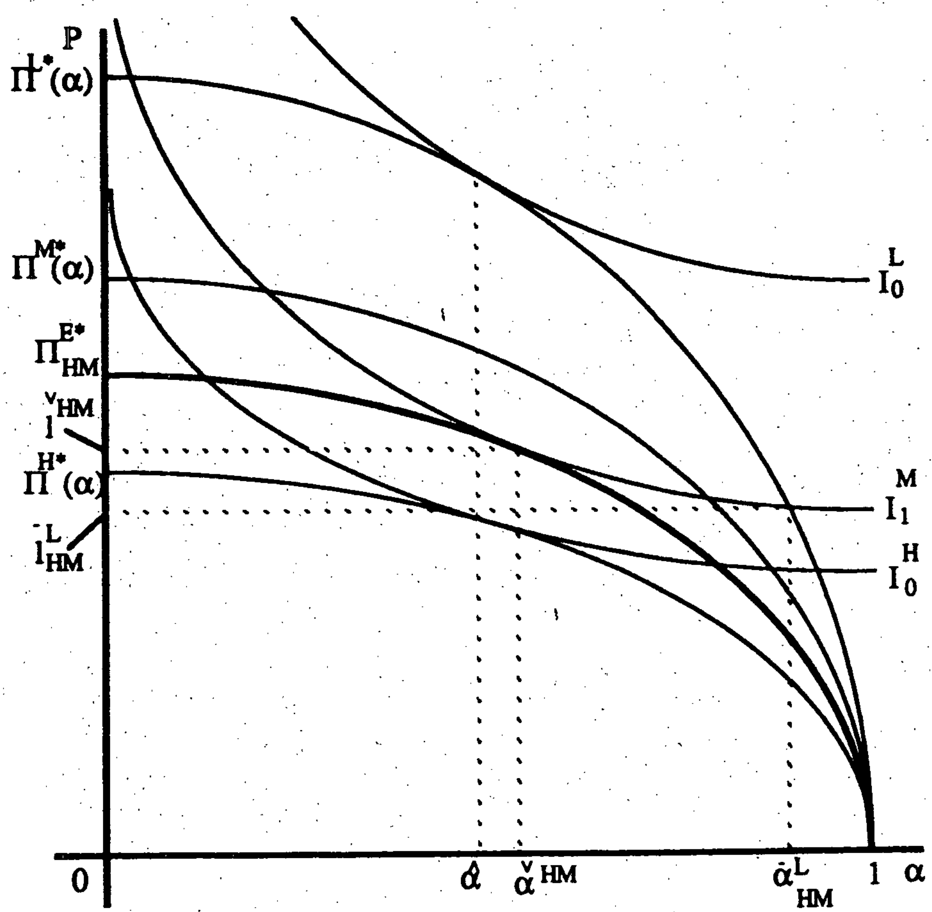
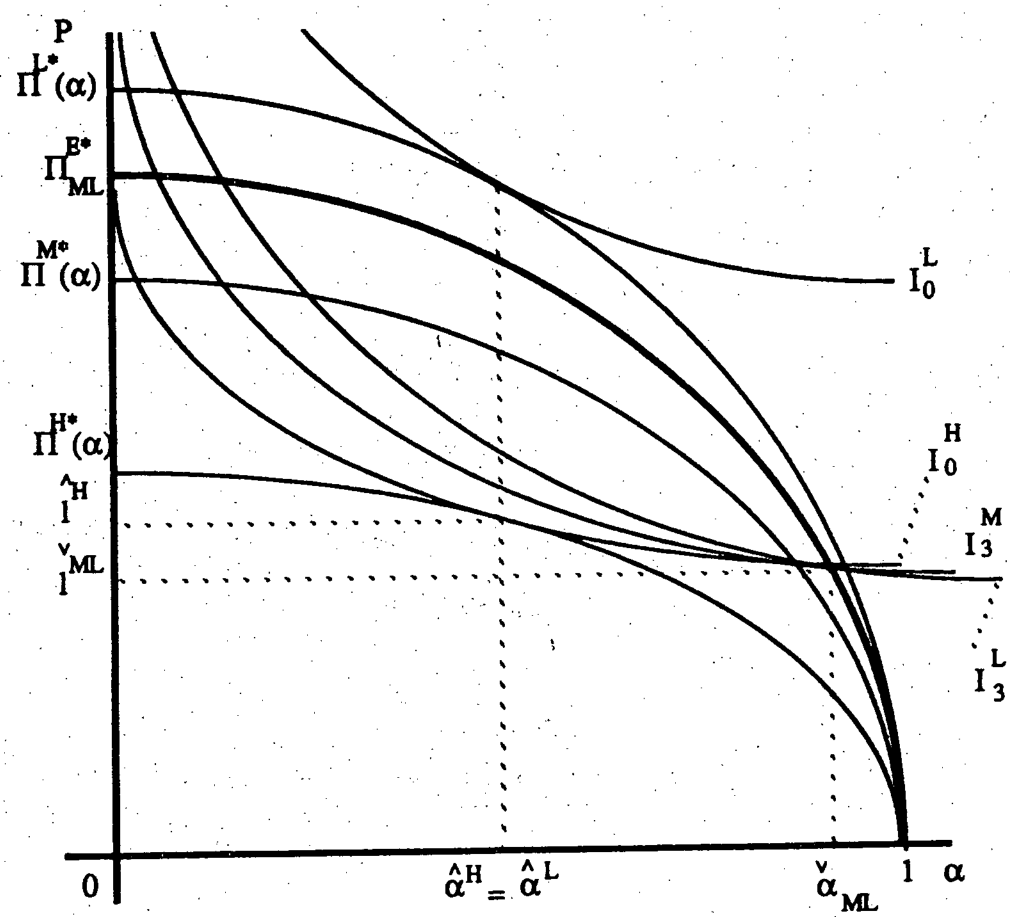

P
$\Pi^{L*}(\alpha)$
$\Pi^{M*}(\alpha)$
Π^{E*}_{HM}
$\check{I}_{HM}$
$\Pi^{H*}(\alpha)$
$\bar{I}^{L}_{HM}$
I^L_0
I^M_1
I^H_0
0
$\hat{\alpha}$
$\check{\alpha}_{HM}$
$\bar{\alpha}^L_{HM}$
1
α

Figure 15


P
$\Pi^{L*}(\alpha)$
Π^{E*}_{ML}
$\Pi^{M*}(\alpha)$
$\Pi^{H*}(\alpha)$
$\hat{l}^{H}$
$\check{l}^{ML}$
I_0^L
I_0^H
I_3^M
I_3^L
0
$\hat{\alpha}^H = \hat{\alpha}^L$
$\check{\alpha}_{ML}$
1
α

This is an analogous proposition to Proposition 3.4 and follows like Proposition 3.4, because $(\hat{\Pi}^H + \hat{\Pi}^{H*})$ is always available via a license agreement.

If the medium or low cost technology had occurred, then a similar comparison to (5.14) would establish how the technology is transferred.

Stage One

Looking forward to Stage Three and Stage Two the monopolist chooses R&D to maximise expected profit in Stage One. The monopolist's problem is

Problem 5:

$$\max_R \quad \rho^L(R) \cdot \pi^L + \rho^M(R) \cdot \pi^M + \rho^H(R) \cdot \pi^H - \omega R, \tag{5.15}$$

where π^i is the profit obtained when the optimal mode of transfer is chosen by the monopolist.[4]

For all R, it is assumed that $\rho^{L'}(R) > 0$ and $\rho^{H'}(R) < 0$. On the other hand, the sign of $\rho^{M'}(R)$ depends on R as shown in Figure 16. It is further assumed that for all R, $\rho^{L''}(R) < 0$ while $\rho^{H''}(R) > 0$. This further assumption implies that $(\rho^{M''}(R) + \rho^{H''}(R)) > 0$.[5] These assumptions on the probabilities can be

[4] The problem is more complicated than this when two or more technology types are associated with the same license contract as was seen in the analysis of the pooling solution in Stage One of Section 3. However, for expositional purposes, this complication is ignored in this section and ρ^* is assumed to be exogenously given.

[5] Probabilities sum to one so

$$\rho^L(R) + \rho^M(R) + \rho^H(R) = 1. \tag{5.16}$$

Differentiating with respect to R gives

$$\rho^{L'}(R) + \rho^{M'}(R) + \rho^{H'}(R) = 0, \tag{5.17}$$

and differentiating again yields

$$\rho^{L''}(R) = -(\rho^{M''}(R) + \rho^{H''}(R)). \tag{5.18}$$

interpreted as follows. For small R, an increase in R increases the probability of the low cost and medium cost technologies occurring while it decreases the probability of the high cost technology occurring. However, for large R, an increase in R increases the probability of the low cost technology occurring while it decreases the probability of both the medium and high cost technologies occurring. In terms of a cumulative distribution, where type is indexed from high to low on the horizontal axis, the distribution associated with the higher R first order stochastic dominates the distribution associated with the lower R.

The first order condition for Problem 5 is

$$\rho^{L'}(R) \cdot \pi^L + \rho^{M'}(R) \cdot \pi^M + \rho^{H'}(R) \cdot \pi^H - \omega = 0 \tag{5.20}$$

which can be rewritten as

$$\rho^{L'}(R) \cdot (\pi^L - \pi^H) + \rho^{M'}(R) \cdot (\pi^M - \pi^H) = \omega, \tag{5.21}$$

because $\rho^L + \rho^M + \rho^H = 1$. The second order condition for a maximum is satisfied, because of the assumptions made regarding $\rho^{L''}(R)$ and $\rho^{H''}(R)$.[6]

The monopolist then solves (5.21) for the optimal amount of R&D.

Now $\rho^{L''}(R) < 0 \ \forall \ R$, so

$$(\rho^{M''}(R) + \rho^{H''}(R)) > 0 \quad \forall \ R. \tag{5.19}$$

[6] The second order condition for a maximum is

$$\rho^{L''}(R) \cdot (\pi^L - \pi^H) + \rho^{M''}(R) \cdot (\pi^M - \pi^H) < 0. \tag{5.22}$$

Now

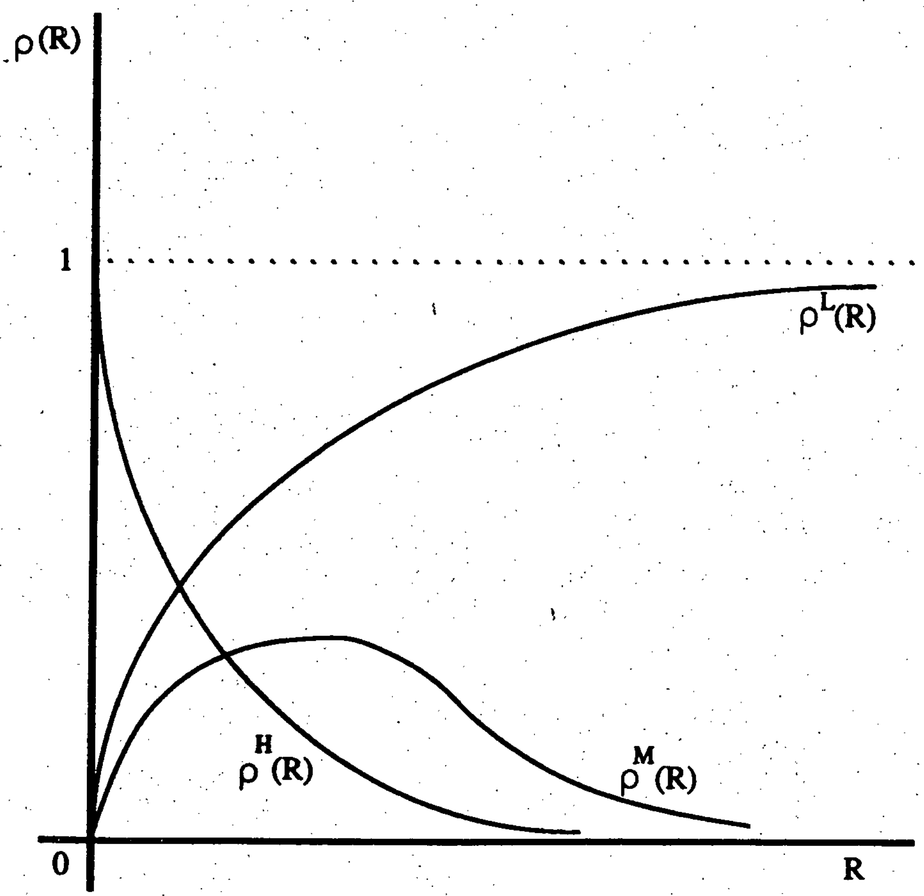
$$\rho^{M''}(R) = -(\rho^{L''}(R) + \rho^{H''}(R)), \tag{5.23}$$

so the second order condition can be rewritten as

$$\rho^{L''}(R) \cdot (\pi^L - \pi^M) - \rho^{H''}(R) \cdot (\pi^M - \pi^H) < 0. \tag{5.24}$$

This condition is satisfied, because $\rho^{L''}(R) < 0$ and $\rho^{H''}(R) > 0$.

Figure 16



Welfare and Policy

In this sub–section only one policy is considered; namely, that of the home country placing a ban on technology transfer via subsidiary or license, when initially the high cost technology was transferred by license and the medium and low cost technologies were transferred via a subsidiary.[7] The ban means that technology transfer can only occur via the export of goods. As in Section 4 there are three effects to consider.

Profit Effect

By optimality of the original scheme of transfer

$$\Pi^E_{SSL} > \Pi^E_{XXX}, \tag{5.25}$$

where the first, second, and third subscripts refer to the mode of transfer for the low, medium, and high cost technologies respectively. Therefore, the ban causes expected profit to fall which tends to reduce expected welfare.

Price Effect

The shift to exports increases the price of output to home country consumers, because $\hat{\alpha}^L$, $\hat{\alpha}^M$, and $\hat{\alpha}^H$ are less than one and marginal cost is increasing in output. As a result of this price effect, the ban reduces consumer surplus for each technology type. This tends to reduce expected consumer surplus.

R&D Effect

For expositional purposes assume that demand and cost conditions are such that

$$(\hat{\Pi}^L + \hat{\Pi}^{L*} - k) - (\hat{\Pi}^H + \hat{\Pi}^{H*}) > \hat{\Pi}^L_X - \hat{\Pi}^H_X \tag{5.26}$$

and

$$(\hat{\Pi}^M + \hat{\Pi}^{M*} - k) - (\hat{\Pi}^H + \hat{\Pi}^{H*}) > \hat{\Pi}^M_X - \hat{\Pi}^H_X. \tag{5.27}$$

[7] This particular case gives the flavour of how the analysis of other cases would proceed.

Therefore, the ban on technology transfer via license or subsidiary reduces the value of $(\pi^L - \pi^H)$ and $(\pi^M - \pi^H)$ in (5.21). Given ω, if $\rho^{L'}(R) > 0$ and $\rho^{M'}(R) > 0$, then the LHS of (5.21) is now less than the RHS. As a result, R&D is reduced until equality in (5.21) is once again obtained.[8] If $\rho^{M'}(R) < 0$, it must be true that $|\rho^{M'}(R)| < \rho^{L'}(R)$ as $\rho^{H'}(R) < 0$. In this case, the L.H.S. of (5.21) is still less than the R.H.S., because $(\pi^L - \pi^H) > (\pi^M - \pi^H) > 0$. Therefore, even if $\rho^{M'}(R) < 0$, when conditions (5.26) and (5.27) hold the ban causes the amount of R&D undertaken to fall. This tends to reduce expected profit and expected consumer surplus, and so tends to reduce expected welfare.

Combining the profit, price, and R&D effects implies that the ban on technology transfer via license or subsidiary unambiguously reduces home country welfare when conditions (5.26) and (5.27) are satisfied. However, in general these conditions are not satisfied, so the effect of the ban on expected home country welfare is generally ambiguous.

The analysis of the model when three technology types are allowed is not continued, because of its similarity to the analysis of Section 3. That is, apart from added complication, extending the model of Section 3 to allow more than two types of technology does not provide any new insights into the process of technology transfer.

[8] The conditions that are required for (5.26) and (5.27) to hold have not been derived. However, Proposition 4.1 suggests that the slope of the demand and cost curves as well as the size of the technology difference are important.

CHAPTER VI

Licensing with a Market Share Restriction, a Lump Sum License Payment, and a Per Unit Royalty

In Section 3 above a license contract contained a market share restriction and a lump sum license payment. Per unit royalties were not considered, because monitoring of the licensee's output by the licensor was assummed to be prohibitively costly. However, Taylor and Silberston (1973, p. 120) found in their sample of 28 firms that per unit or sales based royalties occurred in a majority of license agreements either alone or coupled with lump sum payments. A similar result was found by Contractor (1981, Table 4–15, p. 90–91) in his sample of 12 firms. Therefore, it must be possible to overcome the monitoring problem to some extent, and it seems appropriate to amend the analysis of Section 3 by allowing the license contract to contain a per unit royalty payment.

As in Section 3 it is assumed that the technology is licensed monopolistically to a foreign firm. Given this assumption, the use of per unit royalties is second best, because a per unit royalty distorts the marginal cost curve of the licensee and induces the licensee to produce less than the first best monopoly output [Caves *et al* 1983, p. 258, footnote 8]. Nevertheless, given the information asymmetry, the first best is not attainable, so the per unit royalty may in fact increase the profitability of licensing.

6.1 Stage Three

The analysis of technology transfer via subsidiary production or the export of goods is identical to that of Section 3. However, the analysis of the licensing decision is different. Once again there are two solution to consider; namely, a separating solution and a pooling solution.

Separating Equilibrium

Assume that the high cost technology has occurred. As in Section 3 if

$$(\hat{\alpha}^H, \hat{l}^L) \tag{6.1}$$

is offered by the licensor, then it is accepted by the licensee, because regardless of technology type the licensee's profit is ≥ 0. Contract (6.1) does not involve a per unit royalty, because per unit royalties introduce a distortion which reduces global profit.

Assume that the low cost technology has occurred. Similarly to the analysis of Section 3, the licensor chooses (α^L, l^L, r^L) to maximise global profit subject to certain self–selection and licensee participation constraints. Given $(\hat{\alpha}^H, \hat{l}^H)$, the licensor's problem is

Problem 6:

$$\max_{\alpha^L, l^L, r^L} \quad \{\Pi(L) = \Pi^L(\alpha^L) + l^L + r^L \cdot q^{L*}(\alpha^L, r^L)\} \tag{6.2}$$

subject to :

$$\Pi^H(\hat{\alpha}^H) + \hat{l}^H \geq \Pi^{HL}(\alpha^L) + l^L + r^L \cdot q^{HL*}(\alpha^L, r^L) \tag{6.3}$$

$$\Pi_N^{L*}(\alpha^L, r^L) \geq l^L \tag{6.4}$$

where r^i; $i = H, L$ is the per unit royalty rate applied to the licensee's output, $\Pi_N^{L*}(\alpha^L, r^L)$ denotes the maximised value of the licensee's profit net of royalty payments, $q^{L*}(\alpha^L, r^L)$ denotes the licensee's output that maximises this net profit, and $q^{HL*}(\alpha^L, r^L)$ denotes the licensee's output that maximises net profit when the high cost technology has occurred but the licensee's market share and royalty rate is given by (α^L, r^L).[1] This problem does not have nice curvature properties, because constraints (6.3) and (6.4) are not convex sets. These non convexities make the solution

[1] Only those constraints that bind are included in Problem 6.

of Problem 6 difficult to achieve analytically. Therefore, rather than solving Problem 6 it will be established that at the solution, whatever it may be, the royalty rate is greater than zero.

