Technology Transfer and Entry Deterrence*

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Abstract

We study how an incumbent patent holder can use its licensing policy strategically to reduce the threat of further entry. The patent holder can license its technology to another incumbent firm via a low royalty. This licensing strategy makes the terms of future licensing agreements less favorable to potential entrants, who find entry unprofitable. Our result challenges the conventional wisdom that high royalties are anti-competitive because they raise marginal costs and prices. Specifically, we show that a higher rate of royalty may be accompanied by a more competitive industry structure and may actually lead to lower prices. Within this context, we investigate the incentives of the incumbent firms–patent holder and licensee–to invest in R&D and we show that R&D is the strongest precisely when firms can use the licensing contract to deter entry.

Keywords: Technology transfer, entry deterrence

JEL Classification Codes: L13, L24.

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1 Introduction

Entry deterrence has remained one of the most important issues in oligopoly theory. It is generally perceived that by deterring prospective entrants in a market, an incumbent firm restricts competition and sustains a high price. In his seminal paper, Dixit (1980) argues that entry deterrence entails further inefficiencies as an incumbent firm may have to incur wasteful expenditure to build an "excess capacity" in order to block entry. In this paper we show that the efficiency implications of entry deterrence may well be completely opposite. Specifically, it is shown that if an incumbent firm in an oligopoly holds a superior technology that it can transfer to other incumbent firms as well as potential entrants, then to effectively deter entry it must design technology transfer contracts that make its incumbent rivals more efficient. Situations could then arise where the negative effect of a more concentrated market structure is offset by the enhanced efficiency of incumbent firms. As a consequence, entry deterrence may result in lower rather than higher prices in the market.

We carry out our analysis in an oligopoly model where there are two incumbent firms 0 and 1, and a potential entrant, firm 2, who faces a positive cost of entry. Under the existing technology, all firms operate under the same constant unit cost of production. Firm 0 has a patent on a superior technology that lowers this unit cost. Firm 0 can transfer the new technology to firm 1 through licensing. If firm 2 enters the market, 0 can license the technology to 2 as well. We consider licensing contracts that are combinations of fixed upfront fees and linear unit royalties. A royalty distorts the effect of the new technology and raises the unit cost of a licensee. Absent any threat of entry, firm 0's primary objective is to create an inefficient incumbent rival. This is achieved by setting the rate of royalty at its maximum possible level so that firm 1's effective unit cost stays the same as with the existing technology (Shapiro, 1985; Wang, 1998). The threat of entry presents a trade-off for firm 0, as increasing the royalty paid by 1 makes it more likely for firm 2 to enter the market. The threat of entry induces firm 0 to lower the royalty of firm 1 from its maximum down to the point where it is just low enough to achieve entry deterrence (Proposition 1(III)). Thus, on the one hand entry deterrence results in a less competitive market structure in the form of a duopoly rather than a triopoly, but on the other, it yields a lower royalty and hence increased efficiency of the incumbent licensee. Whether entry deterrence leads to higher or lower prices depends on which one of these conflicting factors dominates (Proposition 2).

Deterrence of entry restricts competition and a high rate royalty creates inefficiency. When seen in isolation, each of these two factors is perceived to be anticompetitive. Our results show that looking at these two factors in isolation may often be misleading. As a lower rate of royalty can be used by incumbent firms to achieve entry deterrence, two qualitative conclusions emerge from our analysis: (i) entry deterrence may not necessarily result in higher prices and (ii) a lower royalty may not necessarily result in lower prices.

Our analysis also suggests a strategic explanation for the low royalty rates that are observed in the real world.[1] At first glance, a low royalty benefits consumers, but by blocking entry, this low royalty reduces competition, and therefore has a positive impact on the price. As we show, the overall impact on price may be positive (for intermediate values of the entry cost), so low royalties may very well be anti-competitive. Within this context, we investigate the incentives of the incumbent firms to invest in R&D through a patent race. While it is true that licensing increases the returns to winning the patent, it also increases the value of losing a patent race, as the loser will become the licensee. Therefore licensing does not necessarily encourage innovation. We show that R&D incentives follow a non-monotonic pattern (inverted U-shape) with respect to the cost of entry, where incentives to innovate are the strongest precisely when firms can use the licensing contract to deter entry (Proposition 3).

These results challenge the conventional opinion of antitrust authorities that only high royalties are anti-competitive, or at least a necessary evil.[2] On the one hand, high royalties are necessary to the transfer of new technologies among firms and to ensure proper incentives for innovation. But on the other hand, they raise marginal costs and consumer prices, leading to lower output and consumer welfare. As we show, this view is incomplete in the presence of a threat of entry: low royalties can be anti-competitive and increase the market price, but they are a necessary evil to maximize incentives to innovate. This introduces a new element that public policy should take into consideration.

When we focus on the parameter region where the incumbent patent holder effectively deters entry, we show that licensing to the incumbent firm is anti-competitive. Indeed, the market price would be lower in the absence of a license between the patent holder and the existing competitor. We also consider the impact of the entry deterrence strategy on consumer welfare. We show that entry deterrence can benefit consumers when the cost of entry is relatively low. However, when it is relatively high, a policy that would remove the patent holder's ability to deter entry would lead

[1] Farrell and Gallini (1988) provide evidence for the existence of low royalty rates (only 3-5% of sales) in some industries. This is corroborated by Rockett (1990). In the U.S., the current average royalty rate is 7% across industries (source: RoyaltySource's annual publication in the Licensing Economics Review).

[2] See the FTC (2003) report on "To Promote Innovation: The Proper Balance of Competition and Patent Law and Policy".

to a lower market price and would make consumers better off.

1.1 Literature review

We contribute to three strands of literature: (i) articles on licensing and entry deterrence, (ii) theoretical articles on patent licensing and (iii) the impact of the threat of entry on innovation.

Licensing and entry deterrence. Our paper is closely related to the literature on the strategic use of licensing to (partially) deter entry. In Gallini (1984), the incumbent is faced with a single potential entrant which may discover a superior substitute technology by investing in costly R&D. She shows that the incumbent firm may want to license its current technology to the potential entrant to discourage it from continuing to search for an even better technology.[3] In Rockett (1990), licensing is used to crowd the market with weak competitors and keep the strong competitor out. A patent holder faces two potential entrants, a "strong" one and a "weak" one, in a two-period model (before and after the patent expires). Absent licensing in the first period, the strong firm enters first and the weak firm stays out. However, the innovator can grant a license to the weak firm in the first period, in order to allow it to enter first in the second period (by reducing its entry cost), and keep the strong firm out.[4] Rockett (1990) argues that the threat of entry could come from patent invalidation in court instead of its natural expiration. She suggests the innovator could crowd the market with low royalty licensing contracts, to discourage firms from infringing and avoid the risk of losing a suit.[5] However this is just an intuition and the royalty rate is exogenous, as opposed to our model where we endogenize it. Moreover, in her model, potential competitors have different strengths, and licensing influences their order of entry, while in our model they are identical: one of them is already an incumbent and licensing influences the entrant's decision. Finally, in Rocket (1990) there is no welfare analysis of such licensing contracts, while we show why they may be anti-competitive. Maurer and Scotchmer (2002) also show how licensing can be used to choose competitors. In a model with an unlimited number of potential licensees and imitators, where entrants can bear a cost to duplicate technology (and avoid paying the license), they show that the patent holder has an incentive to license potential competitors and therefore share the market,

[3] This argument that licensing to a competitor may be a way to avoid a patent race and thereby to limit the risk of being replaced if the competitor innovates is also found in Gallini and Winter (1985).

[4] Eswaran (1994) generalized her result to show that an incumbent in a market threatened by entry can exploit its first-mover advantage by licensing its technology not to a potential entrant but to firms that otherwise would have remained outside the industry.

[5] A similar argument is found in Choi (1998), where the innovator chooses not to sue for infringement, in order not to risk allowing potential entrants to enter the market.

in order to avoid entry by an independent inventor (an "imitator"). In our paper we also show that the threat of entry can potentially reduce the market price, however it is through a different channel: the price does not decrease because the patent holder licenses to as many competitors as possible, but because he lowers the royalty paid by the licensee in order to make him more efficient than a potential entrant. Most importantly, the impact on consumers is not always positive, since this strategy potentially blocks further entry. Finally, Duchêne and Serfes (forthcoming) show that high fixed fees in patent settlement agreements can block entry by sending a credible signal to outsiders that the patent is not weak.

Patent licensing. The theoretical literature on patent licensing has focused mainly on comparing fixed fees and royalties as instruments for the licensing of patented cost-reducing innovations. When the innovator is not a producer within the industry (external innovator), licensing a non-drastic innovation by means of a royalty is dominated by other modes of licensing (fixed fee or an auction) both in terms of the patent holder's payoffs and consumer surplus. Much of this literature was reviewed in Kamien et al. (1992).[6] This result is reversed and the optimal licensing contract always includes a positive royalty when the innovation is relatively significant (Sen and Tauman (2007)), or when the patent holder is itself a producer within the industry.[7] Setting a positive royalty in the contract allows the patentee to control the licensees marginal costs, still enjoying a cost advantage over rivals and making them less aggressive in the market. We show that the threat of further entry modifies the optimal licensing contract, and can make licensing welfare reducing.

Threat of entry and innovation. Finally, there is a growing literature on the impact of the threat of entry on firms' incentives to innovate. Aghion et al. (2005) present evidence on an inverted-U relationship between product market competition and innovative activity and find this to be steeper in neck-and-neck industries.[8] In this paper, we also show a non monotonic relationship between incentives to innovate and the cost of entry.

The paper is organized as follows. Section 2 presents the model. Section 3 derives the optimal licensing contract and entry decisions. Section 4 analyzes the patent race between the two incumbent firms. We conclude in Section 5. Proofs are in the Appendix.

[6] See Shapiro (1985), Kamien and Tauman (1986), Katz and Shapiro (1986), Gallini and Wright (1990).

[7] See Wang (1998), Wang and Yang (1999), Kamien and Tauman (2000), Faulí-Oller and Sandonís (2002)).

[8] See also Aghion et al. (2009), where the effect of entry on (incumbent) innovation and productivity is considered a function of distance from the technological frontier (as measured by a labor productivity index relating incumbent industries to their US equivalent).

2 The model

Consider a market for a homogeneous good η that is served by two incumbent firms: 0 and 1. There is a potential entrant in this market, firm 2. This market is a Cournot oligopoly, that is, firms compete in quantities.[9] Let p be the market price and Q the total industry output. The inverse market demand is

$$p = a - Q \text{ if } Q < a \text{ and } p = 0 \text{ if } Q \geq a \text{ where } a > 0. \tag{1}$$

Initially, all firms in the market (0, 1 and potentially 2), have the same constant unit cost $c > 0$. Firm 0 has a patent on a cost-reducing technological innovation that reduces the cost from c to 0. Firm 0 can license its patent to firm 1. Firm 2 can enter the industry incurring the fixed cost of entry $\underline{\phi}$. If it does, firm 0 can also license to firm 2. In order to focus on situations where firm 0 has an incentive to license its patent, we assume that the innovation is non-drastic: $c < a/2$.[10]

The set of licensing policies available to firm 0 is the set of all combinations of an upfront fixed fee and a per unit linear royalty. For $i = 1, 2$, a typical policy offered by firm 0 to firm i is (r_i, f_i) where $r_i \geq 0$ is the royalty that firm i pays for each unit of output that it sells and $f_i \geq 0$ is the upfront fee that firm i pays to firm 0.[11]

Observe that if firm i accepts a licensing policy with royalty r_i, its *effective marginal cost* becomes $0 + r_i = r_i$. If firm i does not have a license, it operates under marginal cost c. So, no firm will accept a policy with $r_i > c$ and we can restrict $r_i \in [0, c]$. Accordingly, one of the following Cournot oligopoly games is played in the market η under inverse demand (1) for $r_1, r_2 \in [0, c]$:

(i) If firm 2 does not enter the industry, the market η is a Cournot duopoly with firms 0 and 1. Denote by $\mathbb{C}^D(r_1)$ the Cournot duopoly game with firms 0 and 1 where firm 0 has cost zero and firm 1 has cost r_1.

