

WORKING PAPERS IN ECONOMICS

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

by

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Abstract

This paper develops a partial equilibrium monopoly model of international technology transfer in which both the extent of technological change and the mode of technology transfer are endogenous. The model is then used to analyse the welfare effects of various policies that are often recommended or enacted in practice. In general the welfare effects are ambiguous as they depend on the parameters of the model; nevertheless, this paper outlines welfare effects that have not been formalised previously and which are important in any proper analysis of policy regarding international technology transfer.

* Department of Economics, The University of Sydney. This paper is drawn from Chapters 3 and 4 of my doctoral dissertation at the University of British Columbia. I thank Brian Copeland, Barbara Spencer, and John Weymark for helpful comments and discussions.

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1. INTRODUCTION

In recent years the international transfer of technology has become an important policy issue. Governments in countries that export technology receive pressure from interested parties to ban particular modes of transfer because some modes are thought to result in a loss of jobs, weaken a country's competitive position in world trade, or erode a technological lead [Teece (1981)]. On the other hand, governments in countries that import technology contemplate bans on particular modes of transfer because some modes are thought to provide little in the way of benefits, for example, technology transfer via subsidiary [Teece (1981), Bardhan (1982)].

The literature that developed to analyse the welfare effects of international technology transfer initially made the assumption that both technological change and the mode of technology transfer were exogenous [Rodriguez (1975), McCulloch and Yellen (1982)]. It is now realised that both of these assumptions are inappropriate for any proper welfare and policy analysis of international technology transfer because both technological change and the mode of technology transfer are decision variables for the firm and so should be endogenous.

Pugel (1982) and Feenstra and Judd (1982) endogenised technological change; however, both failed to endogenise the mode of technology transfer. Similarly, the modern product cycle literature [Krugman (1979), and Jensen and Thursby (1986)] has failed to make the mode of technology transfer a decision variable for the firm.

This paper fills a gap in the literature by developing a model in which both technological change and the mode of technology transfer are decision variables for the firm. A thorough welfare analysis of policies designed to alter the mode of technology transfer is then undertaken. The framework used is partial equilibrium, and monopoly is assumed to capture the idea that a new technology provides at least temporary monopoly power to its owner.

Technological change is endogenised by allowing the owner of the new technology to undertake R&D to lower its production costs. The *eclectic theory* of direct foreign investment [Dunning (1979)] provides the vehicle for endogenising the mode of technology transfer. In this theory, three conditions are necessary for direct foreign investment. The first is an ownership advantage which, for our purposes, is provided by the new technology; the second is a locational advantage so that it is optimal to produce some output in a foreign country (that is, technology is not transferred via the export of goods); and the third is that it must be more beneficial to transfer the ownership advantage (the new technology) internally rather than sell it through arm's length contracts to independent firms (that is, via a license agreement). A novel aspect of this paper is the explicit modelling of the internalisation decision.¹

The choice between technology transfer via a wholly owned subsidiary and technology transfer via a license agreement depends on the interaction of a fixed cost, that is associated with transfer via subsidiary, and an information asymmetry, that is associated with transfer via a license agreement. The fixed cost, k , 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 production cost disadvantage relative to a licensee because 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 . Alternatively, k may be interpreted as the cost associated with the possibility of expropriation by foreign governments or the cost of operating at a distance.

An information asymmetry is present whenever information is being transferred. The owner of the new technology (information) knows its true value whereas potential licensees can only value the technology after it has been examined. However, once it has been

¹ Internalisation was explicitly modelled by Ethier (1986); however, his model of the multinational firm had material inputs being transferred rather than technology.

examined the licensee has no incentive to buy the new technology for the licensee already has all the information necessary to use it.²

The model and assumptions are outlined in section 2 and the licensing problem under asymmetric information is solved. This problem is an example of an informed principal problem [Myerson 1983] whereby the owner of the new technology wants to design a license contract to maximise its profit, given it knows the characteristics of the technology but potential licensees do not. It is shown that a license contract which contains a market share restriction and a lump sum payment can overcome the information asymmetry, though at a cost. This is a new result which is very satisfying as both market share restrictions and lump sum payments are regularly found in actual license contracts [Caves, Crookwell, and Killing (1983)].

The cost associated with the asymmetric information interacts with the fixed cost k and locational considerations to determine the mode of transfer. In a recent paper, Gallini and B. Wright (1988) show that output-based payments (royalties) can be used to solve the licensing problem. However, their model does not allow the owner of the new technology to produce the product nor does it consider the choice between modes of transfer in an international setting.³

In section 2 it is also shown that the amount of R&D undertaken varies with the mode of transfer. This result has important welfare implications which are explored in section 3 which deals with welfare and policy. The welfare measure used for the home country is the sum of expected monopoly profit and expected consumer surplus while for the foreign country welfare is measured by expected consumer surplus alone. It is shown that policies

² An internationally enforceable patent system can overcome the information asymmetry. Nevertheless, because of imitation there are many technologies for which national patent protection is difficult so that international patent protection is virtually impossible [Levin (1986)]. A further complication arises from the patenting process itself because the patent provides information about the technology which may be used by potential licensees at zero cost. In fact, Mansfield and Rowe (1980) argue that imitation usually occurs via reverse engineering and that patent information is often important in this process. In these circumstances it is in the interests of the owner of the new technology to keep details of the technology secret [Horstman, MacDonald and Slivinski (1985)].

³ D.J. Wright (1989) incorporates royalty payments into license contracts in an international setting.

which restrict the mode of transfer can have ambiguous welfare results because a profit, a price and an R&D effect move welfare in different directions depending on the parameters of the model. These welfare effects have not been formalised in the literature to date and yet may be important in analysing international technology transfer policy. Ambiguous results, which depend on the parameters of the model, imply that a case by case approach to policy may be required. Section 4 contains some concluding comments as well as some suggestions for future research.

2. THE MODEL

2.1. THE DECISION STRUCTURE

It is assumed that a firm has discovered a new product that gives this firm monopoly power in the world market. Before beginning production or transferring the technology for producing this product abroad, the monopolist can undertake R&D expenditure in order to reduce production costs (this is the sense in which technological change is endogenous). The objective of the monopolist is to maximise profit by choice of R&D expenditure, the mode of technology transfer, and the global allocation of production. In solving this problem it is natural to assume that the choice of R&D occurs before the choice of the mode of technology transfer and that both of these choices are made prior to the final choice of production levels at home and abroad. Therefore, the structure of this decision process consists of three stages.

In the first stage, the monopolist chooses R&D expenditure. At the time of this choice the monopolist is uncertain about the result of the 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. It is assumed that technology type is immediately revealed to the monopolist once the R&D expenditure is made.

