TECHNOLOGY TRANSFER: BARRIERS AND OPPORTUNITIES

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Abstract. In this paper we study technology transfer in a duopoly model with heterogeneous goods under quantity and price competition. We obtain three conclusions: Firstly, under product heterogeneity, technology transfer can take any form. Secondly, the properties found in the homogeneous case generalize to the heterogeneous case with various degrees of generality. Finally, if demand is not symmetric we may find full technology transfer between firms with different sizes and that firms with similar technology do not engage in technology transfer. We find evidence of the latter in the market for antidepressants.

1. Introduction. Technology transfer (TT in the sequel) is a central issue within the economics of technological change and innovation. It has been analyzed from different perspectives (perfect competition, evolutionary models, etc.). In this paper we will be concerned with TT in static oligopolistic markets.

Economic intuition—borrowed from, say, the theory of international trade—suggests that with zero adoption costs the size of TT should be positively related with the technological distance between firms. However, Katz and Shapiro [5] proved that the properties that characterized TT run counter to this intuition:

(i) TT always occurs between similar firms with similar costs.
(ii) TT never occurs if firms have very different costs.
(iii) Under linear demand, joint profits are U-shaped in the marginal cost of the firm receiving TT (Firm 2 in the sequel), (see also Marjit [6]).

The explanation of these results is that profits of the firm transferring the technology (Firm 1 in the sequel) decrease with the size of TT because the business stealing effect but profits of Firm 2 increase with the size of TT because costs reduction. When the marginal cost of 2 is high the business stealing effect is dominant because TT entails a large loss of profits of 1 but a small increase in profits for 2. When both firms are similar, business stealing is small and cost reduction dominates.

Katz and Shapiro [5] used several simplifying assumptions, including product homogeneity. This assumption is a useful first approximation but restricts too tightly the scope of the market under consideration. On the one hand, from the empirical point of view, product homogeneity does not allow experiences like the Silicon Valley (where a sizeable part of TT occurs among firms producing different products),

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the car industry (where six firms produce the blueprints for all engines) or the consumer electronics industry (where the same invention, e.g. cordless appliances, has been applied to a variety of products). Moreover, product homogeneity implies that all firms face the same demand function and this discards the case in which firms sell in different countries. On the other hand, from the theoretical point of view, product heterogeneity allows to consider Cournot and Bertrand competition and to compare the features of both equilibria.

In this paper we study TT in markets with heterogeneous goods. By simplicity we assume that product heterogeneity is exogenous.\(^1\)

In Section 2 we present some facts gathered from a specific market, that of a class of antidepressants. We see that under product heterogeneity TT takes a variety of forms that are hard to reconcile with the analysis of Katz and Shapiro [5].

Section 3 explains the model and the main concepts.

In Section 4 we consider two examples. Assuming demand is linear or isoelastic we show that Properties I-III above may not hold: The reason is that if Firm 2 faces a small demand, joint profits are maximized if Firm 1 makes no TT. Similarly, TT may happen between firms with very different costs as long as Firm 2 faces a large demand relatively to the one of Firm 1. These possibilities can not arise under good homogeneity because there, all firms face the same demand. This section prepares the ground for the more general findings of the next section.

In Section 5 we consider TT in general duopoly models of price and quantity competition. We show that, even under strong restrictions on the class of admissible demand functions, industry profits and the marginal cost of Firm 2 can be related in any arbitrary form (Proposition 1). This can not happen under product homogeneity where, for instance, joint profits are maximized when Firm 2 produces zero output. The implication is that under product differentiation any TT can arise. We show that joint profits are increasing in the marginal cost of 2 when the output of 2 is close to zero, if and only if goods are substitutes (Proposition 2). Finally, we show that joint profits are increasing in the marginal cost of 2 when firms have a similar output, under symmetric demand and small cross price effects (Proposition 3).

Summing up, we obtain three conclusions that are robust to the consideration of both quantity and price competition. Firstly, under product heterogeneity, TT can take any form. Secondly, the properties found in the homogeneous case generalize to the heterogeneous case with various degrees of generality. Finally, if demand is not symmetric we may find full TT between very different firms and that firms that are similar in technology do not engage in TT. The next section provides some evidence of that.

2. A case study: the market for antidepressants. Empirical evidence on the forms of TT is a difficult task. However, we have found useful the insights and lessons to be learn from TT practices in the pharmaceutical industry related to a specific subset of antidepressants, Selective Serotonine Reuptake Inhibitors (SSRI) for several reasons. Firstly, they involve a high level of innovation and rivalry as their market success have been increasing in the last fifteen years. Secondly, SSRI drugs have been the first antidepressants advertised directly to consumers and recognized by their trademark rather than by their molecules, leading to, possibly spurious,

\(^1\)The only paper with heterogeneous products that we are aware of is Mukherjee and Blasubramanian [8]. They study the impact of the threat of imitation on licencing contracts.
product differentiation.\(^2\) And, finally the period covered allows us to compare the TT policies designed by companies before they faced the threat of generic substitutes and the marketing of new competing drugs.\(^3\)

The set of products includes the so called N6A: Prozac, Paxil/Seroxat; Celexa/Cipramil, Zoloft, Effexor/Efexor/Vandral/Dobupal and Serzone. The patented active principles behind each product are different but still close substitutes in terms of their treatment, prescriptions and effects, specially for the case of Prozac-fluoxetine-, Paxil/Seroxat-paroxetine-; Celexa/Cipramil-citalopram- and Zoloft-sertraline-. Here, the molecules are the basic technology while trademarks represent marketing differentiation.

N6A drug makers and technology holders have followed different technology strategies, ranging from exclusive exploitation granted by a series of patents and applications to full TT. In both situations, the products ranked among the top selling drugs in global sales figures and contributed to firms’ growth dramatically. Several examples of this follow.

