Ex-ante licensing in sequential innovations*

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Abstract

The theoretical literature on the cumulative innovation process has emphasized the role of ex-ante licensing - namely, licensing agreements negotiated before the follow-on innovator has sunk her/his R&D investment - in mitigating the risk of hold-up of future innovation. In this paper, we consider a patent-holder and a follow-on innovator bargaining over the licensing terms, in a realistic context where the former firm is unable to observe the timing of the R&D investment of the latter, i.e. it does not know whether the follow-on innovator is ex-ante or ex-post. We show that, in this case, the possibilities of restoring the R&D incentives by setting the licensing terms appropriately are severely limited.

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1 Introduction

According to several commentators, the dramatic increase in the number of patents that are currently being issued by the different patent offices all over the world might have detrimental consequences for the innovation process. These consequences might be particularly severe in industries where innovation is cumulative; in these cases the presence of strong intellectual property rights might impose a significant burden to follow-on inventors who need to enter into licensing agreements with patent holders. As a consequence, R&D incentives are potentially reduced and this might result in the hold-up of future innovation.[1]

Whether the proliferation of patents will hold future innovation up or not crucially depends on the efficiency of the "market for ideas". If different generations of innovators negotiate efficiently their licensing agreements, then the increased number of patents is unlikely to represent a substantial impediment to future innovations. In this view, the theoretical literature dealing with the cumulative innovation process has argued that the timing of contracting is central. In particular, leading scholars have vigorously emphasized the virtues of ex-ante licensing (or prior agreements, see Scotchmer, 1991). If parties negotiate the licensing agreement before the follow-on inventor has sunk her/his investment then the correct R&D incentives can be restored. With ex-ante licensing the R&D costs of the inventor are taken into account during the negotiation process and this fact mitigates the hold-up problem. In a seminal paper, Green and Scotchmer (1995) show that, in a context of symmetric information, the feasibility of ex-ante negotiations is enough to achieve the efficiency, thus completely eliminating the risk of hold-up.[2]

Nevertheless, legal scholars and practitioners have pointed out the difficulties related to patent negotiations, and to ex-ante licensing in particular. Given the intangible nature of

[1] As argued in Heller and Eisenberg (1998) and Shapiro (2001), the risk of hold-up is compounded when several patents - the so-called patent thicket - simultaneously read on the same technology. See Galasso and Schankerman (2008) for a recent empirical analysis of patent thickets and the related "tragedy of anticommons".

[2] The assumption that ex-ante contracting under symmetric information is feasible has been repeatedly employed in the subsequent theoretical contributions on cumulative innovation; see O'Donoghue et al. (1998), Scotchmer (1996) and and Schankerman and Scotchmer (2001). See also Gallini and Scotchmer (2002) for a recent review of these issues. Two recent exceptions are Bessen (2004) and Bessen and Maskin (2008) . These authors consider the case where the R&D costs of the follow-on innovator are private information, and show that ex-ante licensing does not always ensure efficiency.

the objects of transactions, licensing agreements are inherently difficult to negotiate; indeed, parties might have disparate expectations about the value of the invention, or the validity and the boundaries of patent rights might be unclear.[3] But there are also additional reasons that in several circumstances make ex-ante contracts unfeasible. First and foremost, the follow-on innovator might need to commit significant resources before entering into the licensing negotiations. Furthermore, she/he might ignore the existence of a patent right protecting the technology. As discussed for instance in Graham and Mowery (2004) for the case of the software, in industries where innovation is cumulative patent-holders can strategically hide their property rights until their inventions become a standard for the industry; at that moment, they profitably unveil their patents and ask royalties to those that have embedded their invention.[4,5]

In this paper, we go even further by showing that the possibilities of efficient licensing are likely to be severely limited even in a context where parties have converging views about the value of the patent, and where the follow-on innovator is informed about the fact that her/his innovation is infringing a patent protecting an earlier invention. We show that the simple inability of the patent-holder to observe the timing of the investment of the follow-on innovator prevents parties to sign contracts that restore the efficient level of R&D incentives. This quite striking result rests on a very simple intuition. In our setting, a follow-on inventor obtains an innovation after having undertaken some (non-contractible) R&D investments; this R&D activity determines the probability that the innovation has a large or a small value, V^G or V^B respectively. The follow-on invention infringes the patent held by the earlier innovator, and, if parties do not agree on different terms, the follow-on innovator is mandated by the law to pay L^G or L^B, depending on the commercial value of the innovation,

[3]Merges and Nelson (1990) observe that "patents are inherently difficult to value, their boundaries are blurry and difficult to demarcate, and parties in the cumulative chain of innovation are often unknown in advance, which further restricts the range of ex ante solutions". Similar considerations can be found in a more recent survey on the US patent reform and on the potential effects of the consequent patent proliferation; see Gallini (2002).

[4]In the literature this phenomenon is known as "submarine patents".

[5]Empirical studies dealing with the timing of negotiations in licensing agreements do not abound. Few recent papers consider this issue although they give a definition of "ex-ante" and "ex-post" licensing that differs from the one adopted in the theoretical literature, and that we also use here. These studies define ex-ante licensing as those where a firm commits to licence a technology out before having developed such a technology. See, Anand and Khanna (2000), and Siebert and von Graevenitz (2008).

with $L^G > L^B$. These default payments yield to under-investment that could be avoided if parties were to agree on a different licensing contract specifying a lump-sum payment L. Clearly, the payment has to be such that $L^G > L > L^B$, otherwise either the patent-holder or the follow-on inventor would not sign the licensing contract.

The question is the following: is such contract ever signed? If the patent-holder is willing to accept L, then the follow-on innovator is better-off by undertaking her/his R&D investment first, and negotiate the licensing terms only once she/he has observed the realization of the value of the innovation; i.e., in the paper's jargon, the follow-on innovator is better-off by *coming ex-post*. In this way, the she/he will accept to pay L in case V^G has occurred, while she/he will pay the low fee L^B in case of a low valued innovation V^B. However, given this behavior of the follow-on innovator, the patent-holder will certainly prefer the default payments mandated by the law rather than to accept the lump-sum payment L.