In the second stage, given technology type, the monopolist chooses the mode of technology transfer. The three modes of transfer considered are; (1) exporting the final good, (2) production abroad in wholly-owned subsidiaries, and (3) licensing of foreign producers.⁴ It is assumed that a fixed cost, k , is associated with subsidiary production. It is further assumed that an asymmetry of information exists between the owner of the technology and potential licensees. Specifically, in the 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 assumed that ρ^* is exogenously given.⁵ The interaction of k with the information asymmetry determines whether foreign production is undertaken by wholly owned subsidiaries (internalised) or undertaken by licensees.

In the third stage, given technology type and the mode of technology transfer, the monopolist chooses the global allocation of production. The monopolist's overall problem is a multi-stage maximisation problem and is solved backwards to guarantee that optimal choices are made after the completion of each stage.

2.2. THE ASSUMPTIONS

The new technology is licensed monopolistically to a foreign firm. Bidding for license contracts is competitive and both the licensor and licensee are risk neutral. Technology type is unable to be objectively verified, the licensee's subjective probability that the low cost technology has occurred is identical for all potential licensees and known by the licensor, and third party arbitrage between the market of the licensor and the licensee is prohibitively costly.⁶

⁴ The export of goods is included in the definition of technology transfer because it allows foreigners access to the fruits of the new technology.

⁵ Wright (1989) relaxes this assumption by making ρ^* a function of the observed R&D expenditure of the monopolist. Other methods of endogenising ρ^* are also possible.

⁶ This prohibitive cost may result from larger product service costs for the arbitrager as compared to the licensor or licensee or it may result from firm-specific warranties. The existence of price differences between markets for identical products is documented in Kravis and Lipsey (1977).

License Contracts: License contracts contain a market share restriction of α for the licensor and 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 because it eliminates competition between the licensor and the licensee by giving each monopoly power over a certain segment of the world market. Market share restrictions are also relatively easy to enforce and are often found in actual license agreements.⁷ A lump sum license payment rather than an output based payment is included in the contract because it simplifies the analysis.⁸

License contracts can not be renegotiated after the technology has been transferred. 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), Cooper (1984), Maskin and Riley (1984), and Weymark (1986)]. This assumption 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)]. To overcome this problem it is assumed that the renegotiation process is prohibitively costly.

Cost Conditions: Relative cost conditions determine locational advantage and so determine the global allocation of production. Although the world is assumed to consist of many countries, for simplicity it is assumed that profitable production can take place in only two.⁹ These two countries will be referred to as home and foreign. It is further assumed that the owner of the new product/technology is domiciled in the home country.

The home firm's cost function is given by $c^i(q^i)$, $i = H, L$; where H and L signify

⁷ Caves, Crookwell and Killing (1983), using survey data, found that 34% of license agreements contained a market share restriction.

⁸ Katz and Shapiro (1985) also use lump sum payments in their analysis. Wright (1989) analyses the use of per unit royalties in license contracts.

⁹ 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.

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 marginal cost is positive and increases with output so that $dc^i/dq^i > 0$ and $d^2c^i/dq^{i2} > 0$. The foreign firm's cost function is also assumed to be characterised by positive and increasing marginal cost.¹⁰ The relationship between the high cost and low cost cost function is assumed to be the following

$$c^L(q^i) = \frac{1}{\gamma} \cdot c^H(q^i), \quad \text{where } \gamma \geq 1. \quad (2.1)$$

Demand Conditions: It is assumed that all consumers have identical individual demand curves and that the world demand curve is 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 $p = f^{-1}(Q_d)$. It is further assumed that the monopolist's revenue function is strictly concave, that is $TR''(Q_d) < 0$, where $TR = f^{-1}(Q_d) \cdot Q_d$.

2.3. STAGE THREE

In Stage Three, given technology type and the mode of technology transfer, the monopolist chooses the global allocation of production. For expositional purposes the complete information problem is solved first and then the incomplete (asymmetric) information problem is solved.

2.3.1. COMPLETE INFORMATION

In this sub-section it is assumed that potential licensees know the technology type. Traditionally the monopolist's problem is to maximise global profit by choosing output levels for the home and foreign firm (the foreign firm may be a subsidiary or a licensee).¹¹

¹⁰ These assumptions are made in Horstmann and Markusen (1987), and are standard in the multi-plant monopoly literature.

¹¹ This problem is just the traditional multi-plant monopolist problem extended so that each plant is located in a different country [Scherer *et al.* (1975)].

In this paper the monopolist's stage three problem has two sub-stages. In the first sub-stage the monopolist maximises global profit by choosing the home firm's market share and the foreign firm's lump sum payment. In the second sub-stage, given the market share arising from sub-stage one, each firm maximises profit by choosing output.¹² 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 home firm's demand curve is $q_d = \alpha \cdot f(p)$ and its inverse demand curve is $p = \bar{f}^{-1}(q_d/\alpha)$.¹³ The home firm's second sub-stage problem is

Problem 1:

$$\max_{q^i} p(q^i/\alpha^i) \cdot q^i - c^i(q^i), \quad i = H, L. \quad (2.2)$$

It is assumed that the second order condition for a maximum is satisfied. Let the argmax of (2.2) be given by $q^i(\alpha^i)$. Substituting this into the objective function yields home firm maximised profit as a function of α^i . Let this be given by $\Pi^i(\alpha^i)$. Solving a similar problem for the foreign firm yields $\Pi^{i*}(\alpha^i)$.

The monopolist's first sub-stage problem is

Problem 2:

$$\max_{\alpha^i, l^i} \{\Pi(i) \equiv \Pi^i(\alpha^i) + l^i\}, \quad i = H, L \quad (2.3)$$

subject to:

$$\Pi^{i*}(\alpha^i) - k - l^i \geq 0, \quad (2.4)$$

where l^i is the lump sum transfer paid by the foreign firm to the home firm. Constraint (2.4) is included because the lump sum payment from the foreign firm can not be greater than the profit it derives from a market share of $(1 - \alpha)$ minus the fixed cost k .

The export, subsidiary, and licensing problems are special cases of Problems 1 and 2. The export problem is obtained by fixing $k = 0$, $l^i = 0$, and $\alpha^i = 1$ as all of the world

¹² This problem yields identical solutions for output as the traditional formulation of the monopolist's problem.

¹³ At $\alpha = 0$ it is assumed that $p = 0$.

market is served by the home firm. The subsidiary problem is obtained by fixing $k > 0$, and the licensing problem is obtained by fixing $k = 0$ and interpreting I^i as the license payment under competitive bidding for the technology.

In the subsidiary and licensing problems, constraint (2.4) always binds so it can be substituted into the objective function of Problem 2. Assuming an interior solution, the first order condition for a maximum is

$$\frac{d\Pi(i)}{d\alpha^i} \equiv \frac{d\Pi^i(\alpha^i)}{d\alpha^i} + \frac{d\Pi^{i*}(\alpha^i)}{d\alpha^i} = 0. \quad (2.5)$$

In Appendix 1 it is shown that

$$\frac{d^2\Pi^i(\alpha^i)}{d\alpha^{i2}} < 0 \quad \text{and} \quad \frac{d^2\Pi^{i*}(\alpha^i)}{d\alpha^{i2}} < 0 \quad (2.6)$$

which guarantees that the second order condition for a maximum to Problem 2 is satisfied.