To begin, let $r^L = 0$ in Problem 6. This problem is now identical to Problem 1 in Section 3 and has a solution given by

$$(\bar{\alpha}^L, \bar{l}^L). \tag{6.5}$$

At this solution contraints (6.3) and (6.4) bind. The question to answer is whether it is possible to increase the value of the objective function by increasing r^L above zero and changing α^L in such a way that constraints (6.3) and (6.4) are still satisfied.

Totally differentiating the objective function yields

$$\begin{aligned} d\Pi(L) = {} & \frac{\partial \Pi^L(\alpha^L)}{\partial \alpha^L} \cdot d\alpha^L + dl^L + r^L \cdot \frac{\partial q^{L*}(\alpha^L, r^L)}{\partial r^L} \cdot dr^L \\ & + q^{L*}(\alpha^L, r^L) \cdot dr^L + r^L \cdot \frac{\partial q^{L*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L \end{aligned} \tag{6.6}$$

while total differentiation of constraints (6.3) and (6.4) respectively yields

$$\begin{aligned} 0 = {} & \frac{\partial \Pi^{HL}(\alpha^L)}{\partial \alpha^L} \cdot d\alpha^L + dl^L + r^L \cdot \frac{\partial q^{HL*}(\alpha^L, r^L)}{\partial r^L} \cdot dr^L \\ & + q^{HL*}(\alpha^L, r^L) \cdot dr^L + r^L \cdot \frac{\partial q^{HL*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L \end{aligned} \tag{6.7}$$

and

$$0 = \frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial r^L} \cdot dr^L + \frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L - dl^L. \tag{6.8}$$

In Appendix 16 it is shown that

$$\frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial r^L} = -q^{L*}(\alpha^L, r^L) \tag{6.9}$$

and

$$\frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial \alpha^L} = \frac{dp}{d(q^{L*}/(1-\alpha^L))} \cdot \frac{(q^{L*}(\alpha^L, r^L))^2}{(1-\alpha^L)^2}, \tag{6.10}$$

so that (6.8) can be written as

$$0 = -q^{L*}(\alpha^L, r^L) \cdot dr^L + \frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L - dl^L. \tag{6.11}$$

If r^L is increased, then (6.11) implies that l^L must be decreased by $dl^L = -q^{L*}(\alpha^L, r^L) \cdot dr^L$ for constraint (6.4) to be satisfied.

Given $r^L = 0$ and (6.6), an increase in r^L increases the objective function by $q^{L*}(\alpha^L, r^L) \cdot dr^L$ while the requirement that (6.11) be satisfied reduces the objective function by $-q^{L*}(\alpha^L, r^L) \cdot dr^L$. The net effect on the objective function is zero change. However, the RHS of (6.7) is now less than zero, because $dl^L = -q^{L*}(\alpha^L, r^L) \cdot dr^L$ and $q^{L*}(\alpha^L, r^L) > q^{HL*}(\alpha^L, r^L)$.

If α^L is decreased, then (6.11) demands an increase in l^L of $dl^L = -\frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L$. At $(\bar{\alpha}^L, \bar{l}^L, r^L = 0)$

$$-\frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L > \frac{\partial \Pi^{HL}(\alpha^L)}{\partial \alpha^L} \cdot d\alpha^L, \tag{6.12}$$

so a decrease in α^L brings the RHS of (6.7) back to zero. This decrease in α^L also increases the objective function, because at $(\bar{\alpha}^L, \bar{l}^L, r^L = 0)$

$$-\frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L > \frac{\partial \Pi^{L}(\alpha^L)}{\partial \alpha^L} \cdot d\alpha^L. \tag{6.13}$$

Therefore, an increase in r^L and a decrease in α^L from an initial position of $(\bar{\alpha}^L, \bar{l}^L, r^L = 0)$ increases the objective function while constraints (6.3) and (6.4) remain satisfied.

This establishes the following proposition.

PROPOSITION 6.1: *If a per unit royalty can be used in the license contract, then its optimal value is zero in the contract associated with the high cost technology while its optimal value is greater than zero in the contract associated with the low cost technology. Also, in this latter case, the licensor's profit is greater than if a per unit royalty could not be used.*

This proposition follows, because around $r^L = 0$ the royalty rate affects the objective function and the relevant constraints of Problem 6 in a similar fashion to α^L. This allows the optimal α^L to be reduced below $\bar{\alpha}^L$ and increases the licensor's profit. More specifically, if $r^L = 0$, then $\bar{\alpha}^L > \hat{\alpha}^L$ in Problem 1, because as α^L is increased above $\hat{\alpha}^L$ self selection constraint (3.25) requires l^L to fall by $\frac{\partial \Pi^{HL}(\alpha^L)}{\partial \alpha^L}$ causing a net impact on the objective function (3.24) of $(\frac{\partial \Pi^L(\alpha^L)}{\partial \alpha^L} - \frac{\partial \Pi^{HL}(\alpha^L)}{\partial \alpha^L})$. Now, $\frac{\partial \Pi^L(\alpha^L)}{\partial \alpha^L} > \frac{\partial \Pi^{HL}(\alpha^L)}{\partial \alpha^L}$ from Appendix 9, so

$$(\frac{\partial \Pi^L(\alpha^L)}{\partial \alpha^L} - \frac{\partial \Pi^{HL}(\alpha^L)}{\partial \alpha^L}) > 0. \tag{6.14}$$

At $(r^L = 0, \alpha^L = \hat{\alpha}^L)$, as r^L is increased above $r^L = 0$ self selection constraint (6.3) requires l^L to fall by $-q^{HL*}(\alpha^L, r^L)$. This causes a net impact on the objective function, (6.2), of $(q^{L*}(\alpha^L, r^L) - q^{HL*}(\alpha^L, r^L))$. Now $q^{L*}(\alpha^L, r^L) > q^{HL*}(\alpha^L, r^L)$, so

$$(q^{L*}(\alpha^L, r^L) - q^{HL*}(\alpha^L, r^L)) > 0. \tag{6.15}$$

Therefore, at $(r^L = 0, \alpha^L = \hat{\alpha}^L)$, increases in the royalty rate have a similar net effect on the objective function as increases in the market share. By setting $r^L > 0$ α^L can be reduced from $\bar{\alpha}^L$ and the licensor's profit is increased. The per unit royalty helps in the self selection process as it reduces the licensor's incentive to lie. This happens because the licensor is forced to trade off some of a lump sum payment, (l^L), which is independent of the technology type for royalty payments which depend on the technology type. Let the solution to Problem 6 be given by

$$(\bar{\alpha}_r^L, \bar{l}_r^L, \bar{r}_r^L > 0), \tag{6.16}$$

and let the licensor's maximised profit be given by

$$\bar{\Pi}_r^L(\bar{\alpha}_r^L) + \bar{l}_r^L + \bar{r}_r^L \cdot q^{L*}(\bar{\alpha}_r^L, \bar{r}_r^L) = \bar{\pi}_r^L, \tag{6.17}$$

where subscript r denotes contracts in which per unit royalties are used.

Combining (6.1) and (6.16) yields the following separating solution

$$(\hat{\alpha}^H, \hat{l}^H, r^H = 0) \quad ; \quad (\bar{\alpha}_r^L, \bar{l}_r^L, \bar{r}_r^L > 0) \tag{6.18}$$

Using arguments similar to those in Section 3, this mechanism is the optimal separating mechanism.

Pooling Equilibrium

As in Section 3 a pooling equilibrium is also possible in which the same license contract is offered regardless of technology type. Assume that ρ^* is exogenously given, and that the low cost technology has occurred. The licensor's problem is

Problem 7:

$$\max_{\alpha,l,r} \; \{\Pi(L) = \Pi^L(\alpha) + l + r \cdot q^{L*}(\alpha, r)\} \tag{6.19}$$

subject to:

$$\rho^* \cdot \Pi_N^{L*}(\alpha, r) + (1 - \rho^*) \cdot \Pi_N^{H*}(\alpha, r) \geq l. \tag{6.20}$$

This problem does not have nice curvature properties, because constraint (6.20) is not a convex set. Therefore, the same technique used above in analysing the separating solution is adopted in order to ascertain whether the optimal royalty rate is greater than zero in the pooling solution.

To begin, let $r = 0$ in Problem 7. This problem is now identical to Problem 2 in Section 3, and has a solution given by

$$(\check{\alpha}^L, \check{l}^L) \tag{6.21}$$

in Figure 4. At this solution constraint (6.20) binds.

Totally differentiating the objective function yields

$$\begin{aligned} d\Pi(L) = & \frac{\partial \Pi^L(\alpha)}{\partial \alpha} \cdot d\alpha + dl + r \cdot \frac{\partial q^{L*}(\alpha, r)}{\partial r} \cdot dr \\ & + q^{L*}(\alpha, r) \cdot dr + r \frac{\partial q^{L*}(\alpha, r)}{\partial \alpha} \cdot d\alpha, \end{aligned} \tag{6.22}$$

while totally differentiating constraint (6.20) around solution (6.21) gives

$$\begin{aligned} 0 = \rho^* \cdot & \frac{\partial \Pi_N^{L*}(\alpha, r)}{\partial \alpha} d\alpha + \rho^* \cdot \frac{\partial \Pi_N^{L*}(\alpha, r)}{\partial r} \cdot dr \\ & + (1 - \rho^*) \cdot \frac{\partial \Pi_N^{H*}(\alpha, r)}{\partial \alpha} d\alpha + (1 - \rho^*) \frac{\partial \Pi_N^{H*}(\alpha, r)}{\partial r} \cdot dr - dl. \end{aligned} \tag{6.23}$$

Using the envelope theorem implies that

$$\frac{\partial \Pi_N^{H*}(\alpha, r)}{\partial r} = -q^{H*}(\alpha, r) \tag{6.24}$$

and

$$\frac{\partial \Pi_N^{L*}(\alpha, r)}{\partial r} = -q^{L*}(\alpha, r) \tag{6.25}$$

If r is increased, then (6.23) implies that l must decrease by

$$dl = \left(-\rho^* \cdot q^{L*}(\alpha, r) - (1 - \rho^*) \cdot q^{H*}(\alpha, r)\right) \cdot dr \tag{6.26}$$

for constraint (6.20) to be satisfied. Substituting (6.26) into (6.22), given $d\alpha = 0$, establishes that the net change in the objective function is

$$d\Pi(L) = \Big(q^{L*}(\alpha, r) - \big(\rho^* \cdot q^{L*}(\alpha, r) + (1 - \rho^*) \cdot q^{H*}(\alpha, r)\big)\Big) \cdot dr. \tag{6.27}$$

Now $q^{L*}(\alpha, r) > q^{H*}(\alpha, r)$, so

$$\frac{d\Pi(L)}{dr} > 0 \tag{6.28}$$

when r is increased around $r = 0$.

This establishes the following proposition.

PROPOSITION 6.2: *If a per unit royalty can be used in the license contract, then its optimal value is greater than zero in a pooling equilibrium.*

Using similar arguments to those in Section 3 implies that the mechanism that solves Problem 7 is the only pooling core mechanism. Let this be given by

$$(\check{\alpha}_r^L, \check{l}_r^L, \check{r}_r^L > 0), \tag{6.29}$$

and let the licensor's maximised profit be given by

$$\check{\Pi}_r^L(\check{\alpha}_r^L) + \check{l}_r^L + \check{r}_r^L \cdot q^{L*}(\check{\alpha}_r^L, \check{r}_r^L) = \check{\pi}_r^L. \tag{6.30}$$

Propositions 6.1 and 6.2 are consistent with the observed prevalence of per unit or sales based royalties in license contracts. However, Proposition 6.1 also suggests that there are cases when royalties are not used, namely, when the high cost technology has occurred. In this case the prevalence of royalties may be explained by risk sharing, or other behaviour that is not considered in this model.

6.2 Stage Two

Propositions 6.1 and 6.2 establish that

$$\bar{\pi}_r^L > \bar{\Pi}^L(\bar{\alpha}^L) + \bar{l}^L \tag{6.31}$$

and

$$\check{\pi}_r^L > \check{\Pi}^L(\check{\alpha}^L) + \check{l}^L, \tag{6.32}$$

so the inclusion of a per unit royalty in license contracts increases the profitability of licensing the low cost technology.

PROPOSITION 6.3: *The likelihood of the low cost technology being transferred via license increases, ceteris paribus, with the inclusion of a per unit royalty in the license contract.*

PROOF: Let k, ρ^*, and γ be such that the following equality holds

$$\bar{\Pi}^L(\bar{\alpha}^L) + \bar{l}^L = \check{\Pi}^L(\check{\alpha}^L) + \check{l}^L = \hat{\Pi}^L + \hat{\Pi}^{L*} - k. \tag{6.33}$$

Therefore, the licensor is indifferent between the separating and pooling solution and indifferent between transferring technology via license or subsidiary. The introduction of a per unit royalty into the license contract increases the profitability of licensing the low cost technology. Given (6.33), this implies that licensing is now chosen as the mode of transfer. **(Q.E.D.)**

6.3 Stage One

PROPOSITION 6.4: *The amount of R&D undertaken in the separating equilibrium increases, ceteris paribus, with the inclusion of a per unit royalty payment in the license contract.*

PROOF: Using (6.31) it is clear that

$$\tilde{\pi}_r^L - (\hat{\Pi}^H + \hat{\Pi}^{H*}) > (\bar{\Pi}^L(\bar{\alpha}^L) + \bar{l}^L) - (\hat{\Pi}^H + \hat{\Pi}^{H*}). \tag{6.34}$$

Now (3.63) established that the greater was the difference between the monopolist's total profit in each state the greater was the amount of R&D undertaken. This result together with (6.34) establishes the proposition. **(Q.E.D.)**

Unfortunately a similar proposition for the pooling equilibrium has not been established. This is because an analytical solution for Problem 7 was not obtained. Given ρ^* is exogenous, in the pooling solution the licensor undertakes R&D until condition (3.61) is satisfied, that is, until

$$\rho'(R) = \frac{\omega}{(\pi^L - \pi^H)}. \tag{6.35}$$

Now

$$\check{\pi}_r^L > \check{\Pi}^L(\check{\alpha}^L) + \check{l}^L \tag{6.36}$$

from (6.32), while around $r = 0$

$$\Pi^H(\alpha) + l + r \cdot q^{H*}(\alpha, r) < \check{\Pi}^H(\check{\alpha}^L) + \check{l}^L \tag{6.37}$$

as

$$d\Pi(H) = \left(q^{H*}(\alpha, r) - \left(\rho^* \cdot q^{L*}(\alpha, r) + (1 - \rho^*) \cdot q^{H*}(\alpha, r)\right)\right) \cdot dr. \tag{6.38}$$

(6.38) is obtained in a similar fashion to (6.27) except the high cost technology has been assumed to occur.

Combining (6.36), (6.37), and (6.35) suggests that around $r = 0$ the amount of R&D undertaken in the pooling equilibrium increases, ceteris paribus, with the inclusion of a per unit royalty in the license contract. However, although (6.36) holds at the solution, whatever it may be, it is not clear that (6.37) holds at this solution.

6.4 Welfare and Policy

Home Country Welfare and Policy

The only policy considered in this section is the banning of technology transfer via subsidiary or license. In the absence of a ban, it is assumed that technology would be transferred via licensing under a separating equilibrium.[2] The ban leaves the export of goods as the only option available to the monopolist.

From the optimality of licensing $\bar{\pi}_r^L > \hat{\Pi}_X^L$, so

$$\bar{\Pi}_{r,LL}^E > \hat{\Pi}_{XX}^E. \tag{6.39}$$

Therefore, the ban reduces expected profit and tends to reduce expected welfare.

The shift to exports causes the price of output to rise for home consumers, because $\bar{\alpha}_r^L$ and $\hat{\alpha}^H$ are less than one and marginal cost is increasing in output. In turn, this reduces consumer surplus with each technology type and tends to reduce expected consumer surplus.

Finally, as in Section 4 the effect on R&D is ambiguous, because it depends on the size of $\left(\bar{\pi}_r^L - (\hat{\Pi}^H + \hat{\Pi}^{H*})\right)$ relative to $(\hat{\Pi}_X^L - \hat{\Pi}_X^H)$. However, because $\bar{\pi}_r^L > (\bar{\Pi}^L + \bar{\Pi}^{L*})$ R&D is more likely to fall as a result of the ban where a royalty is allowed in the license contract compared to a situation where a royalty is not allowed in the license contract.

Combining the profit, price, and R&D effects leads to an ambiguous effect on expected welfare though the fact that $\bar{\pi}_r^L > (\bar{\Pi}^L + \bar{\Pi}^{L*})$ suggests that expected welfare is more likely to fall as a result of the ban if per unit royalty payments are allowed in the license contract.

[2] This assumption is made, because (1) the pooling solution has not been analysed under conditions of endogenous R&D and (2) the analysis of Section 4 applies if the low cost technology is transferred via subsidiary while the high cost technology is transferred via license.

Foreign Country Welfare and Policy

The only policy considered in this section is the banning of technology transfer via subsidiary. In the presence of the ban it is assumed that licensing under the separating equilibrium is optimal. It is also assumed that the low cost technology has occurred.

Although the presence of the per unit royalty tends to increase the price of output to foreign consumers, the relationship between $\bar{\alpha}_r^L$ and $\hat{\alpha}^L$ has not been determined. Therefore, the price impact of the ban is unknown.

The ban reduces the amount of R&D undertaken, because $(\hat{\Pi}^L + \hat{\Pi}^{L*} - k) > \bar{\pi}_r^L$. However, this reduction in R&D is not as large as the reduction in R&D that would occur if a royalty payment was not allowed in the license contract, because $\bar{\pi}_r^L > (\bar{\Pi}^L + \bar{\Pi}^{L*})$.

Combining the price and R&D effect leads to an ambiguous effect on expected foreign country welfare, because the price effect is unknown.

CHAPTER VII

Licensing without a Market Share Restriction

To date, it has been assumed that license contracts contain a market share restriction. Although such restrictions are often found in practice, in some countries such restrictions are illegal.[1] It is now time to consider the licensing decison when a market share restriction is not allowed in the license contract. This also allows welfare analysis of a policy that is often advocated or enacted by technology receiving countries, namely, the elimination of market share restrictions from license contracts.[2]

The analysis that follows continues to assume the presence of an information asymmetry, risk neutrality, no ex post renegotiation of contracts, that only two firms can profitably produce the product, that resale of the technology by the licensee is not allowed, and that ρ^* is exogenously given. It is also assumed that having sold the technology once the licensor is not allowed to sell the technology again.[3] Two cases are considered. In the first monitoring of the licensee's output, by the licensor, is not possible. In the second monitoring is possible, so a per unit royalty can be used.

[1] Restrictions of this type may encounter legal problems in the U.S. and the E.E.C., [Caves, Crookwell, and Killing (1983, p.259–260)].

[2] In Australia, ASTEC (1986) pointed out that banning such restrictions may reduce the amount of technology transferred into Australia, nevertheless, concern was still voiced that such restrictions were not in the best interest of the licensee or Australia. Similar concerns are voiced by other technology importing countries [Teece (1981)].

