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## Simultaneous signaling and output royalties in licensing contracts

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## **Simultaneous signaling and output royalties in licensing contracts\***

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### **Resumen**

En este artículo se analiza un modelo de licencia de dos periodos en el que el propietario de una innovación patentada transfiere dicha innovación mediante contratos de royalties a varias empresas situadas "abajo". Dichas empresas compiten a la Cournot en el mercado de producto y el coste de cada una de ellas no es directamente observable para terceros. En este contexto, los royalties óptimos fijados por el propietario de la innovación cuando cada empresa señala su coste a través del output que produce en el primer periodo son comparados con los royalties que fijaría cuando el output no señala el coste. Mostramos que las empresas de bajo coste tienen incentivo a camuflarse como empresas de alto coste. Ello conduce, cuando el diferencial de eficiencia entre las empresas es suficientemente pequeño, a royalties del primer periodo mayores (resp., menores) que si los outputs no señalizan los costes de las empresas siempre que la probabilidad de que las empresas resulten eficientes sea elevada (resp., baja o moderada). Los resultados se amplían al caso en el que el diferencial de eficiencia entre las empresas es elevado y también al caso en el que las empresas que utilizan la innovación producen bienes diferenciados, compiten a la Bertrand y señalizan sus costes a través de los precios que eligen en el primer periodo.

**Palabras clave:** Licencia de patentes, royalties por unidad producida, costes inobservables, equilibrio de señalización y no-señalización

### **Abstract**

This paper analyzes a two-period licensing model where an upstream patent holder licenses an innovation, by per-unit output royalty contracts, to several downstream licensees. Such firms compete in Cournot fashion at the product market and each firm's cost is directly unobservable for third parties. In such a context, the optimal royalties when licensees' outputs signal their costs through the output produced on the first period are examined and compared with those they would be if licensees' outputs were not a signal of such costs. It is shown that low-cost licensees have an incentive to misrepresent themselves as high-cost firms. This leads, when the efficiency gap between licensees is low enough, the first-period per-unit output royalties to be higher (resp. lower) than they would be if firms' output were not a signal of their costs provided that the probability of licensees being low-cost producers is very high (resp. low or moderate). Results are extended to the case of a large efficiency gap between licensees, and that of downstream Bertrand licensees who produce differentiated goods using the innovation and may signal their marginal costs through price choices of the first period.

**JEL classification:** D45, D82, O32

**Keywords:** Patent licensing, per-unit output royalties, unobservable costs, signaling and no-signaling equilibrium

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## 1. Introduction

The socio-economic effects of innovations mainly take place when such innovations are adopted both by firms and consumers, which makes the diffusion process of new technologies to be, at first glance, an essential issue of the economic performance in any industry. In particular, the rhythm and extension of innovation diffusion in new industries are the factors determining their impact on competition, output, prices, employment, and social welfare. Indeed, without the development phase in the R&D activity, there is no transformation of the invention into a truly economically profitable innovation, in such a way that “managing innovation properly is one of the most important challenges faced by developed economies”.<sup>1</sup> In addition, when intellectual inputs dominate, research activities are more likely to be performed by independent research units as for software and biotechnology. In such cases, and given that the full exploitation of innovations may involve such a great amount of complementary assets that their owners are likely to lack, especially when they are out-of-the-industry research labs unable to commercialize them by themselves, (upstream) research units are compelled to license the technology to (downstream) firms capable of industrially exploiting it as the empirical evidence seems to confirm.

A recent survey by Business Planning and Research International consulting firm of 133 firms and 20 universities from Western Europe, Japan and the US, operating in the automotive, engineering, bio-pharmaceutical, and electronics sectors, has shown that 66 percent of organizations find licensing out to be attractive, primarily because of the financial, economic or commercial benefits.<sup>2</sup> This conclusion seems to suggest that technology licensing is not only important for independent research units unable to exploit their inventions by themselves, but also for many large firms capable of exploiting their technology on their own. Prominent examples are Union Carbide and Montecatini that have licensed their polyethylene and polypropylene technology, while many others such as Dow Chemicals, Exxon, Nova Chemicals

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<sup>1</sup> Aghion and Tirole (1994, p. 1205).

<sup>2</sup> See Cesaroni (2001).

and Phillips Petroleum are actively licensing their metallocene catalyst technology for producing plastics (see Arora and Fosfuri, 1998b). Likewise, in the semiconductor sector, IBM expected to generate \$750 million from its patent portfolio, twice as much as it collected just four years earlier (see Grove, 1998), and Texas Instruments is reported to have earned royalties of over \$1.8 billion from 1986 to 1993 through licensing.

These examples illustrate that licensing is a form of making profit from innovations and it has in fact become an area of increasing profitability for knowledge-based companies. Such firms have played an important role in (creating and) diffusing new technologies during the last few years in the chemical,<sup>3</sup> biotechnology, automotive, biopharmaceutical, computer or engineering industries. In sum, the management of technological knowledge and other intellectual property rights is becoming a “core competence” of successful firms.

In the research agenda of IO, technology licensing has become one of the main issues and a number of theoretical and empirical studies have addressed this subject. Regarding the theoretical licensing literature, it has mainly focused on comparing the performance of fixed fee and royalty payments in contractual arrangements to market an innovation. In principle, three different licensing contracts for exploiting the innovations have been considered (royalty, fixed fee and two-part tariff contracts)<sup>4</sup> and the literature has widely explored the optimality of each one of them either when the licensor is a non-producer or a competing firm. Particularly, under perfect information, Kamien and Tauman (1986), Kamien *et al.* (1992) and Muto (1993)<sup>5</sup> examine the case of an out-of-the-industry patent holder, while Katz and Shapiro (1985), Rockett (1990) and Wang (1998) address the issue when the patent holder is internal to the industry.

In empirical terms, and despite studies on licensing contracts being limited, these seem to indicate that royalties tend to predominate. Calvert (1964) and Taylor and Silberston (1973)

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<sup>3</sup> Arora and Fosfuri (1998) report that such firms supplied in the 1980s for more than one third investments in chemical plants worldwide.

<sup>4</sup> The first scenario could arise due, for example, to the fact that riskiness associated to the innovation precludes the use of lump-sum fees. The second one when royalties are feasible due, for example, to the lack of verifiability of the licensees' output. Finally, the third scenario could arise in any other circumstance.

<sup>5</sup> See also Katz and Shapiro (1986) or Erutku and Richelle (2000).

show that about 50 percent of arrangements between patent holders and manufacturing firms are exclusively royalty contracts, 40 percent are two-part tariff contracts, while the remaining 10 percent are fixed fee contracts. In the same line and from a limited sample of US firms, Rostoker (1984) points out that about 39 percent of licensing contracts of surveyed firms are contracts exclusively based on royalties only, 46 percent are two-part tariff contracts and 13 percent are fixed-fee contracts.<sup>6</sup> Likewise, in a study of technology transmission contracts between Spanish and foreign firms, Macho-Stadler *et al.* (1996) find that more than half of the contracts of their sample are based on per-unit output royalties alone. More recently, in a study of 224 licensing contracts involving a French firm (either as a licensor or a licensee), Bessy *et al.* (2003) report that 63.7 percent are based on royalties only.

The predominance of royalties in most licensing contracts led the researchers to find the rationale for such practice. A reason explaining the use of royalty payments is the presence of asymmetric or imperfect information between the licensor and the licensees (see Gallini and Wright 1990, Macho-Stadler and Pérez-Castrillo 1991, Beggs 1992, Macho-Stadler *et al.* 1996, Hornsten 1998 or Hernández-Murillo and Llovet 2002).<sup>7</sup> Gallini and Wright (1990) show that per-unit output royalties in licensing contracts may be preferred to fixed fees when the licensor has superior precontractual information concerning the economic value of the innovation (see also Macho-Stadler and Pérez-Castrillo 1991 and Arora 1995). Likewise, when it is the licensee who has better information than the licensor about the value of the patent, Beggs (1992) shows that royalty contracts, which relate payment to observed output, make a separating equilibrium possible and allow a more efficient outcome than fixed fee contracts.

Nevertheless and to the best of our knowledge, there is no literature that relates informational asymmetries between the proprietor and the users of the innovation, as well as the informational asymmetry among the users of the innovation, with optimal royalty payments in a dynamic setting. The current paper aims to explore the extent to which the existence of private

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<sup>6</sup> The remaining 2 percent of licensing contractual arrangements are more sophisticated contracts.

<sup>7</sup> Other reasons argued to explain royalties are related to risk-sharing between the creator of the technology and the firms finally using it (see Bouquet *et al.* 1998), collusion in the product market (Fauli-Oller and Sandonis 2000, Hernández-Murillo and Llovet 2002), the existence of imperfect capital markets, etc.

information by part of each licensee and its signaling affect the optimal amount of royalties in licensing contracts. This is an interesting issue provided that it incorporates two characteristics that describe the realistic situation in the licensing processes; namely, (i) each particular licensee may have a much better idea about the value of the innovation for itself than the patent holder (as in Beggs 1992), and more than any other potential licensees of the innovation,<sup>8</sup> and (ii) it is also reasonable to assume that each licensee may signal, vertically and horizontally, the production cost of using the new technology. In addition, this rich information structure is well related with two strands of recent industrial organization literature; namely, the literature on regulation in which the cost of the firm to be regulated is unknown for the policymaker (see, e.g., Baron and Myerson 1982 or Laffont and Tirole 1986), and the literature on signaling which assumes the presence of oligopolistic firms that do not know each others' costs (see, e.g., Milgrom and Roberts 1982, Mailath 1989 or Yongmin 1997).