In 2001, Eli Lilly lost the exclusivity for marketing fluoxetine hydrochloride-Prozac- and generic versions became available in the US. In December 2000, paroxetine’s global market share was 24%. The threat of generic Prozac prompted to Eli Lilly to find alternative ways to keep ahead in the profitable SRRIs market-USD 17.1 billion in 2002- by licensing in fluoxetine R from Sepracor. Through that agreement the licensor-Sepracor- transferred to Eli Lilly all the rights to market the new active principle under the name of Prozac-R, launched in 2001. However, Sepracor did not market fluoxetine-R on its own. This case illustrates that full TT may occur even when the creator of the technology does not sell it.

In contrast, full TT occurs in the case of Celexa/Cipramil in which the licensor-Lundbeck- a large Danish pharmaceutical company licensed out citalopram in 1995 to Forest Lab, a small US drug company, that largely contributed to their growth. Moreover, following the innovation path in this segment, Cipralex/Lexapro based on citalopram R, are also the outcome of full TT and co-marketing between these companies. Here we observe full TT from a large to a small firm.

The case concerning paroxetine-Paxil/Seroxat- is quite different from the two mentioned above. After the acquisition of the patent by Beecham Pharmaceuticals, paroxetine was marketed by SmithKline Beecham (SB) which was acquired by GlaxoSmithKline. The threat of generic paroxetine in 2001 pushed GlaxoSmithKline to search for SSRIs alternatives. Since 2002 GlaxoSmithKline markets Paxil-CR in a formulation that uses SkyePharma’s Geomatrix controlled-release technology. SkyePharma received an undisclosed payment from GSK in addition to royalties on net sales. The effects of TT on Skye Pharma’ accounts have been bigger than expected, from 17.7 million sterling pounds in 1999, to 69.6 million in 2002. In this case there was partial TT from a small to a large firm.

The examples above show that TT under product differentiation may take forms that are not possible under product homogeneity and that TT does not always takes place among similar firms as under product homogeneity. We will see that the theoretical model backs these empirical findings.

\(^2\)The results of several clinical trials show that fluoxetine, paroxetine, citalopram and sertraline are technologically homogeneous.

\(^3\)The antidepressant drug market has been studied by Berndt et al. [1] to determine whether marketing and advertising efforts made by pharmaceutical companies shape market shares.
3. The model. There are two firms selling a product each. Firm 1 can sell to
firm 2 a technology that influences its marginal cost. Marginal costs are constant
on output. Let $c_2$ be the value of the marginal cost of firm 2 before transfer of
technology (TT) takes place. Let $c_2$ be a generic value of the marginal cost of firm
2, which belongs to the interval $[c_2, \bar{c}_2]$ where $\bar{c}_2$ is the minimum marginal cost that
can be achieved by TT. Let $c_1$ be the marginal cost of firm 1. Profits of firm $i$ are
$
\pi_i \equiv (p_i - c_i)x_i \text{ where } x_i \text{ is the output and } p_i \text{ is the price charged by } i = 1, 2.
$

Let $y_i$ be the action of firm $i = 1, 2$ where $y_i \in (0, \bar{y}_i)$, some $\bar{y}$. We consider two
scenarios: Price competition, where the firm chooses prices i.e. $y_i \equiv p_i$ and quantity
competition where the firm chooses quantities i.e. $y_i \equiv x_i$. Under price competition,
payoffs are $(p_i - c_i)x_i(p_1, p_2)$ where $x_i = x_i(p_1, p_2)$ is the demand function for firm
$i$, with $\frac{\partial x_i}{\partial p_i} < 0$. We will say that good $i$ is a substitute (resp. complement) of good
$j$ if $\frac{\partial x_i}{\partial p_j} < 0$ (resp. 0). Under quantity competition payoffs are $(p_i(x_1, x_2) - c_i)x_i$
where $p_i = p_i(x_1, x_2)$ is the inverse demand function for firm $i$ with $\frac{\partial p_i}{\partial x_i} < 0$. In this
case, goods are substitutes (resp. complements) if $\frac{\partial p_i}{\partial y_i} < 0$ (resp. $> 0$). Denote by
$\pi_1(y_1, y_2)$ and $\pi_2(y_1, y_2, c_2)$ the payoff functions of firms 1 and 2. We will assume
that they are twice continuously differentiable.

The game has two stages. In the first stage firms decide the value of $c_2$ cooperatively and in the second stage they set their actions non-cooperatively. We will
refer to the second stage as the competition stage that we define below.

**Definition 3.1.** A Nash Equilibrium (NE) in the competition stage is a pair $(y_1^*, y_2^*)$
such that $y_1^*$ maximizes $\pi_1(y_1, y_2^*)$ and $y_2^*$ maximizes $\pi_2(y_1^*, y_2, c_2)$.

Under price competition, a NE has the form $(p_1^*, p_2^*)$ and usually is called a
Bertrand equilibrium (BE) with first order conditions (FOC)
$$
\frac{\partial \pi_i(p_1^*, p_2^*)}{\partial p_i}(p_i^* - c_i) + x_i(p_1^*, p_2^*) = 0, \ i = 1, 2.
$$

Under quantity competition, a NE has the form $(x_1^*, x_2^*)$ and usually is called a
Cournot Equilibrium (CE) with FOC
$$
\frac{\partial p_i(x_1^*, x_2^*)}{\partial x_i}x_i^* + p_i(x_1^*, x_2^*) - c_i = 0, \ i = 1, 2.
$$

We assume that the system of FOC fulfills the Gale-Nikaido Property. Formally:

**Assumption 3.2.** (a) $\frac{\partial^2 \pi_i(y_1, y_2)}{\partial y_i^2} < 0 \ \forall (y_1, y_2) \in [0, \bar{y}]^2, i = 1, 2.$

(b) $\frac{\partial^2 \pi_1(y_1, y_2)}{\partial y_1 \partial y_2} \frac{\partial^2 \pi_2(y_1, y_2)}{\partial y_1 \partial y_2} < 0 \ \forall (y_1, y_2) \in [0, \bar{y}]^2.$

Assumption 3.2 has two parts: a) implies that the profit function of $i$ is strictly
concave in $y_i$. If part a) holds a sufficient condition for b) to hold is that the effect
in absolute value of $y_i$ on $\frac{\partial \pi_i}{\partial y_i}$ is larger than on $\frac{\partial \pi_j}{\partial y_j}, j \neq i$ i.e. that the matrix with
typical element $\frac{\partial^2 \pi_i}{\partial y_i \partial y_j}$ has a Dominant Diagonal (see Friedman [3], Assumption 7,
p. 71). Under quantity competition, Assumption 3.2 reads

a) $2\frac{\partial p_i}{\partial x_i} + x_i \frac{\partial^2 p_i}{\partial x_i^2} < 0, \ i = 1, 2.$

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4For simplicity, when the context is clear, we will not write the arguments of the functions.