Let the solution to (2.5) be given by $\bar{\alpha}^i$, and let $\bar{\Pi}^i$ and $(\bar{\Pi}^{i*} - k)$ represent maximised profit of the home and foreign firms respectively. Given binding constraint (2.4), this latter term equals the lump sum payment made by the foreign firm to the home firm which is denoted by \bar{I}^i . Let $\bar{\Pi}_X^i$ denote maximised profit under technology transfer via the export of goods.

The solutions to the monopolist's export, subsidiary, and licensing problems can be illustrated diagrammatically. The objective of the monopolist is to choose I^i and α^i so that it attains the highest global iso-profit curve subject to $\Pi^{i*}(\alpha^i) - k \geq I^i$. Global iso-profit curves have a slope given by

$$\frac{dI^i}{d\alpha^i} = -\frac{d\Pi^i(\alpha^i)}{d\alpha^i} \quad (2.7)$$

and are strictly convex as it is clear from (2.6) that $\Pi^i(\alpha^i)$ is strictly concave in α^i . The constraint set is a convex set as $\Pi^{i*}(\alpha^i)$ is strictly concave in $(1 - \alpha^i)$.

Combining (2.5) and (2.7) implies that global profit maximisation occurs where

$$\frac{d\Pi^{i*}(\alpha^i)}{d\alpha^i} = -\frac{d\Pi^i(\alpha^i)}{d\alpha^i} = \frac{dI^i}{d\alpha^i}. \quad (2.8)$$

If the high cost technology has occurred, the solution to the licensing problem is given by $(\hat{\alpha}^H, \hat{I}^H)$ and is characterised in Figure 1 by the tangency of $\Pi^{H*}(\alpha^H)$ with global iso-profit curve I_0^H . This occurs at point E. The solution to the subsidiary problem is given by $(\hat{\alpha}^H, \hat{\Pi}^{H*} - k)$ and solution to the export problem occurs at point G where $\alpha = 1$.

In Appendix 2 it is shown that

$$\frac{d\Pi^L}{d\alpha^L} > \frac{d\Pi^H}{d\alpha^H} > 0 \quad \text{for} \quad \alpha^L = \alpha^H. \quad (2.9)$$

If the low cost technology has occurred, the solution to the licensing problem is $(\hat{\alpha}^L, \hat{I}^L)$ and is characterised in Figure 1 by the tangency of $\Pi^{L*}(\alpha^L)$ with global iso-profit curve I_0^L . This occurs at point F.¹⁴ The solution to the subsidiary problem is $(\hat{\alpha}^L, \hat{\Pi}^{L*} - k)$, and the solution to the export problem is $\alpha = 1$.

2.3.2. INCOMPLETE INFORMATION

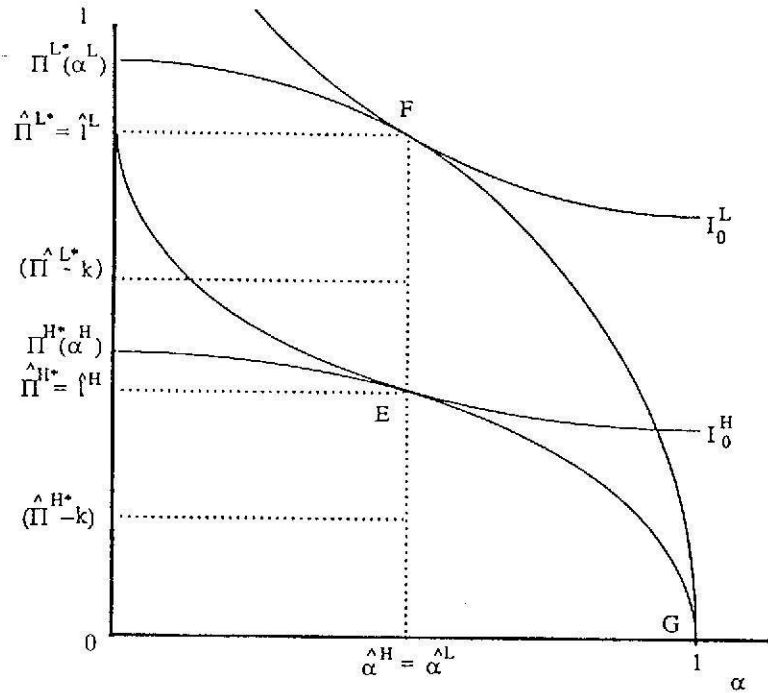
Incomplete or asymmetric information is only present when technology is transferred via license. Given the monopolist knows whether the technology is low cost or high cost while potential licensees only have some subjective probability, ρ^* , that the technology is low cost, the monopolist's licensing problem is to maximise global profit by designing a license contract.

The presence of the information asymmetry ensures that the complete information solution characterised in Figure 1 is not implementable because the contract $(\hat{\alpha}^L, \hat{I}^L)$ is never accepted by a licensee as the licensor offers $(\hat{\alpha}^L, \hat{I}^L)$ regardless of technology type. The Revelation Principle simplifies the monopolist's incomplete information problem by reducing it to one of maximising profit by making a contract offer, subject to certain self selection (truth telling) and participation constraints.¹⁵

¹⁴ For simplicity it has been assumed that $c(q) = c^*(q^*)$ so that $\hat{\alpha}^H = \frac{1}{2} = \hat{\alpha}^L$.

¹⁵ 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).

Figure 1



In general two solutions to the licensor's problem are possible. The first is a separating solution in which a different contract is associated with each technology type and the licensor reveals technology type through the contract offered. As technology type is revealed by the contract offer licensee participation requires

$$l^i \leq \Pi^{i*}(\alpha^i). \quad (2.10)$$

The second solution is a pooling solution in which the same contract is offered regardless of technology type. As technology type is not revealed by the contract offer licensee participation only requires

$$l \leq \rho^* \cdot \Pi^{L*}(\alpha) + (1 - \rho^*) \cdot \Pi^{H*}(\alpha), \quad (2.11)$$

where

$$l^H = l^L = l \quad \text{and} \quad \alpha^H = \alpha^L = \alpha. \quad (2.12)$$

The Separating Solution: If the high cost technology has occurred, the license contract that maximises global profit is given by

$$(\hat{\alpha}^H, \hat{l}^H = \hat{\Pi}^{H*}(\hat{\alpha}^H)). \quad (2.13)$$

This is the complete information solution.

