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Universidade de Santiago de Compostela, Universitat de les Illes Balears

2023

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Abstract

We study the licensing of a product innovation from an external innovator in a duopoly of firms that compete sequentially with each other through quantities or prices. We find that the innovation is only licensed to a single firm, regardless of market competition. However, both the licensee and contractual terms under quantity competition differ from those under price competition. In the first case, the innovation is licensed to the market-leading firm through a non-distorting contract, and in the second case, to the market-following firm by means of a two-part tariff (distorting) contract involving a per-unit royalty.

Keywords: Product innovation, licensing, Stackelberg duopoly, quantity competition, price competition

JEL Classification: D43, D45

1. Introduction

As a tool for promoting economic and social development and enhancing quality of life, the transfer of technology from the agent that owns or holds it to another agent is an important issue and a matter of growing interest. Among others, licensing plays a key role as a primary method to transfer new technologies that improve the efficiency of production processes and/or the quality of market products. In some industries, technology licensing is gaining increasing attention among firms that license their innovations to direct competitors, to the point that a significant proportion of innovation is held by firms that, besides to exploit their innovation for themselves, transfer them to direct rivals (Avagyan et al., 2014; Jiang and Shi, 2018). As an example, Procter & Gamble frequently licenses its manufacturing know-how to direct competitors in the same product market (Parhankangas et al., 2003), whereas Samsung Electronics, HTC Corp. and other Android device manufacturers are direct competitors with Microsoft Corp. in markets such as mobile computing devices and operating systems, and at the same time paying Microsoft Corp. a licensing royalty per Android device for certain device operating system features (Hoffman, 2014). Other examples include Tesla Motors, which in 2014 made its electric vehicle technology patents available to other car makers (Jian and Shi, 2018), and Ford Motor Company, which began licensing, to direct competitors, its industrial property and know-how rights for a passenger-side airbag deactivation switch as far back as 1997, and in 2000, its diesel fuel conditioning module (Fradkin, 2014) and its electric vehicle patents (Arce, 2015).

In other cases, the innovation comes from an innovator external to the industry where the innovation is marketed. At country level, most academics and policy-makers believe that outside innovators, such as foreign firms, may be a source of up-to-date technology for host countries. By way of example, García-Sánchez and Rama (2020) emphasize an acute need for technology transfer in countries that are not at the forefront of science and technology, e.g., many European peripheral countries and emerging economies. Likewise, Elia et al. (2020) report that sourcing technological knowledge from abroad is becoming a popular strategy among emerging market firms. They argue that augmenting technological knowledge through foreign licensing enables these firms to access state-of-the-art technological knowledge, reduce operational costs and risks associated to the innovation process, and develop a knowledge-based competitive advantage that ultimately boosts their financial performance. In 2007, a business survey on the out-licensing of patents, performed by the OECD, the European Patent Office and the University of Tokyo in agreement with the Japanese Patent Office, found that 20% and 29% of respondent firms in

Europe and Japan, respectively, declared having licensed patents to non-affiliated partners (Zuniga and Guellec, 2009).[1]

A crucial aspect of technology transfer is design of the optimal arrangement from the perspective of the innovator, given that this determines the licensing revenue it can earn (Kabiraj, 2004; Sen and Tauman, 2009), the diffusion degree of the innovation and, as a result, whether the social impact of technology licensing is beneficial or not. It is not surprising, then, that technology licensing and its contractual dimension is a topic of particular interest. Of the aspects that the licensor has to consider when deciding how to license a technology, especially important is the way potential licensees compete in the marketplace. They are sometimes in the same market position and, accordingly, either Cournot or Bertrand competition models fit the licensing game well. However, in industries consisting of a well-established firm with sound assets, leaders and followers, in setting the output level (or market price), can be expected to hold; therefore, a market interaction leadership model is preferably for exploring the licensing game. As Tesoriere (2017) argues, a leader and a follower firm may fit well the case in which the leader faces production lags, or is the only incumbent in the market, or has signed short-term contracts with its customers, or sets its capacity after a group of firms has merged into it.[2]

In the context in which an external innovator licenses its cost-reducing innovation to firms that compete in Stackelberg fashion, Wang (2012) shows that the licensor's optimal choice depends on both the feasible licensing contract and the degree of innovation. While with a fixed-fee contract the licensor prefers to transfer the technology to the market leader (follower) firm if the degree of innovation is small (large), with a royalty contract the technology is likely to be transferred to both firms, and with a two-part tariff (2PT) contract it will be sold to the market follower. Moreover, 2PT licensing not only yields a maximum licensing payoff, but also maximum social welfare, so the innovator's licensing decision is Pareto optimal.[3]