5If goods are homogeneous, A.3.2 a) implies $\beta + 2 > 0$ and A.3.2 a) is equivalent to $\beta + 3 > 0$
where $\beta \equiv x \frac{d^2 p(x)}{dx^2} \frac{dx}{dx}$ where $x \equiv x_1 + x_2, \ \beta + 2 > 0$ is equivalent to marginal revenue decreasing
which is the assumption made by Katz and Shapiro [5].
b) \((2 \frac{\partial p_1}{\partial x_1} + x_1 \frac{\partial^2 p_1}{\partial x_1^2})(2 \frac{\partial p_2}{\partial x_2} + x_2 \frac{\partial^2 p_2}{\partial x_2^2}) > (\frac{\partial p_1}{\partial x_1} + x_1 \frac{\partial^2 p_1}{\partial x_1 x_2})(\frac{\partial p_2}{\partial x_2} + x_2 \frac{\partial^2 p_2}{\partial x_1 x_2}).\)

Thus, Assumption 3.2 (part a)) holds if inverse demand is concave. Even if it is convex, the assumption may hold if \(\frac{\partial^2 p_2}{\partial x_2^2}\) is not too large. Assumption 3.2 (part b)) holds if the impact of the own price on marginal revenue is larger than the cross price impact. A similar condition applies under price competition. We now have the following.

**Lemma 3.3.** Under A.3.2 there is a NE. If FOC hold with equality, NE is unique and \(y_i\) are continuously differentiable functions of \(c_i\), \(i = 1,2\).

**Proof.** The existence of a NE follows from Kakutani fixed point theorem (see, e.g. Friedman [3]) since by A.3.2 \(\pi_i(\cdot)\) is continuous and concave and actions belong to a compact set. Uniqueness and differentiability follows from applying Theorem 4 in Gale and Nikaido [4] to FOC of a NE.

We will assume that Firm 1 is always active in any NE. Let \(\bar{c}_2\) be the minimum value of \(c_2\) for which the output of firm 2 is zero in a NE. Under our assumptions this value exists.

By Lemma 3.3 we can write \(y_1\) and \(y_2\) as functions of \(c_2\), i.e. \(\pi_i = y_i(c_2)\), \(i = 1,2\). Write \(\pi_1(c_2) = \pi_1(y_1(c_2), y_2(c_2))\) and \(\pi_2(c_2) = \pi_2(y_1(c_2), y_2(c_2), c_2)\). Thus, industry profits can be written as \(\Pi = \sum_{i=1}^2 \pi_i = \pi_1(c_2) + \pi_2(c_2) \equiv \Pi(c_2)\).

Finally we assume that in the first stage of the game \(c_2\) is chosen from \([\bar{c}_2, \tilde{c}_2]\), to maximize \(\Pi\). Formally,

**Definition 3.4.** \(c_2^*\) solves the TT two stage game if \(\Pi(c_2^*) \geq \Pi(c_2), \forall c_2 \in [\bar{c}_2, \tilde{c}_2]\)

We finally remark that the model is sufficiently flexible to incorporate alternative interpretations. 1) TT may refer to a product that was previously not produced by Firm 2. In this case we set \(\tilde{c}_2 = \bar{c}_2\). 2) Positive adoption costs. Suppose that these costs are a function of the pre-TT output and actual output. Since the former is given, write this as \(F(x_2)\). Thus, under quantity competition, \(\pi_2 \equiv (p_2(x_1, x_2) - c_2) x_2 - F(x_2) = (p_2(x_1, x_2) - F(x_2)/x_2 - c_2) x_2\). Now we can interpret \(p_2(x_1, x_2) - F(x_2)/x_2\) as the inverse demand function of Firm 2 and carry on as before. These two interpretations do not fit well with product homogeneity: The first result happens because joint profits are maximized when Firm 2 does not produce at all so it is impossible to explain any positive TT. The second one, because product homogeneity implies that the two firms face the same demand function.\(^6\)

4. **Two examples.** In this section we explore what difference product differentiation makes to TT by considering two examples. The first deals with quantity competition and generalizes the linear inverse demand case worked out by Katz and Shapiro [5] and Marjit [6]. The second example considers price competition with linear demand.

**Example 4.1** (Quantity competition). Inverse demand functions read

\[p_i = a_i - b_i x_i^\alpha - d_i x_j^\alpha, \quad \alpha, \quad a_i, \quad b_i > 0, \quad i \neq j = 1,2.\]

If \(d_1\) and \(d_2\) are positive (resp. negative), goods are substitutes (resp. complements). It is easy to check that A.3.2 holds and A.3.2 reads \((1 + \alpha)^2 b_1 b_2 > d_1 d_2.\)

\(^6\)See Mukherjee [7] for an extension of this model.
We first calculate the CE for a given \( c_2 \). We have that,

\[
\pi_i^* = ab_i \left( \frac{(1+\alpha)b_j(a_i - c_i) - d_j(a_{ij} - c_j)}{(1+\alpha)^2 b_i b_j - d_1 d_2} \right)^{\frac{1}{\alpha} + 1} \quad i, j = 1, 2, i \neq j. \tag{1}
\]

In order to guarantee that profits are non negative in the CE, we assume that \((1+\alpha)b_1(a_1 - c_1) > d_1(a_2 - c_2)\) and \((1+\alpha)b_1(a_2 - c_2) \geq d_1(a_1 - c_1)\) \( \forall \epsilon_2 \in [c_1, \epsilon_2]. \)

From (1) we get that the sign of \( \frac{d\pi_i}{dc_2} \) equals the sign of

\[
d_1[b_2(a_1 - c_1)(1+\alpha) - (a_2 - c_2)d_1]^{\frac{1}{\alpha}} - (1+\alpha)b_2[(a_2 - c_2)b_1(1+\alpha) - d_2(a_1 - c_1))]^{\frac{1}{\alpha}}. \tag{2}
\]

We now check for the properties I-II-III stated in the Introduction.

