Luca Sandrini
DSEA, University of Padova

INNOVATION, COMPETITION AND INCOMPLETE ADOPTION OF A SUPERIOR TECHNOLOGY

May 2020

Marco Fanno Working Papers - 251

Innovation, Competition, and Incomplete Adoption of a Superior Technology

Luca Sandrini*

QSMS - Budapest University of Technology and economics
sandrini.luca@gtk.bme.hu

April, 2020

Abstract

This paper shows that competition exerts a feedback effect on innovation. First, downstream competition increases the willingness to pay for a more efficient technology (the direct effect). Second, a sufficiently large innovation may provide the licensees with a robust strategic advantage that forces non-adopters out of business. In turn, this raises the licensee's willingness to pay to survive in the market (the indirect effect). More specifically, if the competition is very intense, even a tiny innovation may entail drastic effects in the market. Moreover, this article shows that royalties do not always imply the complete adoption of a superior technology because of competition's indirect effect on innovation. An innovator may prefer to license a large innovation to a subset of firms at a discounted price, regardless of the contract scheme enforced. Finally, this article suggests that the removal of inefficient firms is not welfare-improving from a policy perspective.

JEL Code: L13, L24, O31

Key-Words: Innovation, Licensing, Oligopoly, Competition

*I wish to thank Fabio Manenti, Luciano Greco, José L. Moraga Gonzalez, Evgenia Motchenkova, Jos Jansen, Paola Valbonesi, Carlo Reggiani, and Stefano Comino for their comments on earlier versions of this article. This paper has been presented in the ASSET Conference 2019, the SIEP 2020 Annual Conference and the SIE 2020 Annual Meeting.

1 Introduction

A patent represents an Intellectual Property (IP) protection strategy that enables an innovator to appropriate the public good she creates (knowledge) while guaranteeing the complete disclosure of information in order for the innovative process to keep flowing. Since the seminal work by Arrow (1962), who argues that a perfectly competitive industry is superior to the monopoly in providing firms with incentives to invest in innovation, the literature has analyzed the role and the effect of competition on innovation and the value of a patent. Aghion et al. (2005) show that the relationship between competition and incentives to innovate may exhibit an inverted U-shape, embedding both the Schumpeterian idea of the superiority of monopoly in driving innovative activity and the opposite Arrowian replacement effect.[1] Very recently, Denicolò and Lambertini (2020) prove that, under some plausible conditions, models of competition based on linear demands may be able to predict a non-monotone relationship between competition and incentives to innovate.[2] This article aims to contribute to this large body of literature by highlighting an overlooked aspect of the relationship between competition and innovation, namely the *feedback* effect of competition on the innovative process via the licensing mechanism. More in detail, this article answers this central research question:

What are the direct and indirect effects of downstream competition in altering the size, the diffusion, and the impact of an innovation produced by the upstream innovator?

To answer this question, I design a model in which a monopolist innovator (upstream) licenses her process innovation to many downstream manufacturers. To maximize her profits, the innovator chooses the licensing scheme (royalties or fixed fee), the price of the technology, and the investments in R&D.[3] The patent's value from the innovator's perspective does not consist in the mere quasi-rent granted by the monopoly over the new creation, but also in the revenues derived by the possibility of licensing it to other firms. Focusing on licensing, several scholars have investigated which selling mechanism is the most profitable for the innovators. Licensing under imperfect competition was first analysed by Kamien and Tauman (1986), Kamien et al. (1992) and Katz and Shapiro (1985). All these early contributions look for the most efficient licensing scheme. They suggest that upfront fees dominate royalties from the innovator's perspective, while the auction is the most efficient one for an outside innovator. In the light of these results, the dominance of royalties in empirical evidence has been considered puzzling.[4] An explanation of this fact has been advanced, among others, by Gallini and Wright (1990), who suggest that asymmetry of information can explain the dominance of royalties in empirical evidence. In contrast, Sen (2005) focuses on the technical constraints on the number of adopting firms. However, all these works analyze the licensing outcomes where the innovation's size is exogenously given, while few conclusions on how competition affects the innovation's size and its impact on the market structure can be drawn from existing literature. This paper shows that competition exerts a *feedback* effect on innovation. First, downstream competition magnifies the

[1] See Aghion et al. (2015, 2019) for a detailed survey of the literature on the evidence of inverted-U patterns.

[2] Hermosilla and Wu (2018) provide an interesting analysis of how the market structure affects cooperation in the R&D stage.

[3] The model's vertical structure helps incorporate both the Schumpeterian idea of the superiority of monopoly in the upstream sector and the Arrowian replacement effect downstream.

[4] Rostoker (1984) shows that royalties (39%) and combination of royalties and fees (49%) are largely more common than upfront fees (13%) in corporate licensing transactions.

replacement effect and the monopolistic power to extract surplus from licensees and leads to more significant investments in equilibrium (the direct effect). Second, large innovations imply a strong strategic advantage of adopters versus non-adopters. If the innovation size is sufficiently large, licensees force non-adopters out of business, and market concentration increases. In turn, this raises the licensee's willingness to pay for innovation and the size of innovation in equilibrium (the indirect effect). More specifically, if the competition is very intense, even a tiny innovation may entail drastic effects in the market. This result holds for both the licensing schemes analyzed. Therefore, costly innovations (due, for instance, of the associated risk) are more effective in more competitive markets, while they are unlikely to have consequences on concentrated industries' market structure. To my knowledge, this article is the first to identify this *feedback* effect of competition on innovation explicitly.