In this article, we also consider an external innovator, but with a product innovation, rather than a process innovation. This innovation is marketed in a duopoly where firms

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[1] Universities are important (external) innovators. US universities, for instance, have expanded basic research since the 1970s, from 49% in 1979 (National Science Foundation, 2012) to almost 59% in 2006 (National Science Board, 2016). In addition, expansion in their role in basic research has coincided with increased patenting and licensing of their discoveries, particularly in biotechnology (Thompson et al., 2018).

[2] See also Maskin and Tirole (1988).

[3] Fang et al. (2015) consider an upstream innovator with a technology that may create differentiation between the products and that is licensed to a Bertrand duopoly. Non-exclusive licensing performs better than exclusive licensing under both fixed fees and royalties, and the preferred contract consists of fixed fees only. Finally, the innovator's licensing revenues depend on the magnitude of the innovation, so there is a greater reward to the innovator's institution if the innovation is large. In turn, Zou and Chen (2020) examine licensing of a product innovation in a vertically differentiated Cournot oligopoly and show that optimal licensing depends on product differences and patent exclusivity. Finally, in a spatial setting where licensees compete in prices, Caballero-Sanz et al. (2005) shown that a private innovator licenses a new product by means of a fixed fee with territorial exclusivity, where the number of licences sold is smaller than the socially efficient one. However, a public innovator will not license the technology with territories.

sequentially compete each other in quantities or prices. Initially, both firms manufacture a (low-quality) product and the innovator seeks how and to whom to license a higher quality product by means of contracts that may consist of a fixed payment combined or not with a royalty rate, which, in turn, can be a fixed quantity per unit produced by the licensee (per-unit royalty) or a percentage of the licensee's revenues (ad-valorem royalty).

In this framework, we contribute two main findings to the product innovation licensing literature. First, regardless of whether market competition between firms is in quantities or in prices, the innovation is transferred to a single firm. Exclusive licensing allows the licensor to avoid the Bertrand paradox if price competition holds, and to increase market collusion in the industry under quantity competition, since it creates vertical differentiation between products. Hence, regardless of firms compete through quantities or through prices partial licensing performs better than complete licensing, and, as result, our model rationalizes exclusive licensing, which, according to a 2001 survey by the Association of University Technology Managers (AUTM), represents about 50% of licences (Caballero-Sanz et al., 2005).[4]

Second, the recipient of the innovation and contractual terms depends, however, on how market competition develops by means of quantities or prices. If firms compete in quantities, the licensee is the market-leader firm and the licence agreement consists of a non-distorting contract. The fact that the leader firm acts as a monopolist in its residual market leads the licensor not to distort its production. On the contrary, if firms compete in price, the market-follower firm enjoys the well-known second-mover advantage and receives the innovation through a 2PT (distorting) contract that allows it to increase the market price.

The remainder of the paper is structured as follows. Section 2 outlines the model. Section 3 and Section 4 analyse the licensing game when competition in the marketplace is by means of quantities and prices, respectively. Finally, Section 5 concludes.

2. The model

We consider a duopoly, where firm 1 acts a leader firm in setting the output (or price) in the product market, whereas firm 2 acts as the follower. Currently, each firm i, $i = 1, 2$, manufactures a product of quality $q_i = t$ (a low-quality product), $0 < t < 1$, and the market is composed of a

[4] Li and Wang (2010) document several cases that illustrate the use of exclusive (and non-exclusive) contracts.

continuum of consumers indexed by θ, uniformly distributed in the interval [0, 1], so θ is a taste parameter measuring how quality is valued.[5] The demand to each firm i, $i = 1, 2$, is given by:

$$p_i = t(1 - x_i - x_j) \qquad i, j = 1, 2;\ i \neq j \tag{1}$$

where x_i denotes the quantity produced by each firm and p_i is the per-unit price of the good.

However, an external innovator to the industry (an upstream research lab or a foreign firm, for example) has discovered a product of quality parametrized at 1 (a high-quality product). Therefore, given that $1 - t$ denotes the improvement on the quality of product, a low (high) value of parameter t indicates a substantial (small) improvement in product quality. To profit from the new product, the innovator may license its production and commercialization to a single firm (exclusive licensing) or to all firms (non-exclusive licensing) in the industry.

