

# 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 its R&D investment - in mitigating the risk of hold-up of future innovations. In this paper, we consider a patent-holder and a follow-on innovator bargaining over the licensing terms in a context where the former firm is unable to observe the timing of the R&D investment of the latter. We show that 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 (see Jaffe and Lerner, 2004). These consequences turn out to 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. Therefore, R&D incentives tend to be seriously undermined with the risk of hold-up of future innovations.<sup>1</sup>

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, the increased number of patents is unlikely to represent a substantial impediment to future innovations. Following this view, the theoretical literature dealing with the cumulative innovation process has focussed on the central role of the timing of contracting to mitigate the risk of hold-up. 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 its investment then the correct R&D incentives can be restored. The argument in favor of prior agreements is simple: with ex-ante licensing the R&D costs of the inventor are taken into account during the negotiation process with the effect of mitigating the inefficiency. In a seminal paper, Green and Scotchmer (1995) show that, in a context of symmetric information, the feasibility of prior agreements is enough to restore full efficiency of licensing negotiations, thus completely eliminating the risk of hold-up.<sup>2</sup>

Nevertheless, legal scholars and practitioners have pointed out the difficulties related to patent negotiations, and to ex-ante licensing in particular.<sup>3</sup> Their main argument is rather simple: given the intangible nature of 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. On the top of that, there are also other compelling reasons that might make

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<sup>1</sup>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 (2010) for a recent analysis of patent thickets and the related “tragedy of anti-commons”.

<sup>2</sup>The assumption of feasibility of ex-ante licensing under symmetric information has been repeatedly employed in the subsequent theoretical contributions on cumulative innovation; see O’Donoghue et al. (1998), Scotchmer (1996) and Schankerman and Scotchmer (2001). See also Gallini and Scotchmer (2002) for a review of these issues. Two recent and notable exceptions are Bessen (2004) and Bessen and Maskin (2009). 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.

<sup>3</sup>See, among others, Merges and Nelson (1990) and Gallini (2002) . In a recent empirical study based on a survey of the inventors of more than nine thousands patents granted at the European patent office (the so-called PatVal survey), Gambardella et al. (2007) argue that the market for ideas is largely ineffective due to the presence of substantial costs of transaction; in their study, the authors estimate that the exchange of patented technologies could potentially be 70% larger than what actually is if these frictions were eliminated.

ex-ante contracts impractical. First and foremost, the follow-on innovator might need to invest significant resources before entering into licensing negotiations; as discussed in Gallini (2002), these resources are sunk before negotiations take place and therefore are difficult to recover. In addition to this argument, Bessen and Meurer (2008) suggest that a follow-on researcher might fail to sign an ex-ante licensing agreement simply because it may not be aware of the existence of relevant patents (this phenomenon is called “notice failure” in the legal jargon). This might occur because of different reasons. The patent-holder might strategically keep claims hidden (e.g. by filing “continuing” applications) while the patent is pending. Alternatively, an accurate search of the prior art in the patent databases could be excessively costly for the follow-on innovator; this is frequent in IT-related sectors where the number of potentially relevant patents is often very large.<sup>4</sup>

In this paper, we go even further by arguing that parties are prevented from signing efficient (ex-ante) licensing contracts simply because the patent-holder is unable to observe the timing of the investment of the follow-on innovator. In particular, we consider two parties, a patent-holder, and a follow-on innovator which is on the way to develop a research project. Once this latter has sunk the R&D investment, it privately observes a signal that is informative about both the value of its innovation and whether it will infringe the patent protecting the original invention. We investigate whether parties are able to agree on a licensing contract that provides the follow-on innovator the correct incentives to invest in R&D and where bargaining occurs under the shadow of a Court that intervenes and sets the dispute in case the two parties have not reached an agreement. We show that the follow-on innovator benefits from negotiating ex-post the licensing agreement, that is, once it has sunk the R&D investment, and it has observed the signal about the value and the characteristics of its invention; in this way, the follow-on inventor seats at the negotiating table in a better position having collected superior information about its innovation. However, if this is the behavior of the follow-on innovator, the patent-holder is unwilling to sign an efficiency enhancing contract.

In the following sections we formalize this argument. The model that we investigate is a game with incomplete information and with endogenous types; depending on its decision to negotiate the licensing terms once the R&D investment is sunk or not, the follow-on innovator can be of different types: it might be of an ex-ante type, if it negotiates the licensing agreement before the investment decision has been taken, it can be of an ex-post type knowing that its invention does not infringe the patent of the original innovator, or of an ex-post type that knows that its invention infringes the patent and that it has a given value. Given the complexity of analyzing negotiations under asymmetric information and with endogenous types, in the paper we restrict our attention to two simple bargaining protocols in which

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<sup>4</sup>Very few empirical studies deal with the timing of negotiations in licensing agreements. Furthermore, the papers that consider this issue are of little guidance since they move from definitions of “ex-ante” and “ex-post” licensing that differ from the ones that we adopt here and that are also adopted in the theoretical literature. These studies define ex-ante licensing as those where a firm commits to licence a technology out before it has developed such a technology. See, Anand and Khanna (2000), and Siebert and von Graevenitz (2008).

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 proposal is made by the patent-holder, negotiations turn out to be completely ineffective since the equilibrium licensing fees are identical to those imposed by the Court. When the proposal is made by the follow-on inventor, we prove that at the equilibrium the two parties never sign efficient contracts; moreover, we are also able to provide an upper-bound to the level of efficiency that can be achieved through licensing negotiations.

The crucial ingredient that drives our results is the assumption that the patent-holder is unable to ascertain whether the prospective licensee has already conducted its R&D activity or not. This assumption is practically rooted and it can be easily justified by looking at a basic characteristic of any research activity that is that of being inherently difficult to observe and monitor by outsiders. This is particularly true in industries where the innovation process is cumulative and where firms often conduct several R&D projects at the same time.<sup>5</sup> In these cases, for an external observer such as the patent-holder it might be difficult, if not impossible, to disentangle at a given moment in time what are the inputs of the various projects carried on by the follow-on innovator and which investments have been sunk to develop a specific innovation. On the top of that, innovators often conduct their research activities in several different labs that may be geographically dispersed and this fact makes even more complicated for an external observer to establishing the degree of completion of a specific research project.<sup>6</sup> Finally, it is worth noticing that there is an important reason why the follow-on innovator may not need to enter in *ex ante* negotiations; in industries where the innovation process is cumulative, licensing agreements appear to be motivated mainly by the so-called “freedom to design/operate”, where the follow-on innovator negotiates the licensing agreement in order to protect its production, its marketing and also the use of its invention from possible legal challenges posed by patent holders.<sup>7</sup> In these cases, and differently from what typically happens in sectors such as the chemicals and the pharmaceuticals, a licensing agreement is not intended to obtain a technology transfer from the patent-holder in order to allow/speed up the research project and, therefore, it does not need to be negotiated before investing in R&D. For this reason, our model is more suited to describe the negotiation process in those sectors (e.g. software and semiconductors) where the freedom to design/operate represents the main driver to patent licensing.

The analysis proposed in this paper is also relevant from a 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

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<sup>5</sup>An indirect evidence of the firms’ common practice of conducting several research projects simultaneously can be obtained by looking at patent applications. In this respect, a notable study on semiconductors is in Ziedonis (2004); using a large sample of publicly traded U.S. firms, the author finds that in the period 1980-1994 on average each firm obtained 17.56 patents per year.

<sup>6</sup>Take for instance the Bayer group. During the year 2006 it applied for 501 patents at the European patent office. The large majority of these patents (365) originated from research labs located in Germany. The remaining patents were from U.S. (106), French (22), Belgian (7), Japanese (1) research labs.

<sup>7</sup>This point is raised, among others, in an article published on the WIPO magazine of the World Intellectual Property Organization (see WIPO, 2005).

which is closest to ours is 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.<sup>8</sup>

A major difference with respect to this literature is that, in our setting, the choice to acquire information before the contracting stage (negotiate ex-post the licensing agreement, in our paper) and the choice of investing a certain amount of money in R&D activities collapse into a single decision. The fact that information acquisition is not a separate decision, as in Dang (2008) and in other contributions in this literature, generates an endogenous cost related to the choice of becoming informed: by making the investment before signing the licensing contract, the follow-on innovator faces the risk of selecting a non-optimal investment level. Clearly, this cost is effectively borne by the follow-on innovator whenever, in equilibrium, there is uncertainty about the contract that will bind.

The rest of the paper is organized as follows: in Section 2, we present the outline of the model. In Section 3 we derive the results of our analysis, considering the two bargaining protocols. In Section 4, we discuss some of our modelling assumptions and the policy implications stemming from our analysis. All the proofs that are not essential to understand the main arguments of the paper are presented in the appendix.

## 2 The model

We consider a cumulative innovation process with two inventors, firm 1 and firm 2. Firm 1 has already developed and patented its innovation; at some point in time after the first innovation is available, firm 2 “gets an idea” for a second generation invention. With some positive probability, firm 2’s innovation will infringe the patent that protects the first invention.

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

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 vector  $\{p(r), c(r), V^B, V^G\}$ . The term  $r \geq 0$  represents the amount of R&D activity that firm 2 undertakes in order to develop its idea and  $c(r)$  is the corresponding cost. The R&D activity determines the value of the innovation and the probability of infringing firm 1’s patent. When  $r$  is chosen, then with probability  $p(r) \in (0, 1)$  the value of the innovation is  $V^G$  (the innovation is Good,

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<sup>8</sup>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.

$G$ ) and the probability of infringement is  $0 < \gamma \leq 1$ ; with probability  $1 - p(r)$  the value of the innovation is  $V^B$  (the innovation is Bad,  $B$ ) and the probability of infringement is  $0 < \beta \leq 1$ . In what follows, we assume that  $V^G > V^B > 0$ , and  $\gamma \leq \beta$ . Note that, when  $\gamma < \beta$ , there is a negative correlation between the value of the innovation and the probability of infringement;<sup>9</sup> when  $\gamma = \beta$ , the R&D activity affects the value of the innovation only, while the probability of infringement is exogenous.

All through the paper we will assume that the probability and cost functions satisfy the following conditions:  $p'(r) \geq 0$ ,  $p''(r) \leq 0$ ,  $c'(r) > 0$ ,  $c''(r) > 0$  for all  $r \geq 0$ , and  $c(0) = 0$ ; moreover, we will assume that both the efficient and the equilibrium levels of  $r$  are positive and such that  $0 < p(r) < 1$ .

### Timing, information structure and licensing contracts

The first invention is already available and protected by a patent, and, at some point in time, firm 2 gets an idea for a follow-on innovation. The timing of the game is as follows:

- t=0 firm 2 observes  $\{p(r), c(r), V^B, V^G\}$  and the probabilities of infringement  $\beta$  and  $\gamma$ ;
- t=1 firm 2 chooses the level of R&D activity,  $r$ . Once  $r$  is sunk, firm 2 obtains a perfect signal about both the value of the innovation (either  $V^B$  or  $V^G$ ), and whether it infringes firm 1's patent. The amount of R&D activity  $r$  is neither verifiable nor observable by the first inventor;
- t=2 firm 2 commercializes the innovation and earns  $V^i$ ,  $i = B$  or  $G$ ; licensing payment are made, whenever due. Only at this stage the value of the innovation and the fact that there is infringement or not are observed by firm 1, and are verifiable at no cost by a third party.

Firm 2 can choose to negotiate the licensing terms with the first inventor at two different stages, either: i) between  $t = 0$  and  $t = 1$ , that is, after observing the idea but before having chosen  $r$  (following Green and Scotchmer, 1995, we refer to this case as “ex-ante licensing”), or ii) between  $t = 1$  and  $t = 2$ , that is, once  $r$  has been sunk, and the signal has been obtained (we refer to this case as “ex-post licensing”). We assume that, during the negotiation process, firm 2's idea,  $\{p(r), c(r), V^B, V^G\}$  and the probabilities of infringement are common knowledge; however, firm 1 is unable to observe whether the second innovator has already sunk the R&D investment or not. At the licensing stage, firm 2 can be of four different types. In case  $r$  has not been sunk, firm 2 is of an ex-ante type,  $\omega_A$ . In case

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<sup>9</sup>In most of the literature on the cumulative innovation process, the novelty (hence the probability of non-infringing) and the commercial value of an invention collapse into one single dimension (see, for instance, O'Donoghue et al., 1998); assuming that  $\gamma \leq \beta$  we consider a more general setting. Notice that when  $\gamma < \beta$ , then, by increasing  $r$ , the second innovator both enhances the expected value of the innovation, and also it reduces the probability of infringement. Therefore, our model also incorporates a so-called inventing-around research, namely an activity that an inventor performs in order to reduce the probability of infringement. However, for the sake of simplicity, we do not consider the case where  $\beta$  and  $\gamma$  depend on  $r$ .

$r$  has already been sunk, firm 2 can be: ex-post of type  $N$  (firm 2 knows that there is no infringement),  $\omega_N$ , ex-post of type  $G$  (firm 2 knows that there is infringement and the innovation is worth  $V^G$ ),  $\omega_G$ , or ex-post of type  $B$  (firm 2 knows that there is infringement and the innovation is worth  $V^B$ ),  $\omega_B$ . In what follows, we let  $\mu_i$ , with  $i = A, N, G, B$ , denote the system of beliefs that firm 1 holds at the licensing stage.

We model the licensing negotiations as a bargaining with a take-it-or-leave-it offer; if firms fail to reach an agreement, then, in case infringement has occurred, the terms of licensing are set at  $t = 2$  by the Court. The Court mandates a licensing fee  $L_C^i$  when the value of innovation is  $V^i$ , with  $i = B, G$  (where the subscript  $C$  refers to the fact that these payments are mandated by the Court). We assume that the licensing fees imposed by the Court are such that  $0 \leq L_C^i \leq V^i$ ,  $i = B, G$ .<sup>10</sup>

A licensing contract  $C_j$  is a triple  $(L_j^B, L_j^G, \bar{L}_j)$ , where  $L_j^i \in \mathbb{R}$ ,  $i = B, G$ , is the fee that firm 2 pays at  $t = 2$  contingent on infringement when the value of the innovation is  $V^i$ ,  $i = B, G$ ;  $\bar{L}_j \in \mathbb{R}$  is an upfront payment made (received, if  $\bar{L}_j < 0$ ) by firm 2 when signing the contract. Notice that the licensing fees mandated by the Court are equivalent to a licensing contract  $(L_C^B, L_C^G, 0)$ ; in the rest of the paper, we will refer to this contract as the default contract, denoted by  $C_C$ . It is worthy noticing that when the licensing terms are determined by contract  $C_C$ , firm 2 makes non negative profits, given that  $0 \leq L_C^i \leq V^i$ ,  $i = B, G$ , and  $c(0) = 0$  (it could choose  $r = 0$ , and makes non negative profits).

## 2.1 R&D decision

We start our analysis by determining the efficient level of R&D,  $r^*$ , the one that maximizes the joint profits of the two firms:

$$r^* \equiv \arg \max_r p(r)V^G + (1 - p(r))V^B - c(r).$$

This level of R&D is implicitly defined by the following first order condition:

$$p'(r^*) [V^G - V^B] = c'(r^*). \quad (1)$$

When the licensing terms are determined by contract  $C_j = (L_j^B, L_j^G, \bar{L}_j)$ , then firm 2 chooses an amount of R&D  $r_j$  such that:

$$r_j \equiv \arg \max_r p(r) (V^G - \gamma L_j^G) + (1 - p(r)) (V^B - \beta L_j^B) - \bar{L}_j - c(r).$$

In this case the first order condition reduces to:

$$p'(r_j) (V^G - V^B - (\gamma L_j^G - \beta L_j^B)) = c'(r_j). \quad (2)$$

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<sup>10</sup>An alternative interpretation of the default contract is the following. If parties did not sign any agreement before, then, in case of infringement, the licensing terms are negotiated at  $t = 2$ , when firms are symmetrically informed about the value of the innovation. In this case each firm obtains a share of  $V^i$ ,  $i = B, G$  which is proportional to its bargaining power.

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

$$\left\{ \begin{array}{ll} \text{if } \beta L_j^B < \gamma L_j^G, & \text{firm 2 under-invests, } r_j < r^*, \\ \text{if } \beta L_j^B = \gamma L_j^G, & \text{firm 2 invests efficiently, } r_j = r^*, \\ \text{if } \beta L_j^B > \gamma L_j^G, & \text{firm 2 over-invests, } r_j > r^*. \end{array} \right.$$

In order to make our analysis meaningful, we assume that the default contract induces an inefficient level of R&D, namely,  $\beta L_C^B \neq \gamma L_C^G$ .

In the rest of the paper, we will use the following simplifying notation. When firms sign contract  $C_j$ , and firm 2 chooses  $r_j$  accordingly, we denote  $\pi_j \equiv p(r_j)V^G + (1 - p(r_j))V^B - c(r_j)$  the joint profits of the two firms, and  $E(L_j) \equiv p(r_j)\gamma L_j^G + (1 - p(r_j))\beta L_j^B$  the expected licensing fees.

### 3 Results

Before moving further into the formal analysis, it is useful to stress the crucial role played by the assumption of the non-observability of the timing of firm 2's investment.

If firm 2 has already sunk its R&D investment there is no efficiency gain in signing a licensing contract different than  $C_C$ , and one of the two firms will find it optimal not to sign it. On the contrary, when the second innovator looks ex-ante for a licensing agreement, it is possible to find contracts that induce a level of R&D more efficient than  $r_C$ , the investment induced by the default contract, and that are beneficial for both firms. These arguments suggest that, if the timing of firm 2's investment decision were observable, then licensing would guarantee that the second innovator invests efficiently, as in Green and Scotchmer (1995). Licensing negotiations would take place before the second innovator has chosen  $r$ , and would result in a contract that induces firm 2 to invest efficiently. For instance, a contract  $C_j = (0, 0, \bar{L}_j)$  that specifies that the first innovator licenses its patent in exchange of an upfront payment  $\bar{L}_j$  would induce the second innovator to select  $r^*$ , thus restoring efficiency.

Things go differently if the timing of firm 2's investment cannot be observed by the counterpart. Suppose that firm 1 is willing to license its patent under contract  $C_j = (0, 0, \bar{L}_j)$ . In this case, firm 2 prefers to postpone the agreement, and to negotiate the licensing terms between  $t = 1$  and  $t = 2$  (i.e. after having sunk  $r$  and learned the value of the innovation and whether there is infringement); in this way, the second innovator pays  $\bar{L}_j$  only in case the infringement has actually occurred. A similar argument applies also when infringement occurs with probability one ( $\gamma = \beta = 1$ ), and, therefore, firm 2 always needs to sign a licensing agreement. Suppose, without loss of generality, that the default contract specifies  $L_C^B < L_C^G$ , and notice that, in order to have both firms willing to sign contract  $C_j = (0, 0, \bar{L}_j)$ , the upfront must be such that  $L_C^B < \bar{L}_j < L_C^G$ : contract  $C_j$  such that  $\bar{L}_j \leq L_C^B$  would be rejected by firm 1, while it would be rejected by firm 2 if  $\bar{L}_j \geq L_C^G$ . Also in this case, the second innovator benefits from postponing the agreement, and negotiating the licensing terms between  $t = 1$  and  $t = 2$ ; in this case, firm 2 accepts contract  $C_j$  when the value of

the innovation is  $V^G$  (so that it pays  $\bar{L}_j$  smaller than  $L_C^G$ ) while it signs the default contract when the value of the innovation is  $V^B$  (paying  $L_C^B$  that is smaller than  $\bar{L}_j$ ). Obviously, anticipating the fact that the second innovator will postpone the negotiations after it has observed the signal, firm 1 is unwilling to license its patent under contract  $C_j$ .

The discussion above summarizes the main issue addressed in this paper. In order to restore the appropriate R&D incentives, parties should agree on a licensing contract different from the default one; however, the first innovator is reluctant to sign such a contract since firm 2 may act strategically and postpone the licensing negotiations until it has collected superior information about its innovation. The rest of the paper is devoted to generalizing this argument. In particular, we investigate whether in equilibrium parties sign with some positive probability a contract, denoted by  $C_E$ , different from the default one.

### 3.1 Firm 1 makes the licensing proposal

In this section, we assume that firm 1 has the full bargaining power at the licensing stage: when the second innovator asks for a licensing agreement, firm 1 makes a take-it-or-leave-it proposal to the counterpart.

By proposing a contract  $C_E = (L_E^B, L_E^G, \bar{L}_E)$  which is acceptable by the ex-ante type of firm 2, the expected pay-off of the first innovator is:

$$\mu_A E(L_E) + \mu_B \min \{L_E^B + \bar{L}_E, L_C^B\} + \mu_G \min \{L_E^G + \bar{L}_E, L_C^G\} + \mu_N \min \{\bar{L}_E, 0\}. \quad (3)$$

When firm 2 is of an ex-ante type (probability  $\mu_A$ ), firm 1 obtains an expected pay-off equal to  $E(L_E)$ . Alternatively, the ex-post types of firm 2 accept to sign  $C_E$  only when such contract specifies a payment smaller or equal than the default one. Consider, for instance, type  $\omega_B$ . Under contract  $C_E$ , the overall licensing fees that are due are equal to  $L_E^B + \bar{L}_E$ ; therefore, the ex-post type  $B$  accepts the proposal provided that  $L_E^B + \bar{L}_E \leq L_C^B$ , and rejects it otherwise. A similar reasoning applies to the cases of type  $\omega_G$  and type  $\omega_N$ .

The above expression highlights that, when firm 2 is of an ex-post type, the first innovator cannot benefit from signing a contract different from the default one; therefore, firm 1 is willing to offer  $C_E$  only if firm 2 is of an ex-ante type with a sufficiently large probability.

Within the set of proposals that are acceptable by the ex-ante type of firm 2, the first innovator finds it optimal to select the contract  $C_E$  that satisfies the condition shown in the following lemma.

**Lemma 1.** *If a contract  $C_E$  is proposed in equilibrium by firm 1, then the ex-ante type of firm 2 must be indifferent between accepting and rejecting the proposal.*

*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's expected pay-off is larger under contract  $C_D = (L_E^B, L_E^G, \bar{L}_E + \varepsilon)$  rather than under contract  $C_E$ . In fact, provided that  $\varepsilon$  is small enough, the ex-ante type of firm 2 still accepts the contract and, afterwards, it makes the same investment as under contract  $C_E$ ; therefore,

when firm 2 is ex-ante, the first innovator obtains a larger pay-off under contract  $C_D$  rather than  $C_E$ . Moreover, expression (3) implies that when firm 2 is ex-post, then by offering  $C_D$  firm 1 obtains at least the same pay-off as under  $C_E$ . ■

The result shown in Lemma 1 is driven by the assumption that firm 1 holds the full bargaining power at the licensing stage; 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.

Using the previous lemma we can prove our first main result.

**Proposition 1.** *When firm 1 is the proposer at the licensing stage, licensing occurs under the terms specified by contract  $C_C$ .*

*Proof.* Let us start by proving that a contract different from the default one is never signed in equilibrium. Suppose, by contradiction, that, with some positive probability, firm 1 proposes a contract  $C_E$  different from  $C_C$ , and consider firm 2's licensing payments in the three possible states of nature: i) the second innovation does not infringe the patent of firm 1, ii) the second innovation infringes the patent and  $V^G$  occurs, iii) the second innovation infringes the patent and  $V^B$  occurs. Contract  $C_E$  specifies the payments:  $\bar{L}_E$  in case i),  $L_E^G + \bar{L}_E$  in case ii), and  $L_E^B + \bar{L}_E$  in case iii); contract  $C_C$  specifies the payments 0,  $L_C^G$ , and  $L_C^B$ , respectively. From Lemma 1 we know that the ex-ante type of firm 2 has to be indifferent between contracts  $C_E$  and  $C_C$ ; this fact implies that there is at least one of the three states of nature in which contract  $C_E$  specifies a payment that is strictly lower than the one specified by  $C_C$ , and at least one state of nature in which the opposite occurs. Hence, in case contract  $C_E$  is offered with some positive probability, firm 2 obtains a larger profit by seeking a licensing agreement ex-post, and by accepting  $C_E$  only in the states of nature in which it specifies a payment smaller than the one specified by the default contract. However, given firm 2's behavior, firm 1 does not propose any contract different from the default one.

Finally, the following strategy profiles and system of beliefs are an equilibrium of the game. Firm 2 chooses  $r = r_C$  and asks the licensing agreement between  $t = 1$  and  $t = 2$ . Firm 1 assigns probability zero that firm 2 is of an ex-ante type and proposes the contract  $C_C$ . Firm 2 accepts all contracts that, given its type, provide a pay-off larger or equal than contract  $C_C$ . Namely, type  $\omega_N$  accepts any contract  $C_j$  such that  $\bar{L}_j \leq 0$ , type  $\omega_G$  accepts any contract such that  $L_j^G + \bar{L}_j \leq L_C^G$ , and type  $\omega_B$  accepts any contract such that  $L_j^B + \bar{L}_j \leq L_C^B$ ; the ex-ante type of firm 2 accepts  $C_j$  provided that  $\pi_j - E[L_j] \geq \pi_C - E[L_C]$ . ■

Proposition 1 has an important consequence: since licensing occurs under contract  $C_C$ , at  $t = 1$  firm 2 chooses  $r_C$ .<sup>11</sup> Therefore, the option to sign ex-ante agreements is irrelevant, and firms cannot improve upon the (inefficient) investment level induced by the default contract.

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<sup>11</sup>Notice that there are many equilibria of this game which are payoff equivalent. In all these equilibria, firm 2 comes ex-post with a probability sufficiently large so as to make firm 1 better-off by proposing the default contract rather than any other contract  $C_E$ . Obviously, since licensing always occurs under  $C_C$ , firm 2 is indifferent between coming ex-ante or ex-post, and at  $t = 1$  it chooses  $r_C$ .

### 3.2 Firm 2 makes the licensing proposal

So far we have considered a (more realistic) setting where, at the licensing stage, the first inventor has the full bargaining power; in this section, we show how our results extend to the opposite scenario in which firm 2 makes a take-it-or-leave-it proposal to the counterpart. 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, signaling games show a multiplicity of Perfect Bayesian Equilibria (PBE). In order to focus on reasonable PBE, we will require that the out-of-equilibrium beliefs satisfy the D1 criterion. It is worth giving an informal intuition about how this criterion works. Consider that, at the licensing stage, firm 2 makes an out-of-equilibrium proposal and consider any conjecture that this firm has about the reaction of the first inventor. If, given any conjecture, it happens that a type of firm 2, say type  $\omega_A$ , finds it optimal to make the out-of-equilibrium proposal whenever it is optimal for another type, say  $\omega_B$ , while the opposite does not hold, then the D1 criterion imposes to assign probability zero that the proposer is of type  $\omega_B$ .

The first result that we show is that, also when firm 2 is the proposer of the licensing agreement, there exists an equilibrium where firms are unable to improve upon the default contract.

**Proposition 2.** *When firm 2 is the proposer at the licensing stage, there exists a PBE satisfying the D1 criterion where licensing occurs under the terms specified by contract  $C_C$ .*

*Proof.* Consider the following strategy profiles and system of beliefs. Firm 2 chooses  $r = r_C$ , and, between  $t = 1$  and  $t = 2$ , proposes the default contract; firm 1 accepts to sign contract  $C_C$  and rejects any other proposal  $C_j$  that specifies  $L_j^i + \bar{L}_j < L_C^i$  for  $i = B$  or  $G$ , or  $\bar{L}_j < 0$ . Firm 1's out-of-equilibrium beliefs are such that: the proposer of any contract with  $L_j^i + \bar{L}_j < L_C^i$  is the ex-post type  $\omega_i$ ,  $i = B$  or  $G$ , and the proposer of a contract with  $\bar{L}_j < 0$  is the ex-post type  $\omega_N$  (in case of proposals such that more than one of the previous inequalities are satisfied, then firm 1 still holds the belief that firm 2 is ex-post). It is easy to check that given this system of beliefs the strategies specified above are best responses. Consider now the out-of-equilibrium beliefs. If contract  $C_j$  is such that  $L_j^B + \bar{L}_j < L_C^B$ , then the belief  $\mu_B = 1$  is consistent with the D1 criterion: type  $\omega_B$  benefits from making such out-of-equilibrium proposal no matter how small is the probability that it is accepted by firm 1; in fact, in equilibrium, type  $\omega_B$  pays  $L_C^B$ , while when proposing  $C_j$  it still pays  $L_C^B$  in case of rejection and  $L_j^B + \bar{L}_j (< L_C^B)$  in case of acceptance. The same argument applies for the case where  $L_j^G + \bar{L}_j < L_C^G$  ( $\mu_G = 1$  is consistent with the D1 criterion), and where  $\bar{L}_j < 0$  ( $\mu_N = 1$  is consistent with the D1 criterion). Finally, notice that firm 2 never proposes a contract  $C_j$  with  $L_j^i + \bar{L}_j \geq L_C^i$  for  $i = B, G$ , and  $\bar{L}_j \geq 0$ ; therefore, the beliefs associated to such an out-of-equilibrium proposal, as well as firm 1's acceptance/rejection decision, are irrelevant. ■

Proposition 2 shows the existence of an equilibrium that yields the same outcome as the one highlighted in Proposition 1: licensing occurs under the terms specified by the default contract, and, therefore, at  $t = 1$  firm 2 chooses  $r_C$ . This is an important result that, however, does not rule out the existence of other equilibria, where the patent is licensed

under a contract  $C_E$  different from  $C_C$ . Even though we are not able to characterize the set of equilibria of the game, in what follows, we provide some further evidence that corroborates the analysis we have made so far. In order to do so, we assume that there is a positive even though negligible probability,  $1 - \alpha$ , with  $0 < \alpha < 1$ , that firm 2 learns about the existence of firm 1's patent only at  $t = 1$ , just after having chosen  $r$ . Namely, we modify the information structure of the game at times  $t = 0$  and at  $t = 1$  as follows:<sup>12</sup>

$t=0$  firm 2 gets an idea and observes  $\{p(r), c(r), V^B, V^G\}$ ; with probability  $\alpha < 1$  firm 1 is aware of the existence of firm 1's patent and knows the probabilities of infringement  $\beta$  and  $\gamma$ , with complementary probability  $1 - \alpha$  it ignores the existence of the patent;

$t=1$  firm 2 chooses the level of R&D activity,  $r$ . Once  $r$  is sunk, firm 2 obtains a perfect signal about both the value of the innovation (either  $V^B$  or  $V^G$ ), it realizes the existence of firm 1's patent in case it was unaware of it, and, finally, it learns whether its innovation infringes firm 1's patent. The amount of R&D activity  $r$  is neither verifiable nor observable by the first inventor.

The assumption  $\alpha < 1$  implies that, in any equilibrium of the game, there is a strictly positive probability that firm 2 invests ignoring the existence of the patent, and therefore that it looks for a licensing agreement only ex-post. This is a technical assumption that will be used in the the proof of Lemma 2 below,<sup>13</sup> and that can be justified on empirical grounds by the evidence on the “notice failure” that we have discussed in the introduction.

We now derive some conditions that contract  $C_E$  must satisfy in order to be signed in equilibrium. Consider the first inventor; given its system of beliefs, firm 1 accepts the proposal  $C_E$  provided that the expected licensing fees are greater or equal than under the default contract:

$$\mu_A E(L_E) + \mu_B (L_E^B + \bar{L}_E) + \mu_G (L_E^G + \bar{L}_E) + \mu_N \bar{L}_E \geq \mu_A E(L_C) + \mu_B L_C^B + \mu_G L_C^G. \quad (4)$$

Taking this condition into account, the following Lemma applies:

**Lemma 2.** *When firm 2 is the proposer at the licensing stage and  $\alpha < 1$ , if contract  $C_E$  is signed then  $E(L_E) > E(L_C)$ .*

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<sup>12</sup>The results we have derived so far under the assumption that, at  $t = 0$ , firm 2 is aware about the existence of firm 1's patent ( $\alpha = 1$ ) hold also in the different setting investigated in this section ( $\alpha < 1$ ). We leave the reader to check this assertion by simple inspection of the proofs of the above results.

<sup>13</sup>It is worth noticing that if  $\alpha = 1$  then the case where  $\mu_A = 1$  and  $E(L_E) = E(L_C)$  cannot be excluded in Lemma 2. 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  $E(L_E) > E(L_C)$ .

Proof. Firm 2, given its type, offers contract  $C_E$  provided that it obtains a pay-off larger or equal than with the default contract. In particular, for the ex-ante type of firm 2 it has to be either  $\bar{L}_E < 0$ , or  $L_E^i + \bar{L}_E < L_C^i$ , for either  $i = B$  or  $G$ . Obviously, when  $\bar{L}_E < 0$  also the ex-post type  $\omega_N$  proposes  $C_E$ , and when  $L_E^i + \bar{L}_E < L_C^i$  also type  $\omega_i$  proposes the contract  $C_E$ , with  $i = B$  and/or  $G$ . These facts imply that firm 1 obtains a strictly lower expected pay-off with contract  $C_E$  than with contract  $C_C$  when firm 2 is of an ex-