Besides the relationship between market structure and licensing outcomes, the literature has also focused on the diffusion of innovation entailed by different contract schemes. Typically, royalties guarantee full adoption of the new technology (Sen and Tauman, 2018; Kamien et al., 2002). A notable exception is in Lapan and Moschini (2000): in the case of a multi-input production function, royalty licensing may result in the partial adoption of process innovation. Erutku and Richelle (2007) show that it is always possible to design a two-part tariff scheme that endures complete adoption of the technology and rent extraction that replicates the monopoly profits for the innovator (see also Sen and Stamatopoulos (2016)).[5] Sen and Tauman (2018) and Sen and Tauman (2007) are the closest references for the present article. They provide detailed analysis of the licensing outcomes with different selling mechanisms (royalties and upfront fees), as well as optimal combinations of them that foster incentives to invest in innovation. This article shows that royalties do not necessarily imply complete adoption of a superior technology. If the innovation is substantial, an innovator may prefer to license it at a lower price to a subset of the product market firms. By doing so, the innovator introduces a strategic advantage to the adopters who can expand their outcome and force the non-adopting rivals out of the market. Since the technology price is lower than the cost-reducing effect, the net gain from adoption is positive and the output expansion effect is sufficiently high to outweigh the revenues from full licensing.

Marshall and Parra (2019) and Parra (2019) are also close references. By developing a sequential R&D model, they show that the relationship between product market competition and the leader-follower profits gap drives the effect of competition on the innovation's incentives. However, as they focus on the optimal licensing policy, these articles do not endogenize the size of innovation nor internalize the competition's *feedback* effect on innovation. Furthermore, they do not specifically address the likelihood of a drastic innovation given the market structure and the innovator's characteristics. This paper explicitly addresses the twofold effect of competition on the innovation's size (the direct and indirect effects). If investing in innovation is sufficiently cheap, the innovator licenses the new technology to a subset of the downstream firms, regardless of which contract scheme the innovator enforces. In the case of licensing via a linear price scheme, an outsider innovator may prefer to license only a subset of firms in the product market if the innovation is sufficiently large, with a consequent shake-out of the industry (k-drastic innovations,

[5] Badia et al. (2020) study how competition among innovators may delay innovation diffusion.

see Sen and Tauman (2007)). Similarly, suppose the innovator chooses an upfront fee; then, the result may be full adoption of the innovation, partial adoption with heterogeneous technological endowment, or partial adoption with industry shake-out.

When adoption of the superior technology is partial, and both adopters and non-adopters stay in the market, the policy-maker faces a problem of misallocation of the production, which is detrimental to welfare (as the firms endowed with the old technology are producing positive quantities of the final good). However, this article suggests that the removal of inefficient firms in a model where an upstream patentee licenses the efficient technology is not welfare-improving, as the efficiency gains from the reallocation of the output do not exceed the diseconomies coming from a more concentrated market.[6] Also, this paper updates the result in Lahiri and Ono (1988) that, from the policy-maker perspective, removal of inefficient firms is welfare-improving. The authors show that the gains from the efficient allocation of production to more productive firms compensate the diseconomies from a more concentrated market. This article adds that a licensor of a large innovation achieves a comparable result by offering her technology to a small subset of downstream firms, forcing non-adopters out of the market. However, the model presented in this article differs from Lahiri and Ono (1988), as it assumes ex-ante symmetric firms in a vertical market. The rest of the paper is structured as follows. Section 2 presents the model and the main assumptions; section 3 presents and discusses the results. Finally, section 4 concludes.

2 The model

Consider a model where an outside innovator (u) supplies a superior technology to n identical firms (d) competing in quantities of a homogeneous good. The n firms face a linear inverse demand function $P = a - Q$, with $Q = \sum_{i=1}^{n} q_i$, and have access to a standard technology which is freely available in the market and allows the production of the final good at a constant marginal cost $c < a$. By purchasing the superior technology supplied by the outside innovator, a firm can lower its production cost from c to $c - x$, where $x \in (0, c]$ represents the cost-reducing effect of the innovation. The new technology is developed only once by investing $I(x)$ and is sold to the downstream firms. Formally, the upstream supplier's investment exhibits the convex cost function $I(x) = \gamma x^2$, where γ represents the cost of equipment necessary to the development of the technology.

Similarly to Sen and Tauman (2007), I compare the innovator's incentives embedded into two different licensing scheme regimes: royalties and fixed fee. Moreover, I analyze the direct and indirect effects of downstream competition on the innovation size x, given the innovator's licensing scheme.

I define two types of innovation: non-drastic and k-drastic.

Definition 1. *Sen and Tauman (2007). For $k \geq 1$, a cost-reducing innovation is k-drastic if k is the minimum number such that if k firms have the innovation, all other firms drop out of the market, and a k-firm natural oligopoly is created.*

[6] Absent the inefficient technology, licensing of the production technology by an outside innovator exacerbates market concentration's inefficiencies, as she would create a vertical monopoly.

Licensing Schemes. I assume that the innovator can license her technology either with a non-negative linear price r (royalties) or a non-negative fixed fee F. The linear price r is proportional to the cost-reducing effect x, regardless of the number of firms m that adopt the new technology: $r = \beta x$, with $\beta \in (0, 1]$.