If the only licensee of the innovation is firm i, its demand becomes:

$$p_i = 1 - x_i - tx_j \tag{2}$$

and that of (non-licensee) firm j is:

$$p_j = t(1 - x_j - x_i) \tag{3}$$

are the respective inverse demand functions.

On the other hand, if the new product is licensed to both firms (non-exclusive licensing), then each firm i's demand becomes:

$$p_i = 1 - x_i - x_j \qquad i, j = 1, 2;\ i \neq j \tag{4}$$

Finally, we assume, for simplicity sake, that both the high-quality and low-quality products are manufactured and marketed at zero marginal cost.[6]

The three-stage licensing game that holds has the following timing. In the first stage, the external licensor decides whether or not to license the innovation and how to license it. Hence, it announces the number of licences (one or two) to be granted and the contractual terms offered to the corresponding licensee or licensees on a take-it-or-leave-it basis. Licensing contracts may consist of a fixed-fee payment alone or combined with a non-negative royalty rate that, in turn, may be based on either the licensee's production (per-unit royalty) or the licensee's revenues (ad-valorem royalty).[7] If the licence is only offered to firm 1 (the market leader) and this firm accepts the licensor's proposal, then it becomes the high-quality firm and, in the second stage, adopts a market decision concerning output level to be produced or price to be settled. Finally, in the third

[5] In our analysis, we assume exogenous quality, as in Li and Song (2009) and Li and Wang (2010), meaning that the strategic quality choice by the innovator is absent.
[6] Filippini and Vergari (2012) also consider zero marginal costs.
[7] In our set up ad-valorem royalty is equivalent to profit-sharing royalty since there are no production costs.

stage, firm 2, the low-quality firm, observes firm 1's choice and reacts by adopting a market decision regarding its output to be produced or the price to be charged.

If, on the other hand, the licence is only offered to firm 2 (the market follower) and this firm accepts the licensor's proposal, then it becomes a high-quality firm. In this case, in the second stage firm 1 (the low-quality firm) adopts its output or price decision, and in the third stage firm 2, after observing firm 1's decision, adopts its output or price decision.

Lastly, if two licences are offered, both firms 1 and 2 produce the high-quality product and they sequentially adopt their market decisions in the second and third stage, respectively.

We seek for a subgame perfect Nash equilibrium of this licensing game.

3. Stackelberg quantity competition

In this section, we explore how the innovator behaves when there is quantity competition between potential licensees.

3.1 No licensing

When the innovator does not license its product innovation, both firms produce the low-quality product and their equilibrium outputs are $x_1^n = \frac{1}{2}$ and $x_2^n = \frac{1}{4}$.[8] Hence, equilibrium prices amount to $p_1^n = p_2^n = \frac{1}{4}$, and firms' profits amount to $\pi_1^n(t) = \frac{t}{8}$ and $\pi_2^n(t) = \frac{t}{16}$.

3.2 Fixed-fee licensing

Consider now that the innovator licenses the new product to a single firm i by means of a fixed-fee payment $f_i(t)$. If the licensee is firm 1 (the market leader), its inverse demand function is given by Eq. (2) and that of firm 2 by Eq. (3). Hence, the respective production levels are $x_1^f = \frac{1}{2}$ and $x_2^f = \frac{1}{4}$, which lead to equilibrium prices of $p_1^f = \frac{2-t}{4}$ and $p_2^f = \frac{t}{4}$, and equilibrium profits of $\pi_1^f = \frac{2-t}{8}$ and $\pi_2^f = \frac{t}{16}$. On the contrary, if the licence is offered to firm 2 (the market follower),

[8] Throughout the article, superscripts n, f, u, and v (in equilibrium profits, quantities and prices) denote, respectively, no licensing, licensing through a fixed-fee payment, licensing through a 2PT contract involving a per-unit royalty and licensing through a 2PT contract involving an ad-valorem royalty.

the equilibrium outputs are, respectively, $x_1^f = \frac{1}{2(2-t)}$ and $x_2^f = \frac{4-3t}{4(2-t)}$, which lead to prices $p_1^f = \frac{1}{4}$ and $p_2^f = \frac{4-3t}{4(2-t)}$ and, therefore, to profits $\pi_1^f = \frac{t}{8(2-t)}$ and $\pi_2^f = \frac{(4-3t)^2}{16(2-t)^2}$.