In the rest of the paper we generalize this intuition by considering two simple bargaining protocols in which either the patent-holder or the follow-on innovator make a take-it-or-leave-it proposal to the counterpart. We show that when the patent-holder is the one who proposes the contract, negotiations turn out to be completely useless since the equilibrium licensing fees equal the default ones. When the offer is made by the follow-on inventor, we prove that efficient contracts are never signed in equilibrium; moreover, we are also able to provide an upper-bound to the level of efficiency that can be reached.

The crucial ingredient that drives our results is the assumption that the patent-holder at the moment of the negotiations is unable to tell whether the prospective licensee has already conducted her/his R&D activity or not, namely whether the follow-on innovator is "ex-ante" or "ex-post". It deserves to be stressed that this is a very mild assumption, which is likely to hold in many industries characterized by a cumulative innovation process. As a relevant example, our model seems to represent quite well what happens in the semiconductor and the electronic sectors; as argued by Grindley and Teece (1997), in these sectors, and contrarily to what happens for instance in the chemical or pharmaceutical sectors, active firms negotiate upon their reciprocal property rights in order to avoid infringement and to ensure the so called "freedom to manufacture". In other words licensing and cross-licensing agreements do not appear to be motivated by the need to ensure the exchange of relevant technologies between firms, a fact that seems to confirm that in these sectors follow-on innovators do not have compelling reason to negotiate the licensing terms before investing in R&D.

Beyond these practical applications, the analysis proposed in this paper is also relevant from a more theoretical perspective; in fact, our model bridges across two different streams of literature: that on cumulative innovation with that on (pre-contractual) information acquisition. With respect to this latter, the paper which is closest to ours is the one of Dang (2008). In Dang's model a buyer and seller bargain over an asset whose value can be either high or low. The true value of the asset is ex-ante unknown to the parties, but before making or accepting any bargaining proposal, each party can acquire costly this information. In a way similar to our's, the option for the parties to acquire information on the asset, generates an endogenous lemon problem which, in Dang's paper, can prevent the two parties from trading.[6]

A major difference with respect to this literature is that, in our setting, the choice to acquire information before the contracting stage (equivalent to come ex-post, in our terminology) and the choice of investing a certain amount of money in R&D activities collapse into one single decision. The fact that information acquisition is not a separate decision, as it is instead in Dang (2008) and in the other contributions in this literature, generates an endogenous cost related to the choice of becoming informed: by coming ex-post, the second innovator bears the risk of making an investment which is unsuited to the contract that will be signed. Clearly, this cost materializes whenever, in equilibrium, there is uncertainty about the contract that will be binding.

The rest of the paper is organized as follows: in Section 2, we present the outline the model. In Section 3 we derive the results of our analysis, considering the two bargaining protocols. Section 4 concludes.

2 The model

We consider a cumulative innovation process with two subsequent innovations and two inventors, firm 1 and firm 2. While the follow-on innovation has still to come, the first one has

[6]Other contributions in this field of research generally focus on standard Principal-Agent models where, prior to the contracting stage, the Agent has the possibility of gathering some pay-off relevant information (see, for instance, Crémer et al., 1998a and Crémer et al., 1998b). In these models, the Agent faces a trade-off when the decision on information acquisition needs to be taken; on the one side, by being more informed, she/he may take a better choice when confronting a given contractual offer, while, on the other, information acquisition is costly since it requires a certain amount of effort.

already been developed and patented by firm 1. Once firm 1 has developed its innovation, firm 2, at some point in time, "gets an idea" for a second generation invention. Firm 2's innovation violates the patent that protects the first invention.

In order to develop its idea and to make it commercially valuable, firm 2 has to undertake some R&D activity. Moreover, since its innovation infringes 1's patent, the second inventor needs to negotiate a licensing agreement with firm 1.

Firm's 2 idea may be more or less promising in terms of the commercial benefits that can be generated from it. Formally, we model the idea as a quadruple $\left\{p\left(r\right), c\left(r\right), V^B, V^G\right\}$. The term $r \geq 0$ represents the amount of R&D activity that firm 2 undertakes in order to develop its idea and $c\left(r\right)$ is the corresponding cost. $p(r) \in [0, 1]$ is the probability that the innovation has a commercial value V^G, and we will refer to $p\left(r\right)$ also as the probability that the good, or the G, state of the world occurs; $1 - p(r)$ is the probability that the innovation has a commercial value V^B and we will refer to it also as the probability that the bad, or the B, state of the world occurs, with $V^G > V^B > 0$. All through the paper we will assume that the derivatives of the cost and probability functions satisfy the following conditions: $c'(r) > 0$, $c''(r) > 0$, $p'(r) > 0$, $p''(r) \leq 0$; moreover, we will assume that both the efficient and the equilibrium amounts of firm 2 R&D activity are such that $0 < p(r) < 1$.

Timing, information structure and licensing contracts

The timing of the game is the following:

- a first/early invention is already available and protected by a patent; at some point in time, firm 2 gets an idea about a follow-on innovation i.e. it observes $\left\{p\left(r\right), c\left(r\right), V^B, V^G\right\}$. Given the idea, the firm chooses how much to invest in R&D activities, r. Once r is sunk, firm 2 observes the commercial value of the innovation, either V^G or V^B;