Although licensing royalty contracts may adopt any form, both in the theoretical literature on the subject and the practice of innovative firms, they are commonly based on a constant per-unit output amount.<sup>9</sup> Throughout the paper we will consider licensing through a per-unit output royalty only and the analysis will be conducted in terms of a two-period non-cooperative game involving the (upstream) patent holder and the (downstream) licensees of the innovation. Particularly, two firms compete a la Cournot in the marketplace under asymmetric information and each one may become low-cost (efficient) type or high-cost (inefficient) type from using the innovation. In the first period of the game, the licensor announces a per-unit output royalty for such a period and then the licensees, independently and simultaneously produce using the transferred technology. In this period, licensees do not know their costs and thus royalties have no the potential of inducing revelation on the part of licensees. In the second period of the game, the patent holder turns to announce a per-unit output royalty for such a period and the licensees, independently and simultaneously, decide their outputs. In this period, all players may be

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<sup>8</sup> For example, each potential licensee may know exactly how the innovation will be adapted to its circumstances of production.

<sup>9</sup> Or a percentage on sales.

completely informed (the so-called signaling context) or, conversely, may act in a setting of incomplete information (the no-signaling context).

Our main result indicates that two effects need to be considered by the patent holder when designing the optimal unit royalty for the first period in a signaling context. One is the indirect- or strategic-signaling effect that works as follows. Each high-cost licensee has a horizontal incentive to misrepresent itself as a low-cost firm facing its rival in order to decrease the output of the latter, while each low-cost licensee has a vertical incentive to misrepresent itself facing the patent holder as a high-cost firm with the aim of bearing a lower per-unit output royalty in the licensing contract for the second period. We show that the vertical effect outweighs the horizontal one and leads each licensee to have a net incentive to represent itself as a high-cost firm, regardless of its true cost. This is understood by the patent holder, which establishes, in the first period, a per-unit output royalty lower than in the no-signaling environment in order to reduce the incentive of low-cost licensees to misrepresent themselves (in the signaling context) as high-cost firms.

The second effect that arises in a signaling context is the so-called direct-signaling effect by which signaling commits licensees to produce in the first period a higher expected output than in the no-signaling context. Furthermore, the firms' productive distortion is increasing in the ex-ante probability that firms using the innovation become good users. And in understanding the direct-signaling effect, the patent holder is induced in this way to set a higher per-unit output royalty in the signaling than in the no-signaling environment.

In examining which is the dominant effect of the two, we find that when the probability of licensees being low-cost firms is high enough, the direct-signaling effect outweighs the strategic-signaling effect and the licensor charges in the first period a higher per-unit output royalty with signaling than if signaling were absent. Contrariwise, when the probability of firms to become efficient is sufficiently low, both effects are reinforced and the optimal per-unit output royalty in the presence of signaling is lower than it would be if licensees do not signal their costs. Finally, optimal per-unit output royalties equal those in the no-signaling context only

when signaling costs do not imply productive distortions with respect to the no-signaling context.

In contrast, when licensees signal their costs through prices rather than quantities, the strategic-signaling effect leads them to have an incentive to represent themselves as high-cost firms, regardless of their true type. Furthermore, the direct-signaling effect leads licensees to charge in the first period a higher expected price than in the no-signaling context. Hence, both effects result in a lower per-unit output royalty than in a no-signaling context.

An immediate corollary of our main result is that all the reasonable equilibria either in a Cournot or a Bertrand setting are separating in line with the work on refinement in signaling games, which focus on separating equilibria.<sup>10</sup>

The plan of the paper is as follows. In section 2 we shall introduce the model. The separating sequential equilibrium of the signaling game, and the optimal period 1 and period 2 per-unit royalties are derived in section 3. Section 4 examines the pooling sequential equilibrium. In section 5 we compare the signaling outcome with the no-signaling outcome. Section 6 discusses how things work when cost signaling is made through prices. Conclusions are drawn in section 7.

## 2. The model

Consider an upstream patent holder that has developed and patented a marketable innovation lasting for two periods indexed as  $t=1,2$ . The patent holder does not have access to the downstream final market, since it has no manufacturing facilities, no distribution capability and no retail function. It can profit, however, from the innovation by selling it to a pool of downstream potential licensees. The patent holder seeks to license the innovation so as to maximize its total revenues, the licensing cost is assumed to be zero, and the licensing

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<sup>10</sup> However, in a model where an informed firm's choice of financial structure and the financing contract is observed both by the capital market and a uninformed competing firm, Gertner et al. (1988) obtain that all the reasonable equilibria are pooling.



contractual arrangements are restricted to be contracts based on per-unit output royalties exclusively, which relate payment to observed output—a practice that is widespread in licensing contracts (see, e.g., Arora 1995, or Anand and Khanna 2000).

The downstream industry emerging from the licensing of the innovation is assumed to be composed of two firms indexed as  $i=A,B$ , which produce a homogeneous good. In order to keep the model as simple as possible, we assume that the per-period inverse demand function of the industry is linear and, without further loss of generality, given by

$$p_t(Q_t) = 1 - Q_t, \quad (1)$$

where  $p_t$  denotes the unit price in period  $t$  when  $Q_t = q_t^A + q_t^B$  units of the product are sold,<sup>11</sup> and the absolute size of the market is normalized at one. Such a demand is known for all participants and remains unchanged from one period to the other.

Once obtained the technology, the realized cost of each licensee  $i$  is constant and it either takes a low or a high value, one of which is randomly selected. We also assume that it is the same for all the tenancy periods of the patent, and independent of that realized by the other licensee  $j, j \neq i$ . Specifically,

$$\tilde{c}^i = \begin{cases} 0 & \text{with probability } \gamma \\ c & \text{with probability } 1 - \gamma, \end{cases} \quad (2)$$

where the ex-ante probability  $\gamma, \gamma \in (0,1)$ , is taken as exogenous. Parameter  $c$  captures the efficiency gap or heterogeneity that may arise between both licensees and is assumed to verify  $0 < c < 1/3$ .<sup>12</sup> The upper bound of the value of  $c$  enables us to restrict the analysis to the case of a

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<sup>11</sup> This demand comes from the maximization problem of a representative consumer with a utility function for each period,  $u_t(Q_t), t=1,2$ , separable in money,  $m_t$ , as  $u_t(Q_t) = Q_t - \frac{1}{2}Q_t^2 + m_t$ , where  $Q_t = q_t^A + q_t^B$ .

<sup>12</sup> The case in which  $1/3 \leq c < 1$ , i.e. where the inefficient firm drops out of the market, making the efficient firm a monopoly, will be examined in section 6.

non-drastic innovation for which both licensees will produce a positive level of output when licensing occurs, i.e. no one inefficient firm is so bad (with respect to the efficient one) to have to exit the industry, regardless of both the other players' beliefs about its cost and the rival's cost.

The upstream licensor and the downstream potential licensees play a two-period four-stage game with the following sequence of moves. At the beginning of period 1 (first stage), the patent holder announces and commits to period 1 royalty schedule for potential licensees, and each licensee privately observes its marginal cost using the innovation by which both horizontal and vertical asymmetric information exist. What is common knowledge in this period is (2). Then, at the second stage both licensees choose outputs of the first period and pay the licensor in accordance with the contract. The output of each licensee  $i$  in period 1,  $q_1^i$ , is observed by both the patent holder and rival firm  $j$ , who use such observation to update their probability assessment regarding the marginal cost of licensee  $i$ . Let  $\gamma(q_1^i)$  be the common updated probability assessment as to the likelihood of licensee  $i$  being a low-cost firm.

At the beginning of period 2 (third stage), and given the updated beliefs formed after observing period 1 outputs, the licensor announces and commits to period 2 per-unit output royalties to be paid by the licensees. Finally, given the updated probability assessment and the amount of these royalties, the two licensees choose, in the fourth stage, the outputs corresponding to the second period. The description of the model is completed by assuming that all parties are risk-neutral, the discount parameter is normalized at one, and the patent holder has all the bargaining power in the negotiation.

The equilibrium concept we use for solving the proposed game is the sequential equilibrium (Kreps and Wilson 1982) in which outputs of period 1 must constitute a Bayesian-Cournot equilibrium, outputs of period 2 must be chosen optimally given the updated probability assessments, and beliefs must be consistent in every information set. As usual, two

types of sequential equilibria are considered, separating and pooling equilibria.<sup>13</sup> In a separating sequential equilibrium the outputs produced in period 1 convey information concerning firms' costs, by which the game of period 2 becomes a complete information game. In turn, in a pooling sequential equilibrium both high-cost and low-cost types of each licensee choose the same output in period 1, so no one information is transmitted and updated beliefs after observing period 1 outputs continue to be the same prior assessment; in short, incomplete information holds in the game of period 2.