From here, firm 1 will accept the licensor's offer $f_1(t)$ if $f_1(t) \leq \frac{2-t}{8} - \frac{t}{8(2-t)}$, whereas firm 2 will accept the licensor's offer $f_2(t)$ whenever $f_2(t) \leq \frac{(4-3t)^2}{16(2-t)^2} - \frac{t}{16}$. This leads the licensor to extract the licensing revenues:

$$\pi_{L|1}^f(t) = \frac{4-5t+t^2}{8(2-t)} \tag{5}$$

if the innovation is transferred to firm 1, and the licensing revenues:

$$\pi_{L|2}^f(t) = \frac{16-28t+13t^2-t^3}{16(2-t)^2} \tag{6}$$

if transferred to firm 2. Finally, comparing the revenues in Eqs. (5) and (6), it holds that $\pi_{L|1}^f(t) > \pi_{L|2}^f(t)$ for all t, and hence, the licensor prefers to license to firm 1 rather than to firm 2.

On the other hand, if the licensor issues two licences, one to firm 1 by means of fee $f_1(t)$ and the other to firm 2 by means of fee $f_2(t)$, such payments are, respectively, $f_1(t) = \frac{1}{8} - \frac{t}{8(2-t)} = \frac{1-t}{4(2-t)}$ and $f_2(t) = \frac{1}{16} - \frac{t}{16} = \frac{1-t}{16}$, and yield the licensing revenues:

$$\pi_{L|1+2}^f(t) = \frac{6-7t+t^2}{16(2-t)} \tag{7}$$

Finally, comparison of the revenues given in Eqs. (5) and (7) affords the following result.

Lemma 1. *Under fixed-fee licensing, an external innovator licenses a product innovation only to the market-leading firm, regardless of the improvement size.*

The intuition behind this result is that the licensor seeks to create a quasi-monopoly by granting the right to produce the high-quality product to the (market-leading) firm due to its greater market-share.

3.3. Licensing by means of 2PT contracts involving per-unit royalties

If the innovation is transferred to firm 1 by means of a 2PT contract (f_1, r_1), where r_1 denotes a non-negative per-unit royalty, this firm will produce $x_1^u(r_1,t) = \frac{2-t-2r_1}{2(2-t)}$ and firm 2 will produce $x_2^u(r_1,t) = \frac{2-t+2r_1}{4(2-t)}$. Hence, firm 1's profit amounts to $\pi_1^u(r_1,t) = \frac{(2-t-2r_1)^2}{8(2-t)}$ and the innovator solves the problem:

$$\max_{r_1} f_1 + r_1 \frac{2-t-2r_1}{2(2-t)}, \text{s.t:} \frac{(2-t-2r_1)^2}{8(2-t)} - f_1 \geq \pi_1(r_2; t, 1) \tag{8}$$

where $\pi_1(r_2; t, 1) = \frac{t(1+r_2)^2}{8(2-t)}$ is firm 1's profit if the licence were granted to firm 2 in exchange for a 2PT contract (f_2, r_2). The solution to the problem stated in Eq. (8) affords $r_1 = 0$, and then the 2PT contract is reduced to the fixed payment $f_1(t)$ that holds under fixed-fee licensing. This leads the licensing revenues $\pi_{L|1}^u(t)$ to be that given in Eq. (5).

If, on the other hand, the licence is granted to firm 2 by means of the 2PT contract (f_2, r_2), where r_2 denotes the per-unit royalty, the licensor solves the problem:

$$\max_{r_2} f_2 + r_2 \frac{4-3t-(4-t)r_2}{4(2-t)}, \text{s.t:} \frac{(4-3t-(4-t)r_2)^2}{16(2-t)^2} - f_2 \geq \pi_2(r_1; 1, t) \tag{9}$$

where $\pi_2(r_1; 1, t) = \frac{t(2-t+2r_1)^2}{16(2-t)^2}$ is firm 2's profit if the licence were granted to firm 1 in exchange for a 2PT contract (f_1, r_1). The solution to the problem in Eq. (9) affords $r_2 = -\frac{t}{4-t}$ and, given the non-negativity assumption of the royalty rate, the 2PT contract (f_2, r_2) is reduced to the fixed payment $f_2(t)$ that holds under fixed-fee licensing. Therefore, the licensor obtains the profit $\pi_{L|2}^u = \pi_{L|2}^f$.

