

WORKING PAPERS IN ECONOMICS

INTERNATIONAL TECHNOLOGY TRANSFER
AND PER UNIT ROYALTIES

by

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Abstract

This paper develops a partial equilibrium model of international technology transfer in which the mode of technology transfer is endogenous and per unit royalties play two roles in license contracts. The first is that they facilitate the monopoly solution when a competitor is licensed, and the second is that they help in the self-selection process under conditions of asymmetric information.

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1. INTRODUCTION

The role of per unit or output based royalties has been examined in the technology transfer literature [Katz and Shapiro (1985), Gallini and Winter (1985), Kamien and Tausman (1986), and Gallini and B. Wright (1988)]; however, the majority of the theoretical literature deals with technology transfer within a country rather than between countries. This paper seeks to correct this omission by developing a model of international technology transfer in which the mode of technology transfer is endogenous and per unit royalties play a major role in license contracts. This is an important development because the evidence suggests that output based payment are often found in license contracts [Taylor and Silberston (1973) and Contractor (1981)]. The framework used is partial equilibrium, and initially monopoly is assumed to capture the idea that a new technology provides at least temporary monopoly power to its owner.

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 a 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

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

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

It has been suggested that there are three reasons why output based payments (royalties) can be found in license contracts [Katz and Shapiro (1986)]. The first is risk sharing, the second is to facilitate a monopoly solution, and the third is asymmetric information. This paper only considers the last two reasons. The second is analysed in section 2 where complete information is assumed. It is shown, where a market share restriction is allowed in the license contract, that licensing is always chosen as the mode of transfer as it avoids the fixed cost k . It is also shown that per unit royalties are never optimal as they distort the allocation of production between countries away from the cost minimising allocation. This follows because per unit royalties raise the licensee's marginal cost [Caves, Crookwell, and Killing (1983), p.258, ft.8]. However, where market share restriction are not allowed in the

license contract and the post technology transfer market structure is duopoly it is shown that licensing may still be the optimal mode of technology transfer and it is further shown that per unit royalties play an important role in the license agreement as they reduce the competitive affect of the licensee on the licensor.

Asymmetric information is introduced in section 3 and the licensing problem 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, a per unit royalty, and a lump sum payment can overcome the information asymmetry, though at a cost. This is a new result which is very satisfying as market share restrictions, per unit royalties, 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. It is shown that the likelihood of technology transfer via a license agreement increases with the inclusion of per unit royalties in license contracts.³

Section 4 contains some concluding comments as well as some suggestions for future research.

2. COMPLETE INFORMATION

In this section it is assumed that both the licensor and the licensees know technology type at the time of technology transfer.

³ In a recent paper, Gallini and B. Wright (1986) 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.

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 Romeo (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)].

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. The objective of the monopolist is to maximise profit by choice of the mode of technology transfer and the global allocation of production. In solving this problem it is natural to assume that the choice of the mode of technology transfer precedes the choice of production levels at home and abroad. Therefore, the structure of this decision process consists of two stages.

In the first stage 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

In the second stage, given 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 technology for producing the new product, which is either a low cost or high cost technology, is licensed monopolistically to a foreign firm and bidding for license contracts is competitive.

License Contracts: License contracts contain a market share restriction of α for the licensor, a lump sum payment of l which the licensee pays the licensor in order to obtain the new technology, and a per unit royalty of r . 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

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.

license agreements.⁵ Lump sum license payments and per unit royalties are used to extract rent from the licensee.

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.⁶ 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 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.⁷ 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 TWO

In Stage Two, given the mode of technology transfer, the monopolist's problem is to

⁵ Caves, Crookwell and Killing (1983), using survey data, found that 34% of license agreements contained a market share restriction.

⁶ 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.

⁷ These assumptions are made in Horstmann and Markusen (1987) and are standard in the multi-plant monopoly literature. In the context of this paper, increasing marginal cost is best thought of as resulting from rising factor prices rather than from diseconomies of scale.

maximise global profit by choosing the global allocation of production. 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).⁸ In this paper the monopolist's stage two problem has two sub-stages. In the first sub-stage the monopolist maximises global profit by choosing the home firm's market share, the foreign firm's per unit royalty, and the foreign firm's lump sum payment. In the second sub-stage, given the market share and per unit royalty arising from sub-stage one, each firm maximises profit by choosing output.⁹ 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 $p = f^{-1}(q_d/\alpha)$.¹⁰ The foreign firm's second sub-stage problem is

Problem 1:

$$\max_{q^{i*}} p(q^{i*}/(1-\alpha^i)) \cdot q^{i*} - c^{i*}(q^{i*}) - r^i \cdot q^{i*} \quad i = H, L. \quad (2.2)$$

It is assumed that the second order condition for a maximum is satisfied. Let the argmax of (2.2) be given by $q^{i*}(\alpha^i, r^i)$. Substituting this into the objective function yields foreign firm maximised profit as a function of α^i and r^i . Let this be given by $\Pi_N^{i*}(\alpha^i, r^i)$. The home firm does not pay a per unit royalty, so its maximised profit is a function solely of α^i . Let this be given by $\Pi^i(\alpha^i)$.