- the second innovation violates firm 1's patent and it can be legally brought to the market only once firm 2 has signed a licensing agreement with firm 1. Firm 2 has two options as to when to negotiate the licensing terms: *i)* before having invested in the R&D activities, in this case we say that the firm comes ex-ante (or, equivalently that it goes for an ex-ante licensing agreement), or *ii)* once r has been already sunk, and in this case we say that the firm comes ex-post, (it asks for an ex-post licensing agreement). Under both circumstances, we assume that, during the negotiation process, firm 1 observes firm 2's idea, $\{p(r), c(r), V^B, V^G\}$; however, firm 1 is unable to observe whether firm 2 has already sunk the R&D investment or not: firm 1 is unable to ascertain whether firm 2 is ex-ante or ex-post, unless this latter reveals the realization of V^i, $i = G, B$, thus proving that it is ex-post. We model the negotiation process as a bargaining with take-it-or-leave-it offers and we assume that, in case firms fail to reach an agreement, the terms of licensing are set by the Court. If this is the case, the Court mandates a licensing fee L_C^i, $i = G, B$, which is natural to assume satisfying the two conditions $0 \leq L_C^i \leq V^i$, $i = G, B$, and $L_C^B < L_C^G$; according to the latter assumption, the licensing fees imposed by the Court are increasing in the commercial value of the of the innovation.[7] In the rest of the paper, we will refer to the contract that is implemented by the Court as the default contract.[8]

In what follows, we assume that the R&D activity r is neither verifiable nor observable by the first inventor, while the commercial value of the innovation, V^i, $i = G, B$, is verifiable but only once the second innovation is brought to the market, or in front of the Court; namely, the second innovator can hold this information private till that moment. Given these assumptions, licensing contracts can only be made contingent on the realization of V^i. Formally, a licensing contract j is $C_j = \{L_j^B, L_j^G\}$, where $L_j^i \in \mathbb{R}$ represents the licensing fee that firm 2 pays to the first inventor in case V^i occurs, $i = G$ or B. We denote $C_C = \{L_C^B, L_C^G\}$ the contract implemented by the Court i.e. the default contract.

Finally, it should be noticed that according to structure of our model bargaining about the licensing terms occurs under asymmetry of information. Firm 2, given its option to negotiate ex-ante or ex-post, and given the moves of nature, can be of three different types. In case r has not been sunk, firm 2 is of an ex-ante type, ω_A. In case r has already been sunk, firm 2 can be either ex-post of type B (i.e. it has observed V^B) ω_B, or ex-post of type G (i.e. it has observed V^G) ω_G. In what follows, we let μ_i, with $i = A, B$ and G, to denote the system of beliefs held in equilibrium by firm 1.

[7] This assumption is in line with the liability doctrines of lost profits and unjust enrichment, see Schankerman and Scotchmer, (2001).

[8] An alternative interpretation of the default contract is the following. If parties did not sign any agreement before, then the licensing terms are determined only once the innovation has been commercialized, so that its value has become common knowledge. In this case we can think that each firm obtains a share of V^i, $i = G, B$ proportional to her/his bargaining power.

2.1 First best, under and over-investment

We start our analysis by defining the first best level of investment and by characterizing under what circumstances the contract C_j induces firm 2 to under or to over-invest.

The first best investment, r_{eff}, is the value of r that maximizes the joint profits of the two firms; formally:

$$r_{eff} \equiv \arg\max_{r} \; p(r)V^G + (1 - p(r))\, V^B - c\,(r)\,.$$

The first order condition is simply:

$$p'(r_{eff}) \left[V^G - V^B\right] = c'\,(r_{eff})\,. \tag{1}$$

Consider now the case where firm 2 knows that the licensing terms are determined by contract $C_j = \left\{L_j^B, L_j^G\right\}$. The optimal investment level that firm 2 chooses is:

$$r_j \equiv \arg\max_{r} \; p(r)\left(V^G - L_j^G\right) + (1 - p(r))\left[V^B - L_j^B\right] - c\,(r)\,.$$

In this case, the first order condition reduces to:

$$p'(r_j)\left(V^G - V^B - \left(L_j^G - L_j^B\right)\right) = c^{'}\,(r_j)\,. \tag{2}$$

From a simple comparison between expressions (1) and (2) it turns out that:

$$\begin{cases} \text{if } L_j^B < L_j^G, & \text{firm 2 under-invests, } r_j < r_{eff} \\ \text{if } L_j^B = L_j^G, & \text{firm 2 invests efficiently, } r_j = r_{eff} \\ \text{if } L_j^B > L_j^G, & \text{firm 2 over-invests, } r_j > r_{eff} \end{cases}$$

Notice that the assumption $L_C^B < L_C^G$ implies that the default contract induces under-investment, $r_C < r_{eff}$.

In order to ease the rest of the presentation, it is useful to introduce some additional notation, by defining:

- π_j as the firms expected joint profits when contract C_j is signed with probability 1; formally, $\pi_j \equiv p\,(r_j)\,V^G + (1 - p\,(r_j))\,V^B - c\,(r_j)\,,$ where r_j is as defined above;

- $E\,(L_j)$ as the expected licensing fees when contract C_j is signed with probability 1; formally, $E\,(L_j) \equiv p\,(r_j)\,L_j^G + (1 - p\,(r_j))\,L_j^B$.

3 Results

Before moving further into the formal analysis, it is useful to highlight some preliminary results and to stress the crucial role played by the assumption of the non-observability of the timing of firm 2's investment. In our setting, if firm 2 has already taken its investment decision, firm 1 cannot benefit from signing a contract different from the default one: the ex-post type ω_i, $i = G$ or B, is willing to accept contracts that specify $L_j^i \leq L_C^i$, while firm 1 benefits only from contracts with $L_j^i \geq L_C^i$, $i = G, B$. On the contrary, when the second innovator looks for an ex-ante licensing agreement, it is possible to find contracts more efficient than C_C and that, at the same time, are beneficial for both firms. These arguments suggest that, if the timing of firm 2's investment decision were observable, then licensing would occur under efficient terms, in a way similar to what happens in Green and Scotchmer (1995). Licensing negotiations would take place before the second innovator has taken its investment decision, and the agreement would specify a lump-sum payment L in favor of firm 1; in this way, the second innovator would be induced to select r_{eff} and the efficiency would be perfectly restored. Clearly, in order to satisfy the participation constraints of the two firms, the lump-sum payment should be set at some level L such that $L_C^B < L < L_C^G$.