If the low cost technology has occurred and given $(\hat{\alpha}^H, \hat{l}^H)$, then the monopolist's problem is

Problem 3:

$$\max_{\alpha^L, l^L} \{ \Pi(L) = \Pi^L(\alpha^L) + l^L \} \quad (2.14)$$

subject to:

$$\hat{\Pi}^H(\hat{\alpha}^H) + \hat{l}^H \geq \Pi^{HL}(\alpha^L) + l^L \quad (2.15)$$

and

$$\Pi^{L^*}(\alpha^L) \geq l^L. \quad (2.16)$$

Constraint (2.15) is the self selection constraint which requires that the contract which solves Problem 3 is offered if and only if the low cost technology has occurred. $\Pi^{HL}(\alpha^L)$ is defined as follows

$$\Pi^{HL}(\alpha^L) \equiv \max_{q^{HL}} p(q^{HL}/\alpha^L) \cdot q^{HL} - c^H(q^{HL}), \quad (2.17)$$

and represents maximised home firm profit if the high cost technology has occurred and the licensor offers α^L in the license contract. Constraint (2.16) is the licensee participation constraint.

The solution to Problem 3 is derived in Figure 2. The licensee participation constraint requires (α^L, l^L) to lie on or below $\Pi^{L^*}(\alpha^L)$. Given $(\hat{\alpha}^H, \hat{l}^H)$, the self selection constraint requires (α^L, l^L) to lie on or below I_0^H . Given these constraints, the global profit associated with global iso-profit curve I_1^L is the maximum attainable and is achieved at point B with contract

$$(\bar{\alpha}^L, \bar{l}^L), \quad (2.18)$$

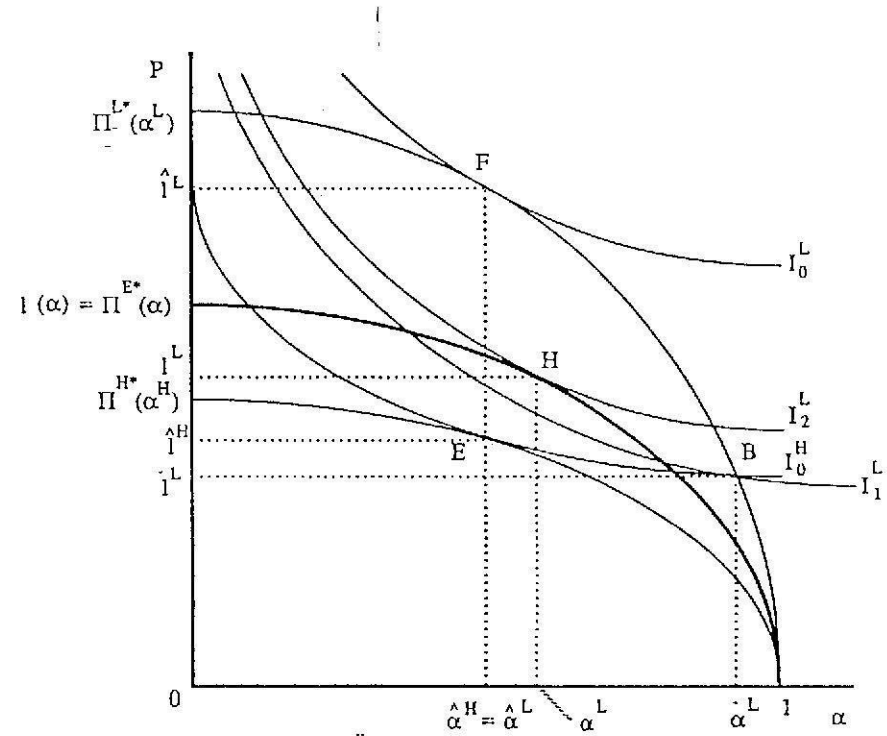
where $\bar{\alpha}^L > \hat{\alpha}^L$ and $\bar{l}^L = \bar{\Pi}^{L^*}(\bar{\alpha}^L) < \hat{l}^L$.¹⁶

Combining (2.13) and (2.18) yields the following separating solution

$$(\hat{\alpha}^H, \hat{l}^H) ; (\bar{\alpha}^L, \bar{l}^L). \quad (2.19)$$

The intuition behind this solution is clear. If the high cost technology has occurred, the licensor is able to obtain complete information 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 has occurred, the licensor must distort its contract offer away from the

Figure 2



¹⁶ This contract arises because $\frac{d\Pi^L}{d\alpha^L} > \frac{d\Pi^H}{d\alpha^L}$ for all α . The result that $\frac{d\Pi^L}{d\alpha^L} > \frac{d\Pi^H}{d\alpha^L}$ for all α is known in the asymmetric information 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) and Maskin and Riley (1984)].

complete information solution to convince the licensee that the low cost technology has occurred. This requires a contract offer of $(\hat{\alpha}^L, \hat{l}^L)$. 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 global profit with contract $(\bar{\alpha}^L, \bar{l}^L)$. In Figure 2 this cost is represented by the vertical distance between global iso-profit curves I_0^L and I_1^L .¹⁷

From the above it is clear that the licensee's subjective probability, ρ^* , does not influence the contracts offered in the separating solution. This is not so in the pooling solution.

The Pooling Solution: If the low cost technology has occurred, the licensor's problem is

Problem 4:

$$\max_{\alpha, l} \{ \Pi(L) = \Pi^L(\alpha) + l \} \quad (2.20)$$

subject to:

$$\Pi^{E*} = \rho^* \cdot \Pi^{L*}(\alpha) + (1 - \rho^*) \cdot \Pi^{H*}(\alpha) \geq l. \quad (2.21)$$

At the solution to this problem (2.21) always binds, so the first order condition for a maximum is

$$\frac{d\Pi^L}{d\alpha} = -(1 - \rho^*) \cdot \frac{d\Pi^{H*}}{d\alpha} - \rho^* \cdot \frac{d\Pi^{L*}}{d\alpha}. \quad (2.22)$$

From (2.6) it is clear that the second order condition for a maximum is satisfied. Let the solution to (2.22) be given by $\hat{\alpha}^L$. At $\hat{\alpha}^L$

$$\frac{d\Pi^L}{d\alpha} > -(1 - \rho^*) \cdot \frac{d\Pi^{H*}}{d\alpha} - \rho^* \cdot \frac{d\Pi^{L*}}{d\alpha}, \quad (2.23)$$

because

$$\frac{d\Pi^{H*}}{d\alpha} > \frac{d\Pi^{L*}}{d\alpha} \quad \text{and} \quad \frac{d\Pi^L}{d\alpha^L} = \frac{d\Pi^{L*}}{d\alpha^L}. \quad (2.24)$$

The second order condition for a maximum together with (2.23) imply that $\hat{\alpha}^L > \bar{\alpha}^L$. That is, in the pooling solution, the market share of the home firm is greater than its complete information market share.