The monopolist's first sub-stage problem is

Problem 2:

$$\max_{\alpha^i, r^i, l^i} \{\Pi(i) = \Pi^i(\alpha^i) + r^i \cdot q^{i*}(\alpha^i, r^i) + l^i\}, \quad i = H, L \quad (2.3)$$

subject to:

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

⁸ 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)].

⁹ This problem yields identical solutions for output as the traditional formulation of the monopolist's problem.

¹⁰ At $\alpha = 0$ it is assumed that $p = 0$.

where r^i is the per unit royalty applied to the foreign firms output; $\Pi_N^{i*}(\alpha^i, r^i)$ is the maximised value of the foreign firm's profit net of royalty payments; $q^{i*}(\alpha^i, r^i)$ is the foreign firm's output that maximises its net profit; and 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 net 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 $k = 0$, $r^i = 0$, $l^i = 0$, and $\alpha^i = 1$ as all of the world market is served by the home firm. The subsidiary problem is obtained by setting $k > 0$, and the licensing problem is obtained by setting $k = 0$ and interpreting l^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 and using the envelope theorem, the first order conditions for a maximum are

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

and

$$\frac{d\Pi(i)}{dr^i} \equiv q^{i*} + r^i \cdot \frac{\partial q^{i*}}{\partial r^i} - q^{i*} = 0. \quad (2.6)$$

(2.6) implies that $r^i = 0$ at the solution to Problem 2. In Appendix 1 it is shown that

$$\frac{d^2\Pi^i(\alpha^i)}{d\alpha^{i2}} < 0 \quad \text{and} \quad \frac{d^2\Pi_N^{i*}(\alpha^i, r^i)}{d\alpha^{i2}} < 0 \quad (2.7)$$

at $r^i = 0$ which guarantees that the second order condition for a maximum to Problem 2 is satisfied.

In the case of technology transfer via subsidiary or license, let the solution to Problem 2 be given by $(\hat{\alpha}^i, \hat{r}^i = 0, \hat{l}^i)$, where $\hat{l}^i = (\hat{\Pi}_N^{i*}(\hat{\alpha}^i, \hat{r}^i = 0) - k)$ and let home firm maximised profit be given by $\hat{\Pi}^i$. In the case of technology transfer via the export of goods, let the solution to Problem 2 be given by $(\alpha^i = 1, r^i = 0, l^i = 0)$ and let home firm maximised profit be given by $\hat{\Pi}_X^i$.

2.4. STAGE ONE

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

$$\hat{\Pi}_X^i, (\hat{\Pi}^i + \hat{\Pi}_N^{i*} - k), \text{ and } (\hat{\Pi}^i + \hat{\Pi}_N^{i*}); \quad i = H, L. \quad (2.8)$$

Proposition 1: *Under conditions of complete information, where a market share restriction is allowed in the license contract and where global monopoly profit maximisation involves output being produced at home and abroad, the optimal mode of technology transfer is licensing.*

Proof: This follows trivially from (2.8) as licensing avoids the fixed cost k . (Q.E.D.)

Therefore, where market share restrictions are allowed in license contracts, the optimal mode of technology transfer is licensing and per unit royalties are not included in the license contract.

2.5. LICENSING WITHOUT MARKET SHARE RESTRICTIONS

Although market share restrictions are often found in license contracts, in some countries they are illegal [Caves, Crookwell, and Killing (1983, p.259)]. Therefore, it seems appropriate to redo the analysis of the previous section without using α as a choice variable for the owner of the new technology.

2.5.1. THE STAGE TWO LICENSING PROBLEM

It is assumed that resale of the technology by the licensee is not allowed and it is also assumed that having sold the technology once the licensor is not allowed to sell the

technology again.¹¹ The effect of the elimination of market share restrictions is to alter the market structure from monopoly to duopoly if the technology is transferred via license to a foreign firm.

In Stage Two the monopolist's licensing problem is to maximise profit by choosing the per unit royalty and the lump sum transfer payment. The Stage Two licensing problem has two sub-stages. In the first sub-stage the monopolist chooses the per unit royalty and the lump sum payment. In the second sub-stage 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

$$\max_{q^*} \{ \Pi^* = p(q + q^*) \cdot q^* - \frac{1}{\gamma} \cdot c^*(q^*) - r \cdot q^* \}, \quad (2.9)$$

where slanted Π^* represents the licensee's duopoly profit and superscript i has been dropped for convenience. The first order condition of this problem is

$$\frac{\partial \Pi^*}{\partial q^*} \equiv \frac{dp}{d(q + q^*)} \cdot q^* + p(q + q^*) - \frac{1}{\gamma} \cdot c^{*\prime}(\cdot) - r = 0. \quad (2.10)$$

The second order condition for a maximum is

$$\frac{d^2 p}{d(q + q^*)^2} \cdot q^* + 2 \frac{dp}{d(q + q^*)} - \frac{1}{\gamma} \cdot c^{*\prime\prime}(\cdot) = a^* < 0 \quad (2.11)$$

¹¹ 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_i (a third of total triopoly profit, assuming identical cost functions), where $\Pi_i < \Pi_d$. Realising this, the licensee pays less than Π_d for the technology in the first instance. This reduces the likelihood of licensing. An enforceable market share restriction overcomes the problem of multiple sales of the technology.

and it is assumed to be satisfied.