[3] If multiple sales of the technology are allowed, then a problem similar to the durable goods monopoly problem [Bulow (1982)] arises. In this case, technological knowledge is the durable good. Consider the following scenario. A monopolist owner of a new technology licenses it to a firm for a payment of Π_d. Having received this payment, the licensor calculates that by licensing the technology to a third firm it will be better off if the sum of two firm's triopoly profits are greater than one firm's duopoly profit. This is possible with linear demand and a quadratic cost function. (The licensee could make the same calculation and realise that by selling the technology, it could also be better off). The original licensee made a payment of Π_d for the technology, but now only receives Π_t (a third of total triopoly profit, assuming identical cost functions), where $\Pi_t < \Pi_d$. Realising this, the licensee pays less than Π_d for the technology in the first instance. This reduces the likehood of licensing. An enforcable market share restriction overcomes the problem of multiple sales of the technology.

7.1 No Per Unit Royalty Allowed

Stage Three

A license contract consists solely of a lump sum payment. With marginal cost increasing in output at home and abroad, a monopolist may license a foreign competitor even though it loses monopoly power, because licensing allows a more efficient allocation of world production between home and abroad (m.c. at home = m.c. abroad). If m.c. was a constant, then the monopolist would never license a foreign competitor.[4]

The licensor's first best problem is to maximise the sum of its duopoly profit and the license payment subject to the license payment being less than the foreign firm's duopoly profit.

$$\max_{l^i} \quad \{\mathit{\Pi}(i) = \mathit{\Pi}^i + l^i\} \quad i = H, L \tag{7.1}$$

subject to:

$$\mathit{\Pi}^{i*} \geq l^i, \tag{7.2}$$

where $\mathit{\Pi}^i$ is the licensor's duopoly profit and $\mathit{\Pi}^{i*}$ is the licensee's duopoly profit (slanted $\mathit{\Pi}$ is used to denote duopoly variables).

Under conditions where only the licensor knows the technology type at the time of transfer, the Revelation Principle allows the monopolist's problem (if the low cost technology has occurred) to be written as

$$\max_{l^L, l^H} \quad \{\mathit{\Pi}(L) = \mathit{\Pi}^L + l^L\} \tag{7.3}$$

subject to:

$$l^L = l^H \tag{7.4}$$

---

4 Rising marginal cost is a country characteristic, not a firm characteristic, and can be thought of as arising from the monopsony model developed in Appendix 1. A new technology which gives its owner monopoly power (a drastic innovation) is never licensed to a potential competitor if marginal cost is constant [Katz and Shapiro (1985)].

and

$$\rho^* \cdot (\Pi^{L*} - l^L) + (1 - \rho^*) \cdot (\Pi^{H*} - l^H) \geq 0. \tag{7.5}$$

(7.4) is the self selection constraint, because if $l^L > l^H$, then the licensor always offers the contract associated with the low cost technology. (7.5) is the zero expected profit condition. The argmax of this problem is

$$\hat{l} = \rho^* \cdot \Pi^{L*} + (1 - \rho^*) \cdot \Pi^{H*}. \tag{7.6}$$

However, there is a difficulty with this solution that did not arise when a market share restriction was allowed. When a market share restriction is allowed the licensor has no incentive to transfer the high cost technology if the low cost technology has occurred, because the licensor and licensee are guaranteed monopoly power over a certain segment of the market. This is not true when a market share restriction is not allowed.

If the license payment is given by (7.6), then the licensor always transfers the high cost technology (as it reduces the competitive threat of the licensee). In fact, no matter what the license payment, the licensor always transfers the high cost technology. Knowing this, the licensee is only prepared to pay $l = \rho^* \cdot \Pi_H^{L*} + (1 - \rho^*) \cdot \Pi^{H*}$ for the technology. Π_H^{L*} is the licensee's profit if the licensor uses the low cost technology, but transfers the high cost technology.

Therefore, (7.5) should be replaced by

$$l = \rho^* \cdot \Pi_H^{L*} + (1 - \rho^*) \cdot \Pi^{H*}. \tag{7.7}$$

The licensor then obtains

$$\Pi_H^L + l \tag{7.8}$$

if the low cost technology occurs, where Π_H^L is the licensor's duopoly profit if it uses the low cost technology and the licensee uses the high cost technology. The licensor obtains

$$\Pi^H + l \tag{7.9}$$

if the high cost technology occurs.

Stage Two

In Stage Two

$$(\Pi_H^L + l) \quad , \quad (\hat{\Pi}^L + \hat{\Pi}^{L*} - k) \quad , \quad and \quad \hat{\Pi}_X^L \tag{7.10}$$

are compared if the low cost technology has occurred. If the high cost technology has occurred the following are compared:

$$(\Pi^H + l) \quad , \quad (\hat{\Pi}^H + \hat{\Pi}^{H*} - k) \quad and \quad \hat{\Pi}_X^H. \tag{7.11}$$

PROPOSITION 7.1: *Relative to the situation in which a market share was allowed in the license contract, the likelihood of licensing being the optimal mode of technology transfer is reduced when a market share restriction is not allowed.*

PROOF: Assume the low cost technology has occurred.

$$\Pi_H^L + l < \Pi^L(\hat{\alpha}^L) + \left(\rho^* \cdot \Pi^{L*}(\hat{\alpha}^L) + (1 - \rho^*) \cdot \Pi^{H*}(\hat{\alpha}^L)\right), \tag{7.12}$$

because (1) the high cost technology is transferred to the licensee rather than the low cost technology which implies that marginal costs are not equated at home and abroad and (2) joint duopoly profit is less than joint monopoly profit.

Now

$$\Pi^L(\hat{\alpha}^L) + \left(\rho^* \cdot \Pi^{L*}(\hat{\alpha}^L) + (1 - \rho^*) \cdot \Pi^{H*}(\hat{\alpha}^L)\right) < \check{\Pi}^L + \check{l}^L, \tag{7.13}$$

so

$$\Pi_H^L + l < \check{\Pi}^L + \check{l}^L. \tag{7.14}$$

(7.14) implies that the likelihood of licensing the low cost technology falls when a market share restriction is not allowed in the license contract.

Assume that the high cost technology has occurred. $\Pi^H + l$ can only be offered if $\Pi_H^L + l$ is the largest value in (7.10); otherwise, the licensee infers that the high cost technology has occurred and is only prepared to pay Π^{H*}.[5] Now (7.14) implies that $\Pi_H^L + l$ is less likely to be the largest value in (7.10) when a market share restriction is not allowed, so $\Pi^H + l$ is less likely to be the outcome for the licensor when the high cost technology occurrs.

If $\Pi_H^L + l$ is not the largest value in (7.10), then the best the monopolist can do from licensing is to obtain $\Pi^H + \Pi^{H*}$. Now

$$\Pi^H + \Pi^{H*} < \hat{\Pi}^H + \hat{\Pi}^{H*}, \tag{7.15}$$

because joint duopoly profit is less than joint monopoly profit. Therefore, the high cost technology is less likely to be licensed when a market share restriction is not allowed in the license contract. **(Q.E.D.)**

Two implications follow from the proof of Proposition 7.1. The first is that the export of goods may now be chosen as the optimal mode of technology transfer. The second is that the high cost technology need not always be licensed, for $\Pi^H + \Pi^{H*} < \Pi^H + \Pi^{H*}$ and so may be less than $\hat{\Pi}^H + \hat{\Pi}^{H*} - k$ or $\hat{\Pi}_X^H$.

Stage One

The monopolist chooses R&D, looking forward to Stages Two and Three, in

[5] This is an identical argument to that used in Section 3, Stage 2.

order to maximise its expected profit.

$$\max_{R} \quad \rho(R) \cdot \pi^{L} + \big(1 - \rho(R)\big) \cdot \pi^{H} - \omega R, \tag{7.16}$$

where π^L is either $(\Pi^L_H + l)$, $(\hat{\Pi}^L + \hat{\Pi}^{L*} - k)$, or $\hat{\Pi}^L_X$, whichever is greater. Similarly for π^H.[6]

Foreign Country Welfare and Policy

The policy considered in this section is the elimination of market share restrictions from license contracts. In the absence of per unit royalties and after market share restrictions are eliminated, the analysis of the licensing option is precisely that carried out above. To derive the welfare implications of eliminating market share restrictions one must compare the outcome of the monopolist's problem in Section 3 with the outcome in this subsection.

For simplicity, assume that if a market share restriction was allowed, then technology transfer would occur via licensing under a separating solution. Also assume that cost functions at home and abroad are identical. The elimination of the market share restriction has a price and an R&D effect.

Price Effect

On first sight eliminating market share restrictions might appear to reduce the price of output and consumer surplus, because the market structure is changed from monopoly to duopoly. However, if it is assumed that the low cost technology has occurred, then in a separating equilibrium $\bar{\alpha}^L > \acute{\alpha}^L$. This inequality implies that the price in the foreign market is less than the first best monopoly price. Therefore, although eliminating market share restrictions would reduce price in a

[6] Under the conditions of Section 7.1, the licensee's subjective probability is exogenous as the licensee can obtain no information about ρ^* from the licensor's problem.

world of complete information this is not necessarily the case in a world of incomplete information. The effect on consumer surplus when the low cost technology has occurred is therefore ambiguous. If the high cost technology had occurred, then the price to foreign consumers would fall as under these circumstances the first best market share is used in the license contract.

R&D effect

In Stage 2 above it was demonstrated that removing market share restrictions from license contracts reduced the likelihood of licensing being chosen as the mode of technology transfer. As a result it is possible that the subsidiary or export option is now optimal.

Assume the export option is now optimal. In Section 4.1 it was shown that changing the optimal mode of technology transfer from licensing under a separating solution to the export of goods had an ambiguous effect on R&D expenditure.

Combining the price and the R&D effect implies that the elimination of market share restrictions has an ambiguous effect on expected consumer surplus of the foreign country, the exact effect depending on the parameters of the model. What is clear though is that there is no unambiguous welfare gain from a policy that eliminates market share restrictions from license contracts.

7.2 Per Unit Royalty Allowed in Contract

Stage Three

COMPLETE INFORMATION

To date only the licensor's complete information problem has been solved. In this problem the licensor maximises the sum of its own duopoly profit, the royalty payments, and the lump sum payment subject to the lump sum payment being less than or equal to the licensee's profit net of royalties.

Stage Three has two sub–stages. In the first the monopolist chooses the royalty and the lump sum payment. In the second the licensor and the licensee play a duopoly game to decide output. In this second sub–stage the equilibrium concept used is Nash in outputs.

Second Sub–Stage

Given royalty rate r, the licensor and the licensee choose output to maximise profit while assuming the other firm leaves its output unchanged. The licensee's problem is

$$\max_{q^*} \quad \{\Pi^* = p(q+q^*)\cdot q^* - \frac{1}{\gamma}\cdot c^*(q^*) - r\cdot q^*\}. \tag{7.17}$$

The first order condition for this problem is

$$\frac{\partial \Pi^*}{\partial q^*} = \frac{dp}{d(q+q^*)}\cdot q^* + p(q+q^*) - \frac{1}{\gamma}\cdot c^{*'}(\cdot) - r = 0. \tag{7.18}$$

The second order condition for a maximum is

$$\frac{d^2p}{\left(d(q+q^*)\right)^2}\cdot q^* + 2\frac{dp}{d(q+q^*)} - \frac{1}{\gamma}\cdot c^{*''}(\cdot) = a^* < 0 \tag{7.19}$$

which is assumed to be satisfied.

Solving (7.18) for q^* gives

$$q^*(q, r, \gamma). \tag{7.20}$$

The licensor's problem is similar to the licensee's except that no royalty rate appears in the problem. The first order condition is solved for

$$q(q^*, \gamma). \tag{7.21}$$

Combining (7.20) and (7.21) gives the equilibrium values of q and q^* as functions of r and γ. Let these equilibrium values be given by

$$q(r,\gamma) \quad and \quad q^*(r,\gamma). \tag{7.22}$$

Appendix 17 outlines the conditions necessary for these equilibrium values to be stable.

Substituting (7.22) into (7.17) gives maximised profit as $\Pi^*\big(q(r,\gamma), q^*(r,\gamma)\big)$. Similarly, maximised duopoly profit for the licensor is given by $\Pi\big(q(r,\gamma), q^*(r,\gamma)\big)$.

First Sub-Stage

The monopolist chooses r and l to maximise its profit.

Problem 9:

$$\max_{r,l} \quad \{\Pi_d = \Pi\big(q(r), q^*(r)\big) + l + r \cdot q^*(r)\} \tag{7.23}$$

subject to:

$$\Pi^*(\cdot) \geq l. \tag{7.24}$$

At a solution, (7.24) always binds, so the F.O.C. for Problem 9 is

$$\frac{\partial \Pi_d}{\partial r} = \frac{\partial \Pi}{\partial r} + \frac{\partial \Pi^*}{\partial r} + r \cdot \frac{\partial q^*}{\partial r} + q^*. \tag{7.25}$$

Using the envelope theorem

$$\frac{\partial \Pi_d}{\partial r} = \frac{dp}{d(q+q^*)} \cdot q \cdot \frac{\partial q^*}{\partial r} + \frac{dp}{d(q+q^*)} \cdot q^* \cdot \frac{\partial q}{\partial r} + r \cdot \frac{\partial q^*}{\partial r}. \tag{7.26}$$

The first order condition for a maximum is

$$\frac{\partial \Pi_d}{\partial r} = 0. \tag{7.27}$$

In Appendix 17 it is shown that the second order condition for a maximum is satisfied when linear demand and linear marginal cost is assumed.

Assume that $c(q) = c^*(q^*)$ which implies that $q = q^*$. This assumption allows condition (7.26) to be written as

$$\frac{\partial \Pi_d}{\partial r} = \frac{dp}{d(q+q^*)} \cdot q \cdot \left(\frac{\partial q^*}{\partial r} + \frac{\partial q}{\partial r}\right), \tag{7.28}$$

at $r = 0$. In Appendix 17 it is shown that

$$\begin{aligned}\left(\frac{\partial q^*}{\partial r} + \frac{\partial q}{\partial r}\right) &= \left(\left(2 \cdot \frac{dp}{d(q+q^*)} - \frac{1}{\gamma} \cdot c'' - \frac{dp}{d(q+q^*)}\right)/\Delta\right) \\ &= \left(\left(\frac{dp}{d(q+q^*)} - \frac{1}{\gamma} \cdot c''\right)/\Delta\right) < 0\end{aligned} \tag{7.29}$$

Therefore, at $r = 0$,

$$\frac{\partial \Pi_d}{\partial r} > 0. \tag{7.30}$$

This implies that the optimal royalty rate for the monopolist is greater than zero.

The prohibitive royalty rate, r_p,(that rate at which it is optimal for the monopolist to transfer technology via the export of goods rather than by license) is obtained by setting $q^* = 0$ in (7.18) and then solving for r. That is,

$$r_p = p(q_m) - \frac{1}{\gamma} \cdot c^{*'}(q^* = 0), \tag{7.31}$$

where q_m = the output that maximises monopoly profit when the export of goods is used as the mode of technology transfer. At r_p, (7.26) becomes

$$\frac{\partial \Pi_d}{\partial r} = \frac{dp}{dq_m} \cdot \frac{\partial q^*}{\partial r} \cdot q_m + r_p \cdot \frac{\partial q^*}{\partial r}. \tag{7.32}$$

Substituting (7.31) into (7.32) gives

$$\frac{\partial \Pi_d}{\partial r} = \left(\frac{dp}{dq_m} \cdot q_m + p(q_m) - \frac{1}{\gamma} \cdot c^{*'}(q^* = 0)\right) \cdot \frac{\partial q^*}{\partial r}. \tag{7.33}$$

Now at r_p

$$\frac{dp}{dq_m} \cdot q_m + p(q_m) - \frac{1}{\gamma} \cdot c'(q^* = 0) = 0 \tag{7.34}$$

from the first order condition for a maximum. Also at r_p, $q_m > q^* = 0$, so

$$c^{*'}(q^* = 0) < c'(q_m). \tag{7.35}$$

Combining (7.33), (7.34), and (7.35), and utilising a result from Appendix 17 that $\frac{\partial q^*}{\partial r} < 0$ implies that at r_p

$$\frac{\partial \Pi_d}{\partial r} < 0. \tag{7.36}$$

That is, the optimal royalty rate for the monopolist is less than the prohibitive rate. Let the optimal royalty rate be given by $\hat{r}_d(\gamma)$.

PROPOSITION 7.1: *Under conditions of linear demand and linear marginal cost, where $c(q) = c^*(q^*)$, the optimal royalty is greater than zero and less than the prohibitive rate, $0 > \hat{r}_d < r_p$. Therefore, the export of goods is never an optimal mode of technology transfer.*

PROOF: See (7.30) and (7.36) above.

The optimal royalty rate is greater than zero, because at $r = 0$ an increase in r causes a net rise in total revenue (see (7.30) and (7.28)). The optimal royalty rate is less than the prohibitive rate, because at $r = r_p$ a decrease in r allows q^* to rise. This in turn increases total profit, because a more efficient allocation of production between home and abroad is achieved (remember that marginal cost rises at home and abroad).[7] The solution to Problem 9 is shown in Figure 17.

$\Pi^*(\cdot)$ is binding constraint (7.24). In Appendix 17 this constraint is shown to be convex in r for linear demand and linear marginal cost. I_0 represents a global

[7] The licensor's problem can also be thought of as maximising gross duopoly profit by choice of

iso–profit curve which is also convex in r. Although the constraint and the global iso–profit curve are convex, in Appendix 17 it is shown that the S.O.C. for a maximum is satisfied which implies that point A does in fact represent a maximum. The object of the licensor is to get on the highest global iso–profit curve, given $\Pi^*(\cdot) \geq l$.

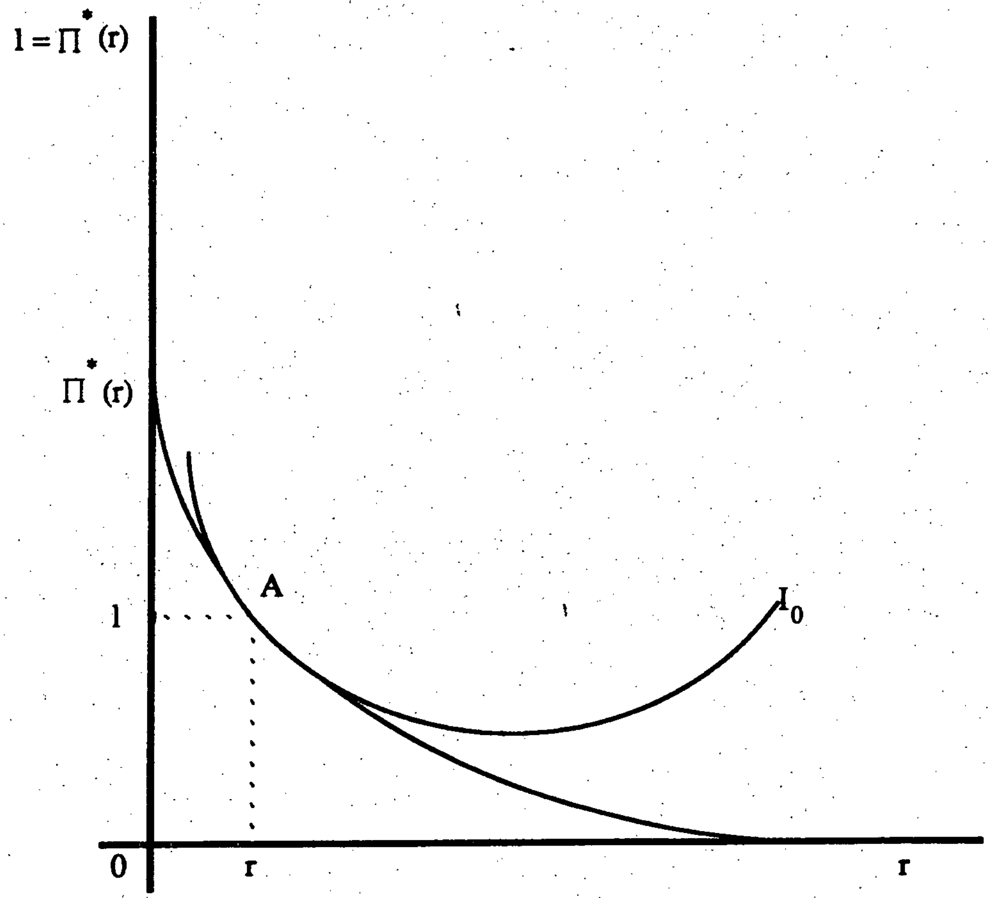
To date the licensor's Stage Three incomplete information problem has not been solved. As in previous sections, this problem involves self selection and participation constraints as well as another constraint which guarantees that the low cost technology is actually transferred whenthe low cost technology occurs. This problem does not have nice curvature properties, and in particular global iso–profit curves do not exhibit the single crossing property. A proposed area of future research is to solve this problem or at least do some simulations to see how altering the parameters of the model influences the solution.

