ASYMMETRIC OLIGOPOLY AND TECHNOLOGY TRANSFERS*

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In the literature there are many models that either assume or generate cost asymmetries (e.g. multi-stage games in which firms engage in cost-reducing R & D). These models are implicitly predicated on the assumption that superior technologies can never be transferred. Using a simple linear Cournot model the paper shows that this need not be the case. In fact, assuming that technologies can be replicated perfectly, a lower-cost firm has always the incentive to transfer its technology and hence a Cournot–Nash equilibrium cannot be fully asymmetric. The economic rationale for this result is straightforward. As is well known, in a Cournot game a firm earns higher profits if it can credibly commit itself to producing more output. A technology transfer (henceforth TT) achieves precisely this, albeit indirectly. It is the firm buying the lower-cost technology that will increase its output and thus benefit from the output contraction by all other firms. The paper shows that this strategic surplus exceeds the loss of profits by the firm selling its superior technology, thereby establishing that any change from a fully asymmetric industry configuration generates a Pareto improvement for any two firms engaged in a technology transfer. Readers familiar with the literature on losses from horizontal mergers (see, for example, Gaudet and Salant (1992)) will note that technology transfers are in a sense the mirror image of partial mergers, in that the latter have the detrimental effect of increasing the outsiders' output, while technology transfers have the opposite effect.

However, the profitability of technology transfers is a two-edged sword. Faced by a possible technology transfer between two of its competitors and resulting loss of its profits, any firm will try to disrupt such transfer by offering a more attractive deal to either firm. The paper shows that each firm will succeed in making itself a preferred technology transfer partner, thus ensuring that a linear Cournot oligopoly game with technology transfers has no non-cooperative Nash equilibria (in pure strategies).

On a less negative note, technology transfers furnish non-cooperative firms with both the motive and the opportunity to collude successfully even in a finitely repeated game. In fact any technology transfer involves some form of licensing agreement and this can be used to provide both the rewards and the punishments to enforce collusion. The paper shows that there exist non-linear transfer payment schedules under which the fully collusive outcome (i.e. joint-profit maximising) can be sustained as a non-cooperative Nash equilibrium.

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I. THE MODEL

First, some notation. Let $c_{ij}^k$ be firm $i$'s (constant) marginal cost in the event of firm $j$ transferring its technology to firm $k$, i.e. indexing firms in ascending order of efficiency (with firm 1 (n) being the most (least) efficient firm), there are three mutually exclusive possibilities:

- if $k = i > j$ then firm $i$ buys firm $j$'s technology,
- if $k > i = j$ then firm $i$ sells its technology to firm $k$,
- if $k,j < i$ then firm $i$ does not engage in a technology transfer.

I shall reserve the notation $c_i^k$ for firm $i$'s marginal cost if no technology transfer takes place anywhere in the industry.

Next, consider the following two-stage game. In the first stage firms decide whether to engage in a technology transfer and, if so, the identity of their TT partner, i.e. a typical firm $i$ chooses its marginal cost $c_i^k$. Notice that marginal costs are assumed to be common knowledge.

In the second stage, each firm chooses an output level $q_i$, given the choice of marginal costs in the previous stage and subject to a linear inverse demand function:

$$P = A - b \sum_{i=1}^{N} q_i. \tag{1}$$

It makes no difference to the model if in the second stage production takes place once and for all or if the same output level is produced for any number of periods. In the latter case, costs and profits would have to be computed on a present-value basis.

Without loss of generality we can set $b = 1$ (by a suitable choice of units) and $c_i^{11} = 0$ (by subtracting $c_i^{11}$ from all constants). I shall consider the case of a fully asymmetric triopoly ($c_3^{33} > c_2^{32} > c_1^{11}$), for $N = 3$ is the minimum number of firms necessary to illustrate the strategic behaviour highlighted in this paper. I shall refer to the above case as the linear Cournot triopoly.