Instead, the fixed fee F extracts the difference between pre- and post-innovation profits of the adopting firms and depends crucially on the number of adopters. Let $\pi_A(x, m)$ and $\pi_B(x, m)$ be the profits of the adopting and non-adopting firms, respectively, given the size of innovation x and the number of adopters m. The maximum fixed fee that the m adopting firms are willing to pay is $F = \pi_d^A(x, m) - \pi_d^B(x, m - 1)$, namely, the difference between what a firm gets by purchasing an innovation and by not doing it, knowing that $m - 1$ rivals are going to produce with the superior technology. In other terms, this is the maximum fee that an innovator can set in order to prevent unilateral deviation of both adopters and non-adopters in a take-it-or-leave-it offer. I define $F(x, m)$ the fee chosen by the innovator intended to elicit the adoption of innovation of size x by exactly m firms. I assume as a tie-breaking rule that firms have preference for innovation - i.e., if it comes at no extra costs, they will always choose the superior technology. Formally, for an innovation of size x to be adopted by m firms it must be that:

$$\pi_d^A(x, m) - F(x, m) \geq \pi_d^B(x, m - 1) \tag{C.1}$$

If condition C.1 is satisfied with equality, it is sufficient for the equilibrium number of adopters to be unique.

The timing of the game. The game is developed in the following stages:

- t=0 The innovator sets the size of innovation x;
- t=1 The innovator chooses the licensing contract (r or F);
- t=2 Given the price charged by the innovator, the downstream firms decide whether or not to adopt the new technology;
- t=3 Downstream firms compete à la Cournot and profits are realized.

Solution is by backward induction.

3 Results and discussion

3.1 Royalties

Non-drastic innovation. I first focus on the subgame where the innovator chooses to license her innovation using a linear price (royalty) r. When the innovation is non-drastic, the level of r cannot exceed the cost-reducing effect of the innovation. This condition represents the Participation Constraint (P.C.) of the innovator's maximization problem ($\beta = 1$ such that $r = x$). As the P.C. is binding, the innovator sets $r = x$ in order to maximize her revenues (Kamien et al., 2002). When this is the case, the price of the technology zeroes out the cost-reducing effect.

Thus, we reach the almost paradoxical conclusion that the downstream production process is as if it was not affected by the innovation.

$$\pi_u^r = r(x)\,Q(x,r) - I(x) = \frac{n\,x\,(a-c)}{n+1} - \gamma\,x^2 \tag{1}$$

$$\frac{\partial\,\pi_u^r}{\partial, x} = 0 \quad\Rightarrow\quad x^r = \frac{n(a-c)}{2\,\gamma(n+1)} \tag{2}$$

where the superscript r stands for **r**oyalty-based licensing scheme. One can see that the equilibrium value of innovation is proportional to the downstream industry output $x_u^r = Q(n)/(2\gamma)$, and it is therefore increasing in the intensity of competition - a well established result in the literature.

K-drastic innovation. When the innovation is sufficiently large, the adoption by a restricted number of downstream firms may imply the exit of the non-adopting firms from the market. Intuitively, suppose the technology's price is equal to the cost-reducing effect of the innovation, as in the case described above. In that case, adopters and non-adopters do not differ in terms of technology, as they end up paying the same marginal costs of production. However, if the innovator sets a lower price for her technologies ($r = \beta\,x < x$), then a strategic advantage emerges for the adopters, while non-adopters suffer a strategic disadvantage.[7] Focusing on the latter, it increases in size together with the net cost-reducing effect ($x - r = x(1-\beta) > 0$ if $\beta < 1$) and the number of adopters m. Formally, an innovation is k-drastic if it satisfies:

$$x \geq \frac{(a-c)}{m(1-\beta)} \quad \text{with} \quad m \in [k, n-1] \tag{C.2}$$

The innovator's choice is the number of licensees to sell. Depending on the desired number of adopters m, she earns:

$$R_u^{Dr}(m,x,\beta) = \begin{cases} \frac{m\,\beta\,x\,(a-c+x(1-\beta))}{m+1} & \text{if} \quad m \in [k, n-1] \\ \frac{n\,x\,(a-c)}{n+1} \equiv R_u^r & \text{if} \quad m = n \end{cases}$$

where the superscript Dr stands for **D**rastic innovation under **r**oyalty-based licensing.[8].

Ultimately, the decision of the innovator depends on which choice is more profitable. One can see that:

$$R_u^{Dr}|_{m<n} \geq R_u^{Dr}|_{m=n} \quad \text{if} \quad x \geq \frac{(a-c)((m+1)n - \beta m(n+1))}{(1-\beta)\beta m(n+1)} \tag{C.3}$$

It is possible to see that, whenever the innovator sets $\beta \in [\beta^*, 1)$, where $\beta^* = \frac{n}{n+1}$, C.3 is subsumed by C.2. By rewriting condition C.2 relatively to m, and using it in the innovator's revenues, it is possible to derive the equilibrium size of the k-drastic innovation and, consequently,

[7] See the mathematical appendix.

[8] Notice that, in this case, the optimal royalty rate is $r = x$. Here, I do not consider the case in which $m < k$, as it is always a dominated strategy for the innovator, who ends up earning lower profits. Moreover, if that is the case, the strategic disadvantage exerted by the $m < k$ adopters on non-adopters would not be sufficiently strong to force the latter out of the market.

the number of licensees in equilibrium:

$$\frac{\partial \pi_u^{Dr}(x,\beta,\gamma)}{\partial, x} = 0 \quad \Rightarrow \quad x^{Dr}(\beta,\gamma) = \frac{(a-c)\beta}{2\gamma}; \quad m^{Dr}(\beta,\gamma) = \frac{2\gamma}{\beta(1-\beta)} \tag{3}$$

With $\gamma \leq \gamma^{Dr} \equiv \frac{\beta(1-\beta)(n-1)}{2}$ to ensure conditions C.2 is satisfied. As before, C.3 holds when $\beta \in [\beta^*, 1)$.