---

r, because

$$\begin{aligned} \Pi_d &= \Pi + \Pi^* + r \cdot q^* \\ &= p(q+q^*) \cdot q - c(q) + p(q+q^*) \cdot q^* - c(q^*) - r \cdot q^* + r \cdot q^* \\ &= p(q+q^*) \cdot (q+q^*) - c(q) - c(q^*) \end{aligned} \tag{7.37}$$

Figure 17



CHAPTER VIII

Conclusion

This thesis has developed a partial equilibrium model of international technology transfer in which both the extent of technological change and the mode of technology transfer are endogenous. Having developed this model, the model was then used to analyse the welfare implications of various policies that are often enacted or recommended in practice.

The extent of technological change was endogenised by explicitly considering the problem faced by a monopolist owner of a new technology that is trying to lower its production costs by undertaking R&D expenditures. It was assumed that more R&D increases the probability that production costs are lowered.

The mode of technology transfer was endogenised by explicitly considering the problem faced by a monopolist owner of a new product/technology that is trying to maximise global profit by transferring the technology abroad. The modes of transfer considered were (1) the export of goods, (2) production abroad in a wholly owned subsidiary, and (3) licensing of a foreign producer. A fixed cost, k, was assumed to be associated with subsidiary production while transfer via license was assumed to involve an information asymmetry. The interaction between the fixed cost and the information asymmetry determined whether technology transfer occurred via a license agreement or via a wholly owned subsidiary.

In a world where the new technology was either high cost or low cost and where the license contract was characterised by two variables that are often found in license contracts in practice, namely, a market share restriction (α) and a lump sum license payment (l), the following results were obtained.

1) Given convex cost functions at home and abroad, licensing always dominated the export of goods as a transfer option.

2) The high cost technology was always licensed.

3) The low cost technology was more likely to be licensed (i) the greater was k and (ii) the greater was the licensee's subjective probability that the low cost technology had occurred.

4) The size of the technology difference between the high and low cost technologies had an ambiguous effect on the likelihood of licensing. This effect depended on the parameters of the model.

5) In a pooling equilibrium, or in a separating equilibrium where the low cost technology had occurred, the market share of the licensor was greater than that which maximised joint monopoly profit.

Using the sum of expected consumer surplus and expected monopoly profit as a measure of expected welfare for the home country, the implications of banning technology transfer via license or subsidiary were derived. In general, the welfare effects were ambiguous depending on the interaction of a profit, price, and R&D effect. In all cases, the profit and price effects reduced expected welfare. The ambiguity arose from the possibility that R&D expenditures might increase as a result of the ban. In the informal literature on international technology transfer this possibility is never considered.

For the foreign country the welfare measure used was expected consumer surplus, and the policy considered was a ban on subsidiary production. Once again the welfare effects of such a ban were found to be ambiguous, because the price response increased expected consumer surplus while the fall in R&D decreased expected consumer surplus. Income taxation was also introduced into the welfare analysis, however, ambiguous results were still obtained.

Given these ambiguous welfare results a case by case approach to policy may be necessary though the information requirements of such an approach might be prohibitive. Nevertheless, the model developed above considers welfare effects that have not been formalised before and which are important in any proper analysis of policy regarding technology transfer.

A number of extensions to the basic model were considered. The first being an increase in the number of possible technology types. This increased the complexity of the problem, however, no new major insights were obtained.

The second extension was the inclusion in license contracts of another variable often found in practise, namely, a per unit royalty. The following results were obtained.

1) In a separating equilibrium the optimal value of the per unit royalty was set at zero for the contract associated with the high cost technology while it was positive in the contract associated with the low cost technology.

2) In the pooling equilibrium the optimal value of the per unit royalty was greater than zero.

3) The inclusion of a per unit royalty increased the likelihood that the low cost technology would be transferred via a license agreement.

4) The amount of R&D undertaken in a separating equilibrium increased with the inclusion of a per unit royalty in the license contract.

The welfare implications of various bans on technology transfer remained ambiguous though the extent of the R&D response changed.

The third and final extension involved removing the market share restriction from license contracts, so that licensees become competitors of the licensor. At this stage, only the complete information licensing decision has been analysed. The major result obtained being that with linear demand and linear marginal cost the optimal per unit royalty is greater than zero. The per unit royalty is used to reduce the competitive effect of the licensee on the licensor. Therefore, first best license contracts are characterised by a per unit royalty and a lump sum license payment.

A proposed area of future research is the solving of the incomplete information licensing problem when no market share restriction is allowed in the license contract. Another possible extension is the introduction of another stage before the monopolist attempts to lower its production costs. In this stage a number of firms would be involved in an R&D race to discover the new product/technology.

BIBLIOGRAPHY

Amano, A., "Determinants of Comparative Advantage: A Theoretical Approach," *Oxford Economic Papers*, **16**, Nov. 1964.

Arrow, K.J., "Economic Welfare and the Allocation of Resources to Invention," in K.J. Arrow, *Essays in The Theory of Risk Bearing*, (Chicago: Markham Publishing Co., 1971).

ASTEC (Australian Science and Technology Council), "Mechanisms for Technolgy Transfer into Australia," prepared by the Technological Change Committee, (Canberra: Australian Government Publishing Service, 1986).

Bardhan, P.K., "Imports, Domestic Production, and Transnational Vertical Integration: A Theoretical Note," *Journal of Political Economy*, **90**, Oct. 1982, 1020–1034.

Baron, D.P., and R.G. Myerson, "Regulating a Monopolist with Unknown Costs," *Econometrica*, **50**, July 1982, 911–930.

Brander, J., and B. Spencer, "Export Subsidies and International Market Share Rivalry," *Journal of International Economics*, **18**, Feb. 1985, 83–100.

Brecher, R.A., "Optimal Policy in the Presence of Licensed Technology from Abroad," *Journal of Political Economy*, **90**, Oct. 1982, 1070–1078.

Bulow, J., "Durable Goods Monopolists," *Journal of Political Economy*, **90**, April 1982, 314–332.

Casson, M., *Alternatives to the Multinational Enterprise*, (London: Macmillan Press, 1979).

Caves, R.E., "International Corporations: The Industrial Economics of Foreign Investment," *Economica*, **38**, 1971, 1–27.

Caves, R.E., "Causes of Direct Investment: Foreign Firms' Shares in Canadian and United Kingdom Manufacturing Industries," *Review of Economics and Statistics*, **56**, August 1974, 279–293.

Caves, R.E., *Multinational Enterprise and Economic Analysis*, (Cambridge: Cambridge University Press, 1982).

Caves, R.E., Crookell, H., and J.P. Killing, "The Imperfect Market for Technology Licenses," *Oxford Bulletin of Economics and Statistics*, **45**, Aug. 1983, 249–267.

Chari, V.V., "Involuntary Unemployment and Implicit Contracts," *Quarterly Journal of Economics*, **98**, supplement 1983, 107–122.

Cheng, L., "International Trade and Technology : A Brief Survey of the Recent Literature," *Weltwirtschaftliches Archiv*, **120**, 1984, 165–189.

Connolly, M.B., "Induced Technical Transfer and Transfer Mechanism," in M.B. Connolly and A.K. Swoboda, eds., *International Trade and Money*, 1973, 55–71.

Cooper, R., "On Allocation Distortions in Problems of Self Selection," *Rand Journal of Economics*, **15**, Winter 1984, 568–577.

Davidson, W.H., and D.G. McFetridge, "International Technology Transactions and the Theory of the Firm," *Journal of Industrial Economics*, **32**, March 1984, 253–264.

Dewatripont, M., "Commitment Through Renegotiation –Proof Contracts with Third Parties," *Review of Economic Studies*, **55**, July 1988, 377–390.

Dixit, A., "Comparative Statics For Oligopoly," *International Economic Review*, **27**, February 1986, 107–122.

Dollar, D., "Technological Innovation, Capital Mobility, and the Product Cycle in North–South Trade," *American Economic Review*, **76**, March 1986, 177–190.

Dunning, J.H., "Explaining Changing Patterns of International Production: In Defence of the Eclectic Theory," *Oxford Bulletin of Economics and Statistics*, **41**, Nov. 1979, 269–295.

Eastman, H.C., and S. Stykolt, *The Tariff and Competition in Canada*, (Toronto: MacMillan of Canada, 1967).

Ethier, W.J., "The Multinational Firm," *Quarterly Journal of Economics*, **101**, Nov. 1986, 805–833.

Feenstra, R.C., and K.L. Judd, "Tariffs, Technology Transfer, and Welfare," *Journal of Political Economy*, **90**, Dec. 1982, 1142–1165.

Grossman, S., "The Informational Role of Warranties and Private Disclosure About Product Quality," *Journal of Law and Economics*, **24**, December 1981, 461–483.

Grossman, S.J., and O.D. Hart, "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration," *Journal of Political Economy*, **94**, 1986, 691–719.

Harris, M., and R.M.Townsend, "Allocation Mechanisms, Asymmetric Information and the 'Revelation Principle'," in Feiwel, G.R., ed., *Issues in Contemporary Microeconomics and Welfare*, 379–394, (London: MacMillan Press, 1985).

Hayes, B., "Unions and Strikes with Asymmetric Information," *Journal of Labor Economics*, **2**, Jan. 1984, 57–83.

Helpman, E., "A Simple Theory of International Trade with Multinational Corporations," *Journal of Political Economy*, **92**, June 1984, 451–471.

Helpman, E., and P.R. Krugman, *Market Structure and Foreign Trade*, (Cambridge: MIT Press, 1985).

Hennart, J.F., *A Theory of Multinational Enterprise*, (Michigan: University of Michigan Press, 1982).

Hirsch, S., "An International Trade and Investment Theory of the Firm," *Oxford Economic Papers*, **28**, July 1976, 258–270.

Horstman, I., and J.R. Markusen, "Licensing versus Direct Investment: A Model of Internalisation by the Multi-National Enterprise," *Canadian Journal of Economics*, **20**, August 1987, 464–481.

Horstman,I., MacDonald, G.M., and A. Slivinski, "Patents as Information Transfer Mechanisms : To Patent or (Maybe) Not to Patent," *Journal of Political Economy*, **93**, 1985, 837–858.

Hymer, S.H., *The International Operation of National Firms: A Study of Direct Foreign Investment*, (Cambridge, Mass. :MIT Press, 1976).

Jensen, R., and M. Thursby, "A Strategic Approach to the Product Life Cycle," *Journal of International Economics*, **21**, November 1987, 269–284.

Jones, R.W., "The Structure of Simple General Equilibrium Models," *Journal of Political Economy*, **73**, Dec. 1965, 557–572.

Jones, R.W., "The Role of Technology in the Theory of International Trade," in R. Vernon, ed., *The Technology Factor in International Trade*, 1970, 73–92.

Kahn, A.E., "The Role of Patents," in J.P. Miller, ed., *Competition Cartels and Their Regulation*, (Amsterdam : North-Holland, 1962).

Katz, M.L., and C. Shapiro, "On the Licensing of Innovations," *Rand Journal of Economics*, **16**, Winter 1985, 504–520.

Klein, B., Crawford, R.G., and A.A. Alchian, "Vertical Integration, Appropriable Rents, and the Competitive Contracting Process," *Journal of Law and Economics*, **21**, Oct. 1978, 297–326.

Kravis, I.B., and R.E. Lipsey, "The Location of Overseas Production and Production for Export by U.S. Multinational Firms," *Journal of International Economics*, **12**, May 1982, 201–223.

Krugman, P., "A Model of Innovation, Technology Transfer, and the World Distribution of Income," *Journal of Political Economy*, **87**, April 1979, 253–266.

Levin, R.C., "A New Look at the Patent System," *American Economic Review*, **76**, Papers and Proceedings May 1986, 199–202.

Lyons, B., "International Trade and Technology Policy," in Dasgupta P., and P. Stoneman, eds., *Economic Policy and Technological Performance*, (Cambridge: Cambridge University Press, 1987).

McCulloch, R., and J.L. Yellen, "Technology Transfer and the National Interest," *International Economic Review*, **22**, June 1982, 421–428.

Mansfield, E., Romeo, A., and S. Wagner, "Foreign Trade and U.S. Research and Development," *Review of Economics and Statistics*, **61**, 1979, 49–57.

Mansfield, E., and A. Romeo, "Technology Transfer to Overseas Subsidiaries by U.S. Based Firms," *Quarterly Journal of Economics*, **95**, December 1980, 737–750.

Mansfield, E., Romeo, A., Schwartz, M., and D. Teece, *Technology Transfer, Productivity, and Economic Policy*, (W.W. Norton and Co., 1982).

Markusen, J.R., "Multinationals, Multiplant Economies, and Gains from Trade," *Journal of International Economics*, **16**, May 1984, 205–226.

Maskin, E., and J. Riley, "Monopoly with Incomplete Information," *Rand Journal of Economics*, **15**, Spring 1984, 171–196.

Myerson, R.B., "Incentive Compatibility and the Bargaining Problem," *Econometrica*, **47**, January 1979, 61–73.

Myerson, R.B., "Optimal Coordination Mechanisms in Generalised Principal–Agent Problems," *Journal of Mathematical Economics*, **10**, June 1982, 67–81.

Myerson, R.B., "Mechanism Design by an Informed Principal," *Econometrica*, **51**, Nov. 1983, 1767–1797.

Myerson, R.B., "An Introduction to Game Theory," in S. Reiter (ed.), *Studies in Mathematical Economics,* (Washington D.C.,:Mathematical Association of America, 1986).

Pugel, T.A., "Technology Transfer and the Neoclassical Theory of International Trade," *Research in International Business and Finance*, **2**, 1981, 11–37.

Pugel, T.A., "Endogenous Technological Change and International Technology Transfer in a Ricardian Trade Model," *Journal of International Economics*, **13**, Nov. 1982, 321–335.

Quirmbach, H.C., "Comparative Statics for Oligopoly: Demand Shift Effects," *International Economic Review*, **29**, August 1988, 451–460.

Repullo, R., "On the Revelation Principle Under Complete and Incomplete Information," in K. Binmore and P. Dasgupta, eds., *Economic Organisations as Games*, (Oxford: Basil Blackwell, 1986).

Rodriguez, C.A., "Trade in Technological Knowledge and National Advantage," *Journal of Political Economy*, **83**, Feb. 1975, 121–135.

Scherer, F.M., Beckenstein, A., Kaufer, E., and R.D. Murphy, *The Economics of Multi–Plant Operation*, (Cambridge, Mass.: Harvard University Press, 1975).

Spencer, B.J., and J.A. Brander, "International R.&D. Rivalry and Industrial Strategy," *Review of Economic Studies*, **50**, Oct. 1983, 707–722.

Taylor, C.T., and Z.A. Silberston, *The Economic Impact of the Patent System*, (Cambridge: Cambridge University Press, 1973).

Teece, D.J., "The Market for Know-How and the Efficient International Transfer of Technology," *The Annals of the American Academy of Political and Social Science*, **458**, Nov. 1981, 82–96.

UNCTAD, "Draft International Code of Conduct on the Transfer of Technology," td/code/tot/20.

Vernon, R., "International Investment and International Trade in the Product Cycle," *Quarterly Journal of Economics*, **80**, May 1966, 190–207.

Vernon, R., *Storm Over The Multinationals*, (Cambridge, Mass. :Harvard University

Press, 1977).

Weymark, J., "A Reduced-Form Optimal Nonlinear Income Tax Problem," *Journal of Public Economics*, **30**, 1986, 199–217.

APPENDIX 1

International trade theory usually assumes constant, or more recently, decreasing marginal cost. Therefore, some justification for assuming increasing marginal cost is required. Assume that the new product is produced with a constant returns to scale technology, but that the monopolist has monopsony power over one of the factors of production. This can generate a convex cost function, and if factors are not mobile internationally a convex cost function may exist at home and abroad. More formally, let skilled labour, SL, be in fixed supply, $\bar{SL}$. Assume that this skilled labour is used to produce two goods, X and Y, where X is produced under competitive conditions and Y is the new product produced by the monopolist. Assume X is produced with a Cobb-Douglas production function given by

$$X = (SL_X)^a \cdot K^b \quad where \quad a + b = 1. \tag{A.1.1}$$

Competition ensures that the wage, w, is given by

$$w = \bar{K}^b \cdot a(SL_X)^{a-1}. \tag{A.1.2}$$

Assume $\bar{K}$ is a specific factor used only in the production of X; then w is a decreasing function of SL_X. Assume Y is produced by a fixed coefficient production function given by

$$Y = d \cdot (SL_Y). \tag{A.1.3}$$

The cost of Y units of output is given by

$$C(Y) = w \cdot \frac{Y}{d}. \tag{A.1.4}$$

Substituting for w yields

$$C(Y) = a\bar{K}^b(\bar{SL} - \frac{Y}{d})^{a-1} \cdot \frac{Y}{d} \tag{A.1.5}$$

which is a convex function of Y. Clearly, monopsony power over a factor of production can generate convex cost functions.

Production at home and abroad could also be generated by the plant location model outlined in Appendix 12. In this model marginal cost is constant. The convexity of the cost function arises from a cost of servicing consumers which is assumed to increase with the distance from the plant. It would be possible to redo the analysis of this thesis with the plant location model though no new insights are expected to arise.