Solving (2.10) for q^* gives

$$q^*(q, r, \gamma). \quad (2.12)$$

The licensor's problem is similar to the licensee's except that no per unit royalty appears in the licensor's problem. The first order condition is solved for

$$q(q^*, \gamma). \quad (2.13)$$

Combining (2.12) and (2.13) gives the equilibrium values of q and q^* as functions of r and γ . Let these equilibrium values be given by

$$q(r, \gamma) \text{ and } q^*(r, \gamma). \quad (2.14)$$

Appendix 2 outlines the conditions necessary for these equilibrium values to be stable.

Substituting (2.14) into (2.9) gives the licensee's maximised profit net of royalty payments. This is given by $\Pi_N^*(q(r, \gamma), q^*(r, \gamma))$. Similarly, maximised duopoly profit for the licensor is given by $\Pi(q(r, \gamma), q^*(r, \gamma))$.

First Sub-Stage

The monopolist chooses r and l to maximise its profit.

Problem 3:

$$\max_{r, l} \{ \Pi_d = \Pi(q(r, \gamma), q^*(r, \gamma)) + l + r \cdot q^*(r, \gamma) \} \quad (2.15)$$

subject to:

$$\Pi_N^*(\cdot) \geq l. \quad (2.16)$$

At the solution (2.16) always binds, so it can be substituted into (2.15). Differentiating Π_d with respect to r yields

$$\frac{\partial \Pi_d}{\partial r} = \frac{\partial \Pi}{\partial r} + \frac{\partial \Pi_N^*}{\partial r} + r \cdot \frac{\partial q^*}{\partial r} + q^*, \quad (2.17)$$

and applying the envelope theorem gives

$$\frac{\partial \Pi_d}{\partial r} = \frac{dp}{d(q+q^*)} \cdot q \cdot \frac{\partial q^*}{\partial r} + \frac{dp}{d(q+q^*)} \cdot q^* \cdot \frac{\partial q}{\partial r} + r \cdot \frac{\partial q^*}{\partial r}. \quad (2.18)$$

The first order condition for a maximum to Problem 3 is

$$\frac{\partial \Pi_d}{\partial r} = 0. \quad (2.19)$$

It is assumed that the second order condition for a maximum to Problem 3 is satisfied.¹² Let the prohibitive royalty rate (that rate at which it is optimal for the monopolist to transfer technology via the export of goods rather than by license) be given by r_p and let the optimal royalty rate be given by $\hat{r}_d(\gamma)$, where the d subscript denotes duopoly.

Proposition 2: *If $c(q) = c^*(q^*)$ and the second order condition for a maximum to Problem 3 is satisfied, then the optimal per unit royalty is greater than zero and less than the prohibitive rate. That is, $0 < \hat{r}_d < r_p$.*

Proof: Appendix 3.

The optimal per unit royalty is greater than zero because at $r = 0$ an increase in r causes total duopoly output to fall and so total duopoly revenue to rise. The optimal per unit royalty 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).¹³ In the absence of a market share restriction, the per unit royalty reduces the

¹² In Appendix 2 it is shown that the second order condition for a maximum is satisfied when linear demand and linear marginal cost is assumed.

¹³ The licensor's problem can also be thought of as maximising gross duopoly profit by choice of r , because

$$\begin{aligned} \Pi_d &= \Pi + \Pi^* + r \cdot q^* \\ &= p(q+q^*) \cdot q - c(q) + p(q+q^*) \cdot q^* - c(q^*) - r \cdot q^* + r \cdot q^* \\ &= p(q+q^*) \cdot (q+q^*) - c(q) - c(q^*) \end{aligned} \quad (2.20)$$

competitive affect of the licensee on the licensor's profit by increasing the licensee's marginal cost. Let the solution to the Stage Two licensing problem (Problem 3) be given by (\hat{r}_d, \hat{l}_d) , where $\hat{l}_d = \Pi_{Nd}^*$, and let the licensor's profit at this solution be

$$\hat{\Pi}_d = \hat{\Pi} + \hat{l}_d + \hat{r}_d \cdot q^*(\hat{r}_d). \quad (2.21)$$

2.5.2. STAGE ONE

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

$$\hat{\Pi}_X^i, (\hat{\Pi}^i + \hat{\Pi}_N^i - k), \text{ and } \hat{\Pi}_d^i \quad i = H, L. \quad (2.22)$$

Proposition 3: *Under conditions of complete information, but where a market share restriction is not allowed in the license contract, it may be optimal to transfer technology via subsidiary.*

Proof: It is well known that the sum of two firm's duopoly profits is less than monopoly profit; therefore, $\hat{\Pi}_d^i \leq \hat{\Pi}^i + \hat{\Pi}_N^i$. This inequality implies that for some k , $\hat{\Pi}^i + \hat{\Pi}_N^i - k > \hat{\Pi}_d^i$. (Q.E.D.)

Proposition 4: *If $c(q) = c^*(q^*)$ and the second order condition for a maximum to Problem 3 is satisfied, then the export of goods is not an optimal mode of technology transfer.*

Proof: A prohibitive per unit royalty is associated with the export of goods. Proposition 2 established that $\hat{r}_d < r_p$, so the prohibitive per unit royalty is not optimal. Therefore, the export of goods is not an optimal mode of technology transfer. (Q.E.D.)