Finally, if a licence is offered to firm 1 through a 2PT contract (f_1, r_1) and a second licence is offered to firm 2 through a 2PT contract (f_2, r_2), then the problem to be solved by the licensor is:

$$\left.\begin{array}{l} \max\limits_{(r_1,r_2)} f_1 + r_1 \frac{1-2r_1+r_2}{2} + f_2 + r_2 \frac{1-3r_2+2r_1}{4} \\ \text{s.t.} \begin{cases} \frac{(1-2r_1+r_2)^2}{8} - f_1 \geq \pi_1(r_2; t, 1) \\ \frac{(1-3r_2+2r_1)^2}{16} - f_2 \geq \pi_2(r_1; 1, t) \end{cases} \end{array}\right\} \tag{10}$$

where $\pi_1(r_2; t, 1) = \frac{t(1+r_2)^2}{8(2-t)}$ is firm 1's profit when it does not have a licence but firm 2 does, and $\pi_2(r_1; 1, t) = \frac{t(2+2r_1-t)^2}{16(2-t)^2}$ is firm 2's profit when it does not have a licence but firm 1 does. The first-order conditions of the problem given in Eq. (10) define the best-reply functions:

$$r_1(r_2; t) = \frac{2(1-t)(2-t)-(2-t)^2 r_2}{2(4-3t+t^2)} \text{ and } r_2(r_1; t) = \frac{2-3t-2(2-t)r_1}{2+t} \tag{11}$$

which, once solved, lead to royalty rates $r_1(t)=\frac{12-16t+5t^2}{2(10-7t+2t^2)}$ and $r_2(t)=-\frac{2-t+t^2}{10-7t+2t^2}$. Therefore, under non-negative royalties it follows that $r_2(t)=0$ and, as result, $r_1(0;t)=\frac{(1-t)(2-t)}{4-3t+t^2}$, by which the optimal contract offered to firm 1 is the 2PT contract $(f_1(t),r_1(t))=\left(-\frac{(1-t)^2t(8-5t+t^2)}{4(2-t)(4-3t+t^2)^2},\frac{(1-t)(2-t)}{4-3t+t^2}\right)$, whereas that offered to firm 2 would be reduced to the fee payment $f_2(t)=\frac{64-180t+189t^2-91t^3+19t^4-t^5}{16(4-3t+t^2)^2}$. Finally, licensing revenues when two licences are granted amount to:

$$\pi^u_{L|1+2}(t)=\frac{32-66t+47t^2-14t^3+t^4}{16(2-t)(4-3t+t^2)} \tag{12}$$

Comparing licensor's payoff given in Eqs. (5) and (12), the following holds.

Lemma 2. *If per-unit royalties are allowed, an external innovator licenses a product innovation to the market-leading firm without making use of any royalty.*

When a single licence is granted (to firm 1), the products become vertically differentiated and the market approaches a quasi-monopoly, in which case a per-unit royalty would reduce firm 1's production and so would be prejudicial for the licensor. Conversely, if two licences were granted, both firms would produce homogenous goods and the use of royalties (a positive royalty for firm 1 and zero royalty for firm 2) would serve to reduce firm 1's production and increase firm 2's production, which again would be prejudicial for the licensor. Hence, although per-unit royalties are feasible, the licensor does not resort to them and behaves as under fixed-fee licensing.

3.4. Licensing by means of 2PT contracts involving an ad-valorem royalty

Finally, we assume that the licence is a 2PT contract consisting of a fixed payment f in combination with an ad-valorem royalty v, $0<v<1$, defined as a percentage of the licensee's revenues. In this case, if a single licence is granted to firm 1 by means of contract (f_1,v_1), the productions are, respectively, $x_1^v=x_1^f$ and $x_2^v=x_2^f$, since the ad-valorem royalty does not distort the firms' productions. Hence, profits amount to $\pi_1^v=(1-v_1)\pi_1^f$ and $\pi_2^v=\pi_2^f$, whereby the innovator solves:

$$\max_{v_1} f_1+v_1\frac{2-t}{8}, \text{s.t:} \frac{(1-v_1)(2-t)}{8}-f_1\geq\pi_1(t,1) \tag{13}$$

where $\pi_1(t,1)=\frac{t}{8(2-t)}$ is firm 1's profit if the licence were granted to firm 2 rather than firm 1 in exchange for a 2PT ad-valorem contract (f_2, v_2). The optimal contract that solves Eq. (13) has no fixed payment, $f_1=0$, and is thus reduced to an ad-valorem royalty $v_1(t)=1-\frac{t}{(2-t)^2}$. As a result, the licensor's payoff amounts to $\pi_{L|1}^{v}=\frac{4-5t+t^2}{8(2-t)}$, which equals that obtained when the innovation is transferred by means of a fixed-fee contract.