APPENDIX 2

Maximised profit as a function of α is given by

$$\Pi^i(\alpha) = p\big(q^i(\alpha)/\alpha\big) \cdot q^i(\alpha) - c^i\big(q^i(\alpha)\big). \tag{A.2.1}$$

Using the envelope theorem gives

$$\frac{d\Pi^i(\alpha)}{d\alpha} = -\frac{dp}{d(q^i/\alpha)} \cdot \frac{\big(q^i(\alpha)\big)^2}{\alpha^2}. \tag{A.2.2}$$

Now

$$\frac{dp}{d(q^i/\alpha)} < 0, \tag{A.2.3}$$

because demand curves are assumed to be downward sloping. Therefore,

$$\frac{d\Pi^i(\alpha)}{d\alpha} > 0. \tag{A.2.4}$$

Differentiating (A.2.2) with respect to α yields

$$\begin{aligned}\frac{d^2\Pi^i(\alpha)}{(d\alpha)^2} = {} & \frac{d^2p}{\big(d(q^i/\alpha)\big)^2} \cdot \left(\frac{q^i(\alpha)}{\alpha^2} - \frac{1}{\alpha} \cdot \frac{dq}{d\alpha}\right) \cdot \frac{\big(q^i(\alpha)\big)^2}{\alpha^2} \\ & + 2 \cdot \frac{dp}{d(q^i/\alpha)} \cdot \frac{\big(q^i(\alpha)\big)^2}{\alpha^3} - 2 \cdot \frac{dp}{d(q^i/\alpha)} \cdot \frac{q^i(\alpha)}{\alpha^2} \cdot \frac{dq}{d\alpha}.\end{aligned} \tag{A.2.5}$$

Rearranging (A.2.5) gives

$$\frac{d^2\Pi^i(\alpha)}{(d\alpha)^2} = \frac{\big(q^i(\alpha)\big)^2}{\alpha^2} \cdot \left(\frac{d^2p}{\big(d(q^i/\alpha)\big)^2} \cdot \frac{q^i(\alpha)}{\alpha^2} + 2 \cdot \frac{dp}{d(q^i/\alpha)} \cdot \frac{1}{\alpha}\right) \cdot \left(1 - \frac{dq}{d\alpha} \cdot \frac{\alpha}{q^i(\alpha)}\right). \tag{A.2.6}$$

Total revenue, TR, is given by

$$TR = p\big(q^i(\alpha)/\alpha\big) \cdot q^i(\alpha). \tag{A.2.7}$$

Differentiating (A.2.7) with respect to q^i yields

$$\frac{\partial TR}{\partial q^i} = \frac{dp}{d(q^i/\alpha)} \cdot \big(q^i(\alpha)/\alpha\big) + p\big(q^i(\alpha)/\alpha\big) \tag{A.2.8}$$

and

$$\frac{\partial^2 TR}{(\partial q^i)^2} = \frac{d^2 p}{\left(d(q^i/\alpha)\right)^2} \cdot \frac{q^i(\alpha)}{\alpha^2} + 2 \cdot \frac{dp}{d(q^i/\alpha)} \cdot \frac{1}{\alpha}. \tag{A.2.9}$$

(A.2.9) is the second term in (A.2.6).

From total differentiation of first order condition (3.3) in the text

$$\frac{dq}{d\alpha} \cdot \frac{\alpha}{q^i(\alpha)} = \frac{\partial^2 TR}{(\partial q^i)^2} \Big/ \left(\frac{\partial^2 TR}{(\partial q^i)^2} - \frac{d^2 c^i}{(dq^i)^2} \right). \tag{A.2.10}$$

The denominator of (A.2.10) is second order condition (3.4) in the text. If total revenue is a strictly concave function of q, the cost function is a strictly convex function of q, and the second order condition for a maximum is satisfied, then

$$0 < \frac{dq}{d\alpha} \cdot \frac{\alpha}{q^i(\alpha)} < 1 \tag{A.2.11}$$

and

$$\frac{d^2 \Pi^i(\alpha)}{(d\alpha)^2} < 0. \tag{A.2.12}$$

APPENDIX 3

Proof of Proposition 3.1

The usual formulation of the monopolist's global profit maximising problem is

$$\max_{q_S^i, q_S^{i*}} \quad \{\Pi(i) = p(q_S^i + q_S^{i*}) \cdot (q_S^i + q_S^{i*}) - c^i(q_S^i) - c^{i*}(q_S^{i*})\}. \tag{A.3.1}$$

The first order conditions are

$$\frac{\partial \Pi(i)}{\partial q_S^i} = \frac{dp(q_S^i + q_S^{i*})}{d(q_S^i + q_S^{i*})} \cdot (q_S^i + q_S^{i*}) + p(q_S^i + q_S^{i*}) - \frac{dc^i}{dq_S^i} = 0 \tag{A.3.2}$$

and

$$\frac{\partial \Pi(i)}{\partial q_S^{i*}} = \frac{dp(q_S^i + q_S^{i*})}{d(q_S^i + q_S^{i*})} \cdot (q_S^i + q_S^{i*}) + p(q_S^i + q_S^{i*}) - \frac{dc^{i*}}{dq_S^{i*}} = 0. \tag{A.3.3}$$

Assume that the second order conditions for a maximum are satisfied. Also assume that the solution to (A.3.2) and (A.3.3) is unique, and given by $\hat{q}_S^i$ and $\hat{q}_S^{i*}$.

Using the market share formulation, world demand is divided between the home and foreign firm. The monopolist's global profit maximising problem in the second sub-stage is given by

$$\begin{aligned} \max_{q^i, q^{i*}} \quad \{\Pi^i + \Pi^{i*} - k = {} & p(q^i/\alpha) \cdot q^i - c^i(q^i) \\ & + p^*(q^{i*}/(1-\alpha)) \cdot q^{i*} - c^{i*}(q^{i*}) - k\}. \end{aligned} \tag{A.3.4}$$

The first order conditions are

$$\frac{\partial(\Pi^i + \Pi^{i*} - k)}{\partial q^i} = \frac{dp}{d(q^i/\alpha)} \cdot (q^i/\alpha) + p(q^i/\alpha) - \frac{dc^i}{dq^i} = 0 \tag{A.3.5}$$

and

$$\begin{aligned} \frac{\partial(\Pi^i + \Pi^{i*} - k)}{\partial q^{i*}} = {} & \frac{dp^*}{d(q^{i*}/(1-\alpha))} \cdot \left(q^{i*}/(1-\alpha)\right) \\ & + p^*\left(q^{i*}/(1-\alpha)\right) - \frac{dc^{i*}}{dq^{i*}} = 0. \end{aligned} \tag{A.3.6}$$

Substitute

$$\alpha = \frac{\hat{q}_S^i}{\hat{q}_S^i + \hat{q}_S^{i*}} \tag{A.3.7}$$

into (A.3.5). By assumption, the solution to (A.3.5) is unique and a maximum. If q^i is chosen so that

$$q^i = \hat{q}^i_S, \tag{A.3.8}$$

then (A.3.5) is identical to (A.3.2) calculated at $(\hat{q}^i_S + \hat{q}^{i*}_S)$. Therefore, (A.3.5) is satisfied if (A.3.8) holds. The uniqueness of the solution of (A.3.5) guarantees that (A.3.5) is the only solution possible.

A similar argument establishes that if (A.3.7) holds, then

$$q^{i*} = \hat{q}^{i*}_S \tag{A.3.9}$$

is the unique solution to (A.3.6). Therefore, if α is chosen so that (A.3.7) holds, then the market share formulation duplicates the solution obtained from the more usual formulation of the monopolist's problem. However, is the α of (A.3.7) the optimal α for the monopolist?

In the first sub-stage the monopolist chooses α to maximise (3.5) of the text subject to (3.6). If (A.3.7), (A.3.8), and (A.3.9) are substituted into $\frac{d\Pi^i_S}{d\alpha}$ of the text, the following is obtained

$$\frac{d\Pi^i_S}{d\alpha} = -\frac{dp}{d(\hat{q}^i_S + \hat{q}^{i*}_S)} \cdot (\hat{q}^i_S + \hat{q}^{i*}_S)^2 + \frac{dp}{d(\hat{q}^i_S + \hat{q}^{i*}_S)} \cdot (\hat{q}^i_S + \hat{q}^{i*}_S)^2. \tag{A.3.10}$$

Inspection of (A.3.10) reveals that if α is given by (A.3.7), then $\frac{d\Pi^i_S}{d\alpha} = 0$. This is the first order condition for a maximum, and the uniqueness of the solution to (3.8) guarantees that

$$\hat{\alpha}^i = \frac{\hat{q}^i_S}{\hat{q}^i_S + \hat{q}^{i*}_S}, \tag{A.3.11}$$

where $\hat{\alpha}^i$ is the optimal choice of α. Given $\hat{\alpha}^i$, it was seen in (A.3.8) and (A.3.9) above that $q^i = \hat{q}^i_S$ and $q^{i*} = \hat{q}^{i*}_S$. This is the solution obtained when outputs are chosen to maximise global profit. **(Q.E.D.)**

At the optimal α, given by (A.3.11), it is also true that $p = p^*$, because

$$(q/\alpha) = q^{i*}/(1-\alpha) = (\hat{q}^i_S + \hat{q}^{i*}_S). \tag{A.3.12}$$

APPENDIX 4

For a given α, price is given by

$$p = p(\frac{q(\alpha)}{\alpha}). \tag{A.4.1}$$

Differentiating with respect to α gives

$$\frac{dp}{d\alpha} = \frac{1}{\alpha} \cdot \frac{dp}{d(q/\alpha)} \left(\frac{dq}{d\alpha} - \frac{q(\alpha)}{\alpha} \right). \tag{A.4.2}$$

From (A.2.10) in Appendix 2

$$\frac{dq}{d\alpha} = \frac{q(\alpha)}{\alpha} \cdot \left(\frac{\partial^2 TR}{(\partial q)^2} / (\frac{\partial^2 TR}{(\partial q)^2} - \frac{d^2 c}{(dq)^2}) \right). \tag{A.4.3}$$

By assumption

$$\frac{\partial^2 TR}{(\partial q)^2} < 0 \quad and \quad \frac{d^2 c}{(dq)^2} > 0, \tag{A.4.4}$$

so

$$0 < \frac{dq}{d\alpha} < \frac{q(\alpha)}{\alpha}. \tag{A.4.5}$$

Therefore,

$$\frac{dp}{d\alpha} > 0. \tag{A.4.6}$$

That is, the larger is the market share the higher is the price.

The importance of the strict convexity of the cost function for this result is seen by assuming that $\frac{d^2 c}{(dq)^2} = 0$. In this case,

$$\frac{dq}{d\alpha} = \frac{q(\alpha)}{\alpha}, \tag{A.4.7}$$

and

$$\frac{dp}{d\alpha} = 0. \tag{A.4.8}$$

That is, price does not change as the market share changes.

APPENDIX 5

Renegotiation Costs

Once the licensee has received the technology and discovered its type, renegotiation of the license contract is feasible whenever the license contract specified a market share other than that which maximised first best global monopoly profit. This follows, because moving to the first best market share results in greater joint profits which can be divided between the licensor and the licensee to obtain a Pareto improvement.

The license contracts specified in mechanisms (3.31) and (3.42) both contain market shares which do not maximise first best global monopoly profit. Therefore, a net gain of

$$(\hat{\Pi}^i(\hat{\alpha}^i) + \hat{\Pi}^{i*}(\hat{\alpha}^i)) - (\Pi^i(\alpha^i) + \Pi^{i*}(\alpha^i)) \qquad \text{(A.5.1)}$$

is available to be renegotiated over after both the licensee and the licensor are made as well off with $\hat{\alpha}^i$ as with α^i (where α^i is the market share offered in the pre–renegotiation license contract). That is, renegotiation should always occur given mechanisms (3.31) and (3.42). To obtain the Pareto improvement, the licensee must know the technology type at the time of renegotiation; otherwise, it does not know how much to compensate the licensor for the licensor reducing its market share to $\hat{\alpha}^i$. That is, $\Pi^i(\alpha^i)$ must be known to the licensee.

In the static model developed in Section 3.1 of the text, the technology is revealed to the licensee on transfer. However, in practise, numerous production runs may be necessary before the licensee is sure of the technology type, because the licensee is using the technology for the first time and requires actual production to iron out any bugs. This delay in discovering technology type delays the renegotiation process, and introduces the possibility that renegotiation is costly.

For example, assume that efficient production requires irreversible capital outlays or labour employment committments. The licensor knowing that the market share is going to be renegotiated to its first best level is reluctant to install capital and make employment committments that would ensure efficient production with the market share in the pre–renegotiation license contract. Therefore, over the renegotiation period output is produced inefficiently, and this inefficient production can be viewed as the cost of renegotiation. If this cost outweighs the net gain from renegotiation, then renegotiation will not occur. This is more likely the larger is the delay the licensee experiences in discovering technology type and the shorter is the period for which the monopolist has monopoly power.[1]

Costly renegotiation arose by introducing time and committment into the analysis, yet both of these elements are not in the static model developed in Section 3.1. It is really inappropriate to justify the lack of renegotiation in a static model by appealing to dynamic factors that are not explicitly modelled. However, as the inclusion of these factors would complicate the analysis greatly, prohibitively costly renegotiation is assumed.[2]

Costless Renegotiation

If renegotiation is costless, the analysis of Section 3.1 must be amended. Let the probability, ρ^*, be such that the separating solution is chosen by the licensor and let the low cost technology occur. Mechanism (3.31) states that the license contract is given by $(\bar{\alpha}^L, \bar{l}^L)$. Once the licensee has obtained the technology a Pareto improvement is possible, because the market share in the contract does not maximise first best global profits. However, if renegotiation of the market share is allowed, then mechanism (3.31) no longer satisfies self selection constraint (3.25).[3] In fact, allowing renegotiation of the market share after the technology is transferred alters the maximisation problem of the licensor.

Assume that the low cost technology has occurred. The net gain from renegoti-

[1] Monopoly power may only be temporary if the firm which discovers the new product /technology is competing with other firms in an ongoing R&D struggle. In this case, the firm with monopoly power transfers technology as soon as possible in order to reap monopoly profit for as long a period as possible.

[2] This assumption and the use of dynamic arguments to rationalise it has precedence in the literature. In an asymmetric information model of strikes Hayes (1984) assumed away renegotiation. Later attempts were made to rationalise this assumption by appealing to reputation in a repeated game. Chari (1983, p. 118) also assumed away renegotiation, and provided a rationalisation by appealing to a reputation model. However, it must be admitted that precedence in the literature does not provide a justification for employing dynamic arguments in a static model, though it is the best the author can do.

[3] With mechanism (3.31), the licensor offers the contract associated with the low cost technology even if the high cost technology has occurred as long as the licensor is able to obtain some of the net gain from renegotiating the market share. Therefore, mechanism (3.31) is not incentive compatible.

ation is given by

$$\Big(\big(\hat{\Pi}^L(\hat{\alpha}^L) + \hat{\Pi}^{L*}(\hat{\alpha}^L)\big) - \big(\Pi^L(\alpha^L) + \Pi^{L*}(\alpha^L)\big)\Big), \tag{A.5.2}$$

where α^L is the market share in the license contract which is offered pre– renegotiation. Let θ be the proportion of the net gain that goes to the licensor in the renegotiation process. Assume the low cost technology has occurred. The licensor's problem is

Problem A.5.1:

$$\max_{\alpha^L, l^L} \quad \{\Pi(L_\theta) = \Pi^L(\alpha^L) + \theta\Big(\big(\hat{\Pi}^L + \hat{\Pi}^{L*}\big) - \big(\Pi^L(\alpha^L) + \Pi^{L*}(\alpha^L)\big)\Big) + l^L\} \tag{A.5.3}$$

subject to:

$$\begin{aligned} \hat{\Pi}^H(\hat{\alpha}^H) + \hat{\Pi}^{H*}(\hat{\alpha}^H) \geq \Pi^{HL}(\alpha^L) + \theta\Big(&\big(\hat{\Pi}^H + \hat{\Pi}^{H*}\big) \\ &- \big(\Pi^{HL}(\alpha^L) + \Pi^{HL*}(\alpha^L)\big)\Big) + l^L, \end{aligned} \tag{A.5.4}$$

$$\Pi^{L*}(\alpha^L) \geq l^L. \tag{A.5.5}$$

Given θ and $(\hat{\alpha}^H, \hat{l}^H = \hat{\Pi}^{H*}(\hat{\alpha}^H))$, the licensor chooses (α^L, l^L) to maximise (A.5.3) subject to (A.5.4) and (A.5.5).

Initially it is assumed that the licensee has all the bargaining power in the renegotiation process, so it is able to extract all the net gain; that is, $\theta = 0$. Substituting $\theta = 0$ into Problem A.5.1 yields Problem 1. Therefore, in this case, the possibility of renegotiation does not alter the mechanism chosen by the licensor.

However, what if the licensor has all the bargaining power, so $\theta = 1$? Given $(\hat{\alpha}^H, \hat{l}^H)$, substituting $\theta = 1$ into Problem A.5.1 yields the following problem

Problem A.5.2:

$$\max_{\alpha^L, l^L} \quad \{\Pi(L_\theta) = \hat{\Pi}^L + \hat{\Pi}^{L*} - \Pi^{L*}(\alpha^L) + l^L\} \tag{A.5.6}$$

subject to:

$$\Pi^{HL*}(\alpha^L) \geq l^L, \tag{A.5.7}$$

$$\Pi^{L*}(\alpha^L) \geq l^L. \tag{A.5.8}$$

Now

$$\Pi^{HL*}(\alpha^L) < \Pi^{L*}(\alpha^L), \qquad 0 \leq \alpha^L < 1 \tag{A.5.9}$$

and

$$\Pi^{HL*}(\alpha^L) = \Pi^{L*}(\alpha^L), \qquad \alpha^L = 1, \tag{A.5.10}$$

so if (A.5.7) is satisfied, then (A.5.8) only binds if $\alpha^L = 1$. This implies that the objective function is maximised when $\alpha^L = 1$; otherwise, $\Pi^{L*}(\alpha^L) > l^L$ and maximised profit is less than $\hat{\Pi}^L + \hat{\Pi}^{L*}$. Therefore, the separating solution is given by

$$(\hat{\alpha}^H, \hat{l}^L) \quad ; \quad (\alpha^L = 1, l^L = 0) \tag{A.5.11}$$

when $\theta = 1$. When $(\alpha^L = 1, l^L = 0)$ is the license contract offered, the licensor is able to obtain $\hat{\Pi}^L + \hat{\Pi}^{L*}$ which is the first best global profit maximising outcome. The intuition for this result is clear. In effect, the licensor provides the low cost technology to the licensee free of any payment, but does not allow the licensee to produce any output, $(\alpha^L = 1)$. The licensee then discovers the technology type and is prepared to pay $l^L = \Pi^{L*}(\alpha^L)$ for the right to a market share of $(1-\alpha)$. To maximise global profit the licensor allows the licensee a market share of $(1 - \hat{\alpha}^L)$, and so obtains complete information profits of $\hat{\Pi}^L + \hat{\Pi}^{L*}$.

For $0 < \theta < 1$ the licensor obtains profits between $(\hat{\Pi}^L + \hat{\Pi}^{L*})$ and $(\bar{\Pi}^L + \bar{\Pi}^{L*})$ when the low cost technology occurs. Therefore, in cases where $0 < \theta \leq 1$, the possibility of renegotiation of market shares after the technology is transferred means that mechanism (3.31) is no longer optimal for the monopolist.

The value of θ is important in determining the optimal values of α and l in the license contract. For example, if $\theta = 1$ and costless, instantaneous renegotiation takes place, then the licensor is able to obtain first best monopoly profit. What value of θ might be expected?