### 3. Separating sequential equilibria

In separating sequential equilibria, the private information about costs of licensees is fully revealed through the outputs produced in period 1. So, the second period game is a complete information game in which each licensee knows the rival's marginal cost and the patent holder knows the cost of each one of the two firms. Denoting by superscripts  $L$  and  $H$  the low-cost and high-cost firms, respectively, a separating equilibrium is, in this setting, a list of actions and beliefs  $\{(r_1^i(c^i), q_1^i(\tilde{c}^i, r_1^i), \gamma(q_1^i), r_2^i(\tilde{c}^i, q_1^i(\cdot)), q_2^i(\tilde{c}^i, r_2^i, q_1^i(\cdot)))\}$  that adopts the form

$$r_1^i(\tilde{c}^i) = r_1^i, \text{ for all } \tilde{c}^i \in \{0, c\}, \quad (3)$$

$$q_1^i(\tilde{c}^i, r_1^i) = \begin{cases} q_{1H}^i, & \text{if } \tilde{c}^i = c \\ q_{1L}^i, & \text{if } \tilde{c}^i = 0, \end{cases} \quad (4)$$

$$\gamma(q_1^i) = \begin{cases} 0, & \text{if } q_1^i = q_{1H}^i \\ 1, & \text{if } q_1^i = q_{1L}^i, \end{cases} \quad (5)$$

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<sup>13</sup> Since the main goal of the paper is to examine the role of the signaling process on royalties and the subsequent transmission of information compared to the case where signaling is totally absent, hybrid equilibria are ignored.

$$r_2^i(\tilde{c}^i, q_1^i(\cdot)) = \begin{cases} r_{2H}^i, & \text{if } q_1^i = q_{1H}^i \\ r_{2L}^i, & \text{if } q_1^i = q_{1L}^i, \end{cases} \quad (6)$$

and

$$q_2^i(\tilde{c}^i, r_2^i, q_1^j(\cdot)) = \begin{cases} q_2^i(c, c), & \text{if } \tilde{c}^i = c \text{ and } q_1^j = q_{1H}^j \\ q_2^i(c, 0), & \text{if } \tilde{c}^i = c \text{ and } q_1^j = q_{1L}^j \\ q_2^i(0, c), & \text{if } \tilde{c}^i = 0 \text{ and } q_1^j = q_{1H}^j \\ q_2^i(0, 0), & \text{if } \tilde{c}^i = 0 \text{ and } q_1^j = q_{1L}^j. \end{cases} \quad (7)$$

That is, the patent holder selects a period 1 royalty given the probability assessment of licensees being low-cost, and licensees choose outputs of period 1 given the probability assessment of each one about the rival's cost. Next, for every  $q_1^i$ ,  $i=A,B$ , the rest of players form an updated belief about the type of licensee  $i$  and take an optimal action given  $i$ 's strategy. The updated beliefs  $\gamma(q_1^i)$  are unrestricted, except that we use Bayes' rule to form them for actions with positive probability in equilibrium. In turn, period 2 actions are taken under complete information. As usual, the separating equilibrium is computed by working backwards from the second period to the first one.

### *Period 2*

In this period, the patent holder knows the marginal cost of each one of the licensees, and chooses the per-unit output royalties to maximize its licensing income. Since these royalties are chosen before the output game is played, we start by determining the Cournot equilibrium quantities for the two licensees in period 2 before payments of any royalties are made. All the licensees are informed of the magnitude of royalties and marginal costs, and simultaneously and independently solve the problem

$$\text{Max}_{q_2^i} (1 - \tilde{c}^i - (q_2^i + q_2^j))q_2^i - r_2^i q_2^i, \quad i,j=A,B; i \neq j, \tilde{c}^i \in \{0, c\}, \quad (8)$$

where  $r_2^i$  is the per-unit output royalty required by the patent holder at period  $t=2$ . The first-order condition of this problem enables us to obtain the Cournot equilibrium outputs<sup>14</sup>

$$q_2^i(\tilde{c}^i, \tilde{c}^j, r_2^i, r_2^j) = \frac{1 - 2\tilde{c}^i + \tilde{c}^j - 2r_2^i + r_2^j}{3} \quad (9)$$

and substituting these Cournot equilibrium outputs into each firm's profit function yields the profit earned by each licensee in the second period of the game

$$\Pi_2^i(\tilde{c}^i, \tilde{c}^j, r_2^i, r_2^j) = \left( \frac{1 - 2\tilde{c}^i + \tilde{c}^j - 2r_2^i + r_2^j}{3} \right)^2. \quad (10)$$

To determine the optimal per-unit output royalties  $r_2^A$  and  $r_2^B$  to be paid in period 2 by licensees, the patent holder solves the problem of maximizing the licensing revenue of this period, i.e.

$$\text{Max}_{r_2^A, r_2^B} r_2^A q_2^A + r_2^B q_2^B, \quad (11)$$

whose first-order conditions yield

$$r_2^i(r_2^j; \tilde{c}^i, \tilde{c}^j) = \frac{1 - 2\tilde{c}^i + \tilde{c}^j + 2r_2^j}{4}, \quad i,j=A,B; i \neq j. \quad (12)$$

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<sup>14</sup> Throughout, both second order conditions for maxima and stability conditions are satisfied.

Note that royalties allow the patent holder to increase the licensees' marginal costs and, thus, lead the licensees to commit themselves to a less aggressive behavior in the market by setting a higher price level. Put differently, given that transaction costs are zero and information in period 2 is complete, royalties enable the patent holder to control the reaction functions of licensees in the marketplace, by which the innovation may be marketed without inducing too much competition there.<sup>15</sup>

Solving (12), we obtain

$$r_2^i(\tilde{c}^i) = \frac{1 - \tilde{c}^i}{2}, \quad \tilde{c}^i \in \{0, c\}, \quad i=A,B, \quad (13)$$

as the optimal per-unit output royalties required by the patent holder for period 2. The fact that royalties are decreasing in the cost level leads each licensee to have a (vertical) incentive to misrepresent itself as a high-cost firm, regardless of its true cost level. Substitution of (13) into (9) gives rise to the outputs

$$q_2^i(\tilde{c}^i, \tilde{c}^j) = \frac{1 - 2\tilde{c}^i + \tilde{c}^j}{6}, \quad (14)$$

and, finally, the corresponding maximized profits of licensees in period 2 are

$$\Pi_2^i(\tilde{c}^i, \tilde{c}^j) = \begin{cases} \left(\frac{1}{6}\right)^2, & \text{if } (\tilde{c}^i, \tilde{c}^j) = (0,0) \\ \left(\frac{1+c}{6}\right)^2, & \text{if } (\tilde{c}^i, \tilde{c}^j) = (0,c) \\ \left(\frac{1-2c}{6}\right)^2, & \text{if } (\tilde{c}^i, \tilde{c}^j) = (c,0) \\ \left(\frac{1-c}{6}\right)^2, & \text{if } (\tilde{c}^i, \tilde{c}^j) = (c,c). \end{cases} \quad (15)$$

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<sup>15</sup> For the role of royalties as a collusive device for licensees, see also Fauli-Oller and Sandonís (2000).

As usual, though the profits of each firm  $i$  when uninformed players hold mistaken beliefs about the value of  $i$ 's cost never arise in equilibrium, they are relevant off the equilibrium path. Define  $\Pi_2^i(0|c,0)$  as the maximized profit of firm  $i$  in the second period when (a) it is low-cost, but signals through first period output that its cost is high from which both the patent holder and the rival firm  $j$  ( $j \neq i$ ) believe that licensee  $i$  is a high-cost firm, and (b) it is common knowledge that licensee  $j$  is a low-cost firm. Similarly, denote by  $\Pi_2^i(0|c,c)$  the profit of a low-cost licensee  $i$  in the second period when it misrepresents itself as a high-cost firm and it is common knowledge that the rival is a high-cost firm, by  $\Pi_2^i(c|0,0)$  the profit of a high-cost licensee  $i$  when it misrepresents itself as a low-cost firm and it is common knowledge that the rival is low-cost, and by  $\Pi_2^i(c|0,c)$  the profit of a high-cost licensee  $i$  when it misrepresents itself as a low-cost firm while it is common knowledge that the rival is a high-cost firm. The following lemma summarizes the profits obtained in period 2 by each type of licensee when it reveals its true type in  $t=1$  as compared with the case in which it mimics the other type.

**Lemma 1.** *The profit obtained by each licensee  $i$ ,  $i=A,B$ , at  $t=2$  is such that:*

- (i)  $\Pi_2^i(0|c,c) > \Pi_2^i(0,c)$  and  $\Pi_2^i(0|c,0) > \Pi_2^i(0,0)$ , if it is of low-cost type.
- (ii)  $\Pi_2^i(c,c) > \Pi_2^i(c|0,c)$  and  $\Pi_2^i(c,0) > \Pi_2^i(c|0,0)$  if it is of high-cost type.

**Proof.** See the Appendix.

This result relies on two forces that interplay. Regardless of its true type, any downstream licensee has (a) an ‘horizontal’ incentive to reveal itself as a low-cost facing its rival, because if it is considered a low-cost firm then the rival firm will produce less output in period 2, and (b) it has a ‘vertical’ incentive to reveal itself as a high-cost firm facing the patent holder, because if it is considered a high-cost firm then it will be charged with a lower per-unit royalty in period 2.

What the lemma states is that the second effect outweighs the first one whereby each low-cost licensee has an (net) incentive to disclose at  $t=1$  a bad realization of its production cost.

### *Period 1*

We proceed now to the first period of the game, in which each licensee  $i$  is privately informed about its marginal cost. Once more, given that period 1 per-unit output royalties are announced and committed before the period 1 output game is played, we need to solve the output game for any per-unit output royalties before computing the optimal period 1 per-unit output royalties.