Things may go differently if the timing of firm 2's investment cannot be observed by the counterpart. Suppose that firm 1 is still willing to license its patent at L, with $L_C^B < L < L_C^G$. Since firm 2 can be licensed either under the terms specified by C_C or through the lump-sum payment L, it clearly prefers to look for an ex-post agreement. By doing so, the follow-on innovator observes the realization of the state of nature, therefore having the option to select the most favorable licensing terms: the lump-sum payment in case state G has occurred, and the default contract in case of state B. However, anticipating firm 2's behavior, the first innovator is unwilling to license its patent at L.

In short, in order to mitigate the hold-up problem, firms should agree on a contract different from the default one. However, firm 1 is reluctant to sign such a contract since it fears that the second innovator may act strategically by looking for an ex-post agreement in order to minimize the licensing fees. The rest of the paper is devoted to generalizing in various directions this simple argument.

In order to simplify the presentation of the results, it is useful to remove from further consideration those contracts that are not relevant to our scopes. Consider any contract C_j, different from the default one, and that specifies payments weakly larger than those of C_C

in both states of the world, $L_j^i \geq L_C^i$ for both $i = G, B$. This contract is never signed by an ex-ante type of firm 2, while an ex-post type ω_i, with $i = G$ or B, is willing to sign it only if $L_j^i = L_C^i$. In this case, contract C_j is equivalent to C_C in terms of firms' payoffs and levels of investment. Therefore, from now on, and without loss of generality, we assume that these contracts are never proposed.

In what follows, we let C_E denote a contract different from the default one, and that can be potentially proposed during the negotiation process. From the previous arguments, we know that C_E must provide for a smaller payment than C_C in at least one state of the world, formally $L_E^i < L_C^i$ for some V^i, $i = G, B$. Moreover, as observed above, the first innovator might benefit from signing a contract C_E only in case there is a positive probability that firm 2 looks for an ex-ante licensing agreement. Hence, since contract C_E must be acceptable both by firm 1 and by the ex-ante type of firm 2, C_E must necessarily be also more efficient than C_C. These two conditions imply the following Lemma.

Lemma 1. *If a contract C_E is signed in equilibrium, then $L_E^G < L_C^G$.*

Proof. Let us proceed by contradiction and suppose that C_E induces over-investment i.e. $L_E^G < L_E^B$. In this case it cannot be that $L_E^G \geq L_C^G$, otherwise the ex-ante type of firm 2 would be paying more than under the default contract in both states of nature. Consider now the case where C_E induces under-investment. Since C_E has to be more efficient than C_C it follows that $L_C^G - L_C^B > L_E^G - L_E^B$. If $L_E^G \geq L_C^G$, then $L_E^B > L_C^B$; and again this is not possible since the ex-ante type of firm 2 would be paying more than under the default contract in both states of nature. ■

3.1 Firm 1 makes the licensing proposal

Consider the case where firm 1 makes a take-it-or-leave-it offer to the counterpart. By proposing a contract C_E which is acceptable by the ex-ante type of firm 2, the first innovator expected payoff is:

$$\mu_A E(L_E) + \mu_B \min\left\{L_E^B, L_C^B\right\} + \mu_G \min\left\{L_E^G, L_C^G\right\}. \tag{3}$$

As noted above, firm 1 might benefit from proposing contract C_E only when μ_A is large enough. Moreover, within the set of proposals that are acceptable by the ex-ante type of firm 2, the first innovator finds it optimal to select a contract C_E that satisfies the following condition.

Lemma 2. *If a contract C_E is proposed in equilibrium, then the ex-ante type of firm 2 must be indifferent between accepting or rejecting the contract.*

Proof. We prove the lemma by contradiction. Suppose that the ex-ante type of firm 2 strictly prefers contract C_E to contract C_C; then it is possible to find an $\varepsilon > 0$ such that firm 1 is better-off by proposing $C_D = \left(L_E^G + \varepsilon, L_E^B + \varepsilon\right)$ rather than C_E. Provided that ε is small enough, the ex-ante type of firm 2 is still willing to accept the contract and, since ε is lump-sum, the same amount of investment is going to be made. Moreover, expression (3) implies that when firm 2 goes for an ex-post agreement, by offering C_D firm 1 obtains at least the same expected pay-off as under C_E. ■

The result shown in Lemma 2 is driven by the assumption that in the licensing dispute firm 1 holds the full bargaining power; the lemma simply follows from the fact that firm 1 exploits its position by making the ex-ante type just indifferent between accepting or rejecting the proposal. Notice that, since from Lemma 1 we know that $L_E^G < L_C^G$, Lemma 2 implies that $L_E^B > L_C^B$; it then follows that:

Proposition 1. *A contract different from the default one is never signed at the equilibrium.*

Proof. Suppose, on the contrary, that in equilibrium firm 1 proposes, with some positive probability, a contract C_E. From Lemma 2 we know that in case firm 2 looks for an ex-ante agreement, and independently of whether C_E is proposed or not, its pay-off is $\pi_C - E\left(L_C\right)\left(= \pi_E - E\left(L_E\right)\right)$. Firm 2 would certainly be better off by seeking a licensing agreement ex-post, i.e. after having invested r_C: in the case a contract C_E is proposed, firm 2 has the option to accept the proposal (thus paying $L_E^G < L_C^G$) when state G occurs, or to reject it (thus paying $L_C^B < L_E^B$) in case of state B. However, since firm 2 finds it optimal to come ex-post, firm 1 will never offer C_E. ■

Note that there are many equilibria of this game which are payoff equivalent. In all these equilibria, firm 2 comes ex-post with a sufficiently large probability so that firm 1 is better-off by offering the default contract rather than any other contract C_E. Obviously, since the default contract is signed with certainty, firm 2 is indifferent between coming ex-ante or ex-post.

Proposition 1 delivers an important consequence. When the licensing proposal is made by firm 1, the option to sign ex-ante agreements is totally irrelevant: firms cannot improve upon the (inefficient) investment level induced by the default contract.