In cases where there is no delay in the licensee determining technology type and where there are many potential licensees, $\theta = 1$. If the first licensee that is offered $(\alpha^L = 1, l^L = 0)$ does not agree to a license payment of $\hat{l}^L = \hat{\Pi}^{L*}$ and a market share of $\hat{\alpha}^L$ in the renegotiation, then the licensor simply refuses to renegotiate and offers $(\alpha^L = 1, l^L = 0)$ to another potential licensee. Competition ensures that the first licensee offered ($\alpha^L = 1, l^L = 0$) pre–renegotiation and offered ($\hat{\alpha}^L, \hat{l}^L$) during renegotiation accepts the offer. Therefore, $\theta = 1$.[4]

However, if time and production of output is needed for the licensee to determine technology type, then $\theta < 1$. The licensee has some bargaining power when it determines technology type, for the licensor can not immediately offer a license contract with renegotiation to another license, as it takes time for the other licensee to discover technology type. In the meantime, the licensor's market share is greater than the first best joint profit maximising level. Therefore, the licensor may yield some of the net gain from renegotiation to the licensee in order to obtain the benefit from the efficient allocation of resources that occurs when $\alpha = \hat{\alpha}^L$. The licensor can not solve this problem by offerring ($\alpha^L = 1, l^L = 0$) to many potential licensees and then only renegotiate with one, because the licensee uses up resources in determining technology type and may not be prepared to undertake production to determine technology type unless guaranteed some market share.

Once again, time has been introduced into a static model to explain why θ may be less than one. The inappropriateness of this is realised, but can be defended on the grounds of simplicity.

If $\theta < 1$, then first best global monopoly profit can not be achieved by the licensor, and a choice still has to be made between licensing and subsidiary production as the mode of technology transfer. With renegotiation allowed, the price of output is the same in the licensor's and licensee's market, thus eliminating the need to assume costly arbitrage.[5]

4 This result is weakened (1) to the extent that $\hat{\alpha}^L = 1$ is more difficult to enforce the greater the number of licensees that are given the technological information and (2) if there are substantial legal costs in writing license contracts.

5 This also leads to different welfare implications than those obtained in the text.

APPENDIX 6

The Relationship Between $\hat{\alpha}^H$ and $\hat{\alpha}^L$.

Quadratic Cost Functions

A quadratic cost function implies that marginal cost is linear. From (A.3.2) and (A.3.3), at the first best optimum, marginal costs at home and abroad are equated. Therefore,

$$a + b \cdot \hat{q}^H = c + d \cdot \hat{q}^{H*}. \tag{A.6.1}$$

Rearranging (A.6.1) gives

$$\hat{q}^{H*} = \frac{(a-c)}{d} + \frac{b \cdot \hat{q}^H}{d}. \tag{A.6.2}$$

From (A.3.11)

$$\hat{\alpha}^H = \frac{\hat{q}^H}{\hat{q}^H + \frac{(a-c)}{d} + \frac{b}{d} \cdot \hat{q}^H}. \tag{A.6.3}$$

Dividing the top and bottom of (A.6.3) by $\hat{q}^H$ yields

$$\hat{\alpha}^H = \frac{1}{1 + \frac{(a-c)}{d \cdot \hat{q}^H} + \frac{b}{d}}. \tag{A.6.4}$$

By assumption

$$c^L(\cdot) = \frac{1}{\gamma} \cdot c^H(\cdot), \quad where \quad \gamma \geq 1, \tag{A.6.5}$$

so at the first best optimum

$$\frac{1}{\gamma} \cdot (a + b \cdot \hat{q}^L) = \frac{1}{\gamma} \cdot (c + d \cdot \hat{q}^{L*}). \tag{A.6.6}$$

Rearranging (A.6.6) gives

$$\hat{\alpha}^L = \frac{1}{1 + \frac{(a-c)}{d \cdot \hat{q}^L} + \frac{b}{d}}. \tag{A.6.7}$$

If $a = c$, then from (A.6.4) and (A.6.7)

$$\hat{\alpha}^H = \hat{\alpha}^L. \tag{A.6.8}$$

That is, $\hat{\alpha}^i$ is independent of γ if the intercepts of the marginal cost curves at home and abroad are identical. If $a > c$, then $\hat{\alpha}^L > \hat{\alpha}^H$, because at the first best optimum it is always true that $\hat{q}^L > \hat{q}^H$ as long as the world demand curve is not vertical.

Quadratic Marginal Cost Curves

Let the marginal cost curve take the following general form

$$e + f \cdot (\hat{q}^i)^2. \tag{A.6.9}$$

At the first best optimum

$$a + b \cdot (\hat{q}^H)^2 = c + d \cdot (\hat{q}^{H*})^2. \tag{A.6.10}$$

Rearranging (A.6.10) and substituting into $\hat{\alpha}^i$ gives

$$\hat{\alpha}^H = \frac{1}{1 + \sqrt{\frac{(a-c)}{d \cdot (\hat{q}^H)^2} + \frac{b}{d}}} \tag{A.6.11}$$

and

$$\hat{\alpha}^L = \frac{1}{1 + \sqrt{\frac{(a-c)}{d \cdot (\hat{q}^L)^2} + \frac{b}{d}}}. \tag{A.6.12}$$

Once again $\hat{\alpha}^L = \hat{\alpha}^H$ if $a = c$.

APPENDIX 7

When contracts that are contingent on an announcement by the licensor of technology type are allowed, the monopolist's problem when it is assumed that the low cost technology has occurred is

$$\max_{\alpha^H, l^H, \alpha^L, l^L} \quad \{\Pi(L) = \Pi^L(\alpha^L) + l^L\} \tag{A.7.1}$$

subject to:

$$\Pi^H(\alpha^H) + l^H \geq \Pi^{HL}(\alpha^L) + l^L, \tag{A.7.2}$$

$$\Pi^L(\alpha^L) + l^L \geq \Pi^{LH}(\alpha^H) + l^H, \tag{A.7.3}$$

$$\rho^* \cdot (\Pi^{L*}(\alpha^L) - l^L) + (1 - \rho^*) \cdot (\Pi^{H*}(\alpha^H) - l^H) \geq 0. \tag{A.7.4}$$

At the solution to this problem the only constraints that bind are (A.7.2) and (A.7.4). The self selection constraint (A.7.3) does not bind, because the licensor is trying to maximise $\Pi^L(\alpha^L) + l^L$ which is the left hand side of the constraint. Constraint (A.7.4) binds, for if not, it is possible to increase the objective function by increasing both l^L and l^H equally and still continue to satisfy constraint (A.7.2). Similarly, constraint (A.7.2) binds, for if not, the objective function could be increased by increasing l^L and decreasing l^H in such a way that (A.7.4) continues to bind.

The simplest way to solve this problem is by substituting the binding constraints into the objective function. To do this, rearrange (A.7.4) to give

$$l^H = \frac{\rho^*}{(1 - \rho^*)} \cdot (\Pi^{L*}(\alpha^L) - l^L) + \Pi^{H*}(\alpha^H). \tag{A.7.5}$$

Next, substitute (A.7.5) into (A.7.2) to yield

$$l^L(\alpha^H, \alpha^L) = \rho^* \Pi^{L*}(\alpha^L) + (1 - \rho^*) \cdot \left(\Pi^{H*}(\alpha^H) + \Pi^H(\alpha^H) - \Pi^{HL}(\alpha^L)\right). \tag{A.7.6}$$

(A.7.6) is the equation of the locus obtained by combining constraints (A.7.4) and (A.7.2). Substituting (A.7.6) into the objective function yields Problem A.7.1.

Problem A.7.1:

$$\begin{aligned} \max_{\alpha^H, \alpha^L} \quad & \{\Pi(L) = \Pi^L(\alpha^L) + \rho^* \Pi^{L*}(\alpha^L) \\ & + (1 - \rho^*) \cdot \left(\Pi^{H*}(\alpha^H) + \Pi^H(\alpha^H) - \Pi^{HL}(\alpha^L)\right)\}. \end{aligned} \tag{A.7.7}$$

The first order conditions for Problem A.7.1 are

$$\frac{\partial \Pi(L)}{\partial \alpha^L} = \frac{d\Pi^L(\alpha^L)}{d\alpha^L} + \rho^* \cdot \frac{d\Pi^{L*}(\alpha^L)}{d\alpha^L} - (1-\rho^*) \cdot \frac{d\Pi^{HL}(\alpha^L)}{d\alpha^L} = 0 \qquad \text{(A.7.8)}$$

and

$$\frac{\partial \Pi(L)}{\partial \alpha^H} = (1-\rho^*) \cdot (\frac{d\Pi^{H*}(\alpha^H)}{d\alpha^H} + \frac{d\Pi^H(\alpha^H)}{d\alpha^H}) = 0. \qquad \text{(A.7.9)}$$

The second order conditions for a maximum are

$$\frac{\partial^2 \Pi(L)}{(\partial \alpha^L)^2} = \frac{d^2\Pi^L}{(d\alpha^L)^2} - (1-\rho^*) \cdot \frac{d^2\Pi^{HL}}{(d\alpha^L)^2} + \rho^* \cdot \frac{d^2\Pi^{L*}}{(d\alpha^L)^2} < 0 \qquad \text{(A.7.10)}$$

and

$$\frac{\partial^2 \Pi(L)}{(\partial \alpha^H)^2} = \frac{d^2\Pi^H}{(d\alpha^H)^2} + \frac{d^2\Pi^{H*}}{(d\alpha^H)^2} < 0. \qquad \text{(A.7.11)}$$

By the concavity of $\Pi^H(\alpha)$ and $\Pi^{H*}(\alpha)$, (A.7.11) is satisfied. However,

$$\frac{d^2\Pi^{HL}}{(d\alpha^L)^2} = \frac{d^2\Pi^H}{(d\alpha^H)^2} < 0, \qquad \text{(A.7.12)}$$

so (A.7.10) may not be satisfied. A sufficient condition for (A.7.10) to be satisfied is

$$-(1-\rho^*) \cdot \frac{d^2\Pi^{HL}}{(d\alpha^L)^2} + \rho^* \cdot \frac{d^2\Pi^{L*}}{(d\alpha^L)^2} < 0. \qquad \text{(A.7.13)}$$

The left hand side of (A.7.13) gives the curvature of locus (A.7.6), for a given α^H. If this locus is concave in α^L, condition (A.7.13) is satisfied, and the solution to (A.7.8) and (A.7.9) is a maximum. Assume ρ^* is large enough for (A.7.13) to be satisfied. (A.7.9) implies that

$$\frac{d\Pi^H}{d\alpha^H} = -\frac{d\Pi^{H*}}{d\alpha^H} \qquad \text{(A.7.14)}$$

which is the condition for first best global profit maximisation if the high cost technology occurred and the technology was transferred via a subsidiary. Therefore, the solution to (A.7.14) is $\alpha^H = \hat{\alpha}^H$.

(A.7.8) implies that at a maximium

$$\frac{d\Pi^L}{d\alpha^L} = (1-\rho^*) \cdot \frac{d\Pi^{HL}}{d\alpha^L} - \rho^* \cdot \frac{d\Pi^{L*}}{d\alpha^L}. \qquad \text{(A.7.15)}$$

Let the solution to (A.7.15) be given by $\tilde{\alpha}^L$. Now

$$\frac{d\Pi^{HL}}{d\alpha^L} = \frac{d\Pi^H}{d\alpha^H} \quad < \quad \frac{d\Pi^L}{d\alpha^L} = -\frac{d\Pi^{L*}}{d\alpha^L} \; at \; \hat{\alpha}^L. \tag{A.7.16}$$

[1] Substituting the relationships of (A.7.16) into (A.7.15) implies that at $\hat{\alpha}^L$

$$\frac{d\Pi^L}{d\alpha^L} > (1-\rho^*)\cdot\frac{d\Pi^{HL}}{d\alpha^L} - \rho^*\cdot\frac{d\Pi^{L*}}{d\alpha^L}. \tag{A.7.17}$$

(A.7.17) together with (A.7.13) and the concavity of $\Pi^L(\alpha^L)$ imply that $\tilde{\alpha}^L > \hat{\alpha}^L$, because as α^L is increased from $\hat{\alpha}^L$ the left hand side of (A.7.17) falls while the right hand side of (A.7.17) increases until eventually (A.7.15) holds. The solution to Problem A.7.1 is illustrated in Figure 18.

$l^L(\hat{\alpha}^H, \alpha^L)$ is the locus obtained by combining constraints (A.7.2) and (A.7.4), given $\alpha^H = \hat{\alpha}^H$. This locus passes through point A, where $l^L = l^H = l = \rho^* \cdot \hat{\Pi}^{L*} + (1-\rho^*)\cdot\hat{\Pi}^{H*}$ and point B, where $l^L = \bar{\Pi}^{L*}(\bar{\alpha}^L)$. The objective of the licensor is to get on the highest possible global iso–profit curve, given the low cost technology has occurred and given $l^L(\hat{\alpha}^H, \alpha^L)$. This occurs at point C, and the mechanism chosen by the monopolist to maximise profit is

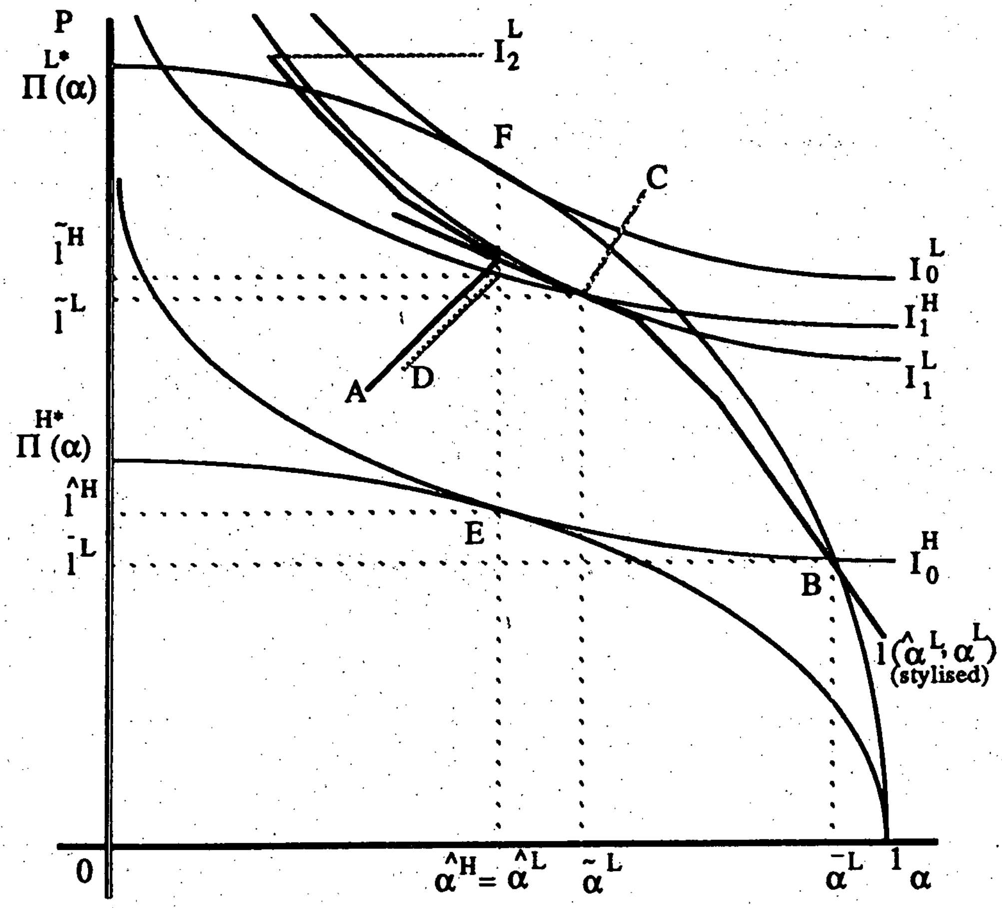
$$(\hat{\alpha}^H, \tilde{l}^H) \quad ; \quad (\tilde{\alpha}^L, \tilde{l}^L). \tag{A.7.18}$$

$\tilde{l}^L$ is obtained by substituting $\hat{\alpha}^H$ and $\tilde{\alpha}^L$ into (A.7.6), and $\tilde{l}^H$ is obtained by substituting $\hat{\alpha}^H$, $\tilde{\alpha}^L$, and $\tilde{l}^L$ into (A.7.5). That is, given $\hat{\alpha}^H$ and $\tilde{\alpha}^L$, $\tilde{l}^H$ and $\tilde{l}^L$ are obtained simultaneously from the binding constraints (A.7.2) and (A.7.4).

If the monopolist announces that the high cost technology has occurred, the license contract is given by $(\hat{\alpha}^H, \tilde{l}^H)$. If the low cost technology is announced, the license contract is given by $(\tilde{\alpha}^L, \tilde{l}^L)$. The intuition for the global profit maximising market share being used in the high cost technology contract follows from the desire to make the left hand side of constraint (A.7.2) as large as possible which, given (A.7.4), is achieved by maximising $\Pi^H(\alpha^H) + \Pi^{H*}(\alpha^H)$. The intuition for $\tilde{\alpha}^L$ being greater than the global profit maximising share in the low cost technology contract follows from (A.7.17). This condition states that an increase in α^L, at $\hat{\alpha}^L$, causes a net increase in the objective function, because $\frac{d\Pi^H}{d\alpha^H} < \frac{d\Pi^L}{d\alpha^L}$.

[1] In Appendix 9 it is shown that $\frac{d\Pi^H}{d\alpha^H} < \frac{d\Pi^L}{d\alpha^L}$.

Figure 18



P
$\Pi^{L*}(\alpha)$
I_2^L
F
C
$\tilde{l}^H$
$\tilde{l}^L$
I_0^L
I_1^H
I_1^L
A
D
$\Pi^{H*}(\alpha)$
$\hat{l}^H$
$\bar{l}^L$
E
B
I_0^H
$l(\hat{\alpha}^L, \alpha^L)$
(stylised)
0
$\hat{\alpha}^H = \hat{\alpha}^L$
$\tilde{\alpha}^L$
$\bar{\alpha}^L$
1
α

The optimum for the monopolist may have occurred on $l^L(\hat{\alpha}^H, \alpha^L)$ to the right of point B. However, this would involve $\tilde{l}^L > \tilde{\Pi}^{L*}(\tilde{\alpha}^L)$ which presently will be shown to be not feasible.

If the high cost technology had occurred, then the objective function of Problem A.7.1 would change to $\Pi^H(\alpha^H) + l^H$. In Appendix 8 it is shown that maximising this objective function subject to constraints (A.7.2), (A.7.3), and (A.7.4) yields the following mechanism

$$(\breve{\alpha}^H, \breve{l}^H) \quad ; \quad (\hat{\alpha}^L, \breve{l}^L) \tag{A.7.19}$$

in which $\breve{l}^H > \breve{\Pi}^{H*}(\breve{\alpha}^H)$, $\breve{\alpha}^H < \hat{\alpha}^H$, and $\alpha^L = \hat{\alpha}^L$.

As (A.7.18) differs from (A.7.19), the mechanism offered by the licensor depends on the technology that actually occurred. The licensee can use this information to make an inference about the technology type and make mechanism (A.7.19) infeasible in practise. That is, knowing that mechanism (A.7.19) is the optimal choice of the high cost licensor allows the licensee to infer that the high cost technology has occurred, otherwise, mechanism (A.7.18) would have been offered. Making this inference means mechanism (A.7.19) is infeasible, for $\breve{l}^H > \breve{\Pi}^{H*}(\breve{\alpha}^H)$ and the expected profit of the licensee is less than zero.