This counterintuitive result states that the innovator, under certain conditions, may be willing to offer a discounted royalty rate $r = \beta x$ to a restricted number of downstream firms m^{Dr}, as this guarantees her higher profits. To understand it, suppose that the cost-benefit x exceeds the price of innovation r. Intuitively, the adopters reduce their marginal cost of production and expand their output (*output-expansion* effect, OEE hereafter). In contrast, non-adopting rivals produce at relatively high marginal costs and suffer a strategic disadvantage. As the price r decreases, the OEE gets more substantial, so does the opportunity cost of not being licensed. Eventually, when the OEE is sufficiently large, non-adopters suffer a disproportionate loss that forces them out of the market. Intuitively, this rationing of licensees that the innovator can put forward is profitable only if it exerts drastic effects on the market (shake-out of the industry) and ensures that the efficiency gain outweighs the diseconomies from a more concentrated market. This result updates the one in Lahiri and Ono (1988). From the policy-maker's perspective, increasing market concentration and excluding the less productive firms from operating in the market is socially enhancing. The authors argue that the reallocation of the production to the efficient firms compensates the diseconomies from a more concentrated market. Here, I add that a patent holder of a superior technology achieves a comparable result if the cost-reducing benefits of the technology she owns are sufficiently large. In such a scenario, reducing the number of licensees and forcing non-adopting firms out of the market is more efficient than offering the same technology to all firms. Intuitively, the innovator's rationing of licenses is socially efficient because it implies expanding the downstream output (and the licensing revenues). The main difference with Lahiri and Ono (1988) is that, in this model, firms are ex-ante symmetric, and any ex-post asymmetry is a product of the strategic interaction between the upstream supplier and the downstream manufacturers.

Proposition 1. *Assume the licensing scheme is a per-unit linear price, and that $\gamma \leq \gamma^{Dr}$. Then the innovator is willing to license the new technology to a restricted number of firms $m^{Dr} < n$ for a discounted royalty-rate $r^{Dr} = \beta x^{Dr}$, with $\beta \in [\beta^*, 1)$. The rationing of licenses is socially efficient.*

One can see that n does not alter the size of innovation in equilibrium. It is so as the innovator's revenues stream only depends on the m^{Dr} adopting firms that are still active in the market, on the cost parameter γ, and the share of cost-reducing effect seized by the innovator β. However, as the intensity of competition increases, the range of compatible βs shrinks. Moreover, if one looks at the condition on the cost parameter $\gamma \leq \gamma^{Dr}$, it is easy to show that $n \uparrow$ implies that the condition is less strict.

Proposition 2. *Competition does not influence **directly** the size of a k-drastic innovation under a royalty-based licensing scheme. However, as $\frac{\partial \gamma^{Dr}}{\partial n} > 0$ and $\frac{\partial \beta^*}{\partial n} > 0$, it **indirectly** increases the*

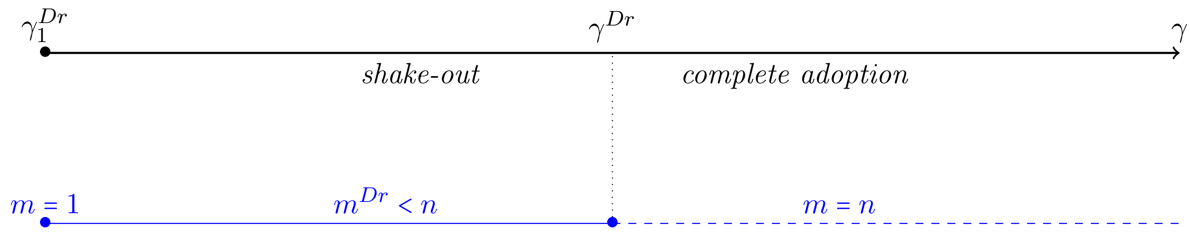

Figure 1: The effects of innovation on market structure, depending on the efficiency of the innovator γ. Notice that $\gamma_1^{Dr} = \frac{\beta(1-\beta)}{2}$ is the threshold below which $m^{Dr} = 1$.

incentives of an innovator to develop a k-drastic innovation.

A potential policy that is often considered in the context of technology adoption is the possibility for a policy-maker to mandate a switch-off of the old technology to speed the diffusion of the innovation up. However, when the market structure is such that the innovative technology is provided by an upstream innovator, removing the standard technology implies that the new one becomes a fundamental input. The consequence is that the innovator is free to set the monopoly price for her innovation, establishing a vertical monopoly. Thus, switching off the standard technology would maximize the double marginalization problem, lowering social welfare.

3.2 Fixed fees

In this subsection, I now turn to the subgame in which the innovator licenses her innovation by using a licensing fee $F(x,m)$.

Non-drastic innovations. At time $t = 2$, the downstream firms observe the pair (F,x) and decide whether to adopt the innovation and reduce their costs to $c - x$ (paying the fee F) or to keep on producing with the freely available standard technology at the constant marginal cost c. Ultimately, the innovation is adopted by m firms if Condition C.1 is satisfied. By solving C.1 with equality, it is possible to derive the maximum fee that an innovator can charge to elicit m firms.

$$F(m,n,x) = \frac{nx(2(a-c) + x(n-2m+2))}{(n+1)^2}$$

Standard profits maximization process yields the equilibrium size of innovation x^F:

$$\pi_u^F = mF(m,n,x) - I(x) = \frac{n\,m\,x(2(a-c) + x(n-2m+2))}{(n+1)^2} - \gamma\,x^2 \tag{4}$$

$$\frac{\partial\,\pi_u^F}{\partial\,x} = 0 \;\Rightarrow\; x^F(m) = \frac{m(a-c)n}{\gamma(n+1)^2 - m(n-2m+2)n} \quad \text{with} \quad m \in [1,n] \tag{5}$$

where the superscript F stands for fixed **F**ee.