[9] We consider homogenous Cournot competition, but as we explain at the end of section 3, the insights we derive are general enough and they do not hinge on that special type of competition. However, the Cournot model allows us to compare profits across the different subgames and to derive clean characterizations.

[10] The innovation is *drastic* (Arrow, 1962) if the monopoly price under zero cost, given by $p_M \equiv a/2$, does not exceed the old cost c, that is, if $c \geq a/2$. If firm 0 has a drastic innovation, it becomes a monopolist and it has no incentive to license the patent.

[11] Existing empirical evidence reveals that most of the licensing contracts observed in practice include a positive royalty. Rostocker (1984), for example, finds that royalty alone is used 39% of the time, fixed fee alone 13%, and both instruments together 46%. Taylor and Silberston (1973), and Macho-Stadler et al. (1996) report similar percentages.

(ii) If firm 2 enters the industry, the market η is a Cournot triopoly with firms 0, 1 and 2. Denote by $\mathbb{C}^T(r_1, r_2)$ the Cournot triopoly game with firms 0, 1 and 2 where firm 0 has cost zero, firm 1 has cost r_1 and firm 2 has cost r_2.

Lemma 1 characterizes Nash Equilibrium (NE) for the games $\mathbb{C}^D(r_1)$ and $\mathbb{C}^T(r_1, r_2)$. The proof is standard and hence omitted.

Lemma 1. *Let $c \in (0, a/2)$ and $r_1, r_2 \in [0, c]$. Under the inverse demand (1), both $\mathbb{C}^D(r_1)$ and $\mathbb{C}^T(r_1, r_2)$ have a unique NE. Let $q_i^D(r_1)$ and $\phi_i^D(r_1)$ be the NE output and profit of firm i in $\mathbb{C}^D(r_1)$. Let $q_i^T(r_1, r_2)$ and $\phi_i^T(r_1, r_2)$ be the corresponding expressions for $\mathbb{C}^T(r_1, r_2)$. Let $p^D(r_1)$ and $p^T(r_1, r_2)$ be the corresponding NE prices. Then $\phi_i^D(r_1) = \left[q_i^D(r_1)\right]^2$, $\phi_i^T(r_1, r_2) = \left[q_i^T(r_1, r_2)\right]^2$ and the following hold.*

(i) *For the Cournot duopoly $\mathbb{C}^D(r_1)$: $q_0^D = (a+r_1)/3$, $q_1^D = (a-2r_1)/3$ and $p^D(r_1) = (a+r_1)/3$.*

(ii) *For the Cournot triopoly $\mathbb{C}^T(r_1, r_2)$:*

(a) *If $r_2 \leq 3r_1 - a$, then $q_0^T = (a+r_2)/3$, $q_1^T = 0$, $q_2^T = (a-2r_2)/3$ and $p^T(r_1, r_2) = p^D(r_2) = (a+r_2)/3 \leq c$.*

(b) *If $3r_1 - a \leq r_2 \leq (a+r_1)/3$, then $q_0^T = (a+r_1+r_2)/4$, $q_1^T = (a-3r_1+r_2)/4$, $q_2^T = (a+r_1-3r_2)/4$ and $p^T(r_1, r_2) = (a+r_1+r_2)/4 \geq c$.*

(c) *If $r_2 \geq (a+r_1)/3$, then $q_0^T = (a+r_1)/3$, $q_1^T = (a-2r_1)/3$, $q_2^T = 0$ and $p^T(r_1, r_2) = p^D(r_1) = (a+r_1)/3 \leq c$.*

The extensive-form game that models the strategic interaction between firms $0, 1$ and 2 is completely characterized by the parameters a, c and $\underline{\phi}$, so we shall denote it $\Gamma(a, c, \underline{\phi})$. Throughout this paper, we shall consider generic values of the parameters, so that inequalities involving functions of these parameters are always strict. This game has the following stages.

Stage I: Firm 0 offers a licensing policy[12] (r_1, f_1) to firm 1. Firm 1 either rejects the policy $(\lambda_1 = 0)$ and has marginal cost c, or it accepts $(\lambda_1 = 1)$, pays the upfront fee f_1 to firm 0 and obtains effective cost r_1. Therefore, the marginal cost of firm 1 is $\widetilde{r}_1 := \lambda_1 r_1 + (1 - \lambda_1)c$.

[12] By offering the policy $(c, 0)$ (i.e. royalty $r_1 = c$ and zero fee) to firm 1, firm 0 can ensure that 1's cost stays at c so that the resulting subgames following this offer are the same as the case when there is no licensing to 1. Therefore, the specific policy $(c, 0)$ is (weakly) superior to no licensing or any policy that results in firm 1 rejecting the licensing offer. For this reason, there is no loss of generality in only considering policies that are accepted by firm 1.

Stage II: Observing the outcome in Stage I, firm 2 either

(i) Does not enter and obtains its reservation payoff $\underline{\phi}$. Then, the Cournot duopoly game $\mathbb{C}^D(\widetilde{r}_1)$ is played. Firm 0 obtains its profit from η plus royalty payments and fees from 1, given by

$$\phi_0^D(\widetilde{r}_1) + \lambda_1[r_1 q_1^D(r_1) + f_1]. \tag{2}$$

Firm 1 obtains $\phi_1^D(\widetilde{r}_1) - \lambda_1 f_1$ (profit from η net of fees).

(ii) Enters the industry, in which case firm 0 offers a licensing policy (r_2, f_2) to firm 2. Firm 2 either rejects the policy ($\lambda_2 = 0$) and has marginal cost c, or it accepts ($\lambda_2 = 1$), pays f_2 to 0 and obtains effective cost r_2. So, the marginal cost of firm 2 is $\widetilde{r}_2 := \lambda_2 r_2 + (1 - \lambda_2)c$. The Cournot triopoly game $\mathbb{C}^T(\widetilde{r}_1, \widetilde{r}_2)$ is played. The payoff of firm 0 is the sum of its profit from η plus royalty payments and fees from 1 and 2, which is given by

$$\phi_0^T(\widetilde{r}_1, \widetilde{r}_2) + \lambda_1 r_1 q_1^T(\widetilde{r}_1, \widetilde{r}_2) + \lambda_2 r_2 q_2^T(\widetilde{r}_1, \widetilde{r}_2) + \lambda_1 f_1 + \lambda_2 f_2. \tag{3}$$

For $i = 1, 2$, firm i obtains $\phi_i^T(\widetilde{r}_1, \widetilde{r}_2) - \lambda_i f_i$.

We seek to determine Subgame Perfect Nash Equilibrium (SPNE) by backward induction.

3 Analysis

Our main goal is to determine whether the patent holder, firm 0, has incentives to use the licensing contract offered to firm 1, and in particular the royalty, in order to block entry of firm 2. Moreover, we are interested in the effect of entry costs on the licensing contract and on the incentives to innovate.

3.1 Stage II: Firm 2's entry decision

Consider stage II of Γ where firm 1 has cost $\widetilde{r}_1$ for some $\lambda_1 \in \{0, 1\}$ and $r_1 \in [0, c]$. Firms 0 and 1 now face the threat of firm 2's entry. If firm 2 does not enter the industry, the duopoly game $\mathbb{C}^D(\widetilde{r}_1)$ is played between firms 0 and 1. Firm 0's payoff is given by (2). Firm 1 obtains $\phi_1^D(\widetilde{r}_1) - \lambda_1 f_1$ and firm 2 obtains its reservation payoff $\underline{\phi}$.

3.1.1 Licensing policy following entry of firm 2

Here we investigate the optimal contract between firm 0 and firm 2, (r_2, f_2), if firm 2 has entered, taking firm 1's marginal cost $\widetilde{r}_1$ as given. If firm 2 rejects the contract, its marginal cost is

c and the game $\mathbb{C}^T(\widetilde{r}_1, c)$ is played, where firm 2 obtains $\phi_2^T(\widetilde{r}_1, c)$. If 2 accepts the contract, the game $\mathbb{C}^T(\widetilde{r}_1, r_2)$ is played and firm 2 obtains $\phi_2^T(\widetilde{r}_1, r_2) - f_1$. So 2 will accept only if $f_2 \leq \phi_2^T(\widetilde{r}_1, r_2) - \phi_2^T(\widetilde{r}_1, c)$. Therefore, for any $r_2 \in [0, c]$, it is optimal for firm 0 to set

$$f_2 = \phi_2^T(\widetilde{r}_1, r_2) - \phi_2^T(\widetilde{r}_1, c) \equiv \Delta_2(\widetilde{r}_1, r_2) \tag{4}$$

so that firm 2 obtains net payoff $\phi_2^T(\widetilde{r}_1, c)$ making it just indifferent between accepting and rejecting the offer. Taking $\lambda_2 = 1$, $\widetilde{r}_2 = r_2$ and $f_2 = \Delta_2(\widetilde{r}_1, r_2)$ in (3), the problem of firm 0 is to choose $r_2 \in [0, c]$ to maximize

$$\pi^{\widetilde{r}_1}(r_2) = \phi_0^T(\widetilde{r}_1, r_2) + \lambda_1 r_1 q_1^T(\widetilde{r}_1, r_2) + r_2 q_2^T(\widetilde{r}_1, r_2) + \lambda_1 f_1 + [\phi_2^T(\widetilde{r}_1, r_2) - \phi_2^T(\widetilde{r}_1, c)]. \tag{5}$$

Ignoring the terms that have no r_2, the problem of firm 0 reduces to choosing $r_2 \in [0, c]$ to maximize

$$\psi^{\widetilde{r}_1}(r_2) = \phi_0^T(\widetilde{r}_1, r_2) + \lambda_1 r_1 q_1^T(\widetilde{r}_1, r_2) + r_2 q_2^T(\widetilde{r}_1, r_2) + \phi_2^T(\widetilde{r}_1, r_2). \tag{6}$$

The Lemma below summarizes the equilibrium in the second stage of the extensive-form game.

Lemma 2.