**I** : If \( a_2 \) is sufficiently small in relationship with \( a_1 \) we see from (1) that \( \Pi \) is increasing on \( c_2 \) so TT never occurs. The reason is that Firm 2 faces a demand curve that, relative to that of Firm 1, is small so is not profitable to transfer technology to a firm that is relatively inefficient selling the good. We will refer to the question of the relative size of demand as the Marketing Effect. Assuming \( a_1 = a_2 = a, b_1 = b_2 = b, d_1 = d_2 = d \), we see from (1) that \( sign \frac{d\Pi}{dc_2} \big|_{c_1 = c_2} = sign \{ (a - c_1)^{\frac{1}{\alpha}}(b(1+\alpha) - d)^{\frac{1}{\alpha}}(d - (1+\alpha)b) \} < 0 \). Thus I holds in our model under symmetric demand.

**II** : From (1) we see that \((1+\alpha)(a_2 - \bar{c}_2)b_1 = d_2(a_1 - c_1)\). Equation (2) implies that \( sign \frac{d\Pi}{dc_2} \big|_{c_2 = \bar{c}_2} = sign \; d_1 \). So \( \frac{d\Pi}{dc_2} \big|_{c_2 = \bar{c}_2} > 0 \) iff good 2 is substitute of good 1. Thus, II holds in our model as long as products are substitutes.

**III** : From (1) we get that \( \frac{d^2\Pi}{dc_2^2} > 0 \). Thus, \( \Pi(\cdot) \) is strictly convex and \( \Pi(\cdot) \) attains a minimum at \( \frac{d\Pi}{dc_2} = 0 \). We now give sufficient conditions for \( \Pi(\cdot) \) to be U-shaped with a minimum at \( \bar{c}_2 \in (c_1, \bar{c}_2) \). Letting \( Q \equiv \left( \frac{(1+\alpha)b_2}{d_1} \right)^\alpha \) we get from (1) that the value of \( c_2 \) which minimizes \( \Pi \) is

\[
\hat{c}_2 = a_2 - \frac{(1+\alpha)(a_1 - c_1)b_2 + (a_1 - c_1)d_2Q}{d_1 + Qb_1(1+\alpha)} < \bar{c}_2 = a_2 - \frac{d_2(a_1 - c_1)}{(1+\alpha)b_1}.
\]

Assume substitute goods (if goods are complements (1) implies \( \frac{d\Pi}{dc_2} > 0 \) so full TT is optimal) and symmetric demand. Keep the notation introduced in I above. If \( \hat{c}_2 \leq c_1 \), we had that

\[
1 \leq \frac{(1+\alpha)b + dQ}{d + Qb(1+\alpha)} \iff Q \leq 1 \iff (1+\alpha)b \leq d, \text{ contradiction. Thus under substitute goods and symmetric demand } \hat{c}_2 > c_1.
\]

**Example 4.2** (Price competition). Demand functions read

\[
x_i = a_i - p_i + d_i p_j, i, j = 1, 2.
\]

If \( d_1 \) and \( d_2 \) are positive (resp. negative), goods are substitutes (resp. complements).\(^8\) It is easy to check that A3.2a) holds an that A3.2b) reads \( 4 > d_1 d_2 \). In a BE,

\[
\pi_i^* = \left( \frac{2(a_i - c_i) + d_i(a_j + c_j + c_i d_j)}{4 - d_1 d_2} \right)^2, \tag{3}
\]

In order to guarantee that BE prices never fall short of marginal costs, we assume \( 2(a_1 - c_1) + d_1(a_2 + c_2 + c_1 d_2) > 0 \) and \( 2(a_2 - c_2) + d_2(a_1 + c_1 + c_2 d_1) \geq 0 \).

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\(^7\)If goods are substitutes these conditions imply A.3.2b). If goods are complements these conditions always hold for \( a_i > c_i \).

\(^8\)If \( d_1 = d_2 = 1 \) demand functions are identical to those in the circular model of Salop [9].
From (3) we get that the sign of \( \frac{d\Pi}{d2} \) equals the sign of
\[
(2(a_1 - c_1) + d_1(a_2 + c_2 + c_1) + c_1d_1)(d_1 + (2(a_2 - c_2) + d_2(a_1 + c_1 + c_2d_1))(d_1d_2 - 2)) \quad (4)
\]
We now check for the properties I-II-III stated in the Introduction.

I) Again, it is easy to see that lack of symmetry may imply \( \frac{d\Pi}{dc} \bigg|_{c_1=c_2} > 0 \). But even under symmetric demand if \( d_1 = d_2 > 0 \) and \( d_1d_2 \geq 2 \), \( \frac{d\Pi}{dc} \bigg|_{c_1=c_2} \geq 0 \). In this case cross substitution effects are very strong and reductions in \( c_2 \) exacerbate competition making TT unprofitable. However if \( d_1, d_2 < 1 \), \( \frac{d\Pi}{dc} \bigg|_{c_1=c_2} > 0 \). So in this case we need symmetry and small cross substitution effects for \( I \) to hold.