To save on notation, denote by subscripts  $H$  and  $L$  the high-cost and the low-cost type of each licensee, respectively. Given that in a separating sequential equilibrium licensees signal each one of their possible costs by selecting a different period 1 output, it is reasonable to assume that the signal sent by each high-cost firm,  $q_{1H}^i$ , assigns the updated belief  $\gamma(q_{1H}^i) = 0$  and the signal of each low-cost firm,  $q_{1L}^i$ , assigns the posterior belief  $\gamma(q_{1L}^i) = 1$ . To complete the specification of the equilibrium, out-of-equilibrium posterior beliefs need to be restricted. In this regard, it suffices that any out-of-equilibrium signal  $z_1^i$ ,  $z_1^i \notin \{q_{1H}^i, q_{1L}^i\}$ , is associated with the posterior belief  $\gamma(z_1^i) = 1$ , in order for neither licensee to be able to make a profitable deviation of the proposed equilibrium.

To be part of a separating sequential equilibrium, the outputs of licensees in period 1 must satisfy the following incentive compatibility conditions

$$q_{1L}^i \equiv f(q_{1H}^i) = \arg \max_{\tilde{c}^j} E \Pi_{1L}^i(0, r_1^i, \tilde{c}^j), \quad (16)$$

$$\gamma \Pi_{1H}^i(c, r_1^i, q_{1H}^i, f(q_{1H}^i)) + (1 - \gamma) \Pi_{1H}^i(c, r_1^i, q_{1H}^i, q_{1H}^j) + E_{c^j} \Pi_{2H}^i(c, r_2^i, \tilde{c}^j)$$



$$\geq \gamma \Pi_{1H}^i(c, r_1^i, h(q_{1H}^j), f(q_{1H}^i)) + (1-\gamma) \Pi_{1H}^i(c, r_1^i, h(q_{1H}^j), q_{1H}^j) + E_{c^j} \Pi_{2H}^i(c|0, r_2^i, \tilde{c}^j), \quad (17)$$

and

$$\begin{aligned} & \gamma \Pi_{1L}^i(0, r_1^i, f(q_{1H}^j), f(q_{1H}^i)) + (1-\gamma) \Pi_{1L}^i(0, r_1^i, f(q_{1H}^j), q_{1H}^j) + E_{c^j} \Pi_{2L}^i(c, r_2^i, \tilde{c}^j) \\ & \geq \gamma \Pi_{1L}^i(0, r_1^i, q_{1H}^j, f(q_{1H}^i)) + (1-\gamma) \Pi_{1L}^i(0, r_1^i, q_{1H}^j, q_{1H}^j) + E_{c^j} \Pi_{2H}^i(c|0, r_2^i, \tilde{c}^j), \quad (18) \end{aligned}$$

where  $q_{1H}^i \equiv h(q_{1H}^j)$  is the best reply function of a low-cost licensee  $i$  competing with a rival  $j$  ( $j \neq i$ ) that is low-cost with probability  $\gamma$  and thus produces output  $q_{1L}^j \equiv f(q_{1H}^i)$ , and is high-cost with probability  $1-\gamma$  in which case it produces output  $q_{1H}^j$ .

Succinctly, condition (16) indicates the best a low-cost licensee can do provided that it is considered a low-cost firm. Likewise, condition (17) is the incentive compatibility constraint for each high-cost licensee. It states that the high-cost type of each licensee would prefer to produce output  $q_{1H}^i$  in the first period (an output that may differ from the profit-maximizing output corresponding to its type) and be perceived as a high-cost firm in period 2, rather than produce the output that maximizes its profits in period 1 as a high-cost firm and then be perceived as a low-cost firm in period 2. Finally, condition (18) is the self-selection constraint for a low-cost licensee. It asserts that the low-cost type of each licensee would prefer to produce output  $q_{1L}^i$  in period 1 and be perceived as a low-cost firm in period 2, rather than be perceived as a high-cost firm and be forced to produce output  $q_{1H}^i$  in period 1.

The resolution of the incentive compatibility conditions (16)-(18) enables us to obtain the result of the following lemma, where superscripts  $S$  and  $II$  stand for separating equilibrium and incomplete information setting, respectively.

**Lemma 2.** *The outputs produced by each licensee  $i$ ,  $i=A,B$ , at  $t=1$  that form part of the unique separating sequential equilibrium of minimum cost are as follows:*

(i) *If parameters  $c$  and  $\gamma$  satisfy the condition  $c < 1/(3+\gamma)$ , each licensee  $i$  produces the output*

$$q_{1H}^{iS} = \frac{1-r_1^i}{3} - \frac{(2+\gamma)\sqrt{((3-2\gamma)c+2)c}}{18} \quad \text{when it is of high-cost type, and } q_{1L}^{iS} = \frac{(2+\gamma)(1-r_1^i)}{3} + \frac{(2+\gamma)(1-\gamma)\sqrt{((3-2\gamma)c+2)c}}{18} \quad \text{when it is a low-cost firm.}$$

(ii) *If parameters  $c$  and  $\gamma$  satisfy  $c \geq 1/(3+\gamma)$ , each licensee  $i$  produces the output*

$$q_{1H}^{iS} = \frac{1-r_1^i}{3} - \frac{(2+\gamma)c}{6} \equiv q_{1H}^{iII} \quad \text{when it is a high-cost firm, and } q_{1L}^{iS} = \frac{1-r_1^i}{3} + \frac{(1-\gamma)c}{6} \equiv q_{1L}^{iII} \quad \text{when it is of low-cost type.}$$

**Proof.** See the Appendix.

Part (i) of the lemma states that if the efficiency gap between users of the innovation is sufficiently low, then the incentive to disclose a bad realization of the cost induces each high-cost licensee, in order to distinguish itself from licensees of low-cost type, to distort its output of period 1 below the level that would maximize its profits in the one-shot incomplete information game of period 1. In other words, high-cost firms ‘under-produce’ in equilibrium, i.e. supply less than their duopoly output,  $q_{1H}^{iS} < q_{1H}^{iII}$ ,  $i=A,B$ . And the fact that outputs are strategic substitutes implies that licensees of low-cost type are induced to over-produce relative the output level that they would produce in the one-shot incomplete information game,  $q_{1L}^{iS} > q_{1L}^{iII}$ . This is the so-called Non-Trivial Separating equilibrium (NTSE). Contrariwise, part (ii) of the lemma shows that when the efficiency gap between licensees is large enough, high-cost licensees need not distort their output downward. It suffices to produce in period 1, the profit maximizing output under incomplete information,  $q_{1H}^{iS} = q_{1H}^{iII}$ . Hence, the low-cost licensees also produce output level that maximizes their profits in the incomplete information period,  $q_{1L}^{iS} = q_{1L}^{iII}$ . This is what we shall call the Trivial Separating equilibrium (TSE).

The patent holder takes this unique equilibrium as given and determines the per-unit output royalties that maximize its expected licensing income over this period. Such optimal per-unit output royalties are contained in the following proposition.

**Proposition 1.** *When period 1 outputs of licensees signal their marginal costs, the optimal per-unit royalty quoted by the patent holder in period 1 to each licensee  $i$ ,  $i=A,B$ , is as follows:*

$$(i) \ r_1^{iS} = \frac{1}{2} - \frac{(1-\gamma)^2(2+\gamma)\sqrt{((3-2\gamma)c+2)c}}{12(1+\gamma+\gamma^2)}, \text{ if parameters } c \text{ and } \gamma \text{ satisfy the condition } c < 1/(3+\gamma).$$

$$(ii) \ r_1^{iS} = \frac{1}{2} - \frac{(1-\gamma)c}{2}, \text{ if parameters } c \text{ and } \gamma \text{ satisfy the condition } c \geq 1/(3+\gamma).$$

**Proof.** See the Appendix.

The intuition behind this proposition rises from the two afore-mentioned signaling effects. One is the presence of a per-unit royalty, which increases the marginal costs of licensees and thus makes any downward output distortion less costly. The other is the presence of signaling, which commits licensees to produce a higher expected output level at  $t=1$  (high-cost licensees produce less, but low-cost licensees produce more). As we will see later on, both are responsible for the different behavior in the signaling environment as compared with the no-signaling context.

Turning back to Lemma 2, we obtain that outputs produced by licensees in period 1 are, in the presence of these royalties,

$$q_{1H}^{iS} = \begin{cases} \frac{1}{6} - \frac{(1+4\gamma+\gamma^2)(2+\gamma)\sqrt{((3-2\gamma)c+2)c}}{36(1+\gamma+\gamma^2)}, & \text{if } c < \frac{1}{3+\gamma} \\ \frac{1-(1+2\gamma)c}{6}, & \text{otherwise,} \end{cases} \quad (19)$$

for each high-cost licensee and

$$q_{1L}^{iS} = \begin{cases} \frac{2+\gamma}{6} + \frac{(1-\gamma)(4+\gamma+\gamma^2)(2+\gamma)\sqrt{((3-2\gamma)c+2)c}}{36(1+\gamma+\gamma^2)}, & \text{if } c < \frac{1}{3+\gamma} \\ \frac{1+2(1-\gamma)c}{6}, & \text{otherwise,} \end{cases} \quad (20)$$

for each low-cost licensee.