The solution to Problem 4 is shown in Figure 2. The area below $l(\alpha)$ represents constraint (2.21). Given this constraint and given that the low cost technology has occurred, the licensor tries to get on its highest global iso-profit curve. This occurs at point II where $l(\alpha)$ and I_2^L are tangent. Therefore the contract offered in the pooling solution is

$$(\hat{\alpha}^L, \hat{l}^L), \quad (2.25)$$

where

$$\bar{\Pi}^{H*}(\hat{\alpha}^L) < \hat{l}^L < \bar{\Pi}^{L*}(\hat{\alpha}^L). \quad (2.26)$$

If the high cost technology has occurred, the best the licensor can do is continue to offer contract (2.25). If a different contract is offered, the licensee must infer that the high cost technology has occurred and so will only accept the offer if the lump sum payment is less than or equal to its profit.¹⁸ From Figure 2 it is clear that such a constraint reduces the licensor's profit because $\bar{\Pi}^{H*}(\alpha^H)$ lies completely inside $\bar{\Pi}^{E*}(\alpha)$. Therefore, the pooling solution involves a contract offer of $(\hat{\alpha}^L, \hat{l}^L)$ 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 1: Let ρ_c^* be the critical ρ^* at which the licensor is indifferent between the

¹⁸ This is an application of the intuitive criterion of Cho and Kreps (1987).

¹⁷ In many adverse selection models [Cooper (1984) and Maskin and Riley (1984)] private information has value and its holder profits from 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.

pooling and separating solutions when the low cost technology has occurred. For $\rho^* > \rho_c^*$ the pooling solution is chosen while for $\rho^* < \rho_c^*$ the separating solution is chosen.

Proof: $\Pi^{E^*}(\alpha)$ is a convex combination of $\Pi^{L^*}(\alpha^L)$ and $\Pi^{H^*}(\alpha^H)$ with weights being given respectively by ρ^* and $(1 - \rho^*)$. Therefore, there exists some $0 < \rho_c^* < 1$ such that the licensor is indifferent between the pooling and separating solutions.

For $\rho^* > \rho_c^*$ the pooling solution is chosen because, regardless of technology type, the licensor makes more profit than with the separating solution. For $\rho^* < \rho_c^*$ the separating solution is chosen because if the pooling solution was offered, the licensee would infer that the high cost technology has occurred and so would not participate in the pooling solution. (Q.E.D.)¹⁹

2.4. STAGE TWO

In Stage Two, given technology type, the monopolist's problem is to maximise global profit by choosing the mode of technology transfer. This is done by choosing the larger of

$$\hat{\Pi}_X^L, \quad (\hat{\Pi}^L + \hat{\Pi}^{L^*} - k), \quad (\bar{\Pi}^L + \bar{I}^L), \quad \text{and} \quad (\bar{\Pi}^L(\bar{\alpha}^L) + \bar{I}^L) \quad (2.27)$$

when the low cost technology has occurred, and the larger of

$$\hat{\Pi}_X^H, \quad (\hat{\Pi}^H + \hat{\Pi}^{H^*} - k), \quad (\hat{\Pi}^H + \hat{\Pi}^{H^*}), \quad \text{and} \quad (\bar{\Pi}^H(\bar{\alpha}^L) + \bar{I}^L) \quad (2.28)$$

when the high cost technology has occurred. Arguments from the previous section require that $(\bar{\Pi}^H(\bar{\alpha}^L) + \bar{I}^L)$ be considered in (2.28) only if $(\hat{\Pi}^L(\bar{\alpha}^L) + \bar{I}^L)$ yielded the most profit of the choices in (2.27).

Proposition 2: *If complete information global profit maximisation involves output being produced at home and abroad ($\hat{\Pi}_X^L < \hat{\Pi}^L + \hat{\Pi}^{L^*}$), then the monopolist never transfers technology via the export of goods because this option is dominated by licensing.*

¹⁹ 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.

Proof: Licensing under the separating solution yields more profit to the licensor than the export of goods because (1) $\hat{\Pi}_X^H < \hat{\Pi}^H + \hat{\Pi}^{H^*}$ by assumption and (2) $\hat{\Pi}_X^L < \hat{\Pi}^L + \hat{\Pi}^{L^*}$ as marginal cost is increasing in output and $0 < \bar{\alpha}^L < 1$. As licensing with the separating solution is always an option available to the monopolist, a profit maximising monopolist never chooses the export of goods as the optimal mode of technology transfer. (Q.E.D.)

Proposition 3: *The high cost technology is always licensed. The contract is given by $(\bar{\alpha}^L, \bar{I}^L)$ if the pooling solution is optimal and $(\bar{\alpha}^H, \bar{I}^H)$ otherwise.*

Proof: The high cost technology is never transferred via subsidiary because a license contract of $(\bar{\alpha}^H, \bar{I}^H)$ avoids the fixed cost of subsidiary production and is always accepted by the licensee. (Q.E.D.)

Proposition 4: *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

$$\bar{\Pi}^L(\bar{\alpha}^L) + \bar{I}^L \geq \hat{\Pi}^L + \hat{\Pi}^{L^*} - k, \quad (2.29)$$

or

$$\bar{\Pi}^L(\bar{\alpha}^L) + \bar{I}^L \geq \hat{\Pi}^L + \hat{\Pi}^{L^*} - k. \quad (2.30)$$

Clearly, conditions (2.29) and (2.30) are more likely to be satisfied the larger is k . (2) For $\rho^* > \rho_c^*$, the higher is ρ^* the greater is $(\hat{\Pi}^L(\bar{\alpha}^L) + \bar{I}^L)$ because the constraint locus $l(\alpha)$ shifts further from the origin. For a given k , condition (2.29) is more likely to be satisfied the larger is $(\bar{\Pi}^L(\bar{\alpha}^L) + \bar{I}^L)$. (Q.E.D.)

Propositions 3, 4, and 5 are new results which have some empirical support. Davidson and McPetridge (1984) found that more radical technologies were more likely to be transferred by subsidiary than license. If more radical technologies can be interpreted as

low cost technologies, then this result provides some support for Proposition 3. Davidson and McFetridge also found that for the U.S. 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 4 which states that the smaller is k the more likely is technology transfer via subsidiary. Caves, Crookwell, and Killing (1983) 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 foreign producer compared to a domestic producer. However, another possibility is that k is greater for transfers between nations than for transfers within nations. This latter interpretation provides some support for Proposition 4.