Propositions 3 and 4 establish that under certain conditions it may be optimal to transfer technology via a wholly owned subsidiary, but that it is not optimal to transfer

technology via the export of goods.¹⁴ Where it is optimal to transfer technology via a license agreement per unit royalties play an important role in that they reduce the competitive affect of the licensee on the licensor's profit.

3. INCOMPLETE INFORMATION

3.1. THE DECISION STRUCTURE AND ASSUMPTIONS

In this subsection the decision structure of the previous section is changed because it is assumed that an information asymmetry exists between the owner of the technology and potential licensees. Specifically, in Stage Two, 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.

It is further assumed that both the licensor and potential licensees are risk neutral, that technology type is unable to be objectively verified, that the licensee's subjective probability that the low cost technology has occurred is identical for all potential licensees and known by the licensor, and that third party arbitrage between the market of the licensor and the licensee is prohibitively costly.¹⁵ Finally it is assumed that 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

¹⁴ This result contrasts with Katz and Shapiro (1985) who find that it is never optimal to license a drastic innovation. This difference arises because of different assumptions regarding marginal cost. In Katz and Shapiro marginal cost is constant while in this paper marginal cost increases with output. This explains why a drastic innovation is licensed rather than transferred via the export of goods because licensing yields a cost saving through world output being distributed more efficiently.

¹⁵ This prohibitive cost may result from larger product service costs for the arbitrageur 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).

(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.

3.2. THE STAGE TWO LICENSING PROBLEM

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 problem is to maximise global profit by designing a license contract. The presence of the information asymmetry ensures that the complete information solution is not implementable because the contract $(\hat{\alpha}^L, \hat{r}^L = 0, \hat{l}^L)$ is never accepted by a licensee as the licensor offers $(\hat{\alpha}^L, \hat{r}^L = 0, \hat{l}^L)$ regardless of technology type.¹⁶

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.¹⁷

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 offer. As technology type is revealed by the contract offer licensee participation requires

$$\Pi_N^i(\alpha^i, r^i) - l^i \geq 0. \quad (3.1)$$

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

$$\rho^* \cdot \Pi_N^{L^*}(\alpha, r) + (1 - \rho^*) \cdot \Pi_N^{H^*}(\alpha, r) \geq l. \quad (3.2)$$

¹⁶ For simplicity it has been assumed that $c(q) = c^*(q^*)$ so that $\hat{\alpha}^H = \frac{1}{2} = \hat{\alpha}^L$.

¹⁷ 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].

where

$$l^H = l^L = l; \quad r^H = r^L = r; \quad \text{and} \quad \alpha^H = \alpha^L = \alpha. \quad (3.3)$$

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

$$(\hat{\alpha}^H, \hat{r}^H = 0, \hat{l}^H). \quad (3.4)$$

This is the complete information solution.

If the low cost technology has occurred and given $(\hat{\alpha}^H, \hat{r}^H = 0, \hat{l}^H)$, then the monopolist's problem is

Problem 4:

$$\max_{\alpha^L, r^L, l^L} \{ \Pi(L) = \Pi^L(\alpha^L) + l^L + r^L \cdot q^{L^*}(\alpha^L, r^L) \} \quad (3.5)$$

subject to :

$$\Pi^H(\hat{\alpha}^H) + \hat{l}^H \geq \Pi^{HL}(\alpha^L) + l^L + r^L \cdot q^{HL^*}(\alpha^L, r^L) \quad (3.6)$$

and

$$\Pi_N^{L^*}(\alpha^L, r^L) \geq l^L \quad (3.7)$$

which is identical to Problem 2, except for the addition of constraint (3.6). This additional constraint is the self-selection constraint which guarantees that the contract which solves Problem 4 is offered if and only if the low cost technology has occurred. $\Pi^{HL}(\alpha^L)$ is defined as follows

$$\Pi^{HL}(\alpha^L) = \max_{q^{HL}} p(q^{HL}/\alpha^L) \cdot q^{HL} - c^H(q^{HL}) \quad (3.8)$$

and represents maximised home firm profit if the high cost technology has occurred and the licensor offers α^L and r^L in the license contract. $q^{HL^*}(\alpha^L, r^L)$ represents the net profit maximising output of the licensee when the high cost technology has occurred but the licensee's market share and per unit royalty rate are given by α^L and r^L . This

problem does not have nice curvature properties because constraints (3.6) and (3.7) are not convex sets. These non convexities make the solution of Problem 4 difficult to achieve analytically. Therefore, rather than solving Problem 4 this paper establishes that at the solution, whatever it may be, the per unit royalty is greater than zero.

Proposition 5: *In the separating solution, 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. In this latter case, the licensor's profit is greater than if a per unit royalty could not be used.*

Proof: Appendix 4.

Let $\bar{\alpha}^L$ be the solution to Problem 4, where r^L is restricted to zero. In Appendix 4 it is argued that $\bar{\alpha}^L > \hat{\alpha}^L$. The intuition behind Proposition 5 is that the per unit royalty helps in the self selection process because it distorts the allocation of global production away from the cost minimising allocation and reduces the licensor's incentive to lie. Increasing the market share of the licensor above $\hat{\alpha}^L$ also distorts the allocation of global production away from the cost minimising allocation. Therefore, the introduction of a per unit royalty allows α^L to be reduced below $\bar{\alpha}^L$ in such a way to increase the licensor's profit.