One can see that the innovator's profits π_u^F reaches its maximum in $m^F = \min\{\bar{m}(n), n\}$, where $\bar{m}(n) = \frac{2\gamma(n+1)^2}{n(n+2)}$. Thus, by using this value into eq. 5 I derive the equilibrium size of the innovation:

$$x^F = \begin{cases} \frac{2n(n+2)(a-c)}{8\gamma(n+1)^2 - n(n+2)^2} & \text{if} \quad \gamma < \gamma^F \\ \frac{n^2(a-c)}{\gamma(n+1)^2 + (n-2)n^2} & \text{otherwise.} \end{cases} \tag{6}$$

where γ^F s.t. $m^F|_{\gamma=\gamma^F} = n$.

Proposition 3. *Let the innovator choose a fixed fee licensing regime to license a non-drastic innovation. Then, competition influences the licensing outcome in two main ways. First, increasing the competitive pressure (given the adoption rate m^F) magnifies the strategic advantage of adopters and, consequently, their willingness to pay for the innovation, with a positive effect on the equilibrium size x^F. Second, as competition lowers the profit margins of the downstream firms, it also hampers the surplus extraction of the innovator. Thus, in order to shield her revenue stream from licensing, the innovator reduces the number of contracts to be licensed in equilibrium ($\bar{m}'_n < 0$)*

$$\frac{\partial x^F}{\partial n}\begin{cases} > 0 & \textit{if} \quad \gamma \geq \frac{n^3}{2n+2} \\ < 0 & \textit{if} \quad \frac{n^3}{2n+2} > \gamma \geq \gamma^F \\ > 0 & \textit{if} \quad \gamma^F > \gamma \end{cases}$$

K-drastic innovations. A k-drastic innovation satisfies $x \geq \frac{a-c}{m}$. From the literature, we know that when the innovation has a size $x = \frac{a-c}{k}$, with $k \leq n-1$, the optimal number of licensees is $m^* = k$ (Kamien and Tauman, 1986).

The innovator sells the drastic innovation to $m^* = k$ downstream firms and lets those who do not become licensees exit the market. The adopters' licensing fee cannot exceed the replacement effect measured as the difference between the profits they would earn with the new technology, minus their opportunity cost of adoption (the participation constraint is binding). Thus, the higher fee that the innovator can charge is:

$$F^{DF}(m,n,x) = \frac{\Big((a-c)(m+n+2) + x\left(-m^2+n+2\right)\Big)\Big((a-c)(n-m) + x\left(m^2+n\right)\Big)}{(m+1)^2(n+1)^2}$$

where the superscript DF indicates the scenario with a k-**D**rastic innovation licensed via a fixed **F**ee. Notice that, as $x = \frac{a-c}{m}$ with $m \in [k, n-1]$ is the condition for the innovation to be k-drastic, then it is possible to rewrite the number of adopters as $m^* = \frac{a-c}{x}$. Using this value, it is possible to derive the equilibrium size of innovation:

$$x^{DF} = \begin{cases} \frac{n(n+2)(a-c)}{2\gamma(n+1)^2} & \text{if} \quad \gamma_1^{DF} < \gamma < \gamma^{DF} \\ \frac{a-c}{4\gamma-1} & \text{if} \quad \gamma \leq \gamma_1^{DF} \end{cases} \tag{7}$$

where $\gamma^{DF} = \frac{n(n+2)^2}{4(n+1)^2}$ and $\gamma_1^{DF} = \frac{n(n+2)}{2(n+1)^2}$ are the thresholds that sorts non-drastic from k-drastic innovations, and k-drastic from 1-drastic innovations, respectively.

Using 7, it is now possible to determine the profit-maximizing number of adopters in equilibrium:

$$m^* = k = \frac{a-c}{x^*} = \frac{2\gamma(n+1)^2}{n(n+2)} \equiv \bar{m} \tag{8}$$

Interestingly, one can see that m^{DF} is a decreasing function of n, and coincides with the number of licensees derived in the case of non-drastic innovations $m^* = \bar{m}$. Intuitively, there is a lower bound to the number of licensees in equilibrium $m \geq 1$. There is no reason why the innovator should not sign any contract, as this would imply earning no profits at all. From these results it follows that the equilibrium number of licensees is $m^{DF} = \max\{1, \bar{m}\}$. Moreover, the stronger the competition, the larger the innovation, and, consequently, the fewer the licensees. Finally, turning on the effect of competition on the size of innovation, we can state that:

Proposition 4. *Let the innovator choose a fixed fee licensing regime to license a k-drastic innovation. Then, competition influences the size of innovation by altering the exposure of the market to k-drastic innovations - i.e., by increasing the fragility of the market. In fact, the more intense the competition, the higher the willingness to pay to be among the restricted number of adopters. In turns, this means the innovator would invest more and that the resulting innovation would exert an even larger strategic disadvantage to non-adopters, lowering the required number of contracts necessary for the innovation to have drastic effects on the market ($\bar{m}'_n < 0$). However, if the innovation is 1-drastic, competition ceases to have any effect on the incentives to invest in innovation:*

$$\frac{\partial x^{DF}}{\partial n} \begin{cases} > 0 & \text{if} \quad \gamma^{DF} \geq \gamma > \gamma_1^{DF} \\ = 0 & \text{if} \quad \gamma_1^{DF} \geq \gamma \end{cases}$$

By combining the results derived in the previous paragraphs, we can see that the number of contracts offered by the upstream innovator depends monotonically on the cost parameter γ that measures how costly the investment in innovation is.