#### 4. Pooling sequential equilibrium

A simultaneous pooling sequential equilibrium has both high-cost and low-cost types of each downstream licensee  $i$  producing the same output level at  $t=1$ , by which no additional information concerning their costs is provided by observing first-period outputs. Thus, at  $t=2$  both the patent holder and rival firm  $j$  ( $j \neq i$ ) continue to use  $\gamma$  as their probability assessment that licensee  $i$  is a firm of a low-cost type. Formally, a simultaneous pooling equilibrium is a list of actions and beliefs  $\{(r_1^i(\tilde{c}^i), q_1^i(\tilde{c}^i, r_1^i), \gamma(q_1^i), r_2^i(\tilde{c}^i), q_2^i(\tilde{c}^i, r_2^i, q_1^i(\cdot)))\}$  that takes the form

$$r_1^i(\tilde{c}^i) = r_1^{iP}, \text{ for all } \tilde{c}^i \in \{0, c\}, \quad (21)$$

$$q_1^i(\tilde{c}^i, r_1^i) = q_1^{iP}, \text{ for all } \tilde{c}^i \in \{0, c\}, \quad (22)$$

$$\gamma(q_1^i) = \begin{cases} \gamma, & \text{if } q_1^i = q_1^{iP} \\ 1, & \text{if } q_1^i < q_1^{iP} \\ 0, & \text{if } q_1^i > q_1^{iP}, \end{cases} \quad (23)$$

$$r_2^i(\tilde{c}^i) = r_2^{iP}, \text{ for all } \tilde{c}^i \in \{0, c\}, \quad (24)$$

and

$$q_2^i(\tilde{c}^i, r_2^i, q_1^j(\cdot)) = \begin{cases} q_2^{iH}, & \text{if } q_1^j = q_1^{jP} \\ \hat{q}_{2L}^i, & \text{if } q_1^j < q_1^{jP} \\ \hat{q}_{2H}^i, & \text{if } q_1^j > q_1^{jP}, \end{cases} \quad (25)$$

where superscript  $P$  stands for pooling, superscript  $H$  denotes that no information was inferred and thus the second period is a simple Cournot game under incomplete information,  $\hat{q}_{2L}^i$  is the period 2 output of licensee  $i$  when it is considered as a low-cost firm by both the competitor and the patent holder, and  $\hat{q}_{2H}^i$  is the period 2 output of licensee  $i$  when it is taken by its rival and the patent holder as a high-cost firm.<sup>16</sup> To obtain the pooling equilibrium defined in (21)-(25), we proceed as usual by backwards induction.

#### Period 2

Given the probability assessment and the per-unit output royalties, the problem of each licensee  $i$  in period 2 is

$$\begin{aligned} \text{Max}_{q_2^i} \gamma \left\{ (1 - \tilde{c}^i - (q_2^i + q_{2L}^j)) q_2^i - r_2^i q_2^i \right\} + (1 - \gamma) \left\{ (1 - \tilde{c}^i - (q_2^i + q_{2H}^j)) q_2^i - r_2^i q_2^i \right\}, \\ \tilde{c}^i \in \{0, c\}, \quad i, j = A, B, \quad i \neq j, \quad (26) \end{aligned}$$

which if solved affords the optimal output levels

$$q_{2H}^{iP} = \frac{2(1-c) - \gamma c - 4r_2^i + 2r_2^j}{6}, \quad (27)$$

for each high-cost licensee, and

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<sup>16</sup> On the other hand, updated beliefs given in (23) must induce both types of each licensee to choose the pooling equilibrium output.

$$q_{2L}^{iP} = \frac{2 + (1-\gamma)c - 4r_2^i + 2r_2^j}{6}, \quad (28)$$

for each low-cost licensee. From (27) and (28), the patent holder chooses per-unit output royalties  $r_2^A$  and  $r_2^B$  to maximize its expected profit from licensing, namely

$$\text{Max}_{r_2^i} r_2^{iP} \left\{ 2\gamma q_{2L}^{iP} + 2(1-\gamma)q_{2H}^{iP} \right\}, \quad i=A,B \quad (29)$$

and the first-order condition of this problem yields the optimal per-unit output royalties recorded in the following proposition.

**Proposition 2.** *The optimal per-unit output royalty in period 2 when licensees' output levels produced in period 1 do not signal their costs is  $r_2^{iP} = \frac{1}{2} - \frac{(1-\gamma)c}{2}$ ,  $i=A,B$ .*

**Proof.** See the Appendix.

In this case there are absolutely no signaling effects at all, by which optimal per-unit output royalties are completely unaffected by the aforementioned signaling effects.

Substituting this royalty into (27) and (28) affords the licensees' output level

$$q_{2H}^{iP} = \frac{1 - c - 2\gamma c}{6} \quad (30)$$

for each high-cost firm, and

$$q_{2L}^{iP} = \frac{1 + 2(1-\gamma)c}{6} \quad (31)$$

for each low-cost firm.

*Period 1*

As the licensees' period 1 outputs form part of a pooling sequential equilibrium, both the high-cost and the low-cost type of each licensee must choose the same output in such a period. Any output  $q_1^{iP}$  such that  $q_1^{iP} \in [q_{1H}^i, q_{1L}^i]$  with the associated posterior beliefs  $\gamma(q_1^{iP}) = \gamma$  together with the out-of-equilibrium beliefs  $\gamma(q_1^i) = 1$  if  $q_1^i < q_1^{iP}$  and  $\gamma(q_1^i) = 0$  if  $q_1^i > q_1^{iP}$  should form part of a pooling sequential equilibrium. Nevertheless, none of these outputs would survive as a pooling once we eliminate equilibrium-dominated outputs when forming out-of-equilibrium beliefs. To illustrate, consider the output  $q_1^{iP}$  candidate to be part of a pooling equilibrium. Such output forms part of a pooling only because —following the above-mentioned out-of-equilibrium posterior beliefs— the updated probability after observing an output as  $q_{1H}^i < q_1^{iP}$  is that it arises from a licensee of low-cost, i.e.  $\gamma(q_{1H}^i) = 1$ . However, for each low-cost licensee the output  $q_{1H}^i$  is clearly dominated by the equilibrium output  $q_1^{iP}$  because its profit function,  $\Pi_{1L}^i(\cdot)$ , is a strictly concave function and reaches the maximum at output level  $q_{1L}^i$  satisfying  $q_{1L}^i > q_1^{iP} > q_{1H}^i$ . Hence, a low-cost licensee would deviate from  $q_{1H}^i$  to  $q_1^{iP}$ . Thus, if both the patent holder and licensee  $j$  believe that licensee  $i$  would never choose an equilibrium-dominated output, the unique possible posterior belief they may establish after observing an out-of-equilibrium output as  $q_{1H}^i$  is  $\gamma(q_{1H}^i) = 0$  and not  $\gamma(q_{1H}^i) = 1$ . Therefore, the equilibrium pooling involving the output  $q_1^{iP}$  and supported by the above-mentioned beliefs is broken by  $q_1^{iP}$  and  $\gamma(q_{1H}^i) = 0$ . The posterior belief on which it is based is found to be implausible, since each high-cost licensee (and not each low-cost licensee) would deviate from the equilibrium involving output level  $q_1^{iP}$  to the equilibrium involving output

$q_{1H}^i$ .<sup>17</sup> Summing up, no pooling sequential equilibrium survives in our model once equilibrium-dominated strategies are eliminated when forming updated beliefs in the out-of-equilibrium-path.

## 5. Comparison between signaling and no-signaling equilibrium

When outputs produced by licensees in period 1 do not signal their costs, the equilibrium outputs of the two firms are, in both production periods, the ones corresponding to the Bayesian-Cournot equilibrium defined in (30)-(31) above, and the optimal per-unit output royalty quoted by the patent holder is, in each one of the two periods, that derived in Proposition 2. Therefore, differences between outputs  $q_{1H}^{iS}$  and  $q_{2H}^{iP}$ , outputs  $q_{1L}^{iS}$  and  $q_{2L}^{iP}$ , and royalty rates  $r_1^{iS}$  and  $r_2^{iP}$  must be entirely attributable to the role of period 1 output of licensees as a cost signaling device. Comparison of the optimal per-unit output royalties settled in the signaling environment and the no-signaling environment enables us to obtain the following central result.

**Proposition 3.** *The optimal per-unit output royalty quoted by the patent holder to each licensee  $i$ ,  $i=A,B$ , is such that:*

(i) *In the region of parameters  $(\gamma, c)$  defined by the condition  $c < 1/(3+\gamma)$ , i.e. in the NTSE,*

$$(i.1) \quad r_1^{iS} < r_2^{iP}, \text{ if } (1-\gamma)(2+\gamma)\sqrt{((3-2\gamma)c+2)c} - 6(1+\gamma+\gamma^2)c > 0.$$

$$(i.2) \quad r_1^{iS} > r_2^{iP}, \text{ if } (1-\gamma)(2+\gamma)\sqrt{((3-2\gamma)c+2)c} - 6(1+\gamma+\gamma^2)c \leq 0.$$

(ii) *In the  $(\gamma, c)$ -space of parameters satisfying  $c \geq 1/(3+\gamma)$ , i.e. in the TSE,  $r_1^{iS} = r_2^{iP}$ .*

**Proof.** Straightforward from Propositions 1 and 2. □

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<sup>17</sup> A similar argument can be applied for any other out-of-equilibrium output as  $q_{1L}^i > q_{1H}^{iP}$  to show that each low-cost licensee would deviate from the equilibrium involving  $q_{1H}^{iP}$  at  $t=1$  to the equilibrium involving  $q_{1L}^i$  at  $t=1$ .