3.2 Firm 2 makes the licensing proposal

Proposition 1 has been derived under the assumption that firm 1 holds all the bargaining power. It is therefore of interest to consider the opposite scenario where the follow-on innovator makes a take-it-or-leave-it proposal. In this case, the negotiation process takes the form of a signaling game. As it is well known in the literature, in the absence of any restriction on how the out-of-equilibrium beliefs are computed, this class of games shows a multiplicity of Perfect Bayesian Equilibria (PBE). In order to focus on reasonable PBE we will require that the out of equilibrium-path beliefs satisfy the D1 criterion.[9] Moreover, we also assume that with a (infinitely) small probability firm 2 realizes that its invention infringes firm 1's patent only once the R&D investment has been sunk; in this case, the second innovator can only search for an ex-post licensing agreement.

Let α be the probability that firm 2, before making the R&D investment, is informed that its invention violates firm's 1 patent (and $1-\alpha$ represents the probability of being uninformed, i.e. the probability of receiving the information only ex-post). Formally we will assume that $\alpha < 1$, and this implies that in equilibrium firm's 1 beliefs are such that $\mu_A < 1$. We use this assumption to prove Lemma 3.[10]

Suppose that, in equilibrium, firm 2 offers contract C_E; the first innovator will accept

[9] It might worth giving an informal intuition of how this criterion works. Consider that firm 2 makes an out-of-equilibrium proposal and consider any conjecture that this firm has about the reaction of firm 1. If, given any conjecture, it happens that a type, say type ex-ante, finds it optimal to deviate whenever it is optimal for the ex-post type, while the opposite does not hold, then the D1 criterion imposes to assign probability 1 that the proposer is of ex-ante type.

[10] The assumption that $\alpha < 1$ is taken both on empirical and on technical grounds. From an empirical standpoint, the assumption that, initially, the second innovator may be uninformed about the existence of firm 1's patent is reasonable also in light of the phenomenon of the "submarines" patents described in the Introduction. Moreover, from a more technical perspective, it is worth noticing that if $\alpha = 1$ in Lemma 3 the case where $\mu_A = 1$ and $E(L_E) = E(L_C)$ cannot be excluded. However, an equilibrium where firm 1 is willing to sign a contract C_E that provides the same expected pay-off as the default contract would not survive trembling-hand perfection: if there is a small chance that firm 2 comes ex-post by mistake, then firm 1 is willing to sign contract C_E only when $E(L_E) > E(L_C)$.

such proposal provided that:

$$\mu_A E(L_E) + \mu_B L_E^B + \mu_G L_E^G \geq \mu_A E(L_C) + \mu_B L_C^B + \mu_G L_C^G. \tag{4}$$

Lemma 3. *If a contract C_E is signed in equilibrium, then $E(L_E) > E(L_C)$.*

Proof. From Lemma 1 we know that $L_E^G < L_C^G$; since $\mu_A < 1$, then it follows that $\mu_G > 0$ (in fact if type ω_G would propose a different contract, by revealing itself as being of type G, it should pay L_C^G). Moreover, the licensing payments must be either $L_E^B \leq L_C^B$ or $L_E^B > L_C^B$ and $\mu_B = 0$ (in fact type ω_B strictly prefers to sign the default contract in this latter case). Therefore, it follows that condition (4) requires $E(L_E) > E(L_C)$. ■

Lemma 3 states that whenever firm 2 is ex-ante, firm 1 must be granted a pay-off strictly larger than what it would obtain with the default contract; this is in order to compensate the first innovator from the losses it incurs when facing an ex-post type of firm 2. Using this finding, we can prove the following important result:

Proposition 2. *There is no PBE satisfying the D1 criterion where contract C_E is signed and $L_E^B > L_C^B$.*

Proof. See the Appendix. ■

The intuition behind Proposition 2 is the following. Suppose that, contrarily to the statement, a contract C_E such that $L_E^B > L_C^B$ is signed in equilibrium. In the proof we show that this cannot be the case since the out-of-equilibrium proposal $C_D = \left(L_E^B - \varepsilon, L_E^G\right)$, with ε positive but sufficiently small, is beneficial both to firm 1 and to the ex-ante type of firm 2. More precisely we prove that: i) firm 1 believes with probability 1 that the proposer of C_D is the ex-ante type of firm 2, according to the D1 criterion; and ii) given this belief, firm 1 is better-off accepting the proposal. The proof of point i) is simple. Type ω_A prefers C_D to C_E since the former contract specifies a smaller payment in state B and the same payment in state G; for this reason, type ω_G is just indifferent between the two contracts. Moreover, provided that ε is small enough, it is still true that $L_E^B - \varepsilon > L_C^B$ and then type ω_B cannot benefit from proposing C_D. Therefore, ω_A is the type of firm 2 that benefits the most from proposing C_D, and then the D1 criterion imposes the belief $\mu_A = 1$ when this out-of-equilibrium proposal is made. Consider now point ii). Given its beliefs, by accepting contract C_D, firm 1 expects to obtain $E(L_D)$; by taking smaller and smaller values of ε we can make $E(L_D)$ sufficiently close to $E(L_E)$ and such that $E(L_D) > E(L_C)$, by the result of Lemma 3. This last fact implies that firm 1 is better-off accepting C_D.

It is worth noticing that the fact that there cannot be equilibria where the first innovator accepts with certainty to sign a contract C_E, with $L_E^B > L_C^B$, is not surprising as it rests on arguments similar to those of the previous section: if this were the case, then firm 2 would be better-off going ex-post and proposing C_E if G has occurred, and C_C in case of state B. However, Proposition 2 highlights a more important result since it also rules out equilibria where C_E is accepted with a probability smaller than 1. This is a more interesting scenario to be considered; being the part that submits the proposal, firm 2 can make the first innovator indifferent between accepting or rejecting C_E, thus making firm 1 willing to play mixed strategies; more importantly, in this case, the decision to come ex-post entails a cost for firm 2: since there is uncertainty about the contract on which parties will agree, by coming ex-post the second innovator faces the risk of making an investment which is unfit for the contract that will be signed.[11]

The following corollaries highlight two important consequences of Proposition 2.