If firm $i$ buys firm $j$'s technology, the former’s cost function then becomes

$$c_i^j(q_i) = c_i^k + F_{ij} + c^j_i q_i; i \geq j, \tag{2}$$

where $\tau_{ij}$ is the price paid by firm $i$ for firm $j$'s technology, $F_{ij}$ is the fixed cost incurred by firm $i$ in absorbing and implementing firm $j$'s technology (e.g. training of personnel, etc.) and $c^j_i$ is firm $i$’s post-TT marginal cost. Any oligopoly model with cost asymmetries that ignores the possibility of technology

\[1\] As a mnemonic aid it is useful to visualise $c_i^j$ as $c_i^{<j}$ signifying a technology transfer from firm $j$ to firm $k$.

\[2\] There are two main reasons for concentrating on a quantity-setting oligopoly: (i) as shown by Singh and Vives (1984), if choice variables are endogenously determined and goods are substitutes, then firms will always prefer quantity- to price-setting; (ii) in the case of constant marginal costs the lowest-cost producer under Bertrand competition will never transfer technology, for obvious reasons.

\[3\] It should be noted that in Sections I and II I shall consider only lump-sum transfer payments and shall ignore the possibility of royalty-based TT payments. As shown in Section III, royalties can be used to sustain a fully collusive outcome and, with one exception noted below, will result in a net welfare loss. Therefore, royalty-based TTs can be expected to be outlawed on antitrust grounds.

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transfers is based on one of the following implicit assumptions: (i) technologies are not replicable, i.e. for $\forall j < i$, $c_i^j > c_i^i$; (ii) technology transfers involve prohibitively high fixed costs $F$; (iii) firms can never increase their profits by selling a lower-cost technology.

In order to show that assumption (iii) does not hold and that technology transfers can be profitable I can afford the luxury of making the polar assumptions of zero fixed costs ($F = 0$) and perfectly replicable technologies, i.e. technology transfers do not involve any additional marginal costs for the firm buying the new technology: for $\forall i > j$, $c_i^j = c_i^j$. It is simple to relax these assumptions and find the range of values of fixed and marginal costs such that the main results go through.4

To locate the Cournot–Nash sub-game perfect equilibrium we compute profits in stage two under the three possible cases of technology transfers as well as under the no-TT case. Using (1) and (2) and defining $\pi_{k}^{ij}$ as firm $i$'s profits when firm $j$ sells its technology to firm $k$ we obtain:

$$\pi_1^{21} = \frac{(A + c_2^{21} + c_3^{21})^2}{16} ; \quad \pi_1^{31} = \frac{(A + c_2^{31} + c_3^{31})^3}{16} ;$$

$$\pi_1^{22} = \frac{(A + c_2^{32} + c_3^{32})^2}{16} ; \quad \pi_1^{11} = \frac{(A + c_2^{11} + c_3^{11})^2}{16} , \quad (3)$$

$$\pi_2^{31} = \frac{(A - 3c_2^{31} + c_3^{31})^2}{16} ; \quad \pi_2^{21} = \frac{(A - 3c_2^{31} + c_3^{32})^2}{16} ;$$

$$\pi_2^{32} = \frac{(A - 3c_2^{32} + c_3^{32})^2}{16} ; \quad \pi_2^{22} = \frac{(A - 3c_2^{32} + c_3^{22})^2}{16} , \quad (4)$$

$$\pi_3^{31} = \frac{(A + c_2^{31} - 3c_3^{31})^2}{16} ; \quad \pi_3^{21} = \frac{(A + c_2^{31} - 3c_3^{31})^2}{16} ;$$

$$\pi_3^{32} = \frac{(A + c_2^{32} - 3c_3^{32})^2}{16} ; \quad \pi_3^{22} = \frac{(A + c_2^{32} - 3c_3^{22})^2}{16} . \quad (5)$$

II. THE ASYMMETRIC COURNOT OLIGOPOLY WITH TECHNOLOGY TRANSFERS HAS NO NON-COOPERATIVE NASH EQUILIBRIA

For the sake of simplicity I shall consider the case of a fixed industry structure, for allowing for entry does not alter any of the results obtained below.6

**Definition:** A technology transfer between firms $i$ and $j$ is profitable iff:

$$\pi_i^{ii} + \pi_j^{ij} > \pi_i^{ij} + \pi_j^{ij} . \quad (6)$$

Inequality (6) says that a technology transfer between $i$ and $j$ is profitable if it

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4 In La Manna (1992) it is shown that all the results obtained for the case of perfectly replicable technologies hold also to the case of imperfectly replicable technologies (i.e. $\forall j < i$, $c_i^j > c_i^i$), provided certain reasonable restrictions apply.