Suppose $\gamma \leq \gamma^{DF}$, the innovator is always able to set the cost-reducing effect of the innovation at a k-drastic level. In this case, $m^{DF} < n$ firms become licensees and stay active in the market. Instead, the $n - m^{DF}$ non-adopting rivals exit the market as both producing with the old technology and paying the technology's price set by the innovator to become a licensee do not yield any positive profits. Things are less straightforward if $\gamma \in (\gamma^{DF}, \gamma^F)$. In this case, partial adoption of the innovative technology does not imply an industry shake-out. Because the innovation's cost-reducing effect is not sufficiently large, the non-adopting rivals' best reply does not collapse to zero. Thus, a portion of the production is allocated to efficient firms producing with the best technology, and the residual share to some inefficient ones producing with the old technology. Finally, if the cost of setting x is sufficiently high ($\gamma > \gamma^F$), the innovation is small, and the licensing fee is such that the adoption of the new technology is convenient for all the firms in the downstream sector. Figure 2 shows these results graphically.

Proposition 5. *For a given market size n, there is complete adoption of the innovation if the cost of investing is sufficiently high ($\gamma \geq \gamma^F$). Conversely, there is partial adoption ($\gamma < \gamma^F$). Furthermore, when the cost of investing is sufficiently small ($\gamma < \gamma^{DF}$), partial adoption implies an industry shake-out. In this case, only the licensees stay active in the market.*

Corollary 1. *Consider a downstream market of size n, and an innovator that faces a cost of investing in innovation $\gamma \in [\gamma_1^{DF}, \gamma^{DF}]$. The introduction of an innovation licensed via upfront fees results in an inefficient allocation of production in the market. If this is the case, the $n - m^* > 1$ firms that do not adopt the new technology can produce positive quantities of the final good with more inefficient technology.*

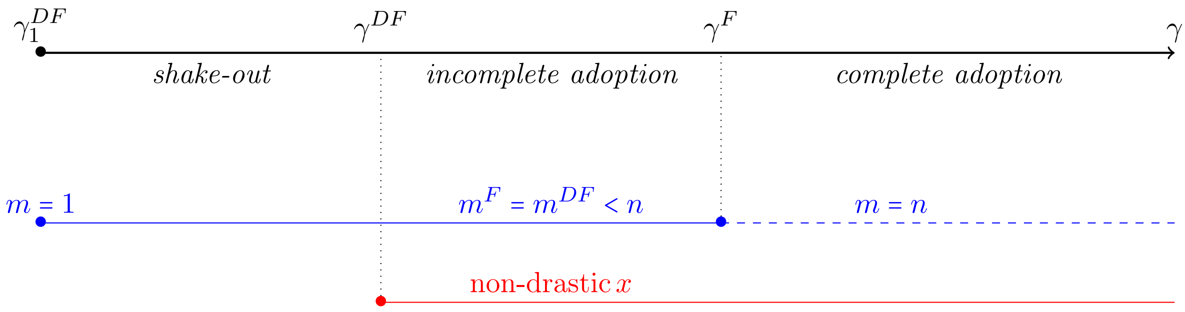

Figure 2: The effects of innovation on market structure, depending on the efficiency of the innovator γ.

Proposition 6. *Under a fixed fee licensing scheme, competition has both a* ***direct*** *and an* ***indirect*** *effect on the incentives to invest in innovation. The* ***direct*** *effect is as described in propositions 3 and 4. Instead, the* ***indirect*** *effect is identified by the sensitivity of the market to drastic effects of the innovation. In particular, as* $\frac{\partial \gamma^{DF}}{\partial n} > 0$ *and* $\frac{\partial \gamma_1^{DF}}{\partial n} > 0$*, the incentives of an innovator to develop a k-drastic innovation increases.*

It is interesting to understand whether the policy-maker may have incentives to foster new technology adoption or help firms endowed with inferior technology to survive in the market. In vertical markets, where a monopolist patentee supplies superior technology, a switch-off of the old technology would imply the innovator's excessive market power. It is easy to observe that the innovator would supply one firm only and let all others exit the market. As the only adopting firm would be a monopolist, she would produce the efficient monopolist output (i.e., the monopolist output with the cost-reducing technology) and transfer all her profits to the innovator via the fixed fee F. Thus, in order for such an aggressive policy (i.e., the witch off of the standard technology) to be beneficial, it must be that:

$$Q^{\text{Mon}}(x) = \frac{a-c+x}{2} > \begin{cases} \left(\frac{m(a-c+x(n-m+1))}{n+1} + \frac{(n-m)(a-c-mx)}{n+1}\right) & = Q^F(m,x) \quad \text{if} \quad \gamma > \gamma_1^{DF} \\ \left(\frac{m(a-c+x)}{m+1}\right) & = Q^{DF}(m,x) \quad \text{if} \quad \gamma \in (\gamma_2^{DF}, \gamma_1^{DF}] \end{cases}$$

which is a condition that is never satisfied in the model.