(I) *Suppose firm 1 has accepted the licensing policy (r_1, f_1) from firm 0 (i.e. $\lambda_1 = 1$).*

- (i) *If firm 2 does not enter the industry, firm 1 obtains $\phi_1^D(r_1) - f_1$.*
- (ii) *If firm 2 enters the industry, firm 0 offers the policy $(r_2, f_2) = (r_1, \Delta_2(r_1, r_1))$ to 2, i.e., firm 2 is offered the same royalty as firm 1. The price at market η exceeds c, firm 1 obtains $\phi_1^T(r_1, r_1) - f_1$ and firm 2 obtains $\phi_2^T(r_1, c) - \underline{\phi}$.*

(II) *Suppose firm 1 has rejected a licensing offer from firm 0 (i.e. $\lambda_1 = 0$).*

- (i) *If firm 2 does not enter the industry, firm 1 obtains $\phi_1^D(c)$.*
- (ii) *If firm 2 enters the industry:*
  - (a) *If $c < a/3$, firm 0 offers a pure fixed fee policy $(r_2, f_2) = (0, \Delta_2(c, 0))$ to firm 2 which 2 accepts. The price at market η exceeds c.*
  - (b) *If $a/3 \leq c < a/2$, firm 0 offers the policy $(r_2, f_2) = (3c - a, \Delta_2(c, 3c - a))$ to firm 2 which 2 accepts. The price at market η exactly equals c and firm 1 drops out of the market.*
  - (c) *In both cases* (a) *and* (b)*, firm 2 obtains $\phi_2^T(c, c) - \underline{\phi}$.*

(d) *Define* $\tau = 1$ *if* $c < a/3$ *and* $\tau = 0$ *if* $a/3 \leq c < a/2$. *Then firm* 1 *obtains* $\tau\phi_1^T(c, 0)$.

The intuition of Lemma 2 is the following. If firm 1 has accepted the policy, its unit cost is r_1. Firm 0 gets a licensing revenue from both firm 1 and firm 2, so it wants them to compete neck to neck and get the same amount from each of them. If firm 1 has rejected the policy, firm 0 will get a royalty and fixed fee only from firm 2. If firm 0 can offer a royalty r_2 that drives firm 1 out of the market (such that $r_2 \leq 3c - a$, according to Lemma 1), the market structure is a duopoly and it is then optimal for firm 0 to offer the maximal possible royalty $r_2 = 3c - a$. If firm 0 cannot drive firm 1 out (if $3c - a \geq 0$), then the market structure is a triopoly and it is optimal for firm 0 to offer the minimum possible royalty $r_2 = 0$. In any case, when firm 2 enters the industry it settles with firm 0 and gets its outside option profit minus the entry cost.

3.1.2 Entry decision of firm 2

If firm 2 stays out, it obtains $\underline{\phi}$. By Lemma 2, if firm 2 enters the industry, it obtains: (i) $\phi_2^T(c, c) > 0$ if firm 1 has rejected firm 0's licensing offer and (ii) $\phi_2^T(r_1, c)$ if firm 1 has accepted a licensing policy (r_1, f_1). Since $r_1 \in [0, c]$ and $\phi_2^T(r_1, c)$ is weakly decreasing in r_1, we have

$$\phi_2^T(0, c) \leq \phi_2^T(r_1, c) \leq \phi_2^T(c, c). \tag{7}$$

Hence, $\phi_2^T(c, c)$ is the maximum possible payoff that firm 2 can obtain and $\phi_2^T(0, c)$ is the minimum possible payoff for firm 2. Lemma 3 describes the optimal entry decision of firm 2.

Lemma 3.

(I) *If* $\underline{\phi} < \phi_2^T(0, c)$, *then firm* 2 *enters the industry.*

(II) *If* $\underline{\phi} > \phi_2^T(c, c)$, *then firm* 2 *stays out of the industry.*

(III) *If* $\phi_2^T(0, c) < \underline{\phi} < \phi_2^T(c, c)$, *there exists a royalty* $r_1^*(\underline{\phi}) := 4\sqrt{\underline{\phi}} + 3c - a \in (0, c)$, *such that* $\phi_2^T(r_1, c) \gtreqless \underline{\phi} \Leftrightarrow r_1 \gtreqless r_1^*(\underline{\phi})$. *Consequently*

(i) *If* 1 *has rejected a licensing policy, then* 2 *enters the industry.*

(ii) *If* 1 *has accepted a licensing policy* (r_1, f_1), *then* 2 *enters if* $r_1 \in (r_1^*(\underline{\phi}), c]$, *stays out if* $r_1 \in [0, r_1^*(\underline{\phi}))$ *and is indifferent between entering and staying out if* $r_1 = r_1^*(\underline{\phi})$.

Lemma 3 is quite intuitive. If the entry cost of firm 2 falls below its minimum possible post-entry payoff, it will enter. On the other hand, if its entry cost exceeds its maximum possible post-entry payoff, it will stay out. For intermediate values of the entry cost, its decision is determined by the efficiency level of firm 1. According to Lemma 2, if firm 2 enters after firm 1 has accepted the licensing policy (r_1, f_1), it settles with firm 0 and gets its outside option $\phi_2^T(r_1, c)$. This profit increases as r_1 increases, so firm 2 will enter for relatively large values of r_1 and stay out for small values of r_1, with $r_1^*(\underline{\phi})$ standing for the entry-deterring threshold.

3.2 Stage I: Equilibrium entry structure

Having characterized the entry decision for firm 2, now we are in a position to state the main result.

Proposition 1 (**Main result**). *For generic values of a, c and $\underline{\phi}$, $\Gamma(a, c, \underline{\phi})$ has a unique SPNE where firm 1 accepts the licensing policy that firm 0 offers to it; if firm 2 enters, it also accepts the licensing policy that firm 0 offers to it. The SPNE has the following properties where $\widehat{c} \in (0, a/3)$.*[13]

(I) **Entry cannot be blocked (C)** *For low values of the entry cost $[\underline{\phi} < \phi_2^T(0, c)]$, firm 0 offers firm 1 a license with the maximum royalty $r_1 = c$ and the fixed fee $f_1 = \phi_1^T(c, c) - \phi_1^T(c, 0) > 0$. Firm 2 enters the industry and firm 0 offers firm 2 a license with the maximum royalty $r_2 = c$ and no fixed fee.*

(II) **No need to block entry (N)** *For high values of the entry cost $[\underline{\phi} > \phi_2^T(c, c)]$, firm 0 offers firm 1 a license with the maximum royalty $r_1 = c$ and no fixed fee. Firm 2 stays out of the market.*

(III) *For intermediate values of the entry cost $[\phi_2^T(0, c) < \underline{\phi} < \phi_2^T(c, c)]$, whether entry is either deterred or accommodated depends on $\widehat{c}$. Specifically*

- (a) **Entry is blocked (B)** *If $c \in (0, \widehat{c})$, entry is deterred. Firm 0 offers firm 1 a license with the royalty $r_1 = r_1^*(\underline{\phi}) \in (0, c)$ and fixed fee $f_1 = \phi_1^D(r_1^*) - \phi_1^T(c, 0) > 0$. Firm 2 stays out of the market.*
- (b) *If $c \in (\widehat{c}, a/2)$ there is a decreasing function $\widehat{\phi}(c) \in (\phi_2^T(0, c), \phi_2^T(c, c))$ such that whether entry is deterred or accommodated depends on $\widehat{\phi}(c)$ as follows.*[14]
  - (i) **Entry is accommodated (A)** *If $\phi_2^T(0, c) < \underline{\phi} < \widehat{\phi}(c)$, entry is accommodated. Firm 0 offers firm 1 a license with the maximum royalty $r_1 = c$ and fixed fee $f_1 = \phi_1^T(c, c)$. Firm 2 enters the industry and firm 0 offers firm 2 a license with the maximum royalty $r_2 = c$ and no fixed fee.*

[13] More specifically, $\widehat{c} = \frac{a}{3}[\frac{3-\sqrt{2}}{2}]$.

[14] More specifically, $\widehat{\phi}(c) = \frac{9(2-\sqrt{2})^2(a-2c)^2}{256}$.

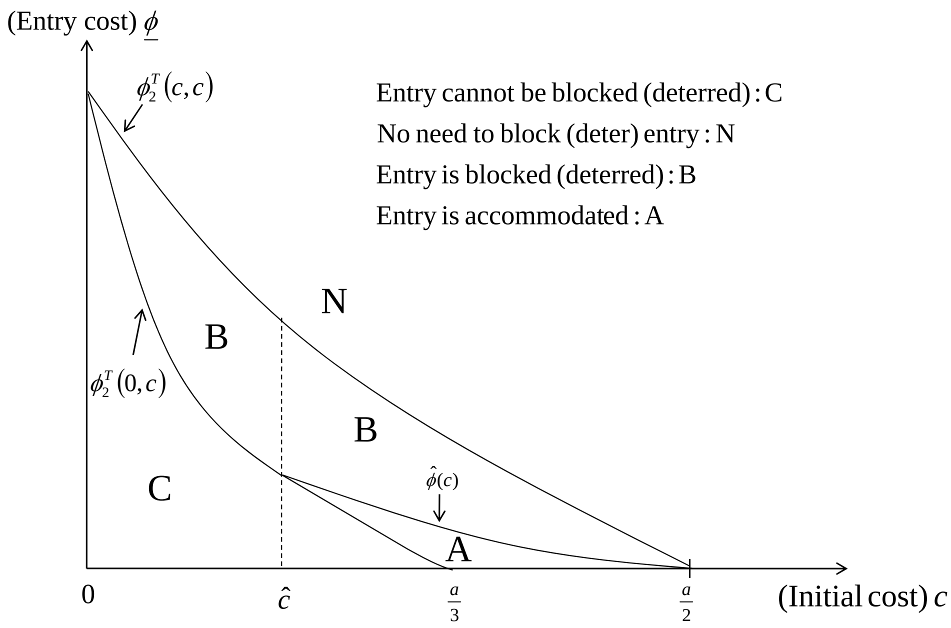

Figure 1: Market structure as a function of initial cost c and entry cost $\underline{\phi}$

(ii) **Entry is blocked (B)** *If* $\underline{\phi} < \widehat{\phi}(c) < \phi_2^T(c,c)$, *entry is deterred and the outcome is the same as* III(a).

Figure 1 depicts our main result. To see the intuition for Proposition 1, first recall that following entry, firm 2 can always ensure a payoff of at least $\phi_2^T(c,c)$, but it can obtain no more than $\phi_2^T(0,c)$. If 2's entry cost $\underline{\phi}$ is below its worst possible post-entry payoff, then entry cannot be deterred (Prop 1(I)). On the other hand, if its entry cost exceeds its best possible post-entry payoff, then it will not enter in any case and therefore entry deterrence is redundant (Prop 1(II)).

For intermediate values of the entry cost $[\phi_2^T(0,c) < \underline{\phi} < \phi_2^T(c,c)]$, firm 0 can use the royalty r_1 it offers to firm 1 to either deter or accommodate entry. In the absence of any threat of entry, it is optimal for firm 0 to set $r_1 = c$ so that its sole rival firm 1 effectively operates under the existing cost. To deter entry from firm 2, firm 0 has to provide an efficiency edge to its incumbent rival firm 1. This is achieved by lowering r_1 from its maximum level c to $r_1^*(\underline{\phi}) < c$ (Lemma 3). Thus, in deciding whether to deter or accommodate entry, firm 0 faces a trade-off. It can deter the entrant only at the cost of creating a more efficient incumbent rival.