5 In line with the notation for marginal costs, $\pi_i^{ii}$ is firm $i$'s profits when no technology transfer takes place.

6 See La Manna (1992) for details.
generates a surplus as compared with a fully asymmetric configuration. At this stage I need not specify how this surplus is shared between the two firms. Obviously any technology transfer that increases industry profits is profitable (as the profits of the ‘excluded’ firm \( k \) always fall after a technology transfer: \( n_k^{it} < n_k^{kk}; \forall k \neq i, j \)). Therefore, at least three firms are required to analyse the more interesting case of technology transfers that are both mutually profitable and make industry profits fall.

We can now establish:

**Proposition 1**: If technologies are perfectly replicable then any technology transfer is profitable, irrespective of the behaviour of industry profits.

The proof of Proposition 1 is as simple as it is intuitive. A bilateral technology transfer involves a reallocation of profits from the firm excluded from the technology transfer to the two parties in the agreement. All we have to show is that the increase in profits of the firm buying the lower-cost technology exceeds the reduction in profits of the firm selling it, thus enabling the two firms to strike a mutually profitable agreement. Proposition 1 follows immediately by substituting (3)–(5) into (6), recalling that in order for firm 3 to be viable in the no-TT configuration, it has to be the case that \( A + c_3^3 > 3c_3^3 \). Q.E.D.

Proposition 1 implies that the standard modelling of Cournot oligopolies with cost asymmetries is correct only if TTs are not feasible. Of course, whether the fixed costs \( F \) of implementing a lower-cost technology are so large to dissipate the strategic surplus of technological transfers and/or superior technologies are not replicable at all is an empirical matter.

Proposition 1 shows that the no-technology-transfer configuration cannot be taken as a bench-mark in so far as the firm excluded from the technology transfer will see its profits fall and hence should be expected to offer an alternative agreement to either parties involved in the transfer. The main result of this section is:

**Proposition 2**: If technologies are perfectly replicable and hence technology transfers are profitable, then the linear Cournot triopoly game has no non-cooperative Nash equilibria in pure strategies.

The proof of Proposition 2 is constructive and with an immediately intuitive appeal. It will be shown that, given any bilateral TT agreement, the ‘excluded’ firm can always bribe either party into entering a more profitable agreement, i.e. the sequence of strictly more profitable deals is a circle.\(^7\)

The structure of the proof is as follows: before establishing the terms of the TT agreement between any two firms \( i \) and \( j \), I shall determine the counter bids that the excluded party (firm \( k \)) is willing to offer to either firms. These will take

\(^7\) Proposition 2 considers only bilateral technology transfers and ignores the case of a three-way agreement with both firms 2 and 3 buying the lowest-cost technology for the simple reason that bilateral agreements are always more profitable than a three-way transfer. It always pays to squeeze the excluded firm’s profits. It is trivial to show that

\[
\gamma_1^n + \gamma_2^n + \gamma_3^n + \gamma_1^{2i} + \gamma_2^{2i} + \gamma_3^{2i} - (\gamma_1^n + \gamma_2^n + \gamma_3^n) < \gamma_1^n + \gamma_2^n + \gamma_3^n + \gamma_j^n; j = 2, 3,
\]

where the LHS (RHS) is the surplus of a three-way technology transfer (of a technology transfer from firm 1 to firm \( j \)) as compared to the no-technology-transfer status quo.
the form of a minimum (maximum) price for the technology being sold (bought). Then, I shall consider two ‘voluntary exchange’ constraints, setting the minimum (maximum) price that the firm selling (buying) the lower-cost technology is willing to accept (pay), given the counter bids of the ‘excluded’ party. In each of the three cases it will be shown that the minimum price for a lower-cost technology, as defined above, exceeds the maximum price the buying firm is willing to pay, thereby establishing the desired result.

I shall illustrate the logic of the proof by considering what may appear as the least likely possibility, i.e. the least efficient firm (firm 3) disrupting a TT between the two more efficient firms 1 and 2.