Using a similar argument, it is clear that mechanism (A.7.18) is not feasible if $\tilde{l}^L > \tilde{\Pi}^{L*}(\tilde{\alpha}^L)$. Therefore, a further constraint must be put on Problem A.7.1, namely, that

$$\tilde{l}^L \leq \tilde{\Pi}^{L*}(\tilde{\alpha}^L). \tag{A.7.20}$$

In cases where $l^L(\hat{\alpha}^H, \alpha^L)$ is concave and the solution to Problem A.7.1 without constraint (A.7.20) lies to the right of point B, the effect of constraint (A.7.20) is to cause a corner solution at point B. If the solution to Problem A.7.1 lies to the left of point B, then constraint (A.7.20) is not binding. In this case, even if the licensee infers from the offer of mechanism (A.7.18) that the low cost technology has occurred, then the licensee will still participate in the mechanism, because $\tilde{l}^L < \tilde{\Pi}^{L*}(\tilde{\alpha}^L)$. Using the terminology of Myerson (1983), mechanism (A.7.18) is a core mechanism, and is the only mechanism that is incentive compatible in practise, given the inferences that the licensee may make about the technology type from the licensor's mechanism offer.

In cases where the second order condition is not satisfied in Problem A.7.1 a corner solution arises at point B in Figure 18. This is because at point A the absolute value of the slope of the global iso-profit curve I_2^L is greater than the absolute value of the slope of $l^L(\hat{\alpha}^H, \alpha^L)$. This together with the requirement that $\tilde{l}^L \leq \tilde{\Pi}^{L*}(\tilde{\alpha}^L)$ gives the optimal mechanism as

$$(\hat{\alpha}^H, \hat{l}^H) \qquad ; \qquad (\bar{\alpha}^L, \bar{l}^L). \tag{A.7.21}$$

This mechanism is represented in Figure 18 by points B and E.

Mechanism (A.7.21) involves a different license contract for each state. In solving Problem A.7.1 the pooling option was available, but never chosen, so mechanism (A.7.21) must dominate the pooling mechanism.

APPENDIX 8

Assume the high cost technology has occurred, the monopolist's problem is

Problem A.8.1:

$$\max_{\alpha^H, l^H, \alpha^L, l^L} \quad \{\Pi(H) = \Pi^H(\alpha^H) + l^H\} \tag{A.8.1}$$

subject to constraints (A.7.2), (A.7.3), and (A.7.4) in the Appendix 7.

At the solution to Problem A.8.1 constraint (A.7.2) does not bind, because the licensor is trying to maximise $\Pi^H(\alpha^H) + l^H$ which is the left hand side of the constraint. Constraint (A.7.4) binds, for if not, it is possible to increase the objective function by increasing both l^H and l^L equally while continuing to satisfy constraint (A.7.3). Similarly, constraint (A.7.3) binds, for if not, the objective function could be increased by increasing l^H and decreasing l^L in such a way that (A.7.4) continues to bind. Substituting constraints (A.7.3) and (A.7.4) into the objective function gives Problem A.8.2.

Problem A.8.2:

$$\begin{aligned}\max_{\alpha^H, \alpha^L} \quad \{\Pi(H) = \Pi^H(\alpha^H) + (1-\rho^*)\cdot \Pi^{H*}(\alpha^H) \\ + \rho \cdot \left(\Pi^{L*}(\alpha^L) + \Pi^L(\alpha^L) - \Pi^{LH}(\alpha^H)\right)\}.\end{aligned} \tag{A.8.2}$$

The first order conditions for Problem A.8.2 are

$$\frac{\partial \Pi(H)}{\partial \alpha^H} = \frac{d\Pi^H}{d\alpha^H} + (1-\rho^*)\cdot \frac{d\Pi^{H*}}{d\alpha^H} - \rho \cdot \frac{d\Pi^{LH}}{d\alpha^H} = 0 \tag{A.8.3}$$

and

$$\frac{\partial \Pi(H)}{\partial \alpha^L} = \rho \cdot \left(\frac{d\Pi^{L*}}{d\alpha^L} + \frac{d\Pi^L}{d\alpha^L}\right) = 0. \tag{A.8.4}$$

Assume that the second order conditions for an interior maximum are satisfied. Condition (A.8.4) implies that $\alpha^L = \hat{\alpha}^L$, while condition (A.8.3) coupled with the following inequalities

$$\frac{d\Pi^H}{d\alpha^H} = \frac{d\Pi^L}{d\alpha^L} > \frac{d\Pi^H}{d\alpha^H} = -\frac{d\Pi^{H*}}{d\alpha^H} \quad at \quad \hat{\alpha}^H \tag{A.8.5}$$

implies that $\breve{\alpha}^H < \hat{\alpha}^H$. Given $\breve{\alpha}^H$ and $\hat{\alpha}^L$, $\breve{l}^H$ and $\breve{l}^L$ are obtained from the simultaneous solution of (A.7.3) and (A.7.4).

APPENDIX 9

Proof that $\frac{d\Pi^H}{d\alpha^H} < \frac{d\Pi^L}{d\alpha^L}$

When γ is explicitly considered, problem (3.2) from the text can be written as

$$\max_q \quad \{\Pi(q,\alpha,\gamma) = p(q/\alpha)\cdot q - \frac{1}{\gamma}\cdot c(q)\}. \tag{A.9.1}$$

The first order condition for this problem is

$$\frac{\partial \Pi}{\partial q} = \frac{dp}{d(q/\alpha)}\cdot(q/\alpha) + p(q/\alpha) - \frac{1}{\gamma}\cdot\frac{dc}{dq} = 0. \tag{A.9.2}$$

Assuming that the second order condition for a maximum is satisfied gives

$$\frac{\partial^2\Pi}{(\partial q)^2} = \frac{d^2p}{\left(d(q/\alpha)\right)^2}\cdot\frac{q}{\alpha^2} + 2\cdot\frac{dp}{d(q/\alpha)}\cdot\frac{1}{\alpha} - \frac{1}{\gamma}\cdot\frac{d^2c}{(dq)^2} < .0 \tag{A.9.3}$$

Let the argmax of (A.9.1) be given by $q(\alpha,\gamma)$. Substituting the solution of (A.9.2) into the objective function and differentiating with respect to α gives

$$\frac{\partial\Pi(\alpha,\gamma)}{\partial\alpha} = -\frac{dp}{d\left(q(\alpha,\gamma)/\alpha\right)}\cdot\left(q(\alpha,\gamma)/\alpha\right)^2. \tag{A.9.4}$$

To obtain the relationship between $\frac{d\Pi^H}{d\alpha^H}$ and $\frac{d\Pi^L}{d\alpha^L}$ differentiate (A.9.4) with respect to γ to get

$$\begin{aligned}\frac{\partial^2\Pi(\alpha,\gamma)}{\partial\gamma\partial\alpha} = -\left(q(\alpha,\gamma)/\alpha\right)\cdot\Bigg(&\frac{d^2p}{\left(d\left(q(\alpha,\gamma)/\alpha\right)\right)^2}\cdot\frac{q(\alpha,\gamma)}{\alpha^2}\\ &+2\cdot\frac{dp}{d\left(q(\alpha,\gamma)/\alpha\right)}\cdot\frac{1}{\alpha}\Bigg)\cdot\frac{\partial q(\alpha,\gamma)}{\partial\gamma}.\end{aligned} \tag{A.9.5}$$

Substituting $q(\alpha,\gamma)$ into (A.9.2) and totally differentiating with respect to q and γ gives

$$\frac{\partial q}{\partial\gamma} = -\frac{\frac{1}{\gamma^2}\cdot\frac{dc}{dq}}{\frac{d^2TR}{(\partial q)^2} - \frac{1}{\gamma}\cdot\frac{d^2c}{(dq)^2}}. \tag{A.9.6}$$

The numerator of (A.9.6) is positive, and the denominator is negative by second order condition (A.9.3). Therefore,

$$\frac{\partial q}{\partial\gamma} > 0. \tag{A.9.7}$$

If the revenue function is strictly concave, then it follows that

$$\frac{\partial^2 \Pi(\alpha, \gamma)}{\partial \gamma \partial \alpha} > 0. \tag{A.9.8}$$

(A.9.8) is true for all γ, so

$$\frac{d\Pi^L}{d\alpha^L} > \frac{d\Pi^H}{d\alpha^H}. \tag{A.9.9}$$

(Q.E.D.)

APPENDIX 10

Derivation of $\frac{d(\hat{\Pi}^L + \hat{\Pi}^{L*})}{d\gamma}$

When γ is explicitly considered, Problem (3.2) from the text can be written as

$$\max_q \quad \Pi^L(q,\alpha,\gamma) = p(q/\alpha)\cdot q - \frac{1}{\gamma}\cdot c(q). \tag{A.10.1}$$

Let the argmax of this problem be given by $q(\alpha,\gamma)$. Substituting this into the objective function of (A.10.1) gives

$$\Pi^L\big(q(\alpha,\gamma),\alpha,\gamma\big) \tag{A.10.2}$$

as the maximised value.

Assume that $k=0$, problem (3.5) from the text is now written as

$$\max_\alpha \quad \{\Pi^L_S(\alpha,\gamma) = \Pi^L(\alpha,\gamma) + \Pi^{L*}(\alpha,\gamma)\}. \tag{A.10.3}$$

Let the argmax of problem (A.10.3) be given by $\hat{\alpha}^L(\gamma)$. Substituting this into (A.10.2) and the objective function of (A.10.3) gives

$$\hat{\Pi}^L\Big(\hat{q}^L(\hat{\alpha}^L(\gamma),\gamma),\hat{\alpha}^L(\gamma),\gamma\Big) + \hat{\Pi}^{L*}\Big(\hat{q}^{L*}(\hat{\alpha}^L(\gamma),\gamma),\hat{\alpha}^L(\gamma),\gamma\Big) \tag{A.10.4}$$

as the maximised value. By the envelope theorem, the indirect effect of γ on α and q can be ignored, so

$$\frac{d(\hat{\Pi}^L + \hat{\Pi}^{L*})}{d\gamma} = \frac{\partial\hat{\Pi}^L(\cdot,\cdot,\gamma)}{\partial\gamma} + \frac{\partial\hat{\Pi}^{L*}(\cdot,\cdot,\gamma)}{\partial\gamma}. \tag{A.10.5}$$

From (A.10.1) and (A.10.2)

$$\frac{\partial\hat{\Pi}^L(\cdot,\cdot,\gamma)}{\partial\gamma} = \frac{1}{\gamma^2}\cdot \hat{c}^L\Big(\hat{q}^L(\hat{\alpha}^L(\gamma),\gamma)\Big), \tag{A.10.6}$$

and by similar reasoning

$$\frac{\partial\hat{\Pi}^{L*}(\cdot,\cdot,\gamma)}{\partial\gamma} = \frac{1}{\gamma^2}\cdot \hat{c}^{L*}\Big(\hat{q}^{L*}(\hat{\alpha}^L(\gamma),\gamma)\Big). \tag{A.10.7}$$

Therefore,

$$\frac{d(\hat{\Pi}^L + \hat{\Pi}^{L*})}{d\gamma} = \frac{1}{\gamma^2} \cdot \left(\hat{c}^L\left(\hat{q}^L(\hat{\alpha}^L(\gamma), \gamma)\right) + \hat{c}^{L*}\left(\hat{q}^{L*}(\hat{\alpha}^L(\gamma), \gamma)\right) \right). \qquad \text{(A.10.8)}$$

Derivation of $\frac{d(\bar{\Pi}^L + \bar{l}^L)}{d\gamma}$

When γ is explicitly considered, Problem 1 from the text can be written as

$$\max_{\alpha^L, l^L} \quad \{\Pi(L) = \Pi^L(\alpha^L, \gamma) + l^L\} \qquad \text{(A.10.9)}$$

subject to :

$$\hat{\Pi}^H(\hat{\alpha}^H) + \hat{l}^H \geq \Pi^{HL}(\alpha^L) + l^L \quad ; \quad \mu^H, \qquad \text{(A.10.10)}$$

$$\Pi^{L*}(\alpha^L, \gamma) \geq l^L \quad ; \quad \lambda^L, \qquad \text{(A.10.11)}$$

where μ^H and λ^L are Lagrange multipliers. Let the argmax of this problem be given by

$$(\bar{\alpha}^L(\gamma), \bar{l}^L). \qquad \text{(A.10.12)}$$

Substituting this solution into the objective function of (A.10.9) gives

$$\bar{\Pi}^L(\bar{\alpha}^L(\gamma), \gamma) + \bar{l}^L. \qquad \text{(A.10.13)}$$

Applying the envelope theorem yields

$$\frac{d(\bar{\Pi}^L + \bar{l}^L)}{d\gamma} = \frac{\partial \bar{\Pi}^L(\cdot, \gamma)}{\partial \gamma} + \lambda^L \cdot \frac{\partial \bar{\Pi}^{L*}(\cdot, \gamma)}{\partial \gamma}, \qquad \text{(A.10.14)}$$

and by similar reasoning to that used in deriving (A.10.6)

$$\frac{d(\bar{\Pi}^L + \bar{l}^L)}{d\gamma} = \frac{1}{\gamma^2} \cdot \left(\bar{c}^L\left(\bar{q}^L(\bar{\alpha}^L(\gamma), \gamma), \gamma\right) + \lambda^L \cdot \bar{c}^{L*}\left(\bar{q}^{L*}(\bar{\alpha}^L(\gamma), \gamma), \gamma\right) \right). \qquad \text{(A.10.15)}$$

Two of the first order conditions of Problem 1 are

$$\frac{\partial \mathcal{L}}{\partial \alpha^L} = \frac{\partial \Pi^L}{\partial \alpha^L} - \mu^H \cdot \frac{\partial \Pi^{HL}}{\partial \alpha^L} + \lambda^L \cdot \frac{\partial \Pi^{L*}}{\partial \alpha^L} = 0 \qquad \text{(A.10.16)}$$

and

$$\frac{\partial \mathcal{L}}{\partial l^L} = 1 - \mu^H - \lambda^L = 0 \qquad \text{(A.10.17)}$$

from which it is clear that $0 < \lambda^L < 1$, as $\mu^H > 0$ and $\lambda^L > 0$. Given γ, combining (A.10.16) and (A.10.17) gives

$$\lambda^L = \left(\frac{\partial \Pi^L}{\partial \alpha^L} - \frac{\partial \Pi^{HL}}{\partial \alpha^L} \right) \Big/ \left(-\frac{\partial \Pi^{L*}}{\partial \alpha^L} - \frac{\partial \Pi^{HL}}{\partial \alpha^L} \right) \qquad \text{(A.10.18)}$$

calculated at $\bar{\alpha}^L$.

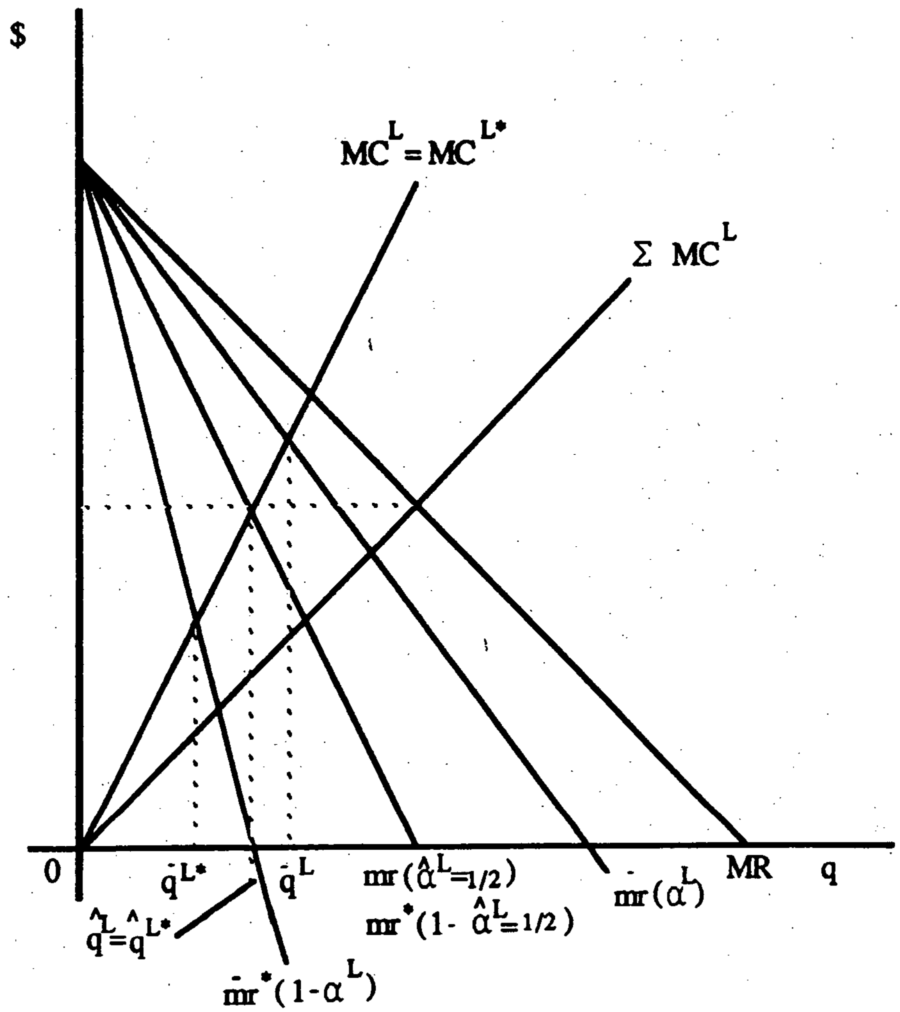
APPENDIX 11

Assume that $c^{L'''}(q) = 0$. This implies that the marginal cost curve is linear. Assume $c^L(q) = c^{L*}(q^*)$. Refer to Figure 19, where the marginal revenue curve of the world demand curve is given by MR and mr is the marginal revenue curve of the home and foreign firms when $\alpha = .5$. Under subsidiary production, output at home and abroad is given by $\hat{q}^L = \hat{q}^{L*}$. Under licensing, $\bar{\alpha}^L > \hat{\alpha}^L$, but from Figure 19 it is clear that although $\bar{q}^L - \hat{q}^L > 0$ it is also true that $\bar{q}^{L*} - \hat{q}^{L*} < 0$ and that

$$(\bar{q}^L - \hat{q}^L) + (\bar{q}^{L*} - \hat{q}^{L*}) < 0. \tag{A.11.1}$$

If marginal cost was convex in q, that is $c^{L'''}(q) > 0$, then this result would be reinforced. **(Q.E.D.)**

Figure 19



$
$MC^L = MC^{L*}$
$\Sigma\ MC^L$
0
$\bar{q}^{L*}$
$\bar{q}^L$
$mr(\hat{\alpha}^L=1/2)$
$mr^*(1-\hat{\alpha}^L=1/2)$
$\bar{mr}(\alpha^L)$
MR
q
$\hat{q}^L=\hat{q}^{L*}$
$\bar{mr}^*(1-\alpha^L)$

APPENDIX 12

A Different Relationship Between c^L and c^H.