Let the solution to Problem 4 be given by

$$(\bar{\alpha}_r^L, \bar{l}_r^L, \bar{r}_r^L > 0), \quad (3.9)$$

and let the licensor's maximised profit be given by

$$\bar{\Pi}_r^L(\bar{\alpha}_r^L) + \bar{l}_r^L + \bar{r}_r^L \cdot q^{L*}(\bar{\alpha}_r^L, \bar{r}_r^L) = \bar{\pi}_r^L, \quad (3.10)$$

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

Combining (3.4) and (3.9) yields the following separating solution

$$(\hat{\alpha}^H, r^H = 0, \hat{l}^H) ; (\bar{\alpha}_r^L, \bar{r}_r^L > 0, \bar{l}_r^L) \quad (3.11)$$

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 $(\hat{\alpha}^H, r^H = 0, \hat{l}^H)$ regardless of technology type. However, if the low cost technology has occurred, the licensor must distort its contract offer away from the complete information solution to convince the licensee that the low cost technology has occurred. This requires a contract offer of $(\bar{\alpha}_r^L, \bar{r}_r^L > 0, \bar{l}_r^L)$. The information asymmetry imposes a cost on the licensor which is given by the difference between global profit with contract $(\hat{\alpha}^L, r^L = 0, \hat{l}^L)$ and global profit with contract $(\bar{\alpha}_r^L, \bar{r}_r^L > 0, \bar{l}_r^L)$.

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 5:**

$$\max_{\alpha, l, r} \{ \Pi(L) = \Pi^L(\alpha) + l + r \cdot q^{L*}(\alpha, r) \} \quad (3.12)$$

subject to:

$$\rho^* \cdot \Pi_N^{L*}(\alpha, r) + (1 - \rho^*) \cdot \Pi_N^{H*}(\alpha, r) \geq l. \quad (3.13)$$

This problem does not have nice curvature properties because constraint (3.13) is not a convex set. Therefore, the same technique used in analysing the separating solution is adopted in order to ascertain whether the optimal per unit royalty is greater than zero in the pooling solution.

Proposition 6: *If a per unit royalty can be used in the license contract, then its optimal value is greater than zero in the pooling solution.*

Proof: Appendix 5

Let the solution to Problem 5 be given by

$$(\tilde{\alpha}_r^L, \tilde{r}_r^L > 0, \tilde{l}_r^L), \quad (3.14)$$

and let the licensor's maximised profit be given by

$$\hat{\Pi}_r^L(\tilde{\alpha}_r^L) + \tilde{l}_r^L + \tilde{r}_r^L \cdot q^{L*}(\tilde{\alpha}_r^L, \tilde{r}_r^L) = \tilde{\pi}_r^L. \quad (3.15)$$

If the high cost technology has occurred, the best the licensor can do is continue to offer contract (3.14). 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 net profit.¹⁸ It is clear that such a constraint reduces the licensor's profit because

$$\Pi_N^{H*}(\alpha, r) \leq \rho^* \cdot \Pi_N^{L*}(\alpha, r) + (1 - \rho^*) \cdot \Pi_N^{H*}(\alpha, r) \quad \forall \alpha, r. \quad (3.16)$$

Therefore, the pooling solution involves a contract offer of $(\tilde{\alpha}_r^L, \tilde{r}_r^L > 0, \tilde{l}_r^L)$ regardless of the technology type that actually occurs.

3.3. STAGE ONE

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

$$\hat{\Pi}_X^L, \quad (\hat{\Pi}^L + \hat{\Pi}^{L*} - k), \quad \tilde{\pi}_r^L, \quad \text{and} \quad \tilde{\pi}_r^L \quad (3.17)$$

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

$$\hat{\Pi}_X^H, \quad (\hat{\Pi}^H + \hat{\Pi}^{H*} - k), \quad (\hat{\Pi}^H + \hat{\Pi}^{H*}), \quad \text{and} \quad \tilde{\pi}_r^H \quad (3.18)$$

when the high cost technology has occurred. Arguments from the previous section require that $\tilde{\pi}_r^H$ be considered in (3.18) only if $\tilde{\pi}_r^L$ yielded the most profit of the choices in (3.17).

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

Propositions 5 and 6 establish that the inclusion of a per unit royalty in license contracts increases the profitability of licensing the low cost technology.¹⁹

Proposition 7: *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 licensor is indifferent between the separating and pooling solution and indifferent between transferring technology via license or subsidiary when the per unit royalty is restricted to zero. The introduction of a positive per unit royalty into the license contract increases the profitability of licensing the low cost technology. This implies that licensing is now chosen as the mode of technology transfer. (Q.E.D.)

Propositions 5 and 6 are consistent with the observed prevalence of per unit or sales based royalties in license contracts. Proposition 7 reinforces this consistency by making licensing more likely when per unit royalties are included in license contracts. However, Proposition 5 also suggests that there are cases where royalties are not used, namely, where the high cost technology has occurred. In this case the prevalence of per unit royalties may be explained by risk sharing, or other behaviour that is not considered in this model.

4. CONCLUSION

This paper has analysed the role played by per unit royalties in a partial equilibrium model of international technology transfer where the mode of technology transfer is an endogenous variable. It was shown that if there is complete information and market share restrictions are allowed in license contracts, then licensing is the optimal mode of technology transfer and per unit royalties are not used in the license contract.