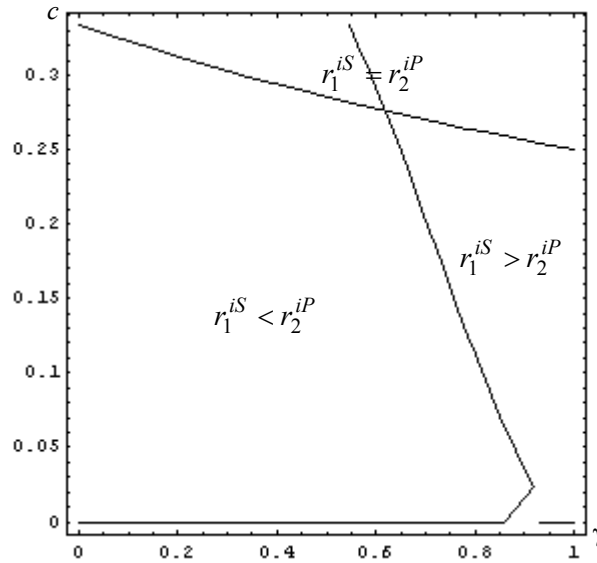


The intuition behind this proposition relies on the trade-off between two forces that interplay. First, the presence of a period 1 per-unit output royalty makes the downward distortion on the output of high-cost licensees to be less costly. From here, an even bigger downwards distortion on output is necessary for each high-cost licensee to convince both the rival firm and the patent holder that it is in fact of high-cost type. Since this increased distortion imposes an over-cost in terms of licensing expected income, the patent holder takes it into account when setting the period 1 optimal per-unit output royalty and is compelled to reduce the royalty rate below the amount it would have in the absence of signaling. This is the so-called indirect- or strategic-signaling effect. Second, the presence of signaling commits licensees to increase the expected period 1 output (high-cost licensees produce less and, as a reaction, low-cost licensees produce more), by which a higher period 1 per-unit output royalty is optimal for the patent holder to maximize its licensing expected rents. This direct-signaling effect leads the patent holder to increase the optimal period 1 royalty regarding the one that would exist if firms' output were not a signal of their costs.

Part (i.1) of the proposition refers to the case in which the probability of licensees being high-cost is moderate or high, and the strategic-signaling effect outweighs the direct-signaling effect. by which the period 1 per-unit output royalty is less than it would be if signaling were absent. Contrariwise, part (i.2) of the proposition establishes that when the probability of licensees becoming low-cost firms is very high, the direct-signaling effect overcompensates the indirect-signaling effect. Hence, the optimal period 1 per-unit output royalty is found to be higher in the presence of signaling than in the absence of signaling. Finally, part (ii) of the proposition shows that when the efficiency gap between licensees is high enough for a TSE to prevail both signaling effects disappear and the per-unit output royalty is the same, regardless of whether or not licensees' outputs signal their costs.<sup>18</sup> This is illustrated in Fig. 1.

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<sup>18</sup> Maintaining all the assumptions of the model unaltered except that the downstream industry is composed of a single firm rather than two, one can prove that when  $0 < c < 2/3$  the separating equilibrium leads the high-cost licensee to produce, in period 1, an output lower than the output it would produce as a monopolist, and the low-cost licensee would produce the monopoly's output that corresponds to its type. So, it holds that  $r_1^S < r_2^P$ . Contrariwise, when  $2/3 \leq c < 1$  it follows that in the separating equilibrium there is no under-production in period 1 by part of the high-cost firm, and  $r_1^S = r_2^P$ . Thus, with a monopoly in the downstream industry the optimal royalty rate in a signaling context



**Fig. 1.** Optimal per-unit output royalty in the  $\{\gamma, c\}$ -space when licensees' costs are signaled and when not

From the analysis above it is clear that in the region of parameters  $(\gamma, c)$  where signaling causes an infra-royalty, such infra-royalty increases as the probability that licensees become low-cost firms decreases and/or the efficiency gap between licensees decreases. Likewise, the over-royalty derived from signaling with respect to the no-signaling scenario—in the  $(\gamma, c)$ -space of parameters where it holds—increases as the probability that licensees become low-cost firms approaches to 1 but decreases as the efficiency gap between licensees increases. The following numerical example illustrates the result.

$\tilde{c}^i, i=A,B$	$\text{Prob}(\tilde{c}^i=0), i=A,B$	$r_1^{iS}$	$r_2^{iP}$	$r_{2H}^i$	$r_{2L}^i$
{0, .1}	.1	.425	.455	.450	.5
	.5	.457	.475	.450	.5
	.9	.497	.495	.450	.5
{0, .25}	.1	.371	.387	.375	.5
	.5	.428	.437	.375	.5
	.9	.495	.487	.375	.5
{0, .3}	.1	.355	.365	.350	.5
	.5	.425	.425	.350	.5
	.9	.485	.485	.350	.5

**Table 1.** A numerical example

is never greater than in a no-signaling context. Comparing this result with that reached when a duopoly exists enables us to conclude that the structure of the downstream industry is not innocuous to characterize the optimal unit royalty in the presence of the informational structure considered.

From Proposition 3 unambiguous results are obtained with respect to the effects on market performance, on consumer surplus and on licensing income of the patent holder coming from the existence of signaling in the product market. These are recorded in the following corollary.

**Corollary 1.** *Compared to the no-signaling context, the presence of signaling in the downstream industry implies,*

(i) *when parameters  $c$  and  $\gamma$  satisfy the condition  $c < 1/(3+\gamma)$ ,*

(i.1) *An increase on expected output in period 1.*

(i.2) *A decrease on expected price in period 1.*

(i.3) *An increase on expected income of period 1 for the patent holder.*

(i.4) *An increase on expected social welfare in period 1.*

(ii) *When parameters  $c$  and  $\gamma$  satisfy  $c \geq 1/(3+\gamma)$ ,*

(ii.1) *The same expected output in period 1.*

(ii.2) *The same expected prices during period 1.*

(ii.3) *The same expected licensing income earned by the patent holder at  $t=1$ .*

(ii.4) *The same expected social welfare in period 1.*

Consumers are better off with signaling, because  $q_{1H}^{iS} < q_{2H}^{iP}$  and  $q_{1L}^{iS} > q_{2L}^{iP}$ ,  $i=A,B$ , and the result of part (i.1) follows. The intuition of this conclusion is quite simple. Given that each licensee of low-cost type has an incentive to disclose as a high-cost firm, for a high-cost licensee to convince both the competitor and the upstream patent holder that it is in fact high-cost it must distort, when  $c$  is low enough, its production level below the level that would maximize its profits in the absence of signaling. And, as a consequence, the best the low-cost licensee can do is to choose an output level above the level that would maximize its profits if signaling were absent. Both productive distortions disappear when parameter  $c$  is sufficiently

high, in which case  $q_{1H}^{iS} = q_{2H}^{iP}$  and  $q_{1L}^{iS} = q_{2L}^{iP}$  and the result of part (ii.1) is reached. The rest of the conclusions follow straightforwardly.

## 6. Extensions

### 6.1 The case of a high efficiency gap

In this subsection we consider the case in which the efficiency gap between the two downstream licensees is high enough, in the sense that parameter  $c$  satisfies  $1/3 \leq c < 1$ , for which a high-cost firm does not always produce when competing with an efficient rival. Clearly, the incentive for each low-cost licensee to misrepresent itself as a high-cost firm is now higher than when  $0 < c < 1/3$ . Hence, in order for the high-cost licensees to separate themselves from low-cost firms, the distortion of their output must be higher than before. This implies a reduction on royalty rates. However, the separation of the high-cost firms from low-cost firms is easier due to the increased efficiency gap between them. This leads the patent holder to increase the unit royalty.

To obtain clear-cut results in the range of values of parameter  $c$  we are interested in, two intervals must be considered separately. One is  $c \in [\frac{1}{3}, \frac{1}{2})$  in which the result of Proposition 3 applies because though the incentive compatibility condition of each high-cost firm for a separating equilibrium differs from the self-selection constraint given in (A6),<sup>19</sup> the incentive compatibility condition of each low-cost licensee is the same as (A7).<sup>20</sup> The other interval of parameter  $c$  to be considered is the one defined by  $c \in [\frac{1}{2}, 1)$  in which both incentive compatibility conditions for a separating equilibrium are changed regarding (A6) and (A7). The separating equilibrium involves the output levels produced in period 1 that equal the profit-maximizing outputs in the one-shot game of period 1. Summing up, there are no productive distortions in period 1, which leads to the result summarized in the following proposition.

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<sup>19</sup> See the Appendix.

<sup>20</sup> See the Appendix.

**Proposition 4.** *When  $1/3 \leq c < 1$ , the optimal per-unit output royalties chosen by the patent holder in a signaling environment equal those in a no-signaling context. Namely,  $r_1^{iS} = r_2^{iP}$ ,  $i=A,B$ .*

**Proof.** See the Appendix.

## 6.2 Simultaneous signaling by prices

Here, we are interested in examining the case in which downstream licensees sell differentiated goods and compete between them by quoting prices rather than quantities. In this case, each low-cost firm has an incentive to misrepresent itself as a high-cost firm (by quoting a high price level in period 1) facing both the competitor and the upstream patent holder. The reason is as follows. If it is thought to be high-cost by the patent holder and the rival firm, then it not only carries a smaller per-unit output royalty in period 2, but it also softens competition in such period since the rival firm charges a higher price for its product. Such incentive is even higher than in the case of Cournot competition; therefore for a high-cost licensee to convince both the rival firm and the patent holder that it is in fact of high-cost type, it needs to distort the price level of its product in period 1 above the level that would maximize its profit in a no-signaling scenario.