To understand how this trade-off is resolved, it is important to observe that firm 0's power in this contractual setting depends on the significance of its patented technology vis-a-vis the existing one. When the initial production cost is sufficiently small ($c < \widehat{c}$), then both firms 1 and 2 are already quite efficient even without the new technology. For this case the patented technology is not very significant, resulting in a weak position for firm 0 in the Cournot market. This gives it a strong incentive to restrict competition, which explains the result that for $c < \widehat{c}$, entry is always deterred (Prop 1(III)(a)).

Once the initial cost of production is relatively large ($c > \widehat{c}$), the entry cost $\underline{\phi}$ comes into play in determining whether it is optimal to deter or accommodate entry. Note that $r_1^*(\underline{\phi})$ is increasing in $\underline{\phi}$, implying that when firm 2 has a smaller cost of entry, firm 0 must make its incumbent rival even more efficient in order to block entry. For small values of $\underline{\phi}$ $[\underline{\phi} < \widehat{\phi}]$, the "entry-deterring royalty" r_1^* is also small, resulting in a very efficient firm 1. For this case the gain from restricting competition is outweighed by the loss of creating a strong incumbent rival. As a result, it is optimal for firm 0 to accommodate entry (Prop 1(III)(b)(i)). For large values of $\underline{\phi}$ $[\underline{\phi} > \widehat{\phi}]$, these relative effects work in the opposite direction, rendering it optimal for firm 0 to deter entry (Prop 1(III)(b)(ii)). Finally observe that as the patented technology becomes more significant (i.e., c increases), it is expected that firm 0 will be able to deter entry even for relatively large values of the entry cost $\underline{\phi}$. This explains why the threshold $\widehat{\phi}(c)$ is decreasing in c.

To sum up, for intermediate values of the entry cost, firm 0 prefers to get a lower royalty from firm 1 in order to deter firm 2's entry, rather than a higher royalty that would induce entry. The gain from a low royalty in terms of competition (leading to a duopoly instead of a triopoly) offsets the loss in terms of cost advantage. Note that this equilibrium outcome gives one explanation for the low royalty rates that are observed in the real world. Our model predicts (see Figure 1) that this is 'more likely' to take place in industries where the entry costs are intermediate. A nice empirical implication of this result is to check whether there is a direct relationship between the magnitudes of the royalty rates specified in the licensing contracts and the barriers to entry in the industry.

The impact of this entry deterrence strategy on welfare is ambiguous. At first glance, a lower royalty raises welfare through a lower market price. However, taking its impact on entry into consideration can reverse this result. In the next section, we perform a welfare analysis.

3.3 Welfare analysis: Are low royalties anti-competitive?

First, we examine the effect of licensing on consumer welfare, and then we analyze the impact of the entry deterrence strategy, and how it would be affected by a policy that would facilitate entry. In what follows in this section we always focus on region B of Proposition 1, where entry is blocked (for values of the entry cost such that $\max\{\phi_2^T(0,c), \hat{\phi}(c)\} \leq \underline{\phi} \leq \phi_2^T(c,c)$).

3.3.1 Does licensing increase consumer welfare?

In this subsection we analyze the welfare impact of licensing between the incumbent firms. We study a situation where firm 0 is not allowed to license its technology to firm 1, but can still license to firm 2. When firm 0 cannot license to firm 1, the equilibrium is described by case (II) of Lemma 2. Firm 2 always enters. Hence, if $c < a/3$ the market structure is triopoly with royalty $r_2 = 0$, while if $a/3 \leq c < a/2$, the market structure is duopoly with royalty $r_2 = 3c - a < c$. If, on the other hand, licensing is allowed then, according to Proposition 1, the market structure is duopoly with $r_1^*(\underline{\phi}) = 4\sqrt{\underline{\phi}} + 3c - a < c$. It is clear that when $c \geq a/3$ licensing leads to a higher market price. When $c < a/3$, following Lemma 1, the market price when licensing is not allowed is $p^T(c, 0) = (a+c)/4$, while when licensing is allowed the market price is $p^D(r_1^*(\underline{\phi})) = (4\sqrt{\underline{\phi}}+3c)/3$. It can be easily verified that licensing leads to higher price. Therefore, licensing unambiguously decreases consumer welfare.

3.3.2 How does entry deterrence affect consumer welfare?

Our objective in this subsection is to study the welfare impact of firm 0's entry deterrence strategy through a lower royalty. We examine how consumer welfare would change if firm 0 was unable to use its licensing agreement with firm 1 in order to block entry. For instance, the government could subsidize entry in that industry, so that firm 2 would always enter in region B of Proposition 1. The impact on the price is not straightforward: while such a policy would increase competition through entry, it would also increase the price through a higher royalty. When firm 0 is willing and able to to block entry, it offers firm 1 a royalty $r_1 = r_1^*(\underline{\phi})$. The resulting market structure is a duopoly, and the corresponding price is $p^D(r_1^*) = (a + r_1^*)/3$. If entry always occurs, firm 0 is not able to block entry anymore, so the market structure will always be a triopoly. Firm 0 then offers firm 1 (as well as firm 2) a higher royalty $r_1 = r_2 = c$. The resulting price is equal to $p^T(c, c) = (a+2c)/4$. The following Proposition compares these two prices. Figure 2 depicts the welfare comparison.

Proposition 2 (**Consumer welfare implications of entry deterrence**).

Let $\max\{\phi_2^T(0, c), \hat{\phi}(c)\} \leq \underline{\phi} \leq \phi_2^T(c, c)$. *There exists a function* $\phi^*(c)$ *with* $\max\{\phi_2^T(0, c), \hat{\phi}(c)\} < \phi^*(c) < \phi_2^T(c, c)$,[15] *such that*

(I) *For relatively low values of the entry cost* ($\underline{\phi} < \phi^*(c)$)*, entry deterrence increases consumer welfare, i.e.,* $p^T(c, c) > p^D(r_1^*(\underline{\phi}))$.

[15] More specifically, $\phi^*(c) = \frac{9(a-2c)^2}{64}$.

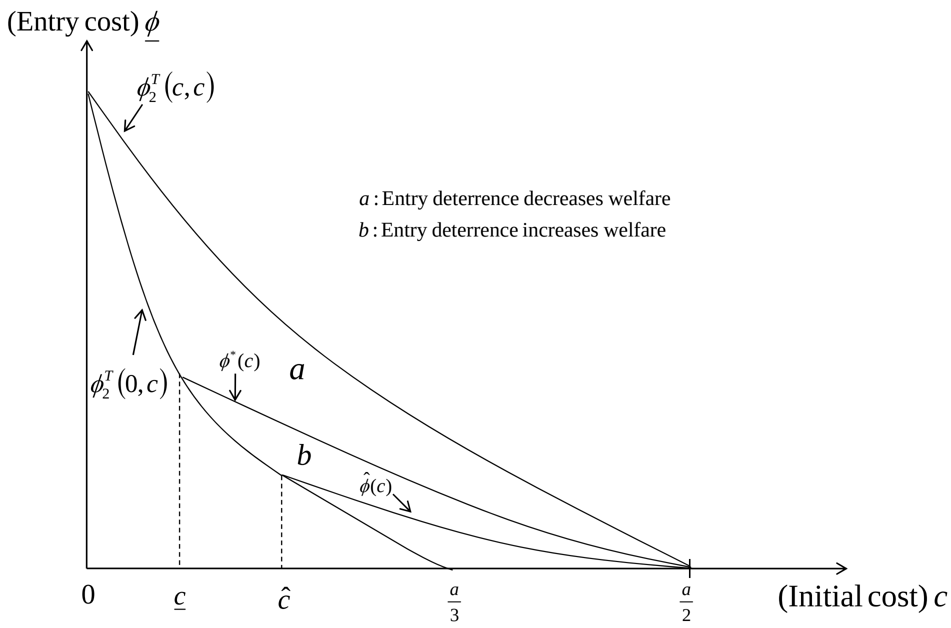

Figure 2: Effect of entry policy on welfare

(II) *For relatively high values of the entry cost ($\underline{\phi} > \phi^*(c)$), entry deterrence decreases consumer welfare, i.e.,* $p^T(c,c) < p^D(r_1^*(\underline{\phi}))$.

Entry deterrence has two effects: i) royalty is lower than what it would have been if entry was not deterred and ii) market structure is a duopoly instead of a triopoly. When the entry cost $\underline{\phi}$ is high, entry is relatively difficult and for entry deterrence to work, royalty need not be very low. In this case the second effect is stronger than the first. The reverse is true when entry cost is low. Therefore, a policy that removes the incumbents' ability to deter entry, such as entry subsidization, would improve consumer welfare when the entry cost $\underline{\phi}$ is relatively high.

What keeps the entrant out of the market is the incumbent patent holder's ability to affect the entrant's outside option by varying the royalty it offers to the rival incumbent firm. Indeed, the entrant's outside option $\phi_2^T(r_1, c)$–which determines the entrant's profit if it enters the market–is decreasing in r_1, the efficiency of one of the firms in the market. A low royalty can drive $\phi_2^T(r_1, c)$ below the entry cost $\underline{\phi}$ and prevent the entrant from entering the market. This result is quite general and does not hinge on the special type of competition we have assumed in this paper. Even in more general models the profit of a firm decreases as a rival becomes more efficient. Nevertheless, the simple structure of the Cournot model allows us to compare profits across the different subgames in order to determine the set of conditions where the entry-deterrence strategy emerges in equilibrium. In a more general model this profit comparison would be extremely hard and not clean.

4 Patent race

In this section we consider the research and development (R&D) stage which takes place prior to patent licensing and product market competition. In this stage the incumbent firms of the industry, firms 0 and 1, compete in a *patent race game*, where they simultaneously choose their non-negative R&D investments. Initially both firms have a constant unit cost equal to c, but if a firm succeeds in R&D and wins a patent, it reduces its cost from c to 0. For any firm, its R&D investment results in either one of the two outcomes: (i) the firm succeeds in R&D or (ii) it fails. Firms have the identical R&D process given by $\rho : R_+ \to [0, 1]$ which stands for the probability of success as function of the investment, i.e., if a firm invests x in R&D, it succeeds with probability $\rho(x)$ and fails with probability $1 - \rho(x)$. It is assumed that ρ is twice continuously differentiable with $\rho(0) = 0$, $\lim_{x\to\infty} \rho(x) = 1$, and for $x > 0$, $\rho'(x) > 0$ and $\rho''(x) < 0$.

Following the simultaneous R&D investment $x_0, x_1 \geq 0$ by firms $0, 1$, the patent race can result in the following (mutually exclusive and exhaustive) events. We specify payoffs in the Lemma below.

(i) *SF*: With probability $\rho(x_i)[1 - \rho(x_j)]$, firm i succeeds and firm j fails. Firm i is granted a patent, and can license this patent to firm j (and also to the potential entrant firm 2). Using the different regions described in Proposition 1, firm i obtains π_0^k (the payoff of the incumbent patent-holder) and firm j obtains π_1^k (the payoff of the other incumbent firm), where $k \in$ {C,A,B,N}.[16]

(ii) *SS*: With probability $\rho(x_i)\rho(x_j)$, both firms succeed. Then each firm wins the patent with probability 1/2. Therefore, firm i obtains the expected payoff $(1/2)\pi_0^k + (1/2)\pi_1^k$, where $k \in$ {C,A,B,N}.