¹⁹ In the case where $r^L = 0$, Wright (1989) established 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. These propositions continue to hold where a positive per unit royalty is included in the license contract.

Where market share restrictions were not allowed in license contracts, but information was still complete, it was shown that licensing may still be the optimal mode of technology transfer even though a competitor is being licensed. This is a new result and contrasts with Katz and Shapiro (1985) who argue that a drastic innovation is never licensed. It is also shown that if it is optimal to transfer technology via a license agreement, then per unit royalties will be included in the license contract as they reduce the competitive affect of the licensee on the licensor's profit.

Finally, under conditions of asymmetric information, but where market share restrictions are allowed in license contracts, it was shown that per unit royalties help in the self-selection process and increase the likelihood that international technology transfer will occur via licensing of independent foreign firms.

These results on per unit royalties are consistent with the observed prevalence of per unit royalties in actual license contracts, though there may be other reasons for this prevalence that have not be discussed in this paper. A proposed area of future research is to introduce asymmetric information into the case where market share restrictions are not allowed.

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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

$$\frac{\partial^2 TR}{\partial q^{i2}} = \frac{d^2p}{d(q^i/\alpha)^2} \cdot \frac{q^i(\alpha)}{\alpha^2} + 2 \cdot \frac{dp}{d(q^i/\alpha)} \cdot \frac{1}{\alpha}. \quad (\text{A.1.7})$$

(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

$$\frac{dq}{d\alpha} \cdot \frac{\alpha}{q^i(\alpha)} = \frac{\partial^2 TR}{\partial q^{i2}} \left/ \left(\frac{\partial^2 TR}{\partial q^{i2}} - \frac{d^2 c^i}{dq^{i2}} \right) \right. \quad (\text{A.1.8})$$

The denominator of (A.1.8) is the second order condition for a maximum to Problem 1. 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

Stability

The duopoly model outlined in Section 2.5 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 2.5 follows this tradition.²⁰ Let

$$a = \frac{d^2p}{d(q+q^*)^2} \cdot q + 2 \cdot \frac{dp}{d(q+q^*)} - \frac{1}{\gamma} \cdot c''(\cdot) < 0, \quad (\text{A.2.1})$$

$$a^* = \frac{d^2p}{d(q+q^*)^2} \cdot q^* + 2 \cdot \frac{dp}{d(q+q^*)} - \frac{1}{\gamma} \cdot c''(\cdot) < 0, \quad (\text{A.2.2})$$

$$b = \frac{d^2p}{d(q+q^*)^2} \cdot q + \frac{dp}{d(q+q^*)}, \quad (\text{A.2.3})$$

and

$$b^* = \frac{d^2p}{d(q+q^*)^2} \cdot q^* + \frac{dp}{d(q+q^*)}. \quad (\text{A.2.4})$$

Stability requires

$$a < 0, \quad a^* < 0, \quad (\text{A.2.5})$$

$$b < 0, \quad b^* < 0, \quad (\text{A.2.6})$$

and

$$\Delta = a \cdot a^* - b \cdot b^* > 0. \quad (\text{A.2.7})$$

These conditions are outlined in Dixit (1986).

Second Order Condition For a Maximum

Differentiating F.O.C. (2.18) with respect to r yields the following

$$\begin{aligned} \frac{\partial^2 \Pi_d}{\partial r^2} &= \frac{d^2p}{d(q+q^*)^2} \cdot \left(\frac{\partial q}{\partial r} + \frac{\partial q^*}{\partial r} \right) \cdot \frac{\partial q^*}{\partial r} \cdot q + \frac{dp}{d(q+q^*)} \cdot \frac{\partial^2 q^*}{\partial r^2} \cdot q \\ &+ \frac{dp}{d(q+q^*)} \cdot \frac{\partial q^*}{\partial r} \cdot \frac{\partial q}{\partial r} + \frac{d^2p}{d(q+q^*)^2} \cdot \left(\frac{\partial q}{\partial r} + \frac{\partial q^*}{\partial r} \right) \cdot \frac{\partial q}{\partial r} \cdot q^* \\ &+ \frac{dp}{d(q+q^*)} \cdot \frac{\partial^2 q}{\partial r^2} \cdot q^* + \frac{dp}{d(q+q^*)} \cdot \frac{\partial q}{\partial r} \cdot \frac{\partial q^*}{\partial r} \\ &+ r \cdot \frac{\partial^2 q^*}{\partial r^2} + \frac{\partial q^*}{\partial r}. \end{aligned} \quad (\text{A.2.8})$$

²⁰ 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.

Assume linear demand and linear marginal cost, then

$$\frac{d^2p}{d(q+q^*)^2} = 0, \quad \frac{\partial^2 q}{\partial r^2} = 0, \quad \text{and} \quad \frac{\partial^2 q^*}{\partial r^2} = 0, \quad (\text{A.2.9})$$

so (A.2.8) equals

$$\frac{\partial^2 \Pi_d}{\partial r^2} = 2 \cdot \frac{dp}{d(q+q^*)} \cdot \frac{\partial q^*}{\partial r} \cdot \frac{\partial q}{\partial r} + \frac{\partial q^*}{\partial r}. \quad (\text{A.2.10})$$