Consider the following model. Assume that consumers buy one unit of output and are uniformly distributed around a circle. Assume that a fixed cost is associated with each production facility. Further assume that the cost of serving consumers increases with their distance from the plant. Assume that production occurs under conditions of constant returns to scale. Under these conditions, the cost function associated with the production and sale of q units of output is

$$C^L(q) = c(q) + (a - \gamma)q, \tag{A.12.1}$$

where $c(q)$ represents service costs (transportation costs), $(a - \gamma)$ represents the unit cost of production, and γ is the technology parameter $(\gamma \geq 0)$.[1] $c(q)$ is a convex function, because each consumer only buys one unit of output and to sell more output requires the firm to service consumers that are more distant from the plant. In this model, the monopolist's problem is to choose plant location and the number of plants to maximise global profit.

PROPOSITION A.12.1 *If*

$$C^L(q) = c(q) + (a - \gamma) \cdot q \tag{A.12.2}$$

and

$$C^{L'}(q) > 0, \quad C^{L''}(q) > 0 \quad \textit{and} \quad C^{L'''}(q) \geq 0, \tag{A.12.3}$$

then

$$\frac{d((\hat{\Pi}^L + \hat{\Pi}^{L*}) - (\bar{\Pi}^L + \bar{l}^L))}{d\gamma} > 0 \quad \textit{for} \quad \textit{all} \quad \gamma. \tag{A.12.4}$$

PROOF: Applying the envelope theorem as in (3.55) of the text yields

$$\frac{d\hat{\Pi}^L(\hat{\alpha}^L(\gamma), \gamma)}{d\gamma} = \hat{q}^L(\hat{\alpha}^L(\gamma), \gamma) \tag{A.12.5}$$

[1] The greater is γ the lower are production costs.

and

$$\frac{d((\hat{\Pi}^L + \hat{\Pi}^{L*}) - (\bar{\Pi}^L + \bar{l}^L))}{d\gamma} = \left(\hat{q}^L(\hat{\alpha}^L(\gamma),\gamma) + \hat{q}^{L*}(\hat{\alpha}^L(\gamma),\gamma)\right) - \left(\bar{q}^L(\bar{\alpha}^L(\gamma),\gamma) + \lambda^L \cdot \bar{q}^{L*}(\bar{\alpha}^L(\gamma),\gamma)\right) \quad \text{(A.12.6)}$$

The first term on the right hand side of (A.12.6) is the direct cost saving that results from a small increase in γ, given the technology is transferred via subsidiary. The second term is the direct increase in the licensor's profits as a result of the increase in γ. This increase in profits consists of a direct cost saving on home production, $\bar{q}^L$, and an increase in the license payment which results from the licensee's direct cost saving, $\lambda^L \cdot \bar{q}^{L*}$. Now for $c^{L'''}(q) \geq 0$

$$\hat{q}^L + \hat{q}^{L*} > \bar{q}^L + \bar{q}^{L*} \quad all \quad \bar{\alpha}. \quad \text{(A.12.7)}$$

Given $0 < \lambda^L < 1$, it is clear that

$$\frac{d((\hat{\Pi}^L + \hat{\Pi}^{L*}) - (\bar{\Pi}^L + \bar{l}^L))}{d\gamma} > 0 \quad for \quad all \quad \gamma. \quad \text{(A.12.8)}$$

(A.12.7) may be satisfied even if $c^{L'''}(q) < 0$, so $c^{L'''}(q) \geq 0$ is a sufficient condition for (A.12.8). That (A.12.7) follows from $c^{L'''}(q) \geq 0$ is shown in Appendix 11. **(Q.E.D.)**

The technology difference between the high and low cost technology exhibited in (A.12.2) shifts the high cost marginal cost curve vertically down by γ, for all q. Given $c^{L'''}(q) \geq 0$, and so (A.12.7), the direct cost saving when a subsidiary is used outweighs the direct cost saving of the licensor and the licensee. Therefore, the mode of technology transfer is more likely to be a subsidiary. This is true for all γ, and establishes that an increase in γ increases the likelihood that the technology will be transferred via a subsidiary.

APPENDIX 13

Proof of Proposition 4.1:

Let

$$p = a - b\frac{q}{\alpha}, \quad where \quad \frac{q}{\alpha} = Q \tag{A.13.1}$$

$$c^L = \frac{d}{\gamma}q^2, \quad where \quad \gamma \geq 1, \tag{A.13.2}$$

and

$$c^L = c^{L*}. \tag{A.13.3}$$

The home production facility solves the following problem.

$$\max_q \ \{\Pi = \left(a - b\frac{q}{\alpha}\right) \cdot q - \frac{d}{\gamma}q^2\}. \tag{A.13.4}$$

The solution to (A.13.4) is

$$q(\alpha, \gamma) = a \Big/ \left(\frac{2b}{\alpha} + \frac{2d}{\gamma}\right). \tag{A.13.5}$$

Substituting (A.13.5) into the objective function gives

$$\Pi(\alpha, \gamma) = \frac{a^2}{2} \Big/ \left(\frac{2b}{\alpha} + \frac{2d}{\gamma}\right) = \frac{a}{2} \cdot q(\alpha, \gamma). \tag{A.13.6}$$

Let the high cost technology be represented by $\gamma = 1$. In this example $\hat{\alpha}^H = \frac{1}{2} = \hat{\alpha}^L$, because $c^H = c^{H*}$ and $c^L = c^{L*}$. Therefore,

$$\hat{\Pi}^H + \hat{\Pi}^{H*} = a^2/(4b + 2d). \tag{A.13.7}$$

Under exporting, $\alpha = 1$, so

$$\hat{\Pi}^H_X = a^2/(4b + 4d). \tag{A.13.8}$$

By similar arguments

$$\hat{\Pi}^L + \hat{\Pi}^{L*} = a^2 \Big/ \left(4b + \frac{2d}{\gamma}\right) \tag{A.13.9}$$

and

$$\hat{\Pi}^L_X = a^2 \Big/ \left(4b + \frac{4d}{\gamma}\right). \tag{A.13.10}$$

Combining (A.13.7), (A.13.8), (A.13.9), and (A.13.10) implies that

$$\hat{\Pi}^L + \hat{\Pi}^{L*} - \hat{\Pi}_X^L > \hat{\Pi}^H + \hat{\Pi}^{H*} - \hat{\Pi}_X^H \tag{A.13.11}$$

if

$$4b^2(1-\gamma) + 2d^2\left(1 - \frac{1}{\gamma}\right) > 0, \tag{A.13.12}$$

that is, if

$$\gamma < \frac{1}{2}\left(\frac{d}{b}\right)^2. \tag{A.13.13}$$

(Q.E.D.)

APPENDIX 14

PROPOSITION A.14.1: *If the technology difference is characterised by the parameter γ in the following cost function*

$$C^L(q) = c(q) + (a - \gamma)q \tag{A.14.1}$$

(This cost function is assumed to have the properties assumed in Appendix 12), then

$$\hat{\Pi}^L + \hat{\Pi}^{L*} - \hat{\Pi}_X^L > \hat{\Pi}^H + \hat{\Pi}^{H*} - \hat{\Pi}_X^H \quad \forall\, \gamma. \tag{A.14.2}$$

PROOF: Given (A.14.1), the low cost marginal cost curve is given by a vertical shift downwards of the high cost marginal cost curve. This is shown in Figure 20, where linear marginal cost and linear demand is also assumed. In the diagram

$$\hat{\Pi}^H + \hat{\Pi}^{H*} - \hat{\Pi}_X^H = abc \tag{A.14.3}$$

and

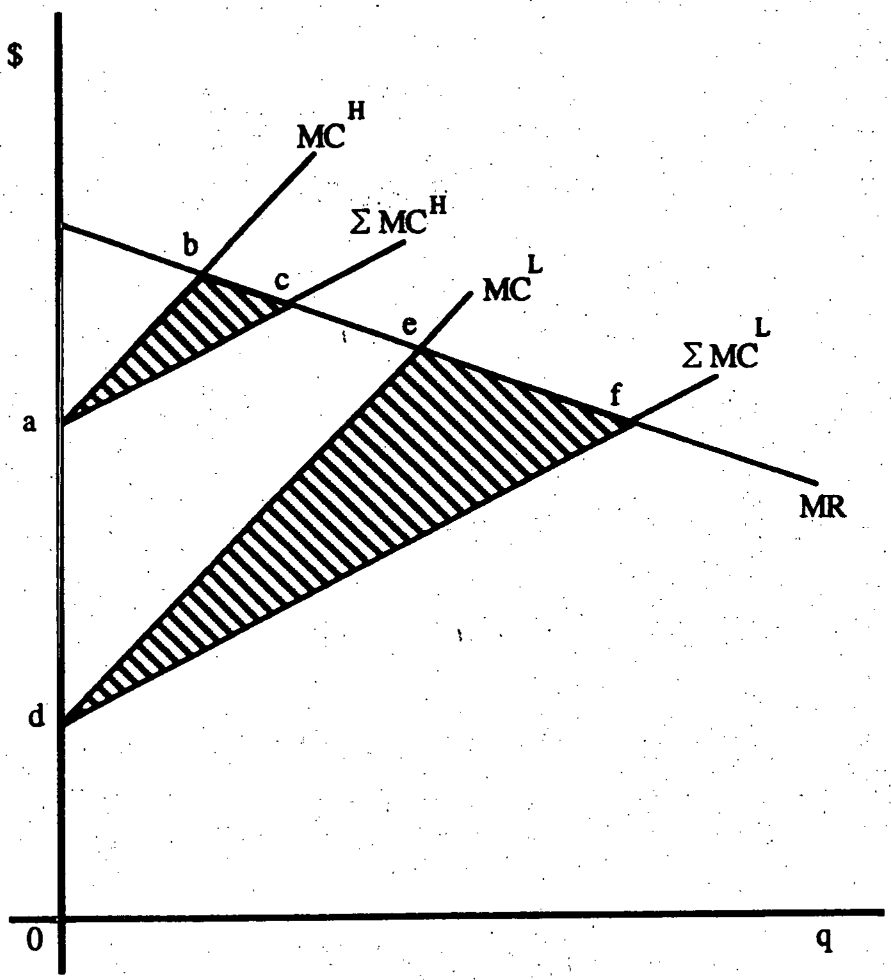
$$\hat{\Pi}^L + \hat{\Pi}^{L*} - \hat{\Pi}_X^L = def. \tag{A.14.4}$$

Clearly

$$\hat{\Pi}^L + \hat{\Pi}^{L*} - \hat{\Pi}_X^L > \hat{\Pi}^H + \hat{\Pi}^{H*} - \hat{\Pi}_X^H. \tag{A.14.5}$$

From the diagram it is also clear that this is true for all $\gamma > 0$, because the low cost technology results in greater output. In fact, (A.14.5) is true for all downward sloping marginal revenue curves and all upward sloping marginal cost curves, because in these circumstances the low cost technology results in greater output. **(Q.E.D.)**

Figure 20



APPENDIX 15

The first order conditions of problem (4.34)–(4.36) in the text are

$$\frac{\partial \mathcal{L}}{\partial \alpha^L} = (1-\tau)\cdot\frac{\partial \Pi^L}{\partial \alpha^L} - \mu^H\cdot(1-\tau)\cdot\frac{\partial \Pi^{HL}}{\partial \alpha^L} + \lambda^L\cdot(1-\tau^*)\cdot\frac{\partial \Pi^{L*}}{\partial \alpha^L} = 0, \quad \text{(A.15.1)}$$

$$\frac{\partial \mathcal{L}}{\partial l^L} = 1 - \mu^H - \lambda^L = 0, \quad \text{(A.15.2)}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda^L} = (1-\tau^*)\cdot\Pi^{L*}(\alpha^L) - l^L = 0, \quad \text{(A.15.3)}$$

$$\frac{\partial \mathcal{L}}{\partial \mu^H} = (1-\tau)\cdot\Pi^H(\hat{\alpha}_T^H) + \hat{l}_T^H - (1-\tau)\cdot\Pi^{HL}(\alpha^L) - l^L = 0. \quad \text{(A.15.4)}$$

Substituting (4.53) and (A.15.3) into (A.15.4), differentiating with respect to τ^* and applying the envelope theorem yields

$$\begin{aligned} &-\left((1-\tau)\cdot\frac{\partial \Pi^{HL}}{\partial \alpha^L} + (1-\tau^*)\cdot\frac{\partial \Pi^{L*}}{\partial \alpha^L}\right)\cdot d\bar{\alpha}_T^L \\ &+ \left(\bar{\Pi}^{L*}(\bar{\alpha}^L) - \hat{\Pi}^{H*}(\hat{\alpha}_T^H)\right)\cdot d\tau^* = 0. \end{aligned} \quad \text{(A.15.5)}$$

Therefore,

$$\frac{d\bar{\alpha}_T^L}{d\tau^*} = \frac{\left(\bar{\Pi}^{L*}(\bar{\alpha}^L) - \hat{\Pi}^{H*}(\hat{\alpha}^H)\right)}{(1-\tau)\cdot\frac{\partial \Pi^{HL}}{\partial \alpha^L} + (1-\tau^*)\cdot\frac{\partial \Pi^{L*}}{\partial \alpha^L}} > 0. \quad \text{(A.15.6)}$$

APPENDIX 16

The licensee's problem is

$$\max_{q^{L*}} \quad \{\Pi(L*) = p\big(q^{L*}/(1-\alpha^L)\big) \cdot q^{L*} - c^{L*}(q^{L*}) - r^L \cdot q^{L*}\} \tag{A.16.1}$$

which is solved for $q^{L*}(\alpha^L, r^L)$ (Assume the second order condition for a maximum is satisfied). Substituting this solution into the objective function gives $\Pi_N^{L*}(\alpha^L, r^L)$. Applying the envelope theorem yields

$$\frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial \alpha^L} = \frac{dp}{d\big(q^{L*}/(1-\alpha^L)\big)} \cdot \frac{\big(q^{L*}(\alpha^L, r^L)\big)^2}{(1-\alpha^L)^2} < 0 \tag{A.16.2}$$

and

$$\frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial r^L} = -q^{L*}(\alpha^L, r^L) < 0. \tag{A.16.3}$$

APPENDIX 17

Stability

The duopoly model outlined in Section 7.2 analyses a static, simultaneous-move game. As such, stability conditions have no real foundation as adjustment processes towards equilibrium do not exist. However, there is a long tradition of using stability conditions to help sign comparative static results, and Section 7.2 follows this tradition.[1] Let

$$a = \frac{d^2p}{\left(d(q+q^*)\right)^2} \cdot q + 2 \cdot \frac{dp}{d(q+q^*)} - \frac{1}{\gamma} \cdot c''(\cdot) < 0, \tag{A.17.1}$$

$$a^* = \frac{d^2p}{\left(d(q+q^*)\right)^2} \cdot q^* + 2\frac{dp}{d(q+q^*)} - \frac{1}{\gamma} \cdot c^{*''}(\cdot) < 0, \tag{A.17.2}$$

$$b = \frac{d^2p}{\left(d(q+q^*)\right)^2} \cdot q + \frac{dp}{d(q+q^*)}, \tag{A.17.3}$$

and

$$b^* = \frac{d^2p}{\left(d(q+q^*)\right)^2} \cdot q^* + \frac{dp}{d(q+q^*)}. \tag{A.17.4}$$

Stability requires

$$a < 0, \quad a^* < 0, \tag{A.17.5}$$

$$b < 0, \quad b^* < 0, \tag{A.17.6}$$

and

$$\Delta = a \cdot a^* - b \cdot b^* > 0. \tag{A.17.7}$$

These conditions are outlined in Dixit (1986).

[1] Dixit (1986) and Quirmbach (1988) discuss the inappropriateness of stability conditions, but in the absence of a genuinely dynamic model they continue to use stability conditions to help sign comparative static results.

Second Order Condition For a Maximum

Differentiating F.O.C. (7.26) with respect to r yields the following

$$\begin{aligned}\frac{\partial^2 \Pi_d}{(\partial r)^2} = & \frac{d^2 p}{\left(d(q+q^*)\right)^2} \cdot \left(\frac{\partial q}{\partial r} + \frac{\partial q^*}{\partial r}\right) \cdot \frac{\partial q^*}{\partial r} \cdot q + \frac{dp}{d(q+q^*)} \cdot \frac{\partial^2 q^*}{(\partial r)^2} \cdot q \\ & + \frac{dp}{d(q+q^*)} \cdot \frac{\partial q^*}{\partial r} \cdot \frac{\partial q}{\partial r} + \frac{d^2 p}{\left(d(q+q^*)\right)^2} \cdot \left(\frac{\partial q}{\partial r} + \frac{\partial q^*}{\partial r}\right) \cdot \frac{\partial q}{\partial r} \cdot q^* \\ & + \frac{dp}{d(q+q^*)} \cdot \frac{\partial^2 q}{(\partial r)^2} \cdot q^* + \frac{dp}{d(q+q^*)} \cdot \frac{\partial q}{\partial r} \cdot \frac{\partial q^*}{\partial r} \\ & + r \cdot \frac{\partial^2 q^*}{(\partial r)^2} + \frac{\partial q^*}{\partial r}.\end{aligned} \tag{A.17.8}$$

Assume linear demand and linear marginal cost, then

$$\frac{d^2 p}{\left(d(q+q^*)\right)^2} = 0, \qquad \frac{\partial^2 q}{(\partial r)^2} = 0, \qquad \textit{and} \qquad \frac{\partial^2 q^*}{(\partial r)^2} = 0, \tag{A.17.9}$$

so (A.17.8) equals

$$\frac{\partial^2 \Pi_d}{(\partial r)^2} = 2 \cdot \frac{dp}{d(q+q^*)} \cdot \frac{\partial q^*}{\partial r} \cdot \frac{\partial q}{\partial r} + \frac{\partial q^*}{\partial r}. \tag{A.17.10}$$

Rearranging (A.17.10) gives

$$\frac{\partial^2 \Pi_d}{(\partial r)^2} = \left(2 \cdot \frac{dp}{d(q+q^*)} \cdot \frac{\partial q}{\partial r} + 1\right) \cdot \frac{\partial q^*}{\partial r}. \tag{A.17.11}$$

Now

$$\frac{\partial q}{\partial r} = \frac{-b}{\Delta} = -\left(\frac{dp}{d(q+q^*)} / \Delta\right) > 0 \tag{A.17.12}$$

and

$$\frac{\partial q^*}{\partial r} = \frac{a}{\Delta} = \left(\left(2 \cdot \frac{dp}{d(q+q^*)} - \frac{1}{\gamma} \cdot c''\right) / \Delta\right) < 0, \tag{A.17.13}$$

so

$$\frac{\partial^2 \Pi_d}{(\partial r)^2} = \left(\frac{-2 \cdot \left(\frac{dp}{d(q+q^*)}\right)^2}{\Delta} + 1\right) \cdot \frac{\partial q^*}{\partial r}. \tag{A.17.14}$$

Now

$$\Delta = 3\left(\frac{dp}{d(q+q^*)}\right)^2 - \frac{2}{\gamma} \cdot \frac{dp}{d(q+q^*)} \cdot (c'' + c^{*''}) + \frac{1}{\gamma^2} \cdot c'' \cdot c^{*''}, \tag{A.17.15}$$

so

$$\Delta > 2\left(\frac{dp}{d(q+q^*)}\right)^2, \tag{A.17.16}$$

and

$$\frac{\partial^2 \Pi_d}{(\partial r)^2} < 0. \tag{A.17.17}$$

Therefore, the second order condition for a maximum is satisfied.