Corollary 1. *Efficient contracts are never signed in equilibrium.*

Efficient contracts specify a lump-sum payment L. As we have already observed, firm 1 is willing to license its technology under a lump-sum contract provided that L is larger than the minimum fee imposed by the default contract: $L > L_C^B$. However, in Proposition 2 we have proved that there are no PBE satisfying the D1 criterion where $L_E^B > L_C^B$.

A second important consequence of Proposition 2 is the following.

Corollary 2. *In each PBE satisfying the D1 criterion, firm 2 under-invests.*

Proposition 2 implies that, if a PBE of the game exists, then $L_E^B \leq L_C^B$. Moreover, notice that it has to be $L_E^B < L_E^G$ otherwise firm 1 would prefer to reject C_E and sign C_C. This last inequality implies that, under contract the C_E, firm 2 under-invests.

Putting together Lemma 1 and Proposition 2 we are left to consider PBE satisfying the D1 criterion where contract C_E, with $L_E^G < L_C^G$ and $L_E^B \leq L_C^B$, is signed with some positive probability. Unfortunately, we are not able neither to exclude nor to prove the existence of such equilibria. To exclude existence, an argument similar to the one used to

[11] As we have pointed out in the Introduction, in this case, coming ex-post and then acquiring information before signing the contract involves a (endogenous) cost.

prove Proposition 2 cannot be easily applied: an out-of-equilibrium proposal such that in state $i = B$ or G firm 2 pays slightly less than under C_E, benefits both the ex-ante and the ex-post type i; in this case, we are unable to compute the out-of-equilibrium belief imposed by the D1 criterion. On the contrary, to prove the existence of such equilibria, we should be able to show that firm 1 rejects out-of-equilibrium proposals since it believes that, with a large probability, they are made by an ex-post type of firm 2. Again, we are prevented from going any further in the analysis due to the difficulties of defining the out of the equilibrium path beliefs satisfying the D1 criterion.

However, even if we are not able to provide a full characterization of the equilibrium, we can still define an upper-bound to the amount of investment undertaken by firm 2; reminding that in the setting under analysis there is an under-investment problem (see Corollary 2), this means that we are able to derive a minimum level of inefficiency that characterizes any possible equilibrium of the game. In order to do so we look for the contract that, at the same time, *i)* minimizes the difference $L^G - L^B$, and *ii)* satisfies the participation constraint of firm 1 given in expression (4). Notice that, the smaller the difference $L^G - L^B$ the closer firm 2's investment to the efficient level, while the fulfillment of inequality (4) represents a necessary condition for a contract to be signed, with some positive probability. Before stating the result, we need to introduce a further piece of notation. Let p denote the probability that the investment level made by firm 2 induces the good state of nature G, when the follow-on innovator is uninformed about the existence of a patent protecting firm 1's technology.

Proposition 3. *Consider the set of PBE satisfying the D1 criterion. The largest investment level that can be induced in any equilibrium of this set is* r_{up} *with* $C_{up} = \left(L_C^B, L_{up}^G\right)$ *, and where* L_{up}^G *is the minimum value of* L^G *satisfying the following condition*

$$\alpha E\left(L_{up}\right) + (1-\alpha)\left(pL^G + (1-p)L_C^B\right) = \alpha E\left(L_C\right) + (1-\alpha)\left(pL_C^G + (1-p)\,L_C^B\right). \qquad (5)$$

Proof. See the Appendix. ■

As we have already pointed out, the most favorable condition for having firm 1 accepting a proposal occurs when the first innovator believes that, with a large probability, firm 2 is ex-ante. Consistently with this observation, condition (5) shows that r_{up} - the upper bound to the equilibrium investment level - is obtained when firm 1 holds the largest belief it can have in equilibrium about firm 2 being ex-ante, $\mu_A = \alpha$. Moreover, the equality characterizing condition (5) implies that r_{up} is induced by contract C_{up} that makes firm 1 indifferent between accepting or rejecting the proposal. Were firm 1's participation constraint satisfied as an inequality, then it would be possible to reduce sightly L^G and find a more efficient contract still being acceptable by the first innovator. Finally, notice that in case of state B, contract C_{up} specifies the fee L_C^B, the same payment as the default contract. In the Appendix, we show that if this were not the case then it would be possible to find a more efficient contract specifying a larger payment in state B and a smaller payment in state G, and that firm 1 would still be willing to accept.

Proposition 3 implies that in any PBE satisfying the D1 criterion firm 2 does not make an investment larger than r_{up}; obviously we are not able to determine whether the upper bound is actually reached in some equilibrium or not. In the Appendix, we present an example where we can derive an explicit expression for the the upper bound. Interestingly, we show that under some circumstances, C_{up} coincides with C_C; this fact implies that in these cases firms cannot do better than under the terms of the default contract, just as in Section 3.1.

Finally, let us conclude the analysis by showing that the set of PBE satisfying the D1 criterion is not empty.