2.5. STAGE ONE

In Stage One the monopolist's problem is to maximise expected profit by choosing R&D expenditure. Although the result of this R&D is uncertain, it is known that either a high or low cost technology results. Let $\rho(R)$ be the probability of the low cost technology occurring if R units of R&D are undertaken. It is assumed that $\rho'(R) > 0$ and $\rho''(R) < 0$.²⁰ The monopolist's problem in Stage One is

Problem 5:

$$\max_R \{ \Pi^E = \rho(R) \cdot \pi^L + (1 - \rho(R)) \cdot \pi^H - \omega R \}, \quad (2.31)$$

where π^i = the global profit of the monopolist with technology i and ω is the unit cost of R&D. This is a general formulation which at present does not distinguish between the

²⁰ The high cost technology can be thought of as the technology associated with the new product at the time of its discovery.

differing modes of technology transfer. The first order condition for this problem is

$$\rho'(R) = \frac{\omega}{(\pi^L - \pi^H)}, \quad (2.32)$$

and the second order condition for a maximum is satisfied because of the concavity of $\rho(R)$. Solving (2.32) for the optimal R (assuming an interior solution exists), substituting into (2.32), and totally differentiating yields

$$\rho''(R)dR = -\frac{\omega}{(\pi^L - \pi^H)^2} \cdot d(\pi^L - \pi^H). \quad (2.33)$$

Rearranging (2.33) and recognising that $\rho(R)$ is concave in R gives

$$\frac{dR}{d(\pi^L - \pi^H)} = -\frac{\omega}{(\pi^L - \pi^H)^2} \cdot \frac{1}{\rho''(R)} > 0. \quad (2.34)$$

In words, the greater is the difference between the monopolist's global profits with each technology type the greater is the amount of R&D undertaken. This result has important welfare and policy implications which are examined in section 4.

3. WELFARE AND POLICY

Welfare and policy are analysed from the point of view of both the technology exporting and technology importing countries. It is assumed that each country's policy is conducted separately so that strategic interactions between policy makers can be ignored. This section does not derive optimal policies for both countries, but rather, given market structure, derives the welfare implications of various policies which are often recommended or used in practice.²¹

²¹ The model developed in Section 3 is a monopoly model with incomplete information, so the optimal policy involves regulating a monopolist with unknown costs [Baron and Myerson (1982)]. Adding this element to the technology transfer problem would complicate the analysis immensely and so and is left for future research.

3.1. TECHNOLOGY EXPORTING COUNTRY

The measure of welfare used in this sub-section is the sum of expected monopoly profit and expected consumer surplus.²² The policy analysed is a ban on technology transfer via license or subsidiary.²³ The result of such a ban is to leave the export of goods as the only option available for technology transfer. Three effects can be isolated; (1) a profit effect, (2) a price effect, and (3) an R&D effect. The latter is considered because greater R&D expenditures increase the probability of the low cost technology occurring and so increase expected profit and expected consumer surplus.

Welfare effects depend on the modes of transfer that would have been optimal for the monopolist in the absence of the ban. For brevity, in this paper only one case is considered; namely, where the low cost technology would have been transferred via subsidiary and the high cost technology would have been transferred via license.

Profit Effect: If these modes of transfer would have been optimal for the monopolist, then $\hat{\Pi}^H + \hat{\Pi}^{H*} > \hat{\Pi}_X^H$ and k must be such that $\hat{\Pi}^L + \hat{\Pi}^{L*} - k > \hat{\Pi}_X^L$. Together, these inequalities imply that

$$\Pi_{XX}^E < \Pi_{SL}^E, \quad (3.1)$$

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

Price Effect: In Appendix 3 it is shown that price is a strictly increasing function of the market share. Therefore, the shift to exports ($\alpha = 1$) increases the price of output for consumers.²⁴ This implies that $CS_X^L < CS_S^L$ and $CS_X^H < CS_L^H$, where CS denotes consumer surplus. This effect unambiguously reduces expected consumer surplus.

²² This is a standard measure of welfare and is used in Barou and Myerson (1982).

²³ This policy is often advocated in order to protect employment, living standards, or a technological lead [Feenstra and Judd (1982) and Teece (1981)].

²⁴ $\alpha < 1$ for technology transfer via subsidiary or license.

R&D Effect: In Section 3 it was shown that the amount of R&D undertaken in Stage One depended on $(\pi^L - \pi^H)$. Therefore,

$$R_{SL} > R_{XX} \quad \text{if} \quad (\hat{\Pi}^L + \hat{\Pi}^{L*} - k) - (\hat{\Pi}^H + \hat{\Pi}^{H*}) > (\hat{\Pi}_X^L - \hat{\Pi}_X^H). \quad (3.2)$$

The second inequality in (3.2) can be rearranged to yield

$$\hat{\Pi}^L + \hat{\Pi}^{L*} - k - \hat{\Pi}_X^L > \hat{\Pi}^H + \hat{\Pi}^{H*} - \hat{\Pi}_X^H. \quad (3.3)$$

A necessary condition for (3.3) to be satisfied is that

$$\hat{\Pi}^L + \hat{\Pi}^{L*} - \hat{\Pi}_X^L > \hat{\Pi}^H + \hat{\Pi}^{H*} - \hat{\Pi}_X^H. \quad (3.4)$$

The general conditions under which (3.4) holds have not been obtained. However, assuming linear demand and linear marginal cost, the following proposition has been established.

Proposition 5: *If the home firm's demand curve is given by*

$$p = a - b \frac{q}{\alpha}, \quad \text{where} \quad \frac{q}{\alpha} = Q, \quad (3.5)$$

its cost function is given by

$$c^L = \frac{d}{\gamma} q^2 \quad \forall \quad \gamma \geq 1, \quad (3.6)$$

and

$$c^L = c^{L*}, \quad (3.7)$$

then necessary condition (3.4) is satisfied when

$$\gamma < \frac{1}{2} \left(\frac{d}{b} \right)^2. \quad (3.8)$$

Proof: This proposition is proved in Appendix 4.

For specific functional forms, Proposition 5 establishes that necessary condition (3.4) is more likely to be satisfied the smaller is γ and the larger is $\left(\frac{d}{b}\right)$. In general, Proposition 5 suggests that the R&D effect of the ban depends on the parameters of the model. This is in sharp contrast to Mansfield, Romeo, and Wagner (1979, p.51) who argue

"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".

To obtain the total welfare effect of the ban the profit, price, and R&D effects are combined. The profit and price effects unambiguously reduce expected welfare while the R&D effect has an ambiguous effect on expected welfare depending on the parameters of the model. If (3.4) is not satisfied, then the ban reduces R&D expenditure and leads to an ambiguous overall welfare effect. On the other hand, if (3.4) and (3.3) are satisfied, then the R&D effect reinforces the profit and price effects so that there is an overall unambiguous reduction in expected welfare. This ambiguity concerning the welfare effects of the ban suggests a case by case approach to policy may be necessary, though the information requirements of such an approach may be prohibitive.

3.2. TECHNOLOGY IMPORTING COUNTRY

The measure of welfare used is expected consumer surplus.²⁵ The policy considered is a ban by the technology importing country of technology transfer via subsidiary, (that is, banning direct foreign investment).²⁶ 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 a subsidiary. After the ban, it is optimal for both technologies to be transferred via license and for brevity it is assumed that this licensing occurs under a separating solution.²⁷ Two welfare effects can be isolated; (1) a price effect and (2) an R&D effect.

Price Effect: In section 3 it was established that $\bar{\alpha}^L > \hat{\alpha}^L$; therefore, the price of output in the technology importing country is less with technology transfer via license than

²⁵ Any profit generated by the foreign firm accrues to individuals in the technology exporting country because wholly owned subsidiaries and competitive bidding for licenses have been assumed. The foreign country can obtain some of the monopoly profit through taxation. The role of taxation is analysed in Wright (1989).