Rearranging (A.2.10) gives

$$\frac{\partial^2 \Pi_d}{\partial r^2} = \left(2 \cdot \frac{dp}{d(q+q^*)} \cdot \frac{\partial q}{\partial r} + 1 \right) \cdot \frac{\partial q^*}{\partial r}. \quad (\text{A.2.11})$$

Now

$$\frac{\partial q}{\partial r} = \frac{-b}{\Delta} = - \left(\frac{dp}{d(q+q^*)} / \Delta \right) > 0 \quad (\text{A.2.12})$$

and

$$\frac{\partial q^*}{\partial r} = \frac{a}{\Delta} = \left(\left(2 \cdot \frac{dp}{d(q+q^*)} - \frac{1}{\gamma} \cdot c'' \right) / \Delta \right) < 0, \quad (\text{A.2.13})$$

so

$$\frac{\partial^2 \Pi_d}{\partial r^2} = \left(\frac{-2 \cdot \left(\frac{dp}{d(q+q^*)} \right)^2}{\Delta} + 1 \right) \cdot \frac{\partial q^*}{\partial r}. \quad (\text{A.2.14})$$

Now

$$\Delta = 3 \left(\frac{dp}{d(q+q^*)} \right)^2 - \frac{2}{\gamma} \cdot \frac{dp}{d(q+q^*)} \cdot (c'' + c^{*''}) + \frac{1}{\gamma^2} \cdot c'' \cdot c^{*''}, \quad (\text{A.2.15})$$

so

$$\Delta > 2 \left(\frac{dp}{d(q+q^*)} \right)^2, \quad (\text{A.2.16})$$

and

$$\frac{\partial^2 \Pi_d}{\partial r^2} < 0. \quad (\text{A.2.17})$$

Therefore, the second order condition for a maximum is satisfied.

APPENDIX 3

Assume that $c(q) = c^*(q^*)$ which in turn implies that $q = q^*$ at $r = 0$. This assumption allows condition (2.18) to be written as

$$\frac{\partial \Pi_d}{\partial r} = \frac{dp}{d(q+q^*)} \cdot q \cdot \left(\frac{\partial q^*}{\partial r} + \frac{\partial q}{\partial r} \right) \quad (\text{A.3.1})$$

at $r = 0$. In Appendix 2 it was shown that

$$\begin{aligned} \left(\frac{\partial q^*}{\partial r} + \frac{\partial q}{\partial r} \right) &= \left(\left(2 \cdot \frac{dp}{d(q+q^*)} - \frac{1}{\gamma} \cdot c'' - \frac{dp}{d(q+q^*)} \right) / \Delta \right) \\ &= \left(\left(\frac{dp}{d(q+q^*)} - \frac{1}{\gamma} \cdot c'' \right) / \Delta \right) < 0. \end{aligned} \quad (\text{A.3.2})$$

Therefore, at $r = 0$

$$\frac{\partial \Pi_d}{\partial r} > 0. \quad (\text{A.3.3})$$

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 (2.10) and then solving for r . That is,

$$r_p = p(q_m) - \frac{1}{\gamma} \cdot c'(q^* = 0), \quad (\text{A.3.4})$$

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 , (2.18) becomes

$$\frac{\partial \Pi_d}{\partial r} = \frac{dp}{dq_m} \cdot \frac{\partial q^*}{\partial r} \cdot q_m + r_p \cdot \frac{\partial q^*}{\partial r}. \quad (\text{A.3.5})$$

Substituting (A.3.4) into (A.3.5) gives

$$\frac{\partial \Pi_d}{\partial r} = \left(\frac{dp}{dq_m} \cdot q_m + p(q_m) - \frac{1}{\gamma} \cdot c'(q^* = 0) \right) \cdot \frac{\partial q^*}{\partial r}. \quad (\text{A.3.6})$$

Now at r_p

$$\frac{dp}{dq_m} \cdot q_m + p(q_m) - \frac{1}{\gamma} \cdot c'(q_m) = 0 \quad (\text{A.3.7})$$

from the first order condition for a maximum to the export problem. Also at r_p , $q_m > q^* = 0$, so

$$c'(q^* = 0) < c'(q_m). \quad (\text{A.3.8})$$

Combining (A.3.6), (A.3.7), and (A.3.8), and utilising a result from Appendix 2 that $\frac{\partial q^*}{\partial r} < 0$ implies that at r_p

$$\frac{\partial \Pi_d}{\partial r} < 0. \quad (\text{A.3.9})$$

That is, the optimal royalty rate for the monopolist is less than the prohibitive rate.

APPENDIX 4

In the case where r^L is restricted to zero Problem 4 has nice curvature properties and Wright (1989) shows that its solution occurs at the intersection of constraints (3.6) and (3.7). Let this solution be given by

$$(\bar{\alpha}^L, \bar{l}^L). \quad (\text{A.4.1})$$

Wright (1989) also shows that $\bar{\alpha}^L > \hat{\alpha}^L$. The intuition for this result is that the licensor increases α^L above $\hat{\alpha}^L$ and distorts the allocation of production away from the cost minimising allocation in order to convince the licensee that the low cost technology has occurred.

The question to answer is whether it is possible to increase the licensor's profit by increasing r^L above zero and changing α^L in such a way that constraints (3.6) and (3.7) are still satisfied.