Proposition 4. *There exists a PBE satisfying the D1 criterion where the default contract is signed with probability one.*

Proof. Consider the following strategy profile and system of beliefs. Firm 2 proposes the default contract; firm 1 accepts C_C and rejects any proposal that specifies $L^i < L_C^i$ for some $i = G$ or B. Firm 1's out-of-equilibrium beliefs are such that the proposer of any contract with $L^i < L_C^i$ is the ex-post type ω_i, $i = B$ or G (in case both $L^B < L_C^B$ and $L^G < L_C^G$ hold it believes with probability 1 the proposer is either type ω_G or ω_B). It is easy to check that given the beliefs the strategies are best responses. Consider now the out-of-equilibrium beliefs. If the contract is such that $L^B < L_C^B$, then belief $\mu_B = 1$ is consistent with the D1 criterion: type ω_B benefits from making such out-of-equilibrium proposal no matter how small is the probability that is accepted by firm 1; in fact, in equilibrium, type ω_B pays L_C^B, while when deviating the payment is the same as in case of rejection and strictly less in case of acceptance. The same arguments apply for the case where $L^G < L_C^G$ is proposed: $\mu_G = 1$ is consistent with the D1 criterion. Note, finally, that firm 2 has no incentive to propose contracts with payments weakly larger than the default ones in both states of nature; therefore, the beliefs associated to these out-of-equilibrium proposals are irrelevant. ■

Notice that the game shows a multiplicity of equilibria which are all payoff equivalent;

firm 2 may look either for an ex-ante or an ex-post licensing agreement, but in all the cases the contract C_C is signed and the second innovator invests r_C.

4 Concluding remarks

The theoretical literature on the cumulative innovation process has emphasized the role of ex-ante licensing in mitigating the risk of hold-up of future innovation. In this paper, we have considered a patent-holder and a follow-on innovator bargaining over the licensing terms, in a realistic context where the former firm is unable to observe the timing of the R&D investment of the latter. We have shown that in this case the possibilities of restoring the R&D incentives by setting the licensing terms appropriately are severely limited. In fact, by asking for a licensing agreement only once the R&D investment has already been sunk the follow-on innovator improves her/his bargaining position: she/he decides about what contracts to accept (what contract to offer when acting as the proposer) based on more detailed information about the research project. This behavior reduces the set of contracts that the patent-holder is willing to accept.

These results have important policy implications. As Gallini and Scotchmer (2002) argue, the existing literature on the role of patents in industries where innovation is cumulative is inconclusive as to whether broad or narrow patents are better suited to encourage innovations. However, "one lesson is clear: the optimal design of IP depends importantly on the ease with which rights holders can contract around conflicts in rights" (Gallini and Scotchmer, 2002 p. 67). Our paper adds to the arguments discussed in the Introduction another reason why ex-ante licensing is unlikely to solve the potential hold-up of future innovation: the simple inability of the patent-holder to tell whether the follow-on innovator is truly ex-ante prevents parties from signing contract that restore the R&D incentives. In this sense our results complement the analysis provided by Bessen and Maskin (2008). These authors show that in a context where patent licensing is inefficient because of an adverse selection problem, the a regime without patents might be preferable.

5 Appendix

Proof of Proposition 2. Let β be the probability that firm 1 accepts contract C_E, and suppose that, contrarily to the statement of Proposition 2, in equilibrium parties sign a contract C_E with $L_E^B > L_C^B$. In order to prove that this cannot be the case, we show that there is an out-of-equilibrium proposal $C_D = \left(L_E^B - \varepsilon, L_E^G\right)$ which is profitable for type ω_A of firm 2, and that is accepted by firm 1. In particular, we show that :

i) according to the D1 criterion, firm 1 assigns probability 1 to the fact that the proposer of the contract C_D is of type ω_A (Claim 1);

ii) given the beliefs defined in i), accepting C_D is a best response for firm 1 (Claim 2).

Claim 1: *The divinity criterion D1 imposes firm 1 to assign probability* 1 *to the fact that the proposer of contract* C_D *is the ex-ante type of firm 2.*

Proof of Claim 1. As first we determine under what conditions the different types of firm 2 prefer to propose C_D rather than C_E.

The following condition guarantees that type ω_A benefits from proposing contract C_D when firm 1 accepts it with probability γ:

$$\gamma\left(\pi_D - E\left(L_D\right)\right) + (1-\gamma)\left(\pi_C - E\left(L_C\right)\right) \geq \beta\left(\pi_E - E\left(L_E\right)\right) + (1-\beta)\left(\pi_C - E\left(L_C\right)\right).$$

Re-arranging the above condition we have:

$$\gamma \geq \beta \frac{\left(\pi_E - E\left(L_E\right) - \pi_C + E\left(L_C\right)\right)}{\left(\pi_D - E\left(L_D\right) - \pi_C + E\left(L_C\right)\right)} \equiv \gamma_A.$$

Therefore, when $\gamma \geq \gamma_A$ type ω_A benefits from the out-of equilibrium proposal C_D. Note that the licensing fees that firm 2 pays under contract C_D are smaller than those paid under contract C_E and therefore $\pi_D - E\left(L_D\right) > \pi_E - E\left(L_E\right)$; this fact implies that $\gamma_A < \beta$.

Similarly, type ω_G benefits from proposing contract C_D provided that firm 1 accepts it with probability γ such that:

$$\gamma\left(L_E^G\right) + (1-\gamma)\, L_C^G \leq \beta L_E^G + (1-\beta)\, L_C^G.$$

After few manipulations the above condition becomes:

$$\gamma \geq \beta \equiv \gamma_G$$

Clearly, from the above arguments $\gamma_A < \gamma_G$

Finally, note that since our starting contract is such that $L_E^B > L_C^B$ we can always find an ε small enough and such that type ω_B never benefits from proposing contract C_D.■

Claim 2: *When $\mu_A = 1$, firm 1' best response is to accept the proposal C_D rather then rejecting it and getting the default pay-off.*

Proof of Claim 2. By Lemma 3 we know that $E(L_E) > E(L_C)$; therefore it is possible to find ε small enough such that $E(L_D)$ is sufficiently close to $E(L_E)$, and $E(L_D) > E(L_C)$. This implies that, when holding the belief $\mu_A = 1$, firm 1 benefits from accepting the proposal C_D.■

Proof of Proposition 3. So far we have proved that in a PBE satisfying the D1 criterion where contract C_E is signed with some positive probability, it has to be: $L_E^G < L_C^G$ (Lemma 1), $L_E^B \leq L_C^B$ (Proposition 2), and $E(L_E) > E(L_C)$ (Lemma 3); moreover it has to be $L_E^B < L_E^G$, otherwise firm 1 would reject C_E. In what follows, we look for the contract such that: condition (4) is satisfied, and the difference $L_E^G - L_E^B$ is minimized.