²⁶ 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. This externality could be the development of indigenous entrepreneurial or managerial skills or other learning by doing benefits [Bardhan (1982)].

²⁷ The welfare effects of licensing under a pooling solution are qualitatively identical.

with technology transfer via subsidiary. As a result, $\bar{C}S^{L*} > \hat{C}S^{L*}$. This increases expected consumer surplus.

R&D Effect: 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 via subsidiary, then

$$\pi^L = \hat{\Pi}^L + \hat{\Pi}^{L*} - k > (\bar{\Pi}^L + \bar{\Pi}^L). \quad (3.9)$$

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

$$\pi^H = \hat{\Pi}^H + \hat{\Pi}^{H*}, \quad (3.10)$$

Combining (3.9) and (3.10) with (2.32) gives

$$R_{SL} > \bar{R}_{LL}. \quad (3.11)$$

Therefore, the ban on technology transfer via subsidiary reduces the amount of R&D undertaken which in turn reduces expected consumer surplus.

The overall effect on welfare is ambiguous as the price and R&D effects have opposite sign. This suggests a case by case approach may be necessary, but once again the information costs of such a policy may be prohibitive.

This may seem an unsatisfactory way to end a section on welfare and policy. However, the above results were obtained from a formal model and highlight welfare effects that have previously been ignored or specified incorrectly.

4. CONCLUSION

This paper has analysed the welfare effects of two policies that are often recommended or used in practise when dealing with international technology transfer. To do this a partial equilibrium monopoly model was developed in which both the extent of technological change and the mode of technology transfer were endogenous.

In developing this model some new results about technology transfer were derived. In particular, it was shown that a license contract which contains a market share restriction and a lump sum payment is capable of overcoming the usual information asymmetry that is associated with the transfer of technology. It was also shown that; (1) licensing always dominated the export of goods as a transfer option, (2) the high cost technology was always licensed, and (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.

Using the sum of expected consumer surplus and expected monopoly profit as a measure of expected welfare for the technology transferring country, the welfare effects of banning technology transfer via license or subsidiary were considered. In general, the welfare effects were ambiguous depending on the interaction of a profit, price, and R&D effect. 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 technology receiving 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.

These ambiguous welfare results suggest that a case by case approach to policy may be necessary though the information requirements of such an approach might be prohibitive. Nevertheless, the model outlines welfare effects that have not been formalised before and which are important in any proper analysis of policy regarding international technology transfer.

Wright (1989) extends the basic model in a number of directions. The first is to allow more than two technology types. The second is the introduction of per unit royalties into license contracts, and the third removes market share restrictions from license contracts.

These extensions do not alter the thrust of the arguments in this paper.

Proposed areas of future research include (1) the introduction of a stage before Stage One in which a number of firms are involved in an R&D race to discover the new product/technology and (2) development of a model in which technology transfer involves a long term relationship between the transferor and the transferee because technology continues to be transferred as new technological improvements occur. A dynamic reputation model along the lines of Grossman (1981) and Horstman and Markusen (1987) seems appropriate.

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APPENDIX 1

Maximised profit as a function of α is given by

$$\Pi^i(\alpha) = p(q^i(\alpha)/\alpha) \cdot q^i(\alpha) - c^i(q^i(\alpha)). \quad (\text{A.1.1})$$

Using the envelope theorem and the assumption that demand curves slope downwards gives

$$\frac{d\Pi^i(\alpha)}{d\alpha} = -\frac{dp}{d(q^i/\alpha)} \cdot \frac{(q^i(\alpha))^2}{\alpha^2} > 0. \quad (\text{A.1.2})$$

Differentiating (A.1.2) with respect to α yields

$$\begin{aligned} \frac{d^2\Pi^i(\alpha)}{d\alpha^2} &= \frac{d^2p}{d(q^i/\alpha)^2} \cdot \left(\frac{q^i(\alpha)}{\alpha^2} - \frac{1}{\alpha} \cdot \frac{dq}{d\alpha} \right) \cdot \frac{(q^i(\alpha))^2}{\alpha^2} \\ &+ 2 \cdot \frac{dp}{d(q^i/\alpha)} \cdot \frac{(q^i(\alpha))^2}{\alpha^3} - 2 \cdot \frac{dp}{d(q^i/\alpha)} \cdot \frac{q^i(\alpha)}{\alpha^2} \cdot \frac{dq}{d\alpha}, \end{aligned} \quad (\text{A.1.3})$$

and rearranging gives

$$\frac{d^2\Pi^i(\alpha)}{d\alpha^2} = \frac{(q^i(\alpha))^2}{\alpha^2} \cdot \left(\frac{d^2p}{d(q^i/\alpha)^2} \cdot \frac{q^i(\alpha)}{\alpha^2} + 2 \cdot \frac{dp}{d(q^i/\alpha)} \cdot \frac{1}{\alpha} \right) \cdot \left(1 - \frac{dq}{d\alpha} \cdot \frac{\alpha}{q^i(\alpha)} \right). \quad (\text{A.1.4})$$

Total revenue, TR, is given by

$$TR = p(q^i(\alpha)/\alpha) \cdot q^i(\alpha). \quad (\text{A.1.5})$$

Differentiating (A.1.5) with respect to q^i yields

$$\frac{\partial TR}{\partial q^i} = \frac{dp}{d(q^i/\alpha)} \cdot (q^i(\alpha)/\alpha) + p(q^i(\alpha)/\alpha), \quad (\text{A.1.6})$$

and differentiating again gives

$$\frac{\partial^2 TR}{\partial q^{i^2}} = \frac{d^2p}{d(q^i/\alpha)^2} \cdot \frac{q^i(\alpha)}{\alpha^2} + 2 \cdot \frac{dp}{d(q^i/\alpha)} \cdot \frac{1}{\alpha}. \quad (\text{A.1.7})$$

(A.1.7) is the second term in (A.1.4).