If the lowest-cost technology is sold by firm 1 to firm 2, then firm 3’s profits would amount to max \{\pi_3^{21}, 0\}. This is the level of profits that determines the maximum prices firm 3 is willing to pay in exchange for either firm 1’s or firm 2’s technology, as defined by the following equalities:

\begin{align*}
\tau_3^{31} &= \pi_3^{31} - \max \{\pi_3^{21}, 0\} \\
\tau_3^{32} &= \pi_3^{32} - \max \{\pi_3^{21}, 0\}.
\end{align*}

Equalities (7)–(8) define the best counter bids that firm 3 can make in order to prevent a TT between its competitors from taking place. Considering that firm 3 is willing to pay \tau_3^{31} for the lowest-cost technology, the minimum price firm 1 is willing to accept from firm 2 (\equiv \lambda_2^{21}) must make firm 1 indifferent between selling to firm 2 and accepting firm 3’s counter bid, i.e.

\begin{equation}
\pi_1^{21} + \tau_2^{21} = \pi_1^{31} + \tau_3^{31}.
\end{equation}

The maximum price firm 2 is willing to pay for firm 1’s technology (\equiv \tau_2^{21}) is defined as the price that would make firm 2 indifferent between buying the lowest-cost technology from firm 1 and accepting firm 3’s counter offer for its own technology, i.e.,

\begin{equation}
\pi_2^{21} - \tau_2^{21} = \pi_2^{32} + \tau_3^{32}.
\end{equation}

Because of the high prices firm 3 is prepared to pay in order not to be squeezed by a technology transfer between firms 1 and 2, no technology transfer between the latter firms is feasible if

\[\lambda_1^{21} > \tau_2^{21}\]

i.e. substituting (7)–(8) into (9)–(10):

\begin{equation}
\pi_1^{21} + \pi_3^{31} + \pi_2^{32} + \pi_3^{32} > 2 \max \{\pi_3^{21}, 0\} + \pi_1^{21} + \pi_2^{31}.
\end{equation}

To see that (11) holds, suppose first that firm 3 would not be forced to exit the industry if firm 2 bought the lowest-cost technology from firm 1 (i.e. \(A > c_3^{21} = c_3^{31}\)). Then (11) can be written as

\begin{equation}
2A(2c_3^{21} - c_2^{31}) - 10(c_2^{21})^2 + 5(c_2^{31})^2
\end{equation}

which holds for \(\forall c_3^{21} = c_3^{31} \geq c_2^{31} = c_2^{21}\).

8 From (4) it is immediate that if \(A + c_3^{31} < 3c_3^{21}\) firm 3 would make negative profits and thus exit the industry earning zero profits.

9 The mnemonics are: \(\tau\) for the top price a firm buying a lower-cost technology is willing to pay and \(A\) for lowest price a firm selling a low-cost technology is prepared to accept.
If $A < c_3^{21} = c_3^{33}$ and thus firm 3 would leave the industry following a TT between firms 1 and 2, then (11) can be written as

$$A^2 - 9Ac_2^{31} + 225(c_2^{31})^2 > 0$$

which always holds.

An identical argument can be deployed to show that any technology transfer between firms 1 and 3 (firms 2 and 3) can always be disrupted by firm 2 (firm 1), thereby establishing the desired result. Q.E.D.

In spite of the cumbersome notation, the logic underlying Proposition 2 is simple. Any two firms engaged in a technology transfer are effectively sharing the spoils of the profits generated by the lower output produced by the firm excluded from the technology transfer. In determining its counter bids the latter takes as a benchmark the lower profits that it would earn in the event of a technology transfer between its rivals taking place. Therefore, in proposing to sell (buy) technology to (from) either parties it will aim not so much at paying (receiving) a low (high) price for the technology being transferred, but rather at preventing its rivals from squeezing its own profits. As a result, the feasibility of technology transfers deprives the otherwise well-behaved standard linear Cournot triopoly of its non-cooperative Nash equilibrium.

III. TECHNOLOGY TRANSFERS AND THE SUSTAINABILITY OF COLLUSIVE EQUILIBRIA

There is an interesting case in which technology transfers are not incompatible with Nash equilibria and this is when technology transfers are deployed to self-enforce the fully collusive outcome.

In order to establish how technology transfers provide an effective means to sustain collusion by non-cooperative behaviours we can use an even simpler model than in the previous section.

Consider the case of a linear Cournot duopoly with linear demand (1), with $o$ and $c$ being the constant marginal costs of firms 1 and 2 respectively.