II) From (4) we get \( \hat{c}_2 = \frac{2a_1 + d_2(a_1 + c_1)}{2 - d_1d_2} \). If goods are substitutes, \( \frac{d\Pi}{dc} \bigg|_{c_2=c_2} > 0 \).

III) From (4), we get that \( \frac{d\Pi}{dc} > 0 \). Thus \( \Pi(\ ) \) is strictly convex. Suppose that \( \Pi(\ ) \) achieves an interior minimum. Then,
\[
\hat{c}_2 = \frac{(2 - d_1d_2)(2a_2 + c_1d_1 + d_2(a_1 + c_1)) - d_1(2a_1 + d_1a_2)}{d_1^2 + (d_1d_2 - 2)^2}.
\]
Convexity of \( \Pi(\ ) \) and \( \frac{d\Pi}{dc} \bigg|_{c_2=c_2} > 0 \) imply that \( \hat{c}_2 < \hat{c}_2 \). Let us prove that \( \hat{c}_2 > c_1 \).
Suppose otherwise. Then,
\[
\hat{c}_2 = \frac{(2 - d^2)(2a + c_1d + d(a + c_1)) - d(2a + da)}{d^2 + (d^2 - 2)^2} \leq c_1 \iff (-d^3 - 3d^2 + 4)a \leq c_1(d^4 - d^3 - 4d + 4).
\]
Since \(-d^3 - 3d^2 + 4 > 0\) for \( 1 < d < 0 \) and \( a > c_1 \), we obtain \( d^4 + 3d^2 > 4d \), which is impossible for \( 0 < d < 1 \). Thus \( \hat{c}_2 > c_1 \).

It is now time to sum up our findings in this section:

1. The assumption of homogeneous product hides two important assumptions: that demand for both firm is the same and that goods are substitutes. If demand functions do not satisfy these assumptions the properties that characterize TT under homogeneous products do not hold. However, once demand is assumed to be symmetric and goods are substitutes these properties also hold in our framework.
2. Quantity competition and price competition yield the same conclusions under similar assumptions. The assumptions necessary for \( I \) to hold are a little bit stronger in the case of price competition.
3. The marketing effect can explain that the owner of a patent does not exploit it, as in the Sepracor/Eli Lilly case in the previous section, or that a large firm licences to a small one, as in the Lundbeck/Forest Lab case. In the first case it may be argued that the success of Prozac gave to Elli Lilly a large advantage in marketing the product. In the second case both firms had relative advantages in marketing the product in different locations, EU and USA.
4. However, as long as demand functions fulfill the properties assumed in this section, partial TT, as in the GlaxoSmithKline/SkyePharma case, can not be explained. Because joint profits are strictly convex on \( c_2 \) the TT policy can only be full transfer or no transfer.

Equipped with these findings we are prepared to study the form of \( \Pi(\ ) \) in a general framework.
5. General properties of technology transfer. In this section we investigate the shape of $\Pi(\cdot)$ in order to derive the implications for the kind of TT that we may expect in general.

Our first result shows that the shape of $\Pi(\cdot)$ is arbitrary even under strong assumptions on the form of demand/inverse demand functions. All proofs are gather in the Appendix.

**Proposition 1.** Let $\Psi : [c_2, c_2] \to \mathbb{R}^+$ be a continuous function with $c_2 > c_1$. There are inverse demand (resp. demand) functions $p_i(\cdot)$ (resp. $x_i(\cdot)$) $i = 1, 2$ that are linear on $x_i$ (resp. $p_i$) yielding payoff functions that satisfy A.3.2 such that: a) There is a unique NE in which Firm 1 is active and Firm 2 inactive iff $c_2 = \bar{c}_2$. b) $\Psi(c_2) = \Pi(c_2) \forall c_2 \in [c_2, \bar{c}_2]$.

Proposition 1 implies that any TT can be rationalized as arising from the maximization of joint profits followed by a competition stage with payoff functions satisfying A.3.2 and demand/inverse demand that are linear in the action controlled by the firm. This result implies that any TT between two firms can be rationalized as arising from these firms playing the previous game with payoff functions satisfying A.1. Thus, we can not expect Properties I-II-III in the Introduction hold when the product is differentiated.

Next, we show that the properties of $\Pi(\cdot)$ in the boundaries, i.e. in $c_2$ and $\bar{c}_2$ found in the case of homogeneous goods hold in our framework under the appropriate assumptions.

First, we study the form of $\Pi(\cdot)$ in $c_2 = \bar{c}_2$. In this case, the property found in the homogeneous good case holds under reasonable circumstances.

**Proposition 2.** Under A.3.2, $\frac{d\Pi}{dc_2}|_{c_2=\bar{c}_2} > 0 \Leftrightarrow$ good 2 substitute of good 1.

Next, we study the form of $\Pi(\cdot)$ in $c_2$. In this case, some extra conditions are needed in order to prove the result obtained under homogeneous goods. Examples 1 and 2 above give us some clues: Demand functions must be symmetric and cross effects must not be very large. Our next two assumptions deal with symmetry.

**Assumption 5.1.** a) $c_2 = c_1$. b) $\pi_1(\cdot) = \pi_2(\cdot, c_1)$.

**Assumption 5.2.** (a) $\frac{\partial \pi_1(0,0)}{\partial y_1} > 0$. (b) There is a $y'$ such that $\frac{\partial \pi_1(y',y')}{\partial y_1} < 0$.

Assumption 5.1 (part a) and b)) is a symmetry assumption. Assumption 5.1 (part a)) says that the minimum marginal cost that can be achieved is that of Firm 1. Assumption 5.1 (part b)) says that demand/inverse demand functions are symmetric. Let us now concentrate on Assumption 5.2 (part a)). Consider quantity competition: From (2.2), $\frac{\partial x_1(0,0)}{\partial y_1} = p_1(0,0) - c_1$. Thus, Assumption 5.2 (part a)) says that $p_1(0,0) > c_1$. If $x_1$ and $x_2$ are very large we expect that prices fall below marginal costs so $\frac{\partial x_1}{\partial x_1} = \frac{\partial p_1}{\partial x_1} x_1 + p_1 - c_1 < 0$ and Assumption 5.2 (part b)) holds. Under price competition from (2.1), $\frac{\partial x_1(0,0)}{\partial y_1} = -\frac{\partial x_1}{\partial p_1} c_1 + x_1 > 0$. If $p_1$ and $p_2$ are very large we expect $x_1 \simeq 0$ and $\frac{\partial x_1}{\partial y_1} \simeq \frac{\partial x_1}{\partial p_1} (p_1 - c_1) < 0$, so Assumption 5.2 (part b)) holds. Thus, the behavior of $\frac{\partial x_1}{\partial y_1}$ assumed by Assumption 5.2 seems reasonable.

**Lemma 5.3.** Under A. 5.1-5.2-5.3, NE is symmetric when $c_1 = c_2$. 
Proof. Consider \( \frac{\partial \pi_1(y,y)}{\partial x_1} \) as a function of \( y \). Let \( f(y) \equiv \frac{\partial \pi_1(y,y)}{\partial x_1} \). By Assumption 5.2, \( f( \cdot ) \) changes sign when we go from \( y = 0 \) to \( y = y' \). By the intermediate value theorem, there is a value of \( y, y^* \) such that \( f(y^*) = 0 \). By Assumption 5.1, say \( y^* \) also solves the FOC of profit maximization for Firm 2 so, under Assumption 3.2 (part a) \( y^* \) is a symmetric NE. By Lemma 1 NE is unique, so the symmetric NE is the only NE. \( \square \)

Now we make assumptions that guarantees that the impact of the action of the competitor on the marginal profit of a firm is smaller than the impact of the action taken by this firm. Let \( p^* \) (resp. \( x^* \)) be the action in the BE (CE) when \( c_1 = c_2 \).

Assumption 5.4. a) \( -\frac{\partial x_i(p^*,p^*)}{\partial p_i} > \frac{\partial x_i(p^*,p^*)}{\partial p_j}, i \neq j \)

b) \( \frac{\partial^2 p_i(x^*,x^*)}{\partial x_i \partial x_j} x^* + \frac{\partial p_i(x^*,x^*)}{\partial x_i} < 0 \) and \( \frac{\partial^2 p_i(x^*,x^*)}{\partial x_i^2} x^* + \frac{\partial p_i(x^*,x^*)}{\partial x_i} \leq 0, i \neq j = 1,2 \)

Under homogeneous products, Assumption 5.4 (part b)) is a local version of the so called strong concavity assumption (Corchón [2]). Notice that, as hinted in Examples 1 and 2, the assumption dealing with price competition is, somehow, stronger than the assumption dealing with quantity competition. Assumption 5.1, 5.2, 5.4–(b) are satisfied by the inverse demand functions used in Example 1 if \( A_1 = A_2 > 0, b_1 = b_2 \) and \( d_1 = d_2 \). \( A.2-3-4 \) are satisfied by the demand functions used in Example 2 if \( a_1 = a_2 \), and \( d_1 = d_2 < 1 \).9 Now we are prepared for the result.

Proposition 3. Assume Assumptions A. 5-1-5.2-5.3. Under price competition and Assumption 5.4, or under quantity competition and Assumption 5.4 (part b)) \( \frac{\partial \Pi}{\partial c_2} |_{c_1=c_2} < 0 \).

Conclusions. In this paper we have explored the consequences of assuming product heterogeneity by considering quantity and price competition. We proved that the three properties that characterized TT under product homogeneity hold in our framework under suitable assumptions. Our analysis has uncovered the importance of symmetry and small substitution effects for these properties to hold. Symmetry is specially important because, in our case, a small firm is not necessarily one with low productivity: It might be that the demand for this firm is small, i.e. the marketing effect is important here.

We also have found new features of TT, specially that under general demand functions the shape of \( \Pi(\cdot) \) is arbitrary.

Summing up, the answer to the question what difference makes the consideration of heterogeneous products is that we expect here a richer set of interactions between firms regarding TT. In particular, we have to keep a close eye on the following possibilities.

(i) If Firm 1 faces a small demand it might be off business after TT. This resembles the Sepracor/Eli Lilly case in Section 2 where Sepracor licensed the product but it did not market it.

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9 We remark that there is no relationship between Assumption 3.2 and Assumption 5.4 (part b). On the one hand Assumption 3.2 is a global assumption, i.e. holds for all prices and quantities and Assumption 5.4 (part b) only apply in points that are a NE when \( c_1 = c_2 \). On the other hand, Proposition 5.1 implies that demand/inverse demand functions satisfying Assumption 3.2 can not yield a result like Proposition 5.3 below.
(ii) Even if $\bar{c}_2$ is high, Firm 2 may receive large quantities of TT if its demand is large relative to that of Firm 1 or the markets in which both firms operate are independent. This resembles the Lundbeck/Forest Lab case in Section 2 where the two firms involved had very different sizes.

(iii) TT may be partial like in the GlaxoSmithKline/SkyePharma case recorded in Section 2.

(iv) Even if $\bar{c}_2$ is close to $c_1$, firm 2 may not receive TT at all because its demand is small or because cross price effects are large. The latter could be a potential candidate to explain why TT seldom occurred among the big companies in the market for antidepressants.

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6. Appendix.

6.1. Proof of Proposition 1. Let us tackle first the case of price competition. Let $\epsilon$ be such that $\epsilon < \Psi(c_2) \forall c_2 \in [\bar{c}_2, \bar{c}].$ Define the candidate demand functions: For good 2, $x_2 = \max(0, b(\bar{c}_2 - p_2))$ and for good 1, $x_1 = b(\bar{c}_2 - p_1)$. Let $f(p_2) = \frac{4\Psi(\max(c_2, \min(2p_2 - \bar{c}_2, \bar{c})) - b(\bar{c}_2 - p_2)^2}{b(\bar{c}_2 - c_1)^2}$.

Take $b$ such that $4\Psi(c_2) - b(\bar{c}_2 - c_1)^2 \geq \epsilon \forall c_2 \in [\bar{c}_2, \bar{c}]$. Thus $f(p_2) > 0$.

The above demand functions fulfill the desired properties: They are linear and satisfy A1. Since demands are linear in their own price and marginal costs are constant, profit functions are strictly concave on their own price. Therefore, the BE for the above demand functions is found by setting $\frac{\partial \pi}{\partial p_i} = 0$. This yields,

$$p_i^* = \frac{\bar{c}_i + c_i}{2}, \quad x_i^* = \frac{b f(p_i^*)(\bar{c}_2 - c_1)}{2}, \quad \text{and} \quad x_2^* = \frac{b \bar{c}_2 - b \bar{c}_2}{2}.$$

$$2p_i^2 - \bar{c}_2 = c_2 \leq \bar{c}_2, \quad \min(2p_i^2 - \bar{c}_2, \bar{c}_2) = c_2 \quad \text{and} \quad \max(c_2, c_2) = c_2.$$

$$f(p_i^2) = \frac{4\Psi(c_2) - b(\bar{c}_2 - p_i^2)^2}{b(\bar{c}_2 - c_1)^2} = \frac{4\Psi(c_2) - b(\bar{c}_2 - \bar{c}_2)^2}{b(\bar{c}_2 - c_1)^2}.$$

$$\pi_1(c_2) = \frac{f(p_2(c_2))(\bar{c}_2 - c_1)^2}{4} \quad \text{and} \quad \pi_2(c_2) = \frac{b(\bar{c}_2 - c_2)^2}{4}.$$

$$\Pi(c_2) = \Psi(c_2) - b(\bar{c}_2 - c_1)^2 + b(\bar{c}_2 - c_1)^2 = \Psi(c_2).$$

Now consider the case of quantity competition. Let $\epsilon$ be such that $0 < \epsilon < \Psi(c_2) \forall c_2 \in [\bar{c}_2, \bar{c}_2].$ Under our conditions $\epsilon$ exists. Let $p_1 = \max(0, \bar{c}_2 - f(x_2)x_1)$, with

$$f(x_2) = \frac{(\bar{c}_2 - c_1)^2}{\max(\Psi(\max(c_2, \bar{c}_2 - 2bx_2)) - bx_2^2, \epsilon)}$$

and $p_2 = \max(0, \bar{c}_2 - bx_2)$ where $b$ is chosen such that

$$\epsilon < \Psi(c_2) - \frac{(\bar{c}_2 - c_2)^2}{4b}, \quad \forall c_2 \in [c_1, \bar{c}_2].$$

These demand functions fulfill the conditions stated in the result: They are linear, satisfy A1 -because $\frac{\partial^2 \pi_2}{\partial x_1x_2} = 0-$ and profit functions are strictly concave on their
own output. Thus, the unique CE for the above inverse demand functions is found by setting \( \frac{\partial \pi}{\partial x_i} = 0 \). Then,

\[
p_i^* = \frac{\bar{c}_2 + c_i}{2}, \quad i = 1, 2. \quad x_i^* = \frac{\bar{c}_2 - c_1}{2f(x_2^*)} \pi_1^* = \frac{(\bar{c}_2 - c_1)^2}{4f(x_2^*)}, \quad x_2^* = \frac{\bar{c}_2 - c_2}{2b} \frac{\pi_2}{\pi_2^*} = \frac{(\bar{c}_2 - c_2)^2}{4b}.
\]

Since \( \bar{c}_2 > c_1, x_1^* > 0 \). Also \( x_2^* = 0 \leftrightarrow c_2 = \bar{c}_2 \), so part a) is proved. Then

\[
\max (c_2, \bar{c}_2 - 2bx_2^*) = \max (c_2, c_2) = c_2.
\]

Thus,

\[
\Psi(c_2) - bx_2^* = \Psi(c_2) - \frac{(\bar{c}_2 - c_2)^2}{4b} > \epsilon.
\]

\[
f(x_2(c_2)) = \frac{b(\bar{c}_2 - c_1)^2}{4b\Psi(c_2)} + (\bar{c}_2 - c_2)^2 \pi_1(c_2) = \frac{(\bar{c}_2 - c_1)^2}{4f(x_2(c_2))} = \Psi(c_2) - \frac{(\bar{c}_2 - c_2)^2}{4b}.
\]

Finally,

\[
\pi_2(c_2) = \frac{(\bar{c}_2 - c_2)^2}{4b}.
\]

Therefore,

\[
\pi_1(c_2) + \pi_2(c_2) = \Psi(c_2).
\]

6.2. **Proof of proposition 2.** Taking into account that in a NE \( \frac{\partial \pi}{\partial y_i} = 0, i = 1, 2 \), we have that

\[
\frac{d\Pi}{dc} = \frac{\partial \pi_1}{\partial y_2} \frac{dy_2}{dc} + \frac{\partial \pi_2}{\partial y_1} \frac{dy_1}{dc} + \frac{\partial \pi_2}{\partial c_2}.
\]

At \( c_2 = \bar{c}_2, x_2 = 0 \). Thus, \( \frac{\partial \pi_2}{\partial c_2} = -x_2 = 0 \). Under CE, \( \frac{\partial \pi_2}{\partial c_1} = \frac{\partial p_2}{\partial c_1}x_2 = 0 \). Under BE \( \frac{\partial \pi_2}{\partial p_1} = (p_2 - \bar{c}_2) \frac{\partial \pi_1}{\partial p_1} = 0 \). Differentiating FOC of NE we obtain that

\[
\frac{dy_1}{dc} = \frac{\partial^2 \pi_1}{\partial y_1 \partial y_2} \frac{\partial^2 \pi_2}{\partial y_2 \partial y_2} - \frac{\partial^2 \pi_1}{\partial y_1 \partial y_2} \frac{\partial^2 \pi_2}{\partial y_2 \partial y_2}, \quad \frac{dy_2}{dc} = \frac{\partial^2 \pi_1}{\partial y_1 \partial y_2} \frac{\partial^2 \pi_2}{\partial y_2 \partial y_2} - \frac{\partial^2 \pi_1}{\partial y_1 \partial y_2} \frac{\partial^2 \pi_2}{\partial y_2 \partial y_2}.
\]

Plugging (8.2) in (8.1), and taking into account A1b

\[
\frac{d\Pi}{dc} \bigg|_{c_2 = \bar{c}_2} = \frac{\partial \pi_1}{\partial y_2} \frac{dy_2}{dc} = \frac{\partial \pi_1}{\partial y_2} \frac{\partial^2 \pi_2}{\partial y_1 \partial y_2} - \frac{\partial \pi_1}{\partial y_1} \frac{\partial^2 \pi_2}{\partial y_2 \partial y_2}, \quad \text{sign} \frac{d\Pi}{dc} \bigg|_{c_2 = \bar{c}_2} = \text{sign} \frac{\partial \pi_1}{\partial y_2} \frac{\partial^2 \pi_2}{\partial c_2 \partial y_2}.
\]

In BE \( \frac{\partial \pi_1}{\partial y_2} = p_1 \frac{\partial x_1}{\partial p_2} \) and \( \frac{\partial^2 \pi_2}{\partial c_2 \partial y_2} > 0 \) and in CE \( \frac{\partial \pi_1}{\partial y_2} = \frac{\partial p_1}{\partial c_2} \) and \( \frac{\partial^2 \pi_2}{\partial c_2 \partial y_2} = -1 \). Thus, in both cases \( \frac{d\Pi}{dc} \bigg|_{c_2 = \bar{c}_2} > 0 \leftrightarrow \text{good 2 is substitute of good 1.} \).
6.3. Proof of proposition 3. From (8.1), A.2 and $\frac{\partial \pi_2}{\partial c_2} = -x^*$, we obtain that

$$\frac{d \Pi}{dc_2} = \frac{\partial \pi_1}{\partial y_2} \frac{dy_2}{dc_2} + \frac{dy_1}{dc_2} = \frac{\partial \pi_2}{\partial c_2} - x^*$$

Now from (8.2), and A.2 again

$$\frac{dy_2}{dc_2} + \frac{dy_1}{dc_2} = \frac{\partial^2 \pi_2}{\partial c_1^2} \left( \frac{\partial^2 \pi_1}{\partial y_1 \partial y_2} - \frac{\partial^2 \pi_1}{\partial y_2^2} \right) = \frac{\partial^2 \pi_2}{\partial c_2 y_2} + \frac{\partial^2 \pi_1}{\partial y_1 y_2}$$

Let us tackle first the case of price competition. In this case, $-\frac{\partial^2 \pi_2}{\partial c_2 y_2} = \frac{\partial c_2}{\partial p_2}$ and $\frac{\partial \pi_2}{\partial y_2} = (p^* - c_1) \frac{\partial x}{\partial p_2}$. From the FOC of a BE ($p^* - c_1 = \frac{-x^*}{\pi_1}$), thus $\frac{\partial \pi_1}{\partial y_2} = \frac{-x^*}{\pi_1} \frac{\partial x}{\partial p_2}$.

Then, using symmetry again,

$$\frac{d \Pi}{dc_2} = -x^* \frac{\partial x_1}{\partial p_2} + \frac{\partial \pi_1}{\partial p_2} - x^* = -x^* \frac{\partial x_1}{\partial p_2} + \frac{\partial \pi_1}{\partial p_2} - x^* \frac{\partial \pi_1}{\partial p_1 p_2}$$

By A1b) the denominator is negative so

$$\text{sign} \frac{d \Pi}{dc_2} = \text{sign} \left( \frac{\partial x_1}{\partial p_2} + \frac{\partial^2 \pi_1}{\partial p_1} + \frac{\partial^2 \pi_1}{\partial p_1 p_2} \right)$$

Computing

$$\frac{\partial^2 \pi_1}{\partial p_1^2} = \frac{\partial^2 x_1}{\partial p_1^2} (p^* - c_1) + 2 \frac{\partial x_1}{\partial p_1}$$

and

$$\frac{\partial^2 \pi_1}{\partial p_1 p_2} = \frac{\partial^2 x_1}{\partial p_1 p_2} (p^* - c_1) + \frac{\partial x_1}{\partial p_2} .$$

Next consider the case of quantity competition. In this case, $\frac{\partial^2 \pi_2}{\partial c_2 y_2} = -1$ and $\frac{\partial \pi_1}{\partial y_2} = x^* \frac{\partial x_1}{\partial x_2}$. Then, using symmetry again,

$$\frac{d \Pi}{dc_2} = x^* \frac{\partial x_1}{\partial p_2} - x^* = x^* \frac{\partial x_1}{\partial p_2} - x^* \frac{\partial^2 \pi_1}{\partial x_1 x_2} x^*$$

By A1b) the denominator is negative so

$$\text{sign} \frac{d \Pi}{dc_2} = \text{sign} \left( \frac{\partial x_1}{\partial x_2} - \frac{\partial^2 \pi_1}{\partial x_1 x_2} \right)$$

Computing,

$$\frac{\partial^2 \pi_1}{\partial x_1 x_2} = \frac{\partial^2 x_1}{\partial x_1 x_2} x^* + \frac{\partial^2 x_1}{\partial x_1 x_2} x^* = \frac{\partial^2 x_1}{\partial x_1 x_2} x^* + \frac{\partial^2 x_1}{\partial x_1 x_2} x^* .$$

$$\text{sign} \frac{d \Pi}{dc_2} = \text{sign} \left[ -\left( \frac{\partial^2 x_1}{\partial x_1 x_2} + \frac{\partial^2 x_1}{\partial x_1 x_2} \right) x^* - 2 \frac{\partial x_1}{\partial x_1} \right] > 0 , \text{ by A.4} .$$
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