Total differentiation of the first order condition of Problem 1 in the text gives

$$\frac{dq}{d\alpha} \cdot \frac{\alpha}{q^i(\alpha)} = \frac{\partial^2 TR}{\partial q^{i^2}} \bigg/ \left(\frac{\partial^2 TR}{\partial q^{i^2}} - \frac{d^2c^i}{dq^{i^2}} \right). \quad (\text{A.1.8})$$

The denominator of (A.1.8) is the second order condition for a maximum to Problem 1 (see Appendix 2). 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 to Problem 1 is satisfied, then

$$0 < \frac{dq}{d\alpha} \cdot \frac{\alpha}{q^i(\alpha)} < 1 \quad (\text{A.1.9})$$

and

$$\frac{d^2\Pi^i(\alpha)}{d\alpha^2} < 0. \quad (\text{A.1.10})$$

APPENDIX 2

When γ is explicitly considered, Problem 1 from the text can be written as

$$\max_q p(q/\alpha) \cdot q - \frac{1}{\gamma} \cdot c(q). \quad (\text{A.2.1})$$

The first order condition for this problem is

$$\frac{dp}{d(q/\alpha)} \cdot (q/\alpha) + p(q/\alpha) - \frac{1}{\gamma} \cdot \frac{dc}{dq} = 0, \quad (\text{A.2.2})$$

and assuming that the second order condition for a maximum is satisfied gives

$$\frac{d^2p}{d(q/\alpha)^2} \cdot \frac{q}{\alpha^2} + 2 \cdot \frac{dp}{d(q/\alpha)} \cdot \frac{1}{\alpha} - \frac{1}{\gamma} \cdot \frac{d^2c}{dq^2} < 0 \quad (\text{A.2.3})$$

Let the argmax of (A.2.1) be given by $q(\alpha, \gamma)$. Substituting the solution of (A.2.2) into the objective function yields home firm maximised profit as a function of α and γ . Let this be given by $\Pi(\alpha, \gamma)$. Differentiating with respect to α gives

$$\frac{\partial \Pi(\alpha, \gamma)}{\partial \alpha} = -\frac{dp}{d(q(\alpha, \gamma)/\alpha)} \cdot (q(\alpha, \gamma)/\alpha)^2 \geq 0. \quad (\text{A.2.4})$$

To obtain the relationship between $\frac{\partial \Pi^H}{\partial \alpha^H}$ and $\frac{\partial \Pi^L}{\partial \alpha^L}$ differentiate (A.2.4) with respect to γ to get

$$\begin{aligned} \frac{\partial^2 \Pi(\alpha, \gamma)}{\partial \gamma \partial \alpha} &= -(q(\alpha, \gamma)/\alpha) \cdot \left(\frac{d^2p}{d(q(\alpha, \gamma)/\alpha)^2} \cdot \frac{q(\alpha, \gamma)}{\alpha^2} \right. \\ &\left. + 2 \cdot \frac{dp}{d(q(\alpha, \gamma)/\alpha)} \cdot \frac{1}{\alpha} \right) \cdot \frac{\partial q(\alpha, \gamma)}{\partial \gamma}. \end{aligned} \quad (\text{A.2.5})$$

Substituting $q(\alpha, \gamma)$ into (A.2.2) and totally differentiating with respect to q and γ gives

$$\frac{\partial q}{\partial \gamma} = -\frac{\frac{1}{\gamma^2} \cdot \frac{dc}{dq}}{\frac{\partial^2 TR}{\partial q^2} - \frac{1}{\gamma} \cdot \frac{d^2c}{dq^2}}. \quad (\text{A.2.6})$$

The numerator of (A.2.6) is positive and the denominator is negative by second order condition (A.2.3). Therefore,

$$\frac{\partial q}{\partial \gamma} > 0. \quad (\text{A.2.7})$$

If the revenue function is strictly concave, then it follows that

$$\frac{\partial^2 \Pi(\alpha, \gamma)}{\partial \gamma \partial \alpha} > 0. \quad (\text{A.2.8})$$

(A.2.8) is true for all γ , so

$$\frac{d\Pi^L}{d\alpha^L} > \frac{d\Pi^H}{d\alpha^H} \geq 0. \quad (\text{A.2.9})$$

APPENDIX 3

For a given α , price is given by

$$p = p\left(\frac{q(\alpha)}{\alpha}\right). \quad (\text{A.3.1})$$

Differentiating with respect to α gives

$$\frac{dp}{d\alpha} = \frac{1}{\alpha} \cdot \frac{dp}{d(q/\alpha)} \left(\frac{dq}{d\alpha} - \frac{q(\alpha)}{\alpha} \right). \quad (\text{A.3.2})$$

From (A.1.8) in Appendix 2

$$\frac{dq}{d\alpha} = \frac{q(\alpha)}{\alpha} \cdot \left(\frac{\partial^2 TR}{\partial q^2} / \left(\frac{\partial^2 TR}{\partial q^2} - \frac{d^2 c}{dq^2} \right) \right). \quad (\text{A.3.3})$$

By assumption

$$\frac{\partial^2 TR}{\partial q^2} < 0 \quad \text{and} \quad \frac{d^2 c}{dq^2} > 0, \quad (\text{A.3.4})$$

so

$$0 < \frac{dq}{d\alpha} < \frac{q(\alpha)}{\alpha} \quad (\text{A.3.5})$$

and

$$\frac{dp}{d\alpha} > 0. \quad (\text{A.3.6})$$

That is, the larger is the market share the higher is the price.

APPENDIX 4

Let

$$p = a - b \frac{q}{\alpha}, \quad \text{where} \quad \frac{q}{\alpha} = Q \quad (\text{A.4.1})$$

$$c^L = \frac{d}{\gamma} q^2, \quad \text{where} \quad \gamma \geq 1, \quad (\text{A.4.2})$$

and

$$c^L = c^{L*}. \quad (\text{A.4.3})$$

The home production facility solves the following problem

$$\max_q = \left(a - b \frac{q}{\alpha} \right) \cdot q - \frac{d}{\gamma} q^2. \quad (\text{A.4.4})$$

The solution to (A.4.4) is

$$q(\alpha, \gamma) = a / \left(\frac{2b}{\alpha} + \frac{2d}{\gamma} \right). \quad (\text{A.4.5})$$

Substituting (A.4.5) into the objective function gives

$$\Pi(\alpha, \gamma) = \frac{a^2}{2} / \left(\frac{2b}{\alpha} + \frac{2d}{\gamma} \right) = \frac{a}{2} \cdot q(\alpha, \gamma). \quad (\text{A.4.6})$$

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,

$$\hat{\Pi}^H + \hat{\Pi}^{H*} = a^2 / (4b + 2d). \quad (\text{A.4.7})$$

Under exporting, $\alpha = 1$, so

$$\hat{\Pi}_X^H = a^2 / (4b + 4d). \quad (\text{A.4.8})$$

By similar arguments

$$\hat{\Pi}^L + \hat{\Pi}^{L*} = a^2 / \left(4b + \frac{2d}{\gamma} \right) \quad (\text{A.4.9})$$

and

$$\hat{\Pi}_X^L = a^2 / \left(4b + \frac{4d}{\gamma} \right). \quad (\text{A.4.10})$$

Combining (A.4.7), (A.4.8), (A.4.9), and (A.4.10) implies that

$$\hat{\Pi}^L + \hat{\Pi}^{L*} - \hat{\Pi}_X^L > \hat{\Pi}^H + \hat{\Pi}^{H*} - \hat{\Pi}_X^H \quad (\text{A.4.11})$$

if

$$4b^2(1 - \gamma) + 2d^2 \left(1 - \frac{1}{\gamma} \right) > 0, \quad (\text{A.4.12})$$

that is, if

$$\gamma < \frac{1}{2} \left(\frac{d}{b} \right)^2. \quad (\text{A.4.13})$$

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