When setting the optimal per-unit output royalty for period 1, the patent holder takes into account that two forces interplay. One refers to the existence of any royalty rate in period 1 that increases firms' marginal costs and makes the upward price distortions of any high-cost licensee less costly. So, the signal is less informative and an even bigger upward price distortion by part of a high-cost licensee is needed to convince both the rival firm and the patent holder that it is in fact of high-cost type. This strategic-signaling effect leads the patent holder to reduce the period 1 per-unit output royalty below the level it would adopt with no signaling.

The second effect to be considered by the patent holder is a direct-signaling effect, which works as follows. Signaling commits licensees to a greater expected level of price in period 1,

because prices are strategic complements by which both the high-cost and the low-cost of each licensee increase the price of its good. So, a smaller period 1 per-unit output royalty is necessary to increase the expected output and thus the expected licensing income. It then allows the patent holder to decrease the optimal period 1 per-unit royalty as compared with the level it would take in the absence of signaling. Summing up, both signaling effects are unambiguously reinforced, which enables us to establish the following proposition.

**Proposition 5.** *When downstream firms produce differentiated goods and compete in Bertrand fashion, the per-unit output royalties chosen by the upstream patent holder are such that*

$$r_1^{iS} < r_2^{iP}, i=A,B.$$

That is, to reduce the incentive of low-cost licensees to misrepresent themselves as high-cost firms (by making it costlier to establish a high price) the upstream patent holder sets a period 1 per-unit output royalty significantly lower when firms' prices of period 1 are a signal of their production costs than it would be if firms' prices of period 1 were not a signal of their costs.

## 7. Concluding remarks

This paper presents a model of technology licensing by royalty contracts that integrates two important features largely unexplored in the licensing literature: the presence of private information on the part of buyers of technology and the possibility of revealing it along time. Both of them are important since (i) they bring together two strands of recent literature on industrial organization, the regulation literature and the cost signaling literature, and (ii) they turn out to have a systematic effect on the optimal royalty contract chosen by the patent holder. We have shown that if licensees produce a homogeneous good, play a Cournot game and simultaneously signal their costs via their output choices of period 1, then low-cost licensees

have an incentive to misrepresent themselves as high-cost firms. This is because if they are considered such firms, they bear a lower per-unit output royalty in period 2 though the rival firm chooses a greater output in such a period. In addition, the signaling process commits licensees to produce a lower expected output in period 1 than they would produce if signaling were absent. As a result of this trade-off, we found that the first-period optimal per-unit output royalty asked by the patent holder to each licensee is lower (higher) than the level it would take with no signaling when the probability of potential licensees being low-cost firms is small or moderate (sufficiently high).

Thus, the paper suggests the importance of considering the signaling process of licensees on the characterization of licensing royalty contracts, since it may significantly modify the amount of the optimal per-unit output royalties with respect to the context in which licensees' outputs do not signal their costs.

When instead of output levels, prices signal the licensees' costs, licensees of low-cost type have an incentive to misrepresent themselves as being of high-cost type. This is because if they are considered high-cost firms, they not only bear a lower royalty rate in period 2, but also induce the rival firms to set a high price in such a period. Both this strategic-signaling effect and the direct-signaling effect result in a per-unit output royalty unambiguously lower in the signaling context than the level it would adopt in the no-signaling one. Therefore, the rationale behind relatively high (respectively, low) per-unit output royalties in a downstream Bertrand environment could rely on the idea that licensees compete in a setting in which prices do not signal (signal) their costs.

Our analysis has been restricted to linear demand and cost functions. A general analysis involves a great deal more computational difficulty. We have also restricted the patent holder to employing royalty contracts to license the innovation. Other alternatives such as the use of a combination of a fee and a royalty, an auction or even more sophisticated forms such as nonlinear royalties would merit further investigation.

## Appendix

### *Proof of Lemma 1*

If licensee  $i$  is of low-cost type, but both licensee  $j$  ( $j \neq i$ ) and the licensor believe that it is a high-cost firm, while it is common knowledge that licensee  $j$  is of low-cost type, then period 2 licensee  $i$ 's profits equal

$$\begin{aligned}\Pi_2^i(0|c,0) &= \left(\frac{1+c}{6}\right)^2 \\ &= \left(\Pi_2^i(0,0) + \frac{c}{6}\right)^2.\end{aligned}\tag{A1}$$

Similarly,

$$\begin{aligned}\Pi_2^i(0|c,c) &= \left(\frac{1+2c}{6}\right)^2 \\ &= \left(\Pi_2^i(0,c) + \frac{c}{6}\right)^2,\end{aligned}\tag{A2}$$

$$\begin{aligned}\Pi_2^i(c|0,0) &= \left(\frac{1-3c}{6}\right)^2 \\ &= \left(\Pi_2^i(c,0) - \frac{c}{6}\right)^2,\end{aligned}\tag{A3}$$

and

$$\begin{aligned}\Pi_2^i(c|0,c) &= \left(\frac{1-2c}{6}\right)^2 \\ &= \left(\Pi_2^i(c,c) - \frac{c}{6}\right)^2.\end{aligned}\tag{A4}$$

Hence, the result claimed in the lemma follows straightforwardly from (A1)-(A4).  $\square$



*Proof of Lemma 2*

Under conditions of symmetry between firms, the self-selection constraints (16)-(18) for a separating sequential equilibrium may be rewritten, respectively, as

$$q_{1L}^i \equiv f(q_{1H}^j) = \frac{1-r_1^i - (1-\gamma)q_{1H}^j}{2+\gamma}, \quad i,j=A,B; i \neq j, \quad (\text{A5})$$

$$\begin{aligned} & \gamma \left(1-c-r_1^i - q_{1H}^i - f(q_{1H}^i)\right) q_{1H}^i + (1-\gamma) \left(1-c-r_1^i - q_{1H}^i - q_{1H}^i\right) q_{1H}^i \\ & + \gamma \left(\frac{1-2c}{6}\right)^2 + (1-\gamma) \left(\frac{1-c}{6}\right)^2 \\ & \geq \gamma \left(1-c-r_1^i - h(q_{1H}^i) - f(q_{1H}^i)\right) h(q_{1H}^i) + (1-\gamma) \left(1-c-r_1^i - h(q_{1H}^i) - q_{1H}^i\right) h(q_{1H}^i) \\ & + \gamma \left(\frac{1-3c}{6}\right)^2 + (1-\gamma) \left(\frac{1-2c}{6}\right)^2 \end{aligned} \quad (\text{A6})$$

and

$$\begin{aligned} & \gamma \left(1-r_1^i - f(q_{1H}^i) - f(q_{1H}^i)\right) f(q_{1H}^i) + (1-\gamma) \left(1-r_1^i - f(q_{1H}^i) - q_{1H}^i\right) f(q_{1H}^i) \\ & + \gamma \left(\frac{1}{6}\right)^2 + (1-\gamma) \left(\frac{1+c}{6}\right)^2 \\ & \geq \gamma \left(1-r_1^i - q_{1H}^i - f(q_{1H}^i)\right) q_{1H}^i + (1-\gamma) \left(1-r_1^i - q_{1H}^i - q_{1H}^i\right) q_{1H}^i \\ & + \gamma \left(\frac{1+c}{6}\right)^2 + (1-\gamma) \left(\frac{1+2c}{6}\right)^2, \end{aligned} \quad (\text{A7})$$

where  $q_{1L}^i \equiv f(q_{1H}^j)$  denotes the best reply of each low-cost licensee  $i$  competing with a rival  $j$ ,  $j \neq i$ , that produces output  $q_{1L}^j \equiv f(q_{1H}^i)$  with probability  $\gamma$  and output  $q_{1H}^j$  with probability

$1-\gamma$  , while  $q_{1H}^i \equiv h(q_{1H}^j) = \frac{2(1-c) - \gamma c - 2r_1 - 2(1-\gamma)q_{1H}^j}{2(2+\gamma)}$  is the best reply of a high-cost

licensee  $i$  competing with a rival  $j$  that produces output  $q_{1L}^j \equiv f(q_{1H}^i)$  with probability  $\gamma$  and output  $q_{1H}^j$  with probability  $1-\gamma$  . Tedious algebraic manipulation of conditions (A6) and (A7)

yields the continuum of separating sequential equilibria given by  $q_{1H}^i \in [r^-, s^-]$ , where

$$r^- = \frac{2(1-c - r_1^i) - \gamma c}{2(4-\gamma)} - \frac{\sqrt{(4-\gamma)(2+\gamma)((1-c)^2 - (2-3c)\gamma c) + 9(\gamma c - 2(1-c - r_1^i))^2}}{6(4-\gamma)} \quad (\text{A8})$$

is the lowest root of the second-degree equation formed from the condition (A6) taken as equality and

$$s^- = \frac{1 - r_1^i}{3} - \frac{(2+\gamma)\sqrt{((3-2\gamma)c + 2)c}}{18} \quad (\text{A9})$$

is the lowest root of the second-degree equation formed from the condition (A7) also taken as equality. From here, it is straightforward to show that a continuum of separating equilibria in outputs exists, since interval  $[r^-, s^-]$  is non-degenerated in the sense that  $r^- < s^-$ . In order to reduce this continuum of separating equilibria it is necessary to invoke restrictions on beliefs. Here, the weak dominance criterion is sufficient to yield a unique outcome. In fact, one can prove that separating equilibria in output levels  $q_{1H}^i < s^-$  does not satisfy weak dominance criterion. To see why, let  $q_{1H}^i < s^-$  be a given output of equilibrium and consider an out-of-equilibrium message such as  $s^- - \varepsilon$  ,  $\forall \varepsilon > 0$ . Clearly, the low-cost type of each licensee should not have incentives to send this signal since it is a strategy that is dominated by  $q_{1L}^i$  (both the rival and the patent holder should use the beliefs  $\gamma(s^- - \varepsilon) = 0$ ). Likewise, the high-cost type of each licensee need not produce an output  $q_{1H}^i < s^-$  to distinguish itself from the low-cost type. The

separating equilibrium of minimum cost is thus the one in which high-cost licensees produce at a level just high enough to distinguish themselves from low-cost licensees,  $q_{1H}^i = s^-$ , in which the self-selection constraint (A7) is binding. So, the low-cost licensees produce in accordance with their best response given in (A5). In addition, it is easy to check that output level  $q_{1H}^{iII} = \frac{2(1-c-r_1^i)-\gamma c}{6}$  satisfies  $q_{1H}^{iII} \leq s^-$  whenever the efficiency gap of the technology is high enough (as stated in part (ii) of the lemma), in which case the output levels that maximize profits in the incomplete information period, namely outputs  $q_{1H}^{iII}$  and  $q_{1L}^{iII}$ , are part of the separating sequential equilibrium that also verifies the intuitive criterion. This completes the proof of the lemma.  $\square$