(iii) *FF*: With probability $[1 - \rho(x_i)][1 - \rho(x_j)]$, both firms fail and continue to have the existing cost c. We restrict our analysis to values of the entry cost $\underline{\phi}$ for which it is then always profitable for firm 2 to enter the market, so the market structure is a triopoly. We denote each firm's payoff by $\overline{\phi} = (a - c)^2/16$, which we assume to be higher than $\underline{\phi}$.[17]

[16]Recall that in C entry cannot be blocked, in A firm 0 chooses to accommodate entry, in B firm 0 chooses to block entry, and in N there is no need to block entry.

[17]Note that $\overline{\phi} > \phi_2^T(c, c)$ (the NE profit of firm 2 in the Cournot triopoly where firm 0 has cost 0 and firms $1, 2$ have cost c). Thus $\overline{\phi}$ is already larger than the entry-deterring upper bound.

The following Lemma describes the profits π_0^k and π_1^k, where $k \in$ {C,A,B,N} depends on the regions analyzed in Proposition 1 and depicted in Figure 1.

Lemma 4. Let $F(p) := pQ(p) = p(a-p)$ be the monopoly profit at price p under the reduced cost 0.[18]

(a) **Entry cannot be blocked (C)** *For low values of the entry cost, such that* $\underline{\phi} < \phi_2^T(0,c)$*, the profits of firms* 0 *and* 1 *are respectively* $\pi_0^C = F\left(p^T(c,c)\right) - \phi_2^T(c,c) - \tau\phi_1^T(c,0)$ *and* $\pi_1^C = \tau\phi_1^T(c,0)$.

(b) **Entry accommodation (A)** *If the entry cost is such that* $\underline{\phi} \in (\phi_2^T(0,c), \widehat{\phi}(c))$*, the profits of firms* 0 *and* 1 *are respectively* $\pi_0^A = \pi_0^C$ *and* $\pi_1^A = \pi_1^C$.

(c) **Entry is blocked (B)** *If the entry cost is such that* $\max\{\widehat{\phi}(c), \phi_2^T(0,c)\} < \underline{\phi} < \phi_2^T(c,c)$*, firms* 0*'s profit* $\pi_0^B = F\left(p^D(r_1^*(\underline{\phi}))\right) - \tau\phi_1^T(c,0)$ *is continuous and increasing in* $\underline{\phi}$*, with* $\pi_0^B > \pi_0^C$*. Firm* 1*'s profit is* $\pi_1^B = \pi_1^C$.

(d) **No need to block entry (N)** *For high values of the entry cost, such that* $\underline{\phi} < \phi_2^T(0,c)$*, the profits of firms* 0 *and* 1 *are respectively* $\pi_0^N = F\left(p^D(c)\right) - \phi_1^D(c) < lim_{\underline{\phi}\uparrow\phi_2^T(c,c)}\pi_0^B$*, and* $\pi_1^N = \phi_1^D(c) > \pi_1^B$.

The intuition is the following. In its licensing contract with firm 1, firm 0 sets the fixed fee such that firm 1 always gets its outside option payoff. If firm 1 rejects the contract, its cost is c, and firm 2 enters the market, so firm 1 gets $\tau\phi_1^T(c,0)$ (see Lemma 2 (II)). Firm 0's profit is the same in regions C and A, where firm 2 enters the market following the licensing contract between firms 0 and 1, which is the same in these two regions. As the fixed cost $\underline{\phi}$ increases and we switch to region B where entry is blocked, the positive impact on firm 0's profit through a gain of market power offsets the negative impact due to the lower royalty and the loss of licensing revenue from firm 2. Therefore firm 0's profit jumps up. As the entry cost increases within region B, the royalty firm 0 can offer to firm 1 such that entry is deterred goes up, so its profit goes up. Once the entry cost goes from right below to right above $\phi_2^T(c,c)$ and we switch from region B to region N, firm 2 does not enter even if firm 1 rejects the contract offered by firm 0, so firm 1's outside option profit increases. Therefore, firm 0 must decrease the fixed fee it offers to firm 1, which decreases its profit compared to region B.

[18] In each of the following cases, firm 0's payoff is $F(p)$ net of the SPNE payoffs of the active firms in the industry. This result is driven by the fact when firm 0 uses the upfront fee of its licensing policy to make other firms just indifferent between accepting and rejecting the licensing policy.

Using the probabilities of the outcomes from (i)-(iii), the expected payoff π_i of firm i net of R&D investment is given as follows, where $i, j = 0, 1$ and $i \neq j$.

$$\pi_i(x_i, x_j) = \rho(x_i)[1 - \rho(x_j)]\pi_0^k + \rho(x_j)[1 - \rho(x_i)]\pi_1^k$$

$$+\rho(x_i)\rho(x_j)[(1/2)\pi_0^k + (1/2)\pi_1^k] + [1 - \rho(x_i)][1 - \rho(x_j)]\overline{\phi} - x_i \quad (8)$$

Firm chooses i maximizes its payoff with respect to its R&D investment x_i, which leads to the following first order condition:

$$\rho'(x_i)\{\pi_0^k - \overline{\phi} - \rho(x_j)[(1/2)\pi_0^k + (1/2)\pi_1^k - \overline{\phi}]\} - 1 = 0 \quad (9)$$

It is easy to check that $(1/2)\pi_0^k + (1/2)\pi_1^k - \overline{\phi} > 0 \,\forall\, k \in \{\text{C,A,B,N}\}$, so firms' R&D investments are strategic substitutes.[19] At the equilibrium, firms' investments are identical: $x_i = x_j$. Since the equilibrium R&D investment depends on k, we denote it x^k, such that $\forall\, k \in \{\text{C,A,B,N}\}$:

$$\rho'(x^k)\{\pi_0^k - \overline{\phi} - \rho(x^k)[(1/2)\pi_0^k + (1/2)\pi_1^k - \overline{\phi}]\} - 1 = 0. \quad (10)$$

The following Proposition analyzes the impact of the entry cost $\underline{\phi}$ on the equilibrium R&D investment x^k.

Proposition 3. In equilibrium, the optimal R&D investment x^k is a non monotonic function of $\underline{\phi}$. More specifically,

- **Regions A and C** When the entry cost is relatively low, such that $\underline{\phi} < \max\{\widehat{\phi}(c), \phi_2^T(0, c)\}$, firms invest a constant amount $x^{\text{C}} = x^{\text{A}}$.

- **Region B** For intermediate values of the entry cost, such that $\max\{\widehat{\phi}(c), \phi_2^T(0, c)\} < \underline{\phi} < \phi_2^T(c, c)$, the equilibrium R&D investment x^{B} is an increasing function of $\underline{\phi}$, with $x^{\text{B}} > x^{\text{C}} = x^{\text{A}}$.

- **Region N** Finally, when the entry cost is relatively high, such that $\phi_2^T(c, c) < \underline{\phi} < \overline{\phi}$, firms invest a constant amount $x^{\text{N}} < x^{\text{B}}$.

Proof See the Appendix. ■

Proposition 3 emphasizes the non-monotonic relationship between incentives to innovate and the threat of entry, measured by a reduction in the entry cost $\underline{\phi}$. We show that in an industry

[19]Moreover, the second order condition is satisfied, as $\rho''(x_i) < 0$ and $\pi_0^k - \overline{\phi} - \rho(x_j)[(1/2)\pi_0^k + (1/2)\pi_1^k - \overline{\phi}] > 0$. Indeed, $\pi_0^k - \overline{\phi} - \rho(x_j)[(1/2)\pi_0^k + (1/2)\pi_1^k - \overline{\phi}] \geq (1/2)\pi_0^k - (1/2)\pi_1^k > 0$.

initially not threatened by entry, the sudden introduction of potential entrants (a shift from region N to region B) will increase incentives to innovate. But once the threat of entry exists, incentives to innovate decrease as entry becomes easier (a decrease in $\underline{\phi}$ within region B, or a shift from region B to regions A and C). The intuition is the following. When a reduction in the entry cost leads to a shift from region N to region B, entry becomes a threat. It is deterred through a lower royalty between firm 0 (the patent race winner) and firm 1 (the patent race loser), but winning the race becomes more attractive since the difference between firm 0 and firm 1's profits increases, as shown in Lemma 1. Once the threat of entry exists but can be deterred (within region B), a reduction in the entry cost reduces the royalty necessary to block entry, and hence firm 0's profit, so winning the race becomes relatively less attractive. This issue is related to Aghion et al. (2009). They find that the threat of entry spurs innovation incentives in sectors close to the technology frontier, where successful innovation allows incumbents to survive the threat, but discourages innovation in laggard sectors, where the threat reduces incumbents expected rents from innovating.

Let's now re-examine the implications of entry deterrence. Proposition 3 shows that R&D is the strongest when the entry cost is $\underline{\phi} = \phi_2^T(c, c) - \varepsilon$. We have shown that for that value of the entry cost, firm 0 chooses to deter entry through a lower royalty, which harms consumers because of a higher market price (than if entry was accommodated). Therefore, taking into account the positive impact of entry deterrence on R&D incentives moderates its possible negative impact on consumers through the price. More precisely, if the model parameters lie in the area a of Figure 2, then entry deterrence results in two opposing forces: higher market price, but stronger R&D incentives. In area b however, the ability of the patent holder to use the licensing contract to deter entry leads to a lower price *and* stronger R&D incentives.

5 Conclusion

High royalties in technology transfer agreements are usually viewed as anti-competitive by antitrust authorities, because they increase the marginal costs of the firms and restrict output. In this paper, we challenge this conventional wisdom by developing an oligopoly model that takes the threat of entry explicitly into account. We show that high royalties may very well be pro-competitive. In particular, our model consists of two incumbent Cournot competitors and one potential entrant. One of the incumbent firms holds a patent on a cost-reducing technology. Technology transfer can take place via royalty plus fixed-fee licensing contracts. Under certain conditions, the patent holder finds it optimal to use the licensing contract strategically to deter further entry. To achieve this, royalty is set at low levels so that the firm who obtains the license is made more efficient relative to the potential entrant, who finds entry unprofitable. Given its ability to restraint competition, this type of a licensing agreement can be anti-competitive.

Licensing is always anti-competitive in our model, in the parameter region where the patent holder can use the licensing contract to deter entry. A policy that facilitates entry, on the other hand, is more likely to be welfare-enhancing when the cost of entry is higher, when the R&D expenditures are fixed. Nevertheless, incentives to innovate are strongest when the incumbent can use the licensing contract to deter entry and entry costs are relatively high.

Appendix

Proof of Lemma 2 (I)(i) & (II)(i): If 1 has accepted the policy (r_1, f_1) and 2 does not enter the industry, then the duopoly game $\mathbb{C}^D(r_1)$ is played between firms 0 and 1 in the market η. Firm 1 obtains $\phi_1^D(r_1) - f_1$ (its NE profit at $\mathbb{C}^D(r_1)$ net of fees) and firm 2 obtains its reservation payoff $\underline{\phi}$, which proves (I)(i). If 1 has rejected a licensing offer and 2 does not enter the industry, then the duopoly game $\mathbb{C}^D(c)$ is played between firms 0 and 1 in the market η. Firm 1 obtains $\phi_1^D(c)$ and firm 2 obtains $\underline{\phi}$, which proves (II)(i).