Analogously, if the innovation is granted to firm 2, the licensor solves:

$$\max_{v_2} f_2+v_2\frac{(4-3t)^2}{16(2-t)^2}, \text{s.t:} (1-v_2)\frac{(4-3t)^2}{16(2-t)^2}-f_2\geq\pi_2(1,t) \tag{14}$$

where $\pi_2(1,t)=\frac{t}{16}$ is firm 2's profit if the licence were granted to firm 1 in exchange for a 2PT ad-valorem contract (f_1, v_1) and, as result, firm 2 produces the low-quality product. The solution to the problem in Eq. (14) is the pure ad-valorem royalty $v_2(t)=1-\frac{t(2-t)^2}{(4-3t)^2}$, which renders the payoff $\pi_{L|2}^{v}=\frac{16-28t+13t^2-t^3}{16(2-t)^2}$ to the licensor. Once more, this payoff equals that obtained when the licence to firm 2 is issued by means of fee payment $f_2(t)$ as stated in Eq. (6).

Finally, if two licences are granted, the licensor solves:

$$\left.\begin{array}{c}\max_{v_1,v_2} f_1+v_1\frac{1}{8}+f_2+v_2\frac{1}{16},\\ \text{s.t.}\begin{cases}(1-v_1)\frac{1}{8}-f_1\geq\pi_1(t,1)\\(1-v_2)\frac{1}{16}-f_2\geq\pi_2(1,t)\end{cases}\end{array}\right\} \tag{15}$$

where $\pi_1(t,1)=\frac{\mathrm{t}}{8(2-t)}$ and $\pi_2(1,t)=\frac{t}{16}$. The solution to the problem in Eq. (15) affords $v_1=1-\frac{\mathrm{t}}{2-t}$ and $v_2=1-t$. As a result, $f_1=f_2=0$, and the licensor's revenues amount to:

$$\pi_{L|1+2}^{v}(t)=\frac{(6-t)(1-t)}{16(2-t)} \tag{16}$$

when granting two licences by means of pure ad-valorem contracts.

Comparison of this revenue with that rendered by a single licence to firm 1 allows us to establish the following result.

Lemma 3. *If ad-valorem royalties are allowed, the innovation is licensed to the market-leading firm by means of a pure ad-valorem (or profit-sharing) royalty.*

From Lemmas 1-3, the following result can be stated.

Proposition 1. *If quantity competition holds in the marketplace, an external innovator licenses a product innovation to the market-leading firm by means of a fixed-fee contract (or, indistinctly, a pure ad-valorem, or profit-sharing, contract).*

That is, a product of better quality than currently produced in a Stackelberg-quantity duopoly is only licensed to the market leader, regardless of the quality improvement embedded in the product. The reason is that when the leading firm is the only one that produces the high-quality product, vertical differentiation is created between products, and the market leader becomes a quasi-monopoly. This allows the licensor, using a fixed payment or, alternatively, a non-distorting royalty, to appropriate the maximum possible profit.

4. Stackelberg price competition

In this section, we analyse the licensing game when firms compete with each other by setting prices. In this case, if there is no licensing, both firms continue to produce the low-quality product, and the Bertrand paradox arises whereby their respective profits amount to $\pi_1^n = \pi_2^n = 0$. Since this situation would also hold if the high-quality product were licensed to both firms, the innovator, in order to avoid reproduction of the zero-profit situation, would only grant a single licence to either the market leader or the market follower.

4.1. Fixed-fee licensing

If the innovation is transferred to firm 1 (the leader firm in setting the price) by means of a fixed fee $f_1(t)$, its direct demand is:

$$x_1 = 1 - \frac{1}{1-t}p_1 + \frac{1}{1-t}p_2 \quad (17)$$

and that of firm 2 is:

$$x_2 = \frac{1}{1-t}p_1 - \frac{1}{t(1-t)}p_2 \quad (18)$$

whereby equilibrium prices are $p_1^f = \frac{1-t}{2-t}$ and $p_2^f = \frac{t(1-t)}{2(2-t)}$. Thus, the firms' profits amount to $\pi_1^f = \frac{1-t}{2(2-t)}$ and $\pi_2^f = \frac{t(1-t)}{4(2-t)^2}$. From here, and taking into account that if firm 2 (the follower firm in setting the price) has the licence instead of firm 1, the profit for this firm is $\pi_1^f(t,1) = \frac{t(1-t)}{8(2-t)}$, and the licensor can ask firm 1 for the fixed payment:

$$f_1(t) = \frac{1-t}{2(2-t)} - \frac{t(1-t)}{8(2-t)} = \frac{4-5t+t^2}{8(2-t)} \quad (19)$$