*Proof of Proposition 1*

Given the absence of discrimination in royalty rates, the patent holder solves the problem

$$\begin{aligned} \text{Max}_{r_1} \left\{ 2\gamma r_1 \left( \frac{(2+\gamma)(1-r_1)}{3} + \frac{(2+\gamma)(1-\gamma)\sqrt{((3-2\gamma)c+2)c}}{18} \right) \right. \\ \left. + 2(1-\gamma)r_1 \left( \frac{1-r_1}{3} - \frac{(2+\gamma)\sqrt{((3-2\gamma)c+2)c}}{18} \right) \right\}, \quad (\text{A10}) \end{aligned}$$

when parameters  $c$  and  $\gamma$  satisfy the condition  $c < 1/(3+\gamma)$  or the problem

$$\text{Max}_{r_1} \left\{ 2\gamma r_1 \left( \frac{1-r_1}{3} + \frac{(1-\gamma)c}{6} \right) + 2(1-\gamma)r_1 \left( \frac{1-r_1}{3} - \frac{(2+\gamma)c}{6} \right) \right\}, \quad (\text{A11})$$

when parameters  $c$  and  $\gamma$  satisfy the condition  $c \geq 1/(3+\gamma)$ . The first-order condition of (A10),

$$2\gamma \left( \frac{(2+\gamma)(1-2r_1)}{3} + \frac{(2+\gamma)(1-\gamma)\sqrt{((3-2\gamma)c+2)c}}{18} \right)$$

$$+ 2(1-\gamma) \left( \frac{1-2r_1}{3} + \frac{(2+\gamma)\sqrt{((3-2\gamma)c+2)c}}{18} \right) = 0, \quad (\text{A12})$$

enables us to obtain the result of part (i) of the proposition, while the first-order condition of (A11),

$$2\gamma \left( \frac{1-2r_1}{3} + \frac{(1-\gamma)c}{6} \right) + 2(1-\gamma) \left( \frac{1-2r_1}{3} + \frac{(2+\gamma)c}{6} \right) = 0, \quad (\text{A13})$$

affords the result claimed in part (ii).  $\square$

#### *Proof of Proposition 2*

Given the optimal outputs in a no-signaling scenario derived in (27)-(28), the problem of the patent holder defined in (29) has the first-order condition

$$2\gamma \left( \frac{2+(1-\gamma)c-6r_2^i}{6} \right) + 2(1-\gamma) \left( \frac{2(1-c)-\gamma c-6r_2^i}{6} \right) = 0, \quad i=A,B, \quad (\text{A13})$$

which yields the result claimed in the proposition.  $\square$

#### *Proof of Proposition 4*

Using the same notation as in Lemma 1, we have

$$\Pi_2^i(0, c) = \begin{cases} \left(\frac{1+c}{6}\right)^2, & \text{if } \frac{1}{3} \leq c < \frac{1}{2} \\ \left(\frac{1}{4}\right)^2, & \text{if } c \geq \frac{1}{2}, \end{cases} \quad (\text{A14})$$

$$\Pi_2^i(c,0) = \begin{cases} \left(\frac{1-2c}{6}\right)^2, & \text{if } \frac{1}{3} \leq c < \frac{1}{2} \\ 0, & \text{if } c \geq \frac{1}{2}, \end{cases} \quad (\text{A15})$$

$$\Pi_2^i(c|0,0) = 0 \quad (\text{A16})$$

and

$$\Pi_2^i(c|0,c) = \begin{cases} \left(\frac{1-2c}{6}\right)^2 = \left(\Pi_2^i(c,c) - \frac{c}{6}\right)^2, & \text{if } \frac{1}{3} \leq c < \frac{1}{2} \\ 0, & \text{if } c \geq \frac{1}{2}. \end{cases} \quad (\text{A17})$$

The expression of the maximized profits in the rest of the cases has the same form as when  $0 < c < 1/3$ . We need to analyze separately two regions of parameter  $c$ :

- Region  $1/3 \leq c < 1/2$ . For these values of parameter  $c$  the separating equilibrium of minimum cost involves the same outputs of period 1 as when  $0 < c < 1/3$ , because constraint (A7) remains unchanged. However, it is easy to check that the lowest root of (A7) given by  $s^-$  (see A9) and output of a high-cost firm that maximizes its profit in the one-shot game,  $q_{1H}^{iH} = \frac{2(1-c) - (2+\gamma)c}{6}$ , verify

$$\frac{1-r_1^i}{3} - \frac{(2+\gamma)\sqrt{c(2+c(3-2\gamma))}}{18} > \frac{2-(2+\gamma)c-2r_1^i}{6} \quad (\text{A18})$$

for all  $(\gamma, c)$  such that  $\gamma \in (0,1)$  and  $1/3 \leq c < 1/2$ . So, in this region it follows that  $r_1^{iS} = r_2^{iP}$ ,  $i=A,B$ .

- Region  $1/2 \leq c < 1$ . In this case the self-selection restrictions (A6) and (A7) become, respectively,

$$\gamma(1-c-r_1^i - q_{1H}^i - f(q_{1H}^i))q_{1H}^i + (1-\gamma)(1-c-r_1^i - q_{1H}^i - q_{1H}^i)q_{1H}^i + (1-\gamma)\left(\frac{1-c}{6}\right)^2$$

$$\geq \gamma \left(1 - c - r_1^i - h(q_{1H}^i) - f(q_{1H}^i)\right) h(q_{1H}^i) + (1 - \gamma) \left(1 - c - r_1^i - h(q_{1H}^i) - q_{1H}^i\right) h(q_{1H}^i) \quad (\text{A6a})$$

and

$$\begin{aligned} & \gamma \left(1 - r_1^i - f(q_{1H}^i) - f(q_{1H}^i)\right) f(q_{1H}^i) + (1 - \gamma) \left(1 - r_1^i - f(q_{1H}^i) - q_{1H}^i\right) f(q_{1H}^i) + \gamma \left(\frac{1}{6}\right)^2 + (1 - \gamma) \left(\frac{1}{4}\right)^2 \\ & \geq \gamma \left(1 - r_1^i - q_{1H}^i - f(q_{1H}^i)\right) q_{1H}^i + (1 - \gamma) \left(1 - r_1^i - q_{1H}^i - q_{1H}^i\right) q_{1H}^i + \gamma \left(\frac{1+c}{6}\right)^2 + (1 - \gamma) \left(\frac{1+2c}{6}\right)^2. \end{aligned} \quad (\text{A7a})$$

The roots of the second-degree equation formed by taking (A6a) as equality are

$$q_{1H}^i = \frac{2 - (2 + \gamma)c - 2r_1^i}{2(4 - \gamma)} \pm \frac{\sqrt{(1 - c)^2(4 - \gamma)(2 - \gamma - \gamma^2) + 9(-2 + 2c + c\gamma + 2r_1^i)^2}}{6(4 - \gamma)} \quad (\text{A19})$$

and those of the second-degree equation formed by taking (A7a) also with equality are

$$q_{1H}^i = \frac{1 - r_1^i}{3} \pm \frac{(2 + \gamma)\sqrt{4c(4 + 4c - 2\gamma - 3\gamma c) - 5(1 - \gamma)}}{36}. \quad (\text{A20})$$

Finally, from (A20) it is not difficult to verify that

$$\frac{1 - r_1^i}{3} - \frac{(2 + \gamma)\sqrt{4c(4 + 4c - 2\gamma - 3\gamma c) - 5(1 - \gamma)}}{36} > \frac{2 - (2 + \gamma)c - 2r_1^i}{6} \quad (\text{A21})$$

in the region of parameters  $(\gamma, c)$  where  $\gamma \in (0, 1)$  and  $1/2 \leq c < 1$ . Hence, it follows that  $q_{1H}^{iS} = q_{1H}^{iII}$

and, consequently,  $q_{1L}^{iS} = q_{1L}^{iIII}$ . That is, the separating equilibrium of minimum cost is now formed by outputs of period 1 that are the maximizing-profit outputs in the one-shot incomplete

information game of period 1 (the so-called TSE). So, we conclude that  $r_1^{iS} = r_2^{iP}$ ,  $i=A,B$ , and the result of the proposition follows.  $\square$

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