Totally differentiating the objective function yields

$$\begin{aligned} d\Pi(L) &= \frac{\partial \Pi^L(\alpha^L)}{\partial \alpha^L} \cdot d\alpha^L + dl^L + r^L \cdot \frac{\partial q^{L*}(\alpha^L, r^L)}{\partial r^L} \cdot dr^L \\ &\quad + q^{L*}(\alpha^L, r^L) \cdot dr^L + r^L \cdot \frac{\partial q^{L*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L \end{aligned} \quad (\text{A.4.2})$$

and total differentiation of constraints (3.6) and (3.7) respectively yields

$$\begin{aligned} 0 &= \frac{\partial \Pi^{HL}(\alpha^L)}{\partial \alpha^L} \cdot d\alpha^L + dl^L + r^L \cdot \frac{\partial q^{HL*}(\alpha^L, r^L)}{\partial r^L} \cdot dr^L \\ &\quad + q^{HL*}(\alpha^L, r^L) \cdot dr^L + r^L \cdot \frac{\partial q^{HL*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L \end{aligned} \quad (\text{A.4.3})$$

and

$$0 = \frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial r^L} \cdot dr^L + \frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L - dl^L. \quad (\text{A.4.4})$$

By the envelope theorem

$$\frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial r^L} = -q^{L*}(\alpha^L, r^L), \quad (\text{A.4.5})$$

so that (A.4.4) can be written as

$$0 = -q^{L*}(\alpha^L, r^L) \cdot dr^L + \frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L - dl^L. \quad (\text{A.4.6})$$

If r^L is increased, then (A.4.6) implies that l^L must be decreased by $dl^L = -q^{L*}(\alpha^L, r^L) \cdot dr^L$ for constraint (3.7) to be satisfied.

Given $r^L = 0$ and (A.4.2), an increase in r^L increases the objective function by $q^{L*}(\alpha^L, r^L) \cdot dr^L$ while the requirement that (A.4.6) 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 right hand side of (A.4.3) 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 (A.4.6) 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 $(\bar{\alpha}^L, \bar{l}^L, r^L = 0)$

$$-\frac{\partial \Pi_N^{L*}(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L > \frac{\partial \Pi^{HL}(\alpha^L)}{\partial \alpha^L} \cdot d\alpha^L, \quad (\text{A.4.7})$$

so a decrease in α^L brings the right hand side of (A.4.3) back to zero. This decrease in α^L also increases the objective function because at $(\bar{\alpha}^L, \bar{l}^L, r^L = 0)$

$$-\frac{\partial \Pi_N^L(\alpha^L, r^L)}{\partial \alpha^L} \cdot d\alpha^L > \frac{\partial \Pi^L(\alpha^L)}{\partial \alpha^L} \cdot d\alpha^L. \quad (\text{A.4.8})$$

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 (3.6) and (3.7) remain satisfied.

APPENDIX 5

In the case where r^L is restricted to zero Problem 5 has nice curvature properties and Wright (1989) shows that the solution occurs at the tangency of constraint (3.13) with a level curve of the objective function. Let this solution be given by

$$(\bar{\alpha}^L, \bar{l}^L). \quad (\text{A.5.1})$$

Totally differentiating the objective function yields

$$d\Pi(L) = \frac{\partial \Pi^L(\alpha)}{\partial \alpha} \cdot d\alpha + dl + r \cdot \frac{\partial q^{L^*}(\alpha, r)}{\partial r} \cdot dr + q^{L^*}(\alpha, r) \cdot dr + r \frac{\partial q^{L^*}(\alpha, r)}{\partial \alpha} \cdot d\alpha, \quad (\text{A.5.2})$$

while totally differentiating constraint (3.13) around solution (A.5.1) gives

$$0 = \rho^* \cdot \frac{\partial \Pi_N^L(\alpha, r)}{\partial \alpha} d\alpha + \rho^* \cdot \frac{\partial \Pi_N^L(\alpha, r)}{\partial r} \cdot dr + (1 - \rho^*) \cdot \frac{\partial \Pi_N^{H^*}(\alpha, r)}{\partial \alpha} d\alpha + (1 - \rho^*) \frac{\partial \Pi_N^{H^*}(\alpha, r)}{\partial r} \cdot dr - dl. \quad (\text{A.5.3})$$

By the envelope theorem

$$\frac{\partial \Pi_N^{H^*}(\alpha, r)}{\partial r} = -q^{H^*}(\alpha, r) \quad (\text{A.5.4})$$

and

$$\frac{\partial \Pi_N^L(\alpha, r)}{\partial r} = -q^{L^*}(\alpha, r). \quad (\text{A.5.5})$$

If r is increased, then (A.5.3) implies that l must decrease by

$$dl = (-\rho^* \cdot q^{L^*}(\alpha, r) - (1 - \rho^*) \cdot q^{H^*}(\alpha, r)) \cdot dr \quad (\text{A.5.6})$$

for constraint (3.13) to be satisfied. Substituting (A.5.6) into (A.5.2), given $d\alpha = 0$, establishes that the net change in the objective function is

$$d\Pi(L) = (q^{L^*}(\alpha, r) - (\rho^* \cdot q^{L^*}(\alpha, r) + (1 - \rho^*) \cdot q^{H^*}(\alpha, r))) \cdot dr. \quad (\text{A.5.7})$$

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

$$\frac{d\Pi(L)}{dr} > 0 \quad (\text{A.5.8})$$

when r is increased around $r = 0$.

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