A similar reasoning allows us to conclude that firm 2 will be willing to pay the fixed payment:

$$f_2(t) = \frac{(1-t)(4-t)^2}{16(2-t)^2} - \frac{t(1-t)}{4(2-t)^2} = \frac{(1-t)(16-12t+t^2)}{16(2-t)^2} \quad (20)$$

for the innovation if the licence is only offered to this firm. Since comparison of the payments in Eqs. (19) and (20) leads to $f_1(t) > f_2(t)$, we can conclude that, under fixed-fee licensing, the innovation is granted to the price leading firm.

Lemma 4. *Under fixed-fee licensing, an external innovator licenses a product innovation to the market-leading firm under the same (non-distorting) contract as under quantity competition.*

Since the market-leader firm acts as a monopoly in its residual market and achieves larger market share than the follower, the licensor prefers this firm as producer of the high-quality product, instead of the following firm, and uses a non-distorting contract.

4.2. Per-unit royalty licensing

In this case, if the licence is granted to firm 1 by means of the 2PT contract (f_1, r_1), the firms' equilibrium prices amount to $p_1^u(r_1,t) = \frac{2(1-t)+(2-t)r_1}{2(2-t)}$ and $p_2^u(r_1,t) = \frac{2t(1-t)+t(2-t)r_1}{4(2-t)}$. Hence, taking into account that firms' productions amount to $x_1^u(r_1,t) = \frac{2(1-t)-(2-t)r_1}{4(1-t)}$ and $x_2^u(r_1,t) = \frac{2(1-t)+(2-t)r_1}{4(2-t)(1-t)}$, the licensor solves the problem:

$$\max_{r_1} f_1 + r_1 \frac{2(1-t)-(2-t)r_1}{4(1-t)}, \text{ s.t: } \frac{(2(1-t)-(2-t)r_1)^2}{8(2-t)(1-t)} - f_1 \geq \pi_1(r_2; t, 1) \quad (21)$$

where $\pi_1(r_2;t,1)=\frac{t(1-t+r_2)^2}{8(2-t)(1-t)}$ is firm 1's profit if the licensor offers the innovation to firm 2 rather than firm 1. The solution to the problem in Eq. (21) is $r_1=0$, and hence, the contract offered to the market leader is reduced to a fixed-fee payment.

On the other hand, if the innovation is licensed to firm 2 by means of the 2PT contract (f_2,r_2), the firms' equilibrium prices are $p_1^u(r_2,t)=\frac{t(1-t+r_2)}{2(2-t)}$ and $p_2^u(r_2,t)=\frac{(4-t)(1-t+r_2)}{4(2-t)}$, leading to equilibrium outputs $x_1^u(r_2,t)=\frac{1-t+r_2}{4(1-t)}$ and $x_2^u(r_2,t)=\frac{(4-t)(1-t)-(4-3t)r_2}{4(2-t)(1-t)}$. Hence, the licensor's problem consists of:

$$\max_{r_2} f_2+r_2\frac{(4-t)(1-t)-(4-3t)r_2}{4(2-t)(1-t)}, \text{ s.t: } \frac{((4-t)(1-t)-(4-3t)r_2)^2}{16(2-t)^2(1-t)}-f_2\geq\pi_2(r_1;1,t) \quad (22)$$

where $\pi_2(r_1;1,t)=\frac{t(2(1-t)+(2-t)r_1)^2}{16(2-t)^2(1-t)}$ is firm 2's profit if the innovation is offered to firm 1 rather than firm 2. The solution to the problem in Eq. (22) is $r_2(t)=\frac{t(1-t)}{4-3t}$.