(I)(ii) & (II)(ii): Suppose 2 enters the industry. In that case, by (5), the problem of firm 0 is to choose $r_2 \in [0, c]$ to maximize[20]

$$\psi(r_2) = \phi_0^T(\widetilde{r}_1, r_2) + \lambda_1 r_1 q_1^T(\widetilde{r}_1, r_2) + r_2 q_2^T(\widetilde{r}_1, r_2) + \phi_2^T(\widetilde{r}_1, r_2) \tag{11}$$

If $r_2 \leq 3\widetilde{r}_1 - a$, then by Lemma 1(ii)(a), $q_1^T = 0$ and $\psi(r_2) = (a + r_2)^2/9 + r_2(a - 2r_2)/3 + (a - 2r_2)^2/9$. As $\psi'(r_2) = (a - 2r_2)/9 \geq (a - 2c)/9 > 0$, $\psi(r_2)$ is increasing for $r_2 \leq 3\widetilde{r}_1 - a$, so it is sufficient to consider $r_2 \geq 3\widetilde{r}_1 - a$. Next observe that if $r_2 \geq (a + \widetilde{r}_1)/3$, then by Lemma 1(ii)(c), $q_2^T = \phi_2^T = 0$ and $\psi(r_2)$ is independent of r_2. Therefore, to determine optimal r_2, it is sufficient to consider $r_2 \in [3\widetilde{r}_1 - a, (a + \widetilde{r}_1)/3] \equiv I$.

(I)(ii) Suppose firm 1 has accepted the policy (r_1, f_1). Then $\lambda_1 = 1$, $\widetilde{r}_1 = r_1$ and $I = [3r_1 - a, (a + r_1)/3]$. Using these in (11), by Lemma 1(ii)(b) it follows that for $r_1 \in I$,

$$\psi(r_2) = (a + r_1 + r_2)^2/16 + r_1(a - 3r_1 + r_2)/4 + r_2(a + r_1 - 3r_2)/4 + (a + r_1 - 3r_2)^2/16$$

As $\psi'(r_2) = (r_1 - r_2)/4 \gtreqqless 0 \Leftrightarrow r_2 \lesseqqgtr r_1$, it follows that the unconstrained maximum of $\psi(r_2)$ is attained at $r_2 = r_1$. Since $2r_1 \leq 2c < a$, we have $r_1 \in (3r_1 - a, (a + r_1)/3)$. So the maximum of $\psi(r_2)$ over I (and hence the global maximum) is attained at $r_2 = r_1$ so that $f_2 = \phi_2^T(r_1, r_1) - \phi_2^T(r_1, c)$ making firm 2 just indifferent between accepting and rejecting. Therefore firm 2 obtains net payoff $\phi_2^T(r_1, c)$ and firm 1 obtains $\phi_1^T(r_1, r_1) - f_1$. Since $r_2 = r_1 \in (3r_1 - a, (a + r_1)/3)$, by Lemma 1(ii)(b) it follows that the price at market η exceeds c.

(II)(ii) Suppose firm 1 has rejected the licensing offer. Then $\lambda_1 = 0$, $\widetilde{r}_1 = c$ and $I = [3c - a, (a + c)/3]$. Using these in (11), by Lemma 1(ii)(b) it follows that for $r_1 \in I$,

$$\psi(r_2) = (a + c + r_2)^2/16 + r_2(a + c - 3r_2)/4 + (a + c - 3r_2)^2/16$$

[20] The superscript $\widetilde{r}_1$ is dropped from the function ψ for notational ease.

As $\psi'(0) = 0$ and $\psi'(r_2) = -r_2/4 < 0$ for $r_2 > 0$, the unconstrained maximum of $\psi(r_2)$ is attained at $r_2 = 0 < (a+c)/3$.

(a) If $c < a/3$, then $0 \in (3c - a, (a+c)/3)$, so the maximum over $r_2 \in I$ (and the global maximum) is attained at $r_2 = 0$. This is pure fixed fee policy with fee $f_2 = \Delta_2(c, 0)$ (by (4)). Taking $r_1 = c$ and $r_2 = 0 \in (3c - a, (a+c)/3)$, it follows from Lemma 2(ii)(b) that the price at market η exceeds c.

(b) If $a/3 \leq c < a/2$, then $0 < 3c - a$ and $\psi'(r_2) = -r_2/4 < 0$ for $r_2 \in I = [3c - a, (a+c)/3]$, so that the maximum of $\psi(r_2)$ over I, and the global maximum is attained at $r_2 = 3c - a$. By (4), the fixed fee that 0 charges to firm 2 is $f_2 = \Delta_2(c, 3c - a)$. Taking $r_1 = c$ and $r_2 = 3c - a$ in Lemma 1(ii)(a), it follows that the price at market exactly equals c and firm 1 is driven out of the market.

(c) Since for this case the cost of firm 1 is c, firm 2 would obtain $\phi_2^T(c, c)$ if it rejects the licensing offer. Since the optimal licensing policy makes firm 2 indifferent between accepting and rejecting, the result follows.

(d) If $c < a/3$, then $r_2 = 0$ (by part (a)), so 1 obtains $\phi_1^T(c, 0)$. If $a/3 \leq c < a/2$, then by part (b), firm 1 drops out of the market and obtains zero payoff, which proves the result. ■

Lemma A1 *Consider the triopoly* $\mathbb{C}^T(r_1, c)$. *Denote* $\theta \equiv \max\{0, 3c - a\} \in [0, c)$. *Then* $\phi_2^T(r_1, c) = 0$ *for* $r_1 \in [0, \theta]$ *and* $\phi_2^T(r_1, c)$ *is positive and increasing for* $r_1 \in (\theta, c]$.

Proof As $c < a/2$, we have $\theta \in [0, c)$ and $3r_1 - a \leq 3c - a < c$. Taking $r_2 = c$, parts (b)-(c) of Lemma 1(ii) applies for $\mathbb{C}^T(r_1, c)$. Whether $\phi_2^T(r_1, c)$ is positive or zero depends on whether or not $c \leq (a + r_1)/3 \Leftrightarrow r_1 \geq 3c - a$. Then the result follows by Lemma 1(ii)(b)-(c). ■

Proof of Lemma 3 (i)-(ii): It follows from (7) that if firm 2 enters the industry, it obtains at least $\phi_2^T(0, c)$ and at most $\phi_2^T(c, c)$, which proves (i)-(ii).

(iii) Let $\phi_2^T(0, c) < \underline{\phi} < \phi_2^T(c, c)$. Since $\phi_2^T(r_1, c) = 0$ for $r_1 \in [0, \theta]$, $\phi_2^T(r_1, c)$ is positive and increasing for $r_1 \in (\theta, c]$ (Lemma A1) and $\underline{\phi} > 0$, $\exists\, r_1^*(\underline{\phi}) \in (\theta, c) \subseteq (0, c)$ such that $\phi_2^T(r_1, c) \gtreqqless \underline{\phi} \Leftrightarrow r_1 \gtreqqless r_1^*$. Since $r_1^*(\underline{\phi}) \in (\theta, c)$, by Lemma 1(ii)(b), we have $\phi_2^T(r_1^*, c) = (a + r_1^* - 3c)^2/16$ and equating this with $\underline{\phi}$, we obtain $r_1^*(\underline{\phi}) = 4\sqrt{\underline{\phi}} + 3c - a$.

To prove parts (a)-(b), first observe that if firm 1 rejects the licensing offer and firm 2 enters the industry, then 2 obtains $\phi_2^T(c, c) > \underline{\phi}$. So 2 enters the industry if 1 rejects the licensing offer. If 2 enters the industry following the acceptance of the policy (r_1, f_1) by firm 1, then 2 obtains $\phi_2^T(r_1, c)$. Since $\phi_2^T(r_1, c) \gtreqqless \underline{\phi} \Leftrightarrow r_1 \gtreqqless r_1^*$, it follows that 2 enters if $r_1 \in (r_1^*, c]$ and it does not enter if $r_1 \in [0, r_1^*]$. ■

It will be useful to define for any price p, the function

$$F(p) := pQ(p) = p(a-p) \tag{12}$$

Note that $F(p)$ presents the monopoly profit at price p under the reduced cost 0 so its unique maximum is attained at the monopoly price $p_M \equiv a/2 > c$. Thus, $F(p)$ is increasing for $p < p_M$ and decreasing for $p > p_M$.

Lemma A2 *Suppose* $\phi_2^T(0,c) < \underline{\phi} < \phi_2^T(c,c)$. *Denote* $r_1^*(\underline{\phi}) := 4\sqrt{\underline{\phi}} + 3c - a$ *and*

$$h^c(\underline{\phi}) := F\left(p^D(r_1^*(\underline{\phi}))\right) - F\left(p^T(c,c)\right) + \phi_2^T(c,c) \tag{13}$$

This function has the following properties.

(i) $h^c(\underline{\phi})$ *is increasing in* $\underline{\phi}$.

(ii) $\exists\ \widehat{c} \equiv (3-\sqrt{2})a/6 \in (0, a/3)$ *such that*

- (a) *If* $c \in (0, \widehat{c}]$, *then* $h^c(\underline{\phi}) > 0$ *for all* $\underline{\phi} \in (\phi_2^T(0,c), \phi_2^T(c,c))$.
- (b) *If* $c \in (\widehat{c}, a/2)$, *then* $\exists\ \widehat{\phi}(c) \in (\phi_2^T(0,c), \phi_2^T(c,c))$, *given by*

$$\widehat{\phi}(c) = 9(2-\sqrt{2})^2(a-2c)^2/256 \tag{14}$$

such that $h^c(\underline{\phi}) \gtreqqless 0 \Leftrightarrow \underline{\phi} \gtreqqless \widehat{\phi}(c)$.

Proof (i) Since $p^D(r_1^*(\underline{\phi}))$ is increasing in $\underline{\phi}$ and less than p_M, and $F(p)$ is increasing for $p < p_M$, it follows that $F\left(p^D(r_1^*(\underline{\phi}))\right)$ is increasing in $\underline{\phi}$, and so is $h^c(\underline{\phi})$.

(ii) Recall from Lemma 1 that $p^T(c,c) = (a+2c)/4 < p_M$. If $\underline{\phi} = \phi_2^T(c,c) = (a-2c)^2/16$, then $p^D(r_1^*(\phi_2^T(c,c))) = (a+c)/3$ and $p^D(r_1^*) - p^T(c,c) = (a/2-c)/6 > 0$. Since both $p^D(r_1^*)$ and $p^T(c,c)$ are less than p_M, for this case, we have $F\left(p^D(r_1^*)\right) > F\left(p^T(c,c)\right)$. Then by (13), $h^c(\phi_2^T(c,c)) > F\left(p^D(r_1^*(\phi_2^T(c,c)))\right) - F\left(p^T(c,c)\right) > 0$.