Remark 1. *In a vertical market where an innovator supplies a superior production technology, a switch-off of the old technology is never welfare improving. The benefits from efficient reallocation of the production output do not exceed a more concentrated market's diseconomies.*

4 Concluding remarks

This paper aims not to provide novel results on *what* contract scheme provides the innovator with the highest incentives to invest in innovation. Instead, its goal is to perform a thorough analysis of how competition intensity interacts with the innovator's private incentives to innovate, *depending* on the licensing scheme adopted. The main result is that it is possible to identify a twofold effect of competition on the incentives to innovate, *regardless* of the type of contract enforced by the innovator. Intuitively, because fixed fees and royalties enter the downstream firms' objective function differently, the *direct* way in which competition interacts with the incentives to innovate differs across the two regimes. Royalties are such that the innovator's revenues are proportional to the output level, while fixed fees allow the patentee to exploit the downstream firms' willingness to pay. In contrast, the *indirect* effect is similar in the two licensing schemes considered in the analysis. As competition intensifies, the ex-ante market structure becomes more fragile. So, even small innovation may imply a reorganization of the market, with some firms that survive and others that fail (industry shake-out). At the limit, when $n \to \infty$, any marginal innovation is a 1-drastic innovation. This article puts together the *feedback* effect of competition on incentives to innovate and states that, as competition increases the incentives to invest in innovation, it also increases the likelihood that the equilibrium size innovation would be substantial enough to have a drastic effect on the market structure. The innovator internalizes this positive *feedback* effect and invests even more in R&D. Interestingly, this article show that licensing via royalties may as well result in partial diffusion of the innovation if the innovation is sufficiently large. This article does not deal with risks related to the innovative process. Indeed, the model implicitly assumes that the patent holder R&D expenditures consist in developing a technology that has already been discovered. How risk and competition interact and how such interaction alters the *feedback* effect described in this article is left as a subject of further research.

Appendix

Non-drastic innovations with royalties

Eq. 2 follows from simple maximization of the innovator's profits. First, the innovator sets the price r that maximizes her profits:

$$\pi_u^r = r\, Q_d(x,r) - \gamma\, x^2 \tag{A.1}$$

under the participation constraint, the cost of innovation per unit of output must not exceed the cost-reducing effect x. As this condition is binding - i.e., the monopolist price is larger than x - the innovator sets the maximum price she can charge for eliciting adoption, which is $r = x$. Thus, the innovation is neutral from the downstream adopters' perspective, and their payoffs in this subgame are the standard n-oligopoly Cournot profits. By using these payoffs in the innovator's objective function, it is easy to derive eq. 1. Finally, simple differentiation w.r.t. x yields the result in eq 2.

K-drastic innovations with royalties

Suppose $\beta < 1$. Then the downstream firms' payoffs are:

$$\pi_d^A = \frac{(a - c + (n - m + 1)x(1 - \beta))^2}{(n + 1)^2} \tag{A.2}$$

$$\pi_d^B = \frac{(a - c - m(1 - \beta)x)^2}{(n + 1)^2} \tag{A.3}$$

where superscripts A and B indicate strategies "adoption" and "non-adoption", respectively. Eq. A.3 clearly states that non-adopting firms are not able to sustain the strategic disadvantage if $x > \frac{(a-c)}{m(1-\beta)}$, with $m \in [k, n-1]$. Namely, this means that the non-adopters stay active only if the innovation is non-drastic. Suppose the innovation is k-drastic, then the adopters' payoff can be rewritten as:

$$\pi_d^A = \frac{(a-c+x(1-\beta))^2}{(m+1)^2} \qquad \text{A.4}$$

Condition C.3 illustrates the value of x above which rationing the licensees is profit maximising for the innovator. The condition is derived from the comparison of the innovator's revenues if she sells the k-drastic innovation to all downstream firms and if she sells it to a subset m:

$$\frac{m\beta x(a-c+x(1-\beta))}{m+1} > \frac{nx(a-c+x)}{n+1} \quad \text{if C.3 holds} \qquad \text{A.5}$$

It is easy to show that:

$$\text{C.2} \equiv \frac{(a-c)}{m(1-\beta)} \geq \frac{(a-c)((m+1)n-\beta m(n+1))}{(1-\beta)\beta m(n+1)} \equiv \text{C.3} \quad \text{if} \quad \beta \in [\beta^*, 1) \qquad \text{A.6}$$

with $\beta^* = \frac{n}{n+1}$. The derivation of the equilibrium size of innovation follows the standard procedure for SPNE games.

Non-drastic innovations with fixed fees

Under fixed fees, the cost-reducing effect on the adopters' marginal cost of production is not mitigated. However, the innovation must guarantee a minimum level of profitability that depends on the size of the fee, the intensity of competition, and the rivals' choices. Standard computations yield the $t = 3$ payoff of the downstream firms, given the size of innovation and the fee F. The profits of the m adopting firms are:

$$\pi_d^A(x,m) = \frac{(a-c+x(n-m+1))^2}{(n+1)^2} - F(x,m) \qquad \text{A.7}$$

while non adopters gain:

$$\pi_d^B(x,m) = \frac{(a-c-mx)^2}{(n+1)^2} \qquad \text{A.8}$$

At time $t = 2$, the innovator sets the price $F(x,m)$ to elicit the number of adoption that maximizes her profit functions. Condition C.1 states the sufficient condition for the problem to have a unique equilibrium. Using eqs. A.7 and A.8, C.1 becomes :

$$F(m,n,x) = \frac{(a-c+x(n-m+1))^2}{(n+1)^2} - \frac{(a-c-(m-1)x)^2}{(n+1)^2} = \frac{nx(2(a-c-x(m-1))+xn)}{(n+1)^2} \qquad \text{A.8}$$

The innovator maximizes her profits by choosing m and x, namely, the number of contracts and the size of innovation. She faces a trade-off between the size of the fees and the adoption rate, as the larger the fee posted, the lower the number of adopters in equilibrium. The maximization problem of the innovator is:

$$\max_{m,x} \quad \pi_u^F = m\,F(m,n,x) - \gamma\,x^2 \tag{A.9}$$

from which it is easy to derive the equilibrium size of innovation.