Consider a contract C_E such that: condition (4) is satisfied and firm 1 accepts it with probability 1. Notice that:

a) Condition (4) has to hold as an equality; if it holds as a strict inequality, then it is possible to find an $\varepsilon > 0$ such that contract $\left(L_E^B, L_E^G - \varepsilon\right)$ still satisfies condition (4), and it is such that the difference $L_E^G - L_E^B$ is reduced.

b) It has to be $\mu_A = \alpha$. Suppose that $\mu_A < \alpha$ and notice that since $L_E^G < L_C^G$, $L_E^B \leq L_C^B$, and $E(L_E) > E(L_C)$, then with $\mu_A = \alpha$, condition (4) is satisfied as a strict inequality. Therefore, applying the same reasoning as above, with $\mu_A = \alpha$ it is possible to find and $\varepsilon > 0$ such that contract $\left(L_E^B, L_E^G - \varepsilon\right)$ still satisfies (4) and it is such that the difference $L_E^G - L_E^B$ is reduced.

c) It has to be $L_E^B = L_C^B$. Suppose that $L_E^B < L_C^B$ and notice that in this case it is possible to find a couple Δ, ε, with $0 < \varepsilon < \Delta$, such that a more efficient contract $\left(L_E^B + \Delta, L_E^G + \Delta - \varepsilon\right)$ still satisfies condition (4). Notice, indeed that contract $\left(L_E^B + \Delta, L_E^G + \Delta - \varepsilon\right)$: provides for larger payments in both states for firm 1 and it induces a larger investment than $\left(L_E^B, L_E^G\right)$, and it reduces the difference the $L_E^G - L_E^B$.

The arguments just developed imply that the upper bound for the level of investment, r_{up}, is induced by contract $C_{up} = \left(L_C^B, L_{up}^G\right)$, where L_{up}^G is the minimum value of L^G such that:

$$\alpha E\left(L_{up}\right)+(1-\alpha)\left(pL^{G}+(1-p)\,L_{C}^{B}\right)=\alpha E\left(L_{C}\right)+(1-\alpha)\left(pL_{C}^{G}+(1-p)\,L_{C}^{B}\right). \qquad (6)$$

Consider now a contract C_E such that: condition (4) is satisfied, and firm 1 accepts it with probability $\beta < 1$. Notice that: a') condition (4) has to hold as an equality since firm 1 is playing mixed strategies; b') $\alpha = \mu_A$, since, whenever informed about the existence of the patent, firm 2 comes ex-ante: there are no benefits in coming ex-post since C_E provides for a smaller payment in both states of nature while the advantage of coming ex-ante is that firm 2 avoids the uncertainty related to firm 1 playing mixed strategies; c') $L_E^B = L_C^B$, since the reasoning of point c) above still applies. Therefore, also in this case the upper bound to the level of investment, r_{up}, is induced by contract C_{up}. This fact implies that the upper bound is reached when firm 1 accepts the proposal with probability 1; when the first innovator plays mixed strategies then: the investment is r_{up} with probability β and $r_C(\leq r_{up}$ with probability $1-\beta$. ■

Example: computation of the upper bound r_{up}

Assume that $p(r) = r,\; c(r) = \frac{r^2}{2}$, $V^G - V^B < 1$, $L_C^i = \rho V_C^i$ with $i = G, B$ and $\rho \in [0,1]$; moreover we will impose also that $\alpha \to 1$.

With simple calculations it is possible to determine: $r_{eff} = V^G - V^B$, $r_C = (1-\rho)\left(V^G - V^B\right)$, $E(L_C) = r_C \rho V^G + (1-r_C)\rho V^B$. To compute the upper-bound we proceed as follows. We consider a contract that specifies a payment $\rho V^B \left(= L_C^B\right)$ in the bad state and xV^G in the good state, with x to be determined. Given this contract firm 2 (when informed about the existence of the patent) selects r to maximize $rV^G(1-x) + (1-r)V^B(1-\rho) - \frac{r^2}{2}$; simple calculations lead to define the optimal investment level $r(x) = V^G(1-x) - V^B(1-\rho)$, and $E(L(x)) = r(x)\,xV^G + (1-r(x))\,\rho V^B$. The value of x characterizes contract C_{up} is the solution of:

$$\alpha E(L(x)) + (1-\alpha)\left(pxV^G + (1-p)\,\rho V^B\right) = \alpha E(L_C) + (1-\alpha)\left(p\rho V^G + (1-p)\,\rho V^B\right).$$

The equation has to solutions $x_1 = \rho$ and $x_2 = \frac{(G-B)(1-\rho)+B\rho}{G} + \frac{p(1-\alpha)}{\alpha G}$; taking $\alpha \to 1$, these reduce to: $x_1 = \rho$ and $x_2 = \frac{\left(V^G - V^B\right)(1-\rho)+\rho V^B}{V^G}$, with $x_1 < x_2$ iff $\rho < \frac{1}{2}$. Therefore:

- When $\rho < \frac{1}{2}$, $r_{up} = r_C$, and therefore firms cannot improve upon the default contract. Notice that in this case we can exclude the existence of equilibria where a contract different from C_C is signed. The arguments developed here show that parties never agree on a contract more efficient than C_C; moreover, a contract less efficient than C_C cannot be simultaneously accepted by firm 1 and by the ex-ante type of firm 2. Therefore, in any equilibrium of the game licensing is determined by the default contract, and firm 2 selects r_C. In this case the level of efficiency attained in equilibrium is $\frac{r_{up}}{r_{eff}} = (1-\rho)$.

- When $\rho \geq \frac{1}{2}$, $r_{up} = \rho\left(V^G - V^B\right)$ (with $r_{up} > r_C$). In this case, the upper bound to the level of efficiency that can be attained in equilibrium is $\frac{r_{up}}{r_{eff}} = \rho$. ■

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