Since $F(p) = p(a-p)$, $p^T(c,c) = (a+2c)/4$ and $\phi_2^T(c,c) = (a-2c)^2/16$, by (13), we have

$$h^c(\underline{\phi}) := F\left(p^D(r_1^*)\right) - (a+2c)(3a-2c)/16 + (a-2c)^2/16 \tag{15}$$

Now suppose $\underline{\phi} = \phi_2^T(0,c)$. Recall from Lemma 1 that

$$\phi_2^T(0,c) = \begin{cases} 0 & \text{if } a/3 \le c < a/2 \\ (a-3c)^2/16 & \text{if } c < a/3 \end{cases} \tag{16}$$

If $a/3 \le c < a/2$, then $r_1^*(\phi_2^T(0,c)) = 3c - a$, $p^D(r_1^*) = c$ and $F\left(p^D(r_1^*)\right) = c(a-c)$. Using this in (15), for this case we have

$$h^c(\phi_2^T(0,c)) = -2(a-2c)^2/16 < 0$$

If $c < a/3$, then $r_1^*(\phi_2^T(0,c)) = 0$, $p^D(r_1^*) = a/3$ and $F\left(p^D(r_1^*)\right) = 2a^2/9$. Using this in (15), for this case we have

$$h^c(\phi_2^T(0,c)) = \omega(c)/72 \text{ where } \omega(c) := 36c^2 - 36ac + 7a^2$$

As $\omega(c)$ is a u-shaped quadratic function of c, $\omega(0) = 7a^2 > 0$ and $\omega(a/3) = -a^2 < 0$, it follows that $\exists\, \widehat{c} \in (0, a/3)$ such that $\omega(c) \gtreqless 0 \Leftrightarrow c \lesseqgtr \widehat{c}$. Solving $\omega(c) = 0$, it can be shown that $\widehat{c} = (3-\sqrt{2})a/6$.

Therefore, $h^{\widehat{c}}(\phi_2^T(0,c)) < 0$, $h^c(\phi_2^T(0,c)) < 0$ if $c \in (\widehat{c}, a/3) \cup [a/3, a/2) = (\widehat{c}, a/2)$ and $h^c(\phi_2^T(0,c)) > 0$ if $c \in (0, \widehat{c})$. Since $h^c(\phi_2^T(c,c)) > 0$, the results (a)-(c) follow by the monotonicity of $h^c(\underline{\phi})$. The expression of $\widehat{\phi}(c)$ is derived by standard computations. ■

Proof of Proposition 1 If firm 2 enters the industry following the acceptance of the policy (r_1, f_1) by firm 1, then firm 0 offers the policy $(r_1, \Delta_2(r_1, r_1))$ to firm 2 [Lemma 2(I)(ii)]. Taking $\lambda_1 = 1$, $\widetilde{r}_1 = r_1$ and $r_2 = r_1$ in (5), the payoff of firm 0 is

$$\varphi(r_1) = \phi_0^T(r_1, r_1) + r_1 q_1^T(r_1, r_1) + r_1 q_2^T(r_1, r_1) + f_1 + \phi_2^T(r_1, r_1) - \phi_2^T(r_1, c) \qquad (17)$$

Part (I) Let $\underline{\phi} < \phi_2^T(0,c)$. For this case, regardless of the decision of firm 1, firm 2 enters the industry [Lemma 3(I)]. If 1 accepts the policy (r_1, f_1), it obtains $\phi_1^T(r_1, r_1) - f_1$ [Lemma 2(I)(ii)] and if it rejects, it obtains $\tau\phi_1^T(c, 0)$ [Lemma 2(II)(ii)(d)]. Therefore for any r_1, it is optimal for firm 0 to set $f_1 = \phi_1^T(r_1, r_1) - \tau\phi_1^T(c, 0)$ that makes firm 1 just indifferent between accepting and rejecting. Noting that $\phi_0^T(r_1, r_1) = p^T(r_1, r_1) q_0^T(r_1, r_1)$ and $\phi_i^T(r_1, r_1) = (p^T(r_1, r_1) - c) q_i^T(r_1, r_1)$, using the optimal f_1 and the function F from (12) in (17), firm 0's problem in stage I is:

$$\text{choose } r_1 \in [0, c] \text{ to maximize } \widetilde{\pi}(r_1) := F\left(p^T(r_1, r_1)\right) - \phi_2^T(r_1, c) - \tau\phi_1^T(c, 0) \qquad (18)$$

Since $p^T(r_1, r_1)$ is less than p_M and increasing and $F(p)$ is increasing for $p < p_M$, it follows that $F\left(p^T(r_1, r_1)\right)$ is increasing in r_1.

First let $r_1 \in [0, \theta]$ where $\theta \equiv \max\{0, 3c - a\}$. Then $\phi_2^T(r_1, c) = 0$ (Lemma A1) and by (18), $\widetilde{\pi}(r_1) = F\left(p^T(r_1, r_1)\right)$, which is increasing in r_1. Hence it is sufficient to consider $r_1 \in [\theta, c]$. In that case, it follows by Lemma 1(ii)(b) that $\phi_2^T(r_1, c) = (a + r_1 - 3c)^2/16$. Since $p^T(r_1, r_1) = (a + 2r_1)/4$, by (18), we have

$$\widetilde{\pi}(r_1) = (a + 2r_1)(3a - 2r_1)/16 - (a + r_1 - 3c)^2/16 - \tau\phi_1^T(c, 0)$$

As $\widetilde{\pi}'(r_1) = (a+3c-5r_1)/8 \geq (a+3c-5c)/8 = (a-2c)/8 > 0$, we conclude that $\widetilde{\pi}(r_1)$ is increasing for $r_1 \in [\theta, c]$. So it is optimal for firm 0 to offer royalty $r_1 = c$ to firm 1. Taking $r_1 = c$, the fee that 0 charges to 1 is $f_1 = \phi_1^T(c,c) - \tau\phi_1^T(c,0) > 0$.

Following the acceptance of this policy by 1, firm 2 enters the industry. Taking $r_1 = c$ in Lemma 2(I)(ii), firm 0 offers the policy $(r_2, f_2) = (c, \Delta_2(c,c))$ to firm 2. Since $\Delta_2(r_1,r_1) = \phi_2^T(r_1,r_1) - \phi_2^T(r_1,c)$ (by (4)), we have $\Delta_2(c,c) = 0$.

Part (II) Let $\underline{\phi} > \phi_2^T(c,c)$. Then regardless of the decision of firm 1, firm 2 stays out of the industry [Lemma 3(II)]. If 1 accepts the policy (r_1, f_1), it obtains $\phi_1^D(r_1) - f_1$ [Lemma 2(I)(i)] and if it rejects, it obtains $\phi_1^D(c)$ [Lemma 2(II)(i)]. Therefore for firm 0, it is optimal to set fee $f_1 = \phi_1^D(r_1) - \phi_1^D(c) = (p^D(r_1) - r_1)q_1^D(r_1) - \phi_1^D(c)$ from firm 1. The payoff of firm 0 is the sum of (i) $\phi_0^D(r_1) = p^D(r_1)q_0^D(r_1)$ (its profit in the market η), (ii) $r_1 q_1^D(r_1)$ (royalty payments from firm 1) and (iii) the fee f_1. Using (i)-(iii) and the function F from (12), firm 0's problem in stage I is:

$$\text{choose } r_1 \in [0,c] \text{ to maximize } F\left(p^D(r_1)\right) - \phi_1^D(c) \tag{19}$$

Since $F(p)$ is increasing for $p < p_M$, and $p^D(r_1)$ is less than p_M and increasing, it follows that $F\left(p^D(r_1)\right)$ is increasing in r_1. Then by (19), it is optimal for firm 0 to offer royalty $r_1 = c$ to firm 1. Taking $r_1 = c$, the fee is $f_1 = \phi_1^D(c) - \phi_1^D(c) = 0$. Following the acceptance of this policy by firm 1, firm 2 stays out of the industry to obtain $\underline{\phi}$.

Part (III) Let $\phi_2^T(0,c) < \underline{\phi} < \phi_2^T(c,c)$. Then by Lemma 3(III), if firm 1 rejects a policy then firm 2 enters the industry and if 1 accepts a policy (r_1, f_1), there is a threshold $r_1^*(\underline{\phi}) = 3c - a + 4\sqrt{\underline{\phi}} \in (0,c)$ that determines the entry decision of firm 2.

Case 1 $r_1 \in [0, r_1^*(\underline{\phi}))$: If firm 1 accepts the policy (r_1, f_1), then firm 2 stays out [Lemma 3(III)], so 1 obtains $\phi_1^D(r_1) - f_1$ [Lemma 2(I)(i)]. If 1 rejects, then 2 enters and firm 1 obtains $\tau\phi_1^T(c,0)$ [Lemma 2(II)(ii)(d)]. So it is optimal for 0 to set the fee $f_1 = \phi_1^D(r_1) - \tau\phi_1^T(c,0) = (p^D(r_1) - r_1)q_1^D(r_1) - \tau\phi_1^T(c,0)$.[21] The payoff of firm 0 is the sum of (i) $\phi_0^D(r_1) = p^D(r_1)q_0^D(r_1)$ (its profit in the market η), (ii) $r_1 q_1^D(r_1)$ (royalty payments from firm 1) and (iii) the fee f_1. Using (i)-(iii) and the function F from (12), firm 0's problem for this case I is:

$$\text{choose } r_1 \in [0, r_1^*) \text{ to maximize } \widehat{\pi}(r_1) := F\left(p^D(r_1)\right) - \tau\phi_1^T(c,0) \tag{20}$$

Since that $F\left(p^D(r_1)\right)$ is increasing in r_1, it follows from (20) that

$$\widehat{\pi}(r_1) < \widehat{\pi}(r_1^*(\underline{\phi})) = F\left(p^D(r_1^*(\underline{\phi}))\right) - \tau\phi_1^T(c,0) \text{ for all } r_1 \in [0, r_1^*(\underline{\phi})) \tag{21}$$

[21] Since $\phi_1^D(r_1) \geq \phi_1^D(c) \geq \phi_1^T(c,0) \geq \tau\phi_1^T(c,0)$, this fee is non-negative.

Case 2 $r_1 \in (r_1^*(\underline{\phi}), c]$: For this case, firm 2 enters regardless of the decision of firm 1 (Lemma 3(III)). From the proof of part (I), firm 0's problem is to maximize $\widetilde{\pi}(r_1)$ given in (18). We know from the proof of part (I) that $\widetilde{\pi}(r_1)$ is increasing, so its maximum for this case is attained at $r_1 = c$, where $f_1 = \phi_1^T(c,c) - \tau\phi_1^T(c,0)$. Taking $r_1 = c$ in (18), the payoff of firm 0 is

$$\widetilde{\pi}(c) = F\left(p^T(c,c)\right) - \phi_2^T(c,c) - \tau\phi_1^T(c,0) \tag{22}$$

Case 3 $r_1 = r_1^*(\underline{\phi})$: If firm 1 accepts a policy that has royalty $r_1 = r_1^*(\underline{\phi})$, then firm 2 is indifferent between entering the industry and staying out [Lemma 3(III)]. Firm 2 entering the industry cannot be sustained as SPNE, because in that case taking $r_1 = r_1^*(\underline{\phi})$ in Case 2, firm 0 would obtain $\widetilde{\pi}(r_1^*(\underline{\phi})) < \widetilde{\pi}(c)$ (since $\widetilde{\pi}(r_1)$ is increasing and $r_1^*(\underline{\phi}) < c$), so 0 can improve its payoff by deviating to $r_1 = c$. Therefore, 1 accepts a policy with $r_1 = r_1^*(\underline{\phi})$ in an SPNE, then firm 2 must stay out so that firm 0 obtains $\widehat{\pi}(r_1^*(\underline{\phi}))$ given in (21).