K-drastic innovations with fixed fees

When $x = \frac{a-c}{k}$, with $k \leq n-1$, we know from Proposition 2 in Kamien and Tauman [1986] that the number of adopters in equilibrium is exactly k - i.e., the innovator will charge a fee $F(x,m)$ such that adoption will be convenient for no more than $m = k$ downstream firms. By rewriting the condition as $m^{DF} = \frac{a-c}{x}$, it is possible to derive the output level and profits of the downstream m-oligopoly:

$$q_d^A = \frac{a-c+x}{m+1} = \frac{a-c+x}{\frac{a-c}{x}+1} = x \tag{A.10}$$

$$\pi_d^A = x^2 - F \tag{A.11}$$

The maximum fee that the innovator can charge to elicit the adoption of the technology by m^{DF} firms is:

$$\begin{aligned} F(x,n) &= x^2 - \frac{(a-c-(m-1)x)^2}{(n+1)^2} = x^2 - \frac{(a-c-(\frac{a-c}{x}-1)x)^2}{(n+1)^2} \\ &= x^2 - \frac{x^2}{(n+1)^2} = \frac{n(2+n)x^2}{(n+1)^2} \end{aligned} \tag{A.12}$$

The number of adopters, however, is lower bounded to $m = 1$, which is the case of a drastic innovation. In this case eqs. (A.10 - A.12) must be rewritten as:

$$q_d^A = \frac{a-c+x}{2} \tag{A.13}$$

$$\pi_d^A = \frac{(a-c+x)^2}{4} - F \tag{A.14}$$

$$F(x,n) = \frac{(a-c+x)^2}{4} - \frac{(a-c)^2}{(n+1)^2} = \frac{((a-c)(n-1)-(n+1)x)((a-c)(n+3)-(n+1)x)}{4(n+1)^2} \tag{A.15}$$

The profit function of the innovator is:

$$\pi_u^* = \begin{cases} \frac{n(n+2)x(a-c)}{(n+1)^2} - \gamma\,x^2 & \text{if} \quad m > 1 \\ \frac{((a-c)(n-1)-(n+1)x)((a-c)(n+3)-(n+1)x)}{4(n+1)^2} - \gamma\,x^2 & \text{if} \quad m = 1 \end{cases} \tag{A.16}$$

Eq. 7 follows from simple maximization of eq. A.16.

References

Aghion, P., Akcigit, U., and Howitt, P. (2015). Lessons from Schumpeterian Growth Theory. *American Economic Review*, 105:94–99.

Aghion, P., Bergeaud, A., Cette, G., Lecat, R., and Maghin, H. (2019). Coase lecture - the inverted-u relationship between credit access and productivity growth. *Economica*, 86(341):1–31.

Aghion, P., Bloom, N., Blundell, R., Griffith, R., and Howitt, P. (2005). Competition and innovation: an inverted-u relationship. *The Quarterly Journal of Economics*, 120(2):701–728.

Arrow, K. (1962). Economic welfare and the allocation of resources for innovation. In Nelson, R. R., editor, *The Rate and Direction of Inventive Activity.*, pages 609–625. Princeton, NJ, Princeton University Press.

Badia, B., Tauman, Y., and Tumendemberel, B. (2020). On the diffusion of competing innovations. *Mathematical Social Sciences*, 108(C):8–13.

Denicolò, V. and Lambertini, L. (2020). Innovation and product market concentration: Schumpeter, Arrow, and the Inverted U-shape Curve. *Oxford Economic Papers*.

Erutku, C. and Richelle, Y. (2007). Optimal licensing contracts and the value of a patent. *Journal of Economics, Management & Strategy*, 16(2):407–436.

Gallini, N. T. and Wright, B. D. (1990). Technology transfer under asymmetric information. *RAND Journal of Economics*, 21(1):147–160.

Hermosilla, M. and Wu, Y. (2018). Market size and innovation: the intermediary role of technology licensing. *Research Policy*, 47(5):980–991.

Kamien, M. I., Oren, S., and Tauman, Y. (1992). Optimal licensing of cost reducing innovation. *Journal of Mathematical Economics*, 21:483–508.

Kamien, M. I., Oren, S., and Tauman, Y. (2002). Patent licensing: the inside story. *The Manchester School*, 70:7–15.

Kamien, M. I. and Tauman, Y. (1986). Fees versus royalties and the private value of a patent. *Quarterly Journal of Economics*, 101(3):471–492.

Katz, M. L. and Shapiro, C. (1985). On licensing of innovations. *RAND Journal of Economics*, 16(4):504–520.

Lahiri, S. and Ono, Y. (1988). Helping minor firms reduces welfare. *The Economic Journal*, 98(393):1199–1202.

Lapan, H. and Moschini, G. (2000). Incomplete adoption of a superior technology. *Economica*, 67:525–542.

Marshall, G. and Parra, A. (2019). Innovation and competition: the role of the product market. *International Journal of Industrial Organization*, 65:221–247.

Parra, A. (2019). Sequential innovation, patent policy and the dynamics of the replacement effect. *RAND Journal of Economics*, 50(3):568–590.

Rostoker, M. D. (1984). A survey of corporate licensing. *IDEA: Journal of Law and Technology*, 24:59–92.

Sen, D. (2005). Fee versus royalty reconsidered. *Games and Economic Behaviour*, 53:141–147.

Sen, D. and Stamatopoulos, G. (2016). Licensing under general demand and cost functions. *European Journal of Operational Research*, 253(3):673–680.

Sen, D. and Tauman, Y. (2007). General licensing scheme for a cost reducing innovation. *Games and Economic Behaviour*, 59:163–186.

Sen, D. and Tauman, Y. (2018). Patent licensing in a cournot duopoly: general results. *Mathematical Social Sciences*, 96:37–48.