The unique Cournot-Nash equilibrium yields:

$$\pi_1^* = \frac{(A+c)^2}{9}; \quad \pi_2^* = \frac{(A-2c)^2}{9}. \quad (13)$$

Suppose now that firm 1 transfers its technology to firm 2 and that the transfer payment, including both a royalty rate $\alpha$ and a lump-sum $\beta$, is contingent on
the output produced by firm 1 according to the following discontinuous schedule:

\[ \tau = \begin{cases} \alpha q_2 + \beta & \text{if } q_1 \leq A/4 \\ 0 & \text{if } q_1 > A/4. \end{cases} \]  

(14)

We can now prove:

**PROPOSITION 3:** For a wide range of parameter values, an own-output-contingent technology transfer schedule including both a royalty rate and a lump-sum sustains the fully collusive outcome as a non-cooperative Nash equilibrium.

Joint-profit maximisation results in \( q_1^* = q_2^* = A/4 \). Substituting \( q_1 = A/4 \) into firm 2’s reaction function, namely, \( R_2(q_1) = (A - \alpha - q_1)/2 \) we obtain that in order for \( q_2 = A/4 \) to be a best reply to \( q_1 = A/4 \) it must be the case that \( \alpha = A/4 \). The lump-sum \( \beta \) is determined as the value that makes the following incentive-compatibility just binding for firm 2:

\[ \pi_2^*(q_1, q_2) - \tau \geq \pi_2^*; \]  

i.e. \( \frac{A^2}{16} - \beta \geq \frac{(A - 2c)^2}{9} \).  

(15)

A corresponding incentive-compatibility constraint has to hold for firm 1:

\[ \pi_1^*(q_1', q_2') + \alpha q_2' + \beta \geq \pi_1^*. \]  

(16)

Substituting into (16) the value of \( \beta \) that makes (15) hold as an equality we obtain:

\[ \frac{A^2}{4} \frac{(A - 2c)^2}{9} > \frac{(A + c)^2}{9}, \]  

(17)

which holds, since \( A > 2c \).

Finally we have to show that firm 1 cannot benefit by deviating unilaterally from the collusive outcome, i.e.

\[ \pi_1^D(q_1^D, q_2^D) < \pi_1^*(q_1^*, q_2^*) + \alpha q_2^* + \beta, \]  

where \( \pi_1^D \) is firm 1’s profits when it deviates optimally from the collusive outcome. Substituting into (18) firm 1’s best-reply output to \( q_2' = A/4 \), i.e. \( q_2^D = 3A/8 \) we obtain

\[ \frac{9A^2}{64} < \frac{A^2}{4} \frac{(A - 2c)^2}{9}, \]  

(19)

which holds for \( 25A > A > 2c \). \( \text{Q.E.D.} \)

The welfare implications of the above result are quite sharp:

**COROLLARY:** If lump-sum-only technology transfers are profitable (not profitable), then allowing the lower-cost duopolist to charge a royalty rate, thereby making the collusive outcome sustainable as a non-cooperative Nash equilibrium, always lowers (raises) welfare.

If the lower-cost duopolist can only charge a lump-sum payment for its technology, a transfer will take place iff \( A > 2\cdot5c \).\(^{11}\) Therefore if \( A > 2\cdot5c \) the

\(^{11}\) See previous footnote.
collusive outcome will always lower welfare on account of the lower quantity of output produced. However, if \( a < 2.5c \), the fact that a collusive agreement sustained by the non-linear transfer payment schedule (14) allows the higher-cost duopolist to produce with the lower-cost technology always more than offsets the loss of output due to the collusive agreement.

IV. CONCLUSION

This paper has shown that technology transfers, when feasible, can have a dramatic effect on the existence and nature of equilibria in asymmetric oligopolies, depending on the specific form of licensing agreements: (i) if royalty-based TT payments are not allowed, then a linear Cournot triopoly will have no Nash non-cooperative equilibria in pure strategies;\(^{12}\) (ii) if no restrictions are imposed on the licensing agreement, then a simple non-linear payment schedule can be used to sustain the fully collusive outcome even in a finitely repeated game.

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\(^{12}\) In these circumstances there is a prima facie case for government intervention; in the triopoly example, a ban on firm 2 from engaging in technology transfers would result in a welfare-improving TT between firms 1 and 3.