Using the conclusion of cases 1-3, there are two candidates for SPNE:

(i) $r_1 = r_1^*(\underline{\phi})$, $f_1 = \phi_1^D(r_1^*(\underline{\phi})) - \tau\phi_1^T(c,0)$, firm 2 stays out to obtain $\underline{\phi}$, market η is a duopoly with price $p^D(r_1^*(\underline{\phi})) = c + 4\sqrt{\underline{\phi}}/3$, firm 0 obtains $\widehat{\pi}(r_1^*(\underline{\phi}))$ and firm 1 obtains $\tau\phi_1^T(c,0)$.

(ii) $r_1 = c$, $f_1 = \phi_1^T(c,c) - \phi_2^T(c,0)$, $r_2 = c$, $f_2 = 0$, firm 2 enters the industry, market η is a triopoly with price $p^T(c,c)$, firm 0 obtains $\widetilde{\pi}(c)$, firm 1 obtains $\tau\phi_1^T(c,0)$ and firm 2 obtains $\phi_2^T(c,c)$.

To determine SPNE, we compare $\widehat{\pi}(r_1^*(\underline{\phi}))$ and $\widetilde{\pi}(c)$ from (21) and (22). Note that $\widehat{\pi}(r_1^*(\underline{\phi})) - \widetilde{\pi}(c) = h^c(\underline{\phi})$, given in (13) of Lemma A2. It follows by Lemma A2(ii) that $\exists\ \widehat{c} \in (0, a/3)$ such that:

(i) If $c \in (0, \widehat{c}]$, then $\widehat{\pi}(r_1^*(\underline{\phi})) > \widetilde{\pi}(c)$ for all $\underline{\phi} \in (\phi_2^T(0,c), \phi_2^T(c,c))$, which proves (III)(a).

(ii) If $c \in (\widehat{c}, a/2)$, then $\exists\ \widehat{\phi}(c) \in (\phi_2^T(0,c), \phi_2^T(c,c))$ such that $\widehat{\pi}(r_1^*(\underline{\phi})) \gtreqqless \widetilde{\pi}(c) \Leftrightarrow \underline{\phi} \gtreqqless \widehat{\phi}(c)$. Hence for $\underline{\phi} \in (\phi_2^T(0,c), \widehat{\phi}(c))$, the result is same as part (I) and for $\underline{\phi} \in (\widehat{\phi}(c), \phi_2^T(c,c))$ the result is same as part (III)(b).

This completes the proof of Proposition 1. ■

Proof of Proposition 2

We focus on region B of Proposition 1, where $\max\{\phi_2^T(0,c), \hat{\phi}(c)\} \leq \underline{\phi} \leq \phi_2^T(c,c)$. When $F0$ can deter entry, the market price is $p^D(r_1^*) = \frac{a+r_1^*}{3}$, where $r_1^* = 4\sqrt{\underline{\phi}} + 3c - a$. When $F0$ is unable to deter entry, the market price is $p^T(c,c) = \frac{a+2c}{4}$. Entry deterrence therefore increases the price iff $p^D(r_1^*) > p^T(c,c) \Leftrightarrow 4r_1^* > 6c - a$. So if $c < a/6$ entry deterrence always increases the price, and if $c < a/6$ it increases the price iff $\underline{\phi} > \frac{9(a-2c)^2}{64} = \phi^*(c)$. This is a decreasing function of c, with $\phi^*(c) \geq \hat{\phi}(c)\,\forall c \leq a/2$, and $phi^*(c) \geq \phi_2^T(0,c)$ iff $c \geq a/6$. ∎

Proof of Lemma 4

Parts (a and b) When the entry cost is such that $\underline{\phi} < \max\{\widehat{\phi}(c), \phi_2^T(0,c)\}$, the market η is a triopoly with firms $0, 1, 2$. Taking $r_1 = r_2 = c$ in Lemma 1(ii), the price is $p^T(c,c) = (a+2c)/4$. Firm 1 obtains $\phi_1^T(c,c) - f_1 = \tau\phi_1^T(c,0)$. Since $f_2 = 0$, firm 2 obtains $\phi_2^T(c,c) - f_2 = \phi_2^T(c,c)$. Firm 0's payoff is given by $\phi_0^T(c,c) + cq_1^T(c,c) + cq_2^T(c,c) + \phi_1^T(c,c) - \tau\phi_1^T(c,0) = F\left(p^T(c,c)\right) - \phi_2^T(c,c) - \tau\phi_1^T(c,0)$ for all $r_1 \in [0, r_1^*(\underline{\phi}))$.

Part (c) If the entry cost is such that $\max\{\widehat{\phi}(c), \phi_2^T(0,c)\} < \underline{\phi} < \phi_2^T(c,c)$, 1 accepts the policy $(r_1^*(\underline{\phi}), f_1)$, then firm 2 stays out [Lemma 3(III)], so firm 1 obtains $\phi_1^D(r_1^*(\underline{\phi})) - f_1$ [Lemma 2(I)(i)], which is equal to its outside option, as in parts (I) and (II). The payoff of firm 0 is the sum of (i) $\phi_0^D(r_1^*(\underline{\phi})) = p^D(r_1^*(\underline{\phi}))q_0^D(r_1^*(\underline{\phi}))$, (ii) $r_1^*(\underline{\phi})q_1^D(r_1^*(\underline{\phi}))$ (royalty payments from firm 1) and (iii) the fee f_1, which is equal to $F\left(p^D(r_1^*(\underline{\phi}))\right) - \tau\phi_1^T(c,0)$. Since $p^D(r_1^*(\underline{\phi})) > p^T(c,c), F\left(p^D(r_1^*(\underline{\phi}))\right) > F\left(p^T(c,c)\right) > F\left(p^T(c,c)\right) - \phi_2^T(c,c)$, so $\pi_0^{\text{III}} > \pi_0^I$.

Part (d) For high values of the entry cost, such that $\underline{\phi} < \phi_2^T(0,c)$, the market is a duopoly with firms 0 and 1. Taking $r_1 = c$ in Lemma 1(i), the price is $p^D(c) = (a+c)/3$. Since $f_1 = 0$, firm 1 obtains $\phi_1^D(c)$. Taking $r_1 = c$ in (19), firm 0 obtains $F\left(p^D(c)\right) - \phi_1^D(c)$. Observe that $\lim_{\underline{\phi}\uparrow\phi_2^T(c,c)} p^D(r_1^*(\underline{\phi})) = c + 4\sqrt{\phi_2^T(c,c)}/3 = (a+c)/3 = p^D(c)$. Hence it follows that $\lim_{\underline{\phi}\uparrow\phi_2^T(c,c)} \pi_0^{\text{III}} = F(p^D(c)) - \tau\phi_1^T(c,0) > F(p^D(c)) - \tau\phi_1^D(c) = \pi_0^{\text{IV}}$. This completes the proof of part (d).

Proof of Proposition 3

According to equation 10,

$$\frac{dx^k}{d\underline{\phi}}\rho''(x^k)\{\pi_0^k - \overline{\phi} - \rho(x^k)[(1/2)\pi_0^k + (1/2)\pi_1^k - \overline{\phi}]\} - \frac{dx^k}{d\underline{\phi}}(\rho'(x^k))^2\{(1/2)\pi_0^k + (1/2)\pi_1^k - \overline{\phi}\}$$
$$+\rho'(x^k)\frac{d\pi_0^k}{d\underline{\phi}}\{1 - (1/2)\rho(x^k)\} = 0$$

Following the second order condition, the first element of this equation is negative. Since $(1/2)\pi_0^k + (1/2)\pi_1^k - \overline{\phi} > 0$, the second element is also negative. Therefore, $\frac{dx^k}{d\underline{\phi}}$ is of the sign of $\frac{d\pi_0^k}{d\underline{\phi}}$. As stated in Lemma 4, $\frac{d\pi_0^{\text{C}}}{d\underline{\phi}} = \frac{d\pi_0^{\text{A}}}{d\underline{\phi}} = \frac{d\pi_0^{\text{N}}}{d\underline{\phi}} = 0$, and $\frac{d\pi_0^{\text{B}}}{d\underline{\phi}} > 0$. Therefore, x^k is a constant in all regions except in (B) where x^{B} is increasing with $\underline{\phi}$.

To show that $x^{\mathrm{B}} > x^{\mathrm{C}}$, we show that the left hand side of the first order condition given in 9 is negative when $k = C$ and $x_i = x^{\mathrm{B}}$. This is equivalent to the following inequality:

$$\rho'(x^{\mathrm{B}})\{\pi_0^{\mathrm{B}} - \overline{\phi} - \rho(x_j)[(1/2)\pi_0^{\mathrm{B}} + (1/2)\pi_1^{\mathrm{B}} - \overline{\phi}]\} > \rho'(x^{\mathrm{B}})\{\pi_0^{\mathrm{C}} - \overline{\phi} - \rho(x_j)[(1/2)\pi_0^{\mathrm{C}} + (1/2)\pi_1^{\mathrm{C}} - \overline{\phi}]\}$$
$$\Leftrightarrow \pi_0^{\mathrm{B}} - \pi_0^{\mathrm{C}} > \rho(x_j)[(1/2)\pi_0^{\mathrm{B}} + (1/2)\pi_1^{\mathrm{B}} - (1/2)\pi_0^{\mathrm{C}} - (1/2)\pi_1^{\mathrm{C}}]$$

According to Lemma 4, $\pi_0^{\mathrm{B}} > \pi_0^{\mathrm{C}}$ and $\pi_1^{\mathrm{B}} = \pi_1^{\mathrm{C}}$, so the right hand side of this inequality is increasing with $\rho(x_j)$. Therefore, a sufficient condition for this inequality to be satisfied is

$$\pi_0^{\mathrm{B}} - \pi_0^{\mathrm{C}} > (1/2)\pi_0^{\mathrm{B}} + (1/2)\pi_1^{\mathrm{B}} - (1/2)\pi_0^{\mathrm{C}} - (1/2)\pi_1^{\mathrm{C}} \Leftrightarrow \pi_0^{\mathrm{B}} - \pi_0^{\mathrm{C}} > \pi_1^{\mathrm{B}} - \pi_1^{\mathrm{C}},$$

which is satisfied following Lemma 4.

We use a similar reasoning to compare x^{B} and x^{N}. We show that $x^{\mathrm{B}} > x^{\mathrm{N}}$ if the following inequality is satisfied:

$$\Leftrightarrow \pi_0^{\mathrm{B}} - \pi_0^{\mathrm{N}} > \rho(x_j)[(1/2)\pi_0^{\mathrm{B}} + (1/2)\pi_1^{\mathrm{B}} - (1/2)\pi_0^{\mathrm{N}} - (1/2)\pi_1^{\mathrm{N}}]$$

According to Lemma 4, $\pi_0^{\mathrm{B}} + \pi_1^{\mathrm{B}} - \pi_0^{\mathrm{N}} - \pi_1^{\mathrm{N}} = F\left(p^D(r_1^*(\underline{\phi}))\right) - F\left(p^D(c)\right) < 0$. Therefore, the right hand side of the above inequality is decreasing with $\rho(x_j)$, so a sufficient condition for this inequality to be satisfied is

$$\pi_0^{\mathrm{B}} - \pi_0^{\mathrm{N}} > 0,$$

which is satisfied following Lemma 4.

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