In sum, if the innovation is only licensed to the market leader, the licensing deal is reduced to the fixed payment:

$$f_1(t)=\frac{(1-t)^2(16-12t+t^2)}{2(4-3t)^2(2-t)} \quad (23)$$

whereas if it is only licensed to the market follower, the deal consists of the 2PT contract $(f_2,r_2)=\left(\frac{(4-t)(1-t)^2}{4(2-t)^2},\frac{t(1-t)}{4-3t}\right)$, in which case the licensor's revenues amount to:

$$\pi_{L|2}^u(t)=\frac{(1-t)(16-24t+11t^2-t^3)}{4(2-t)^2(4-3t)} \quad (24)$$

Comparing the licensing revenues given in Eqs. (23) and (24), we arrive at the following result.

Lemma 5. *If per-unit royalties are allowed, an external innovator licenses its product innovation to the market-following firm by means of a 2PT contract involving a per-unit royalty.*

4.3. Ad-valorem royalty licensing

In this case, a single licence granted to the market leader by means of a 2PT contract (f_1,v_1) leads the licensor to solve the problem:

$$\max_{v_1} f_1+v_1\frac{(1-t)}{2(2-t)}, \text{ s.t: } (1-v_1)\frac{1-t}{2(2-t)}-f_1\geq\pi_1(t,1) \quad (20)$$

where $\pi_1(t,1) = \frac{t(1-t)}{8(2-t)}$ is firm 1's profit if the licence were granted to firm 2 in exchange for a 2PT contract (f_2, v_2). The solution to the problem in Eq. (20) is $v_1(t) = 1 - \frac{t}{4}$, and hence, the 2PT contract is reduced to a pure ad-valorem royalty that renders the payoff $\pi_{L|1}^{v}(t) = \frac{4-5t+t^2}{8(2-t)}$ to the licensor, i.e., the same as for a fixed-fee contract.

Contrariwise, if the licence is granted to firm 2 by means of a 2PT contract (f_2, v_2), the licensor solves:

$$\max_{v_2} f_2 + v_2 \frac{(1-t)(4-t)^2}{16(2-t)^2}, \text{ s.t: } (1 - v_2)\frac{(1-t)(4-t)^2}{16(2-t)^2} - f_2 \geq \pi_2(1,t) \qquad (21)$$

where $\pi_2(1,t) = \frac{t(1-t)}{4(2-t)^2}$ is firm 2's profit if the licence were granted to firm 1 in exchange for a 2PT contract (f_1, v_1). The solution to the problem in Eq. (21) is $v_2(t) = 1 - \frac{4t}{(4-t)^2}$ and the 2PT contract is also reduced to a pure ad-valorem royalty. Finally, $\pi_{L|2}^{v}(t) = \frac{(1-t)(16-12t+t^2)}{16(2-t)^2}$ and the fact that $\pi_{L|1}^{v}(t) > \pi_{L|2}^{v}(t)$ leads the licensor to prefer, as occurs under fixed-fee licensing, to transfer the innovation to the market leader rather than to the market follower.

Taking into account the lemmas above, we can state the following result.

Proposition 2. *If price competition holds in the product market, an external innovator licenses a product innovation to the market-following firm by means of a 2PT contract involving a per-unit royalty.*

This result sharply contrasts with that obtained when firms in the industry where the innovation is applied compete by means of quantities. While under quantity competition, the innovation is transferred to the market leader by means of a non-distorting contract, under price competition the innovation is licensed to the market follower by means of a 2PT (distorting) contract that makes the industry more collusive.

5. Conclusion

In this article we have analysed how an external innovator with a product innovation transfers it to a duopolistic industry in which firms, currently producing a low-quality product, compete sequentially, i.e., one acts as the market leader and the other acts as the market follower. In this context, our findings add two main results to the literature. First, regardless of whether the market competition is through quantity or price and whether the improvement in quality entailed by the innovation is small or large, the innovator only licenses the new product to one of the two firms (exclusive licensing). Complete technology diffusion never holds in order to avoid firms seeing their profits cancelled if competition is in prices, and to lead to a vertically differentiated market, which increases industry profits, in the case of quantity competition.

Second, the recipient of the innovation and the contractual terms employed depends, however, on how the firms compete with each other. When market competition is by quantity, the new product is exclusively licensed to the market leader by means of a non-distorting contract; however, when competition is by price, the product is exclusively transferred to the market follower through a 2PT (distorting) contract involving a per-unit royalty.

Acknowledgements

The authors acknowledge financial aid from a Xunta de Galicia grant (Consolidación e Estruturación – 2019 GRC GI-2060) and from a Spanish Ministry of Science and Innovation grant (ECO2017-86305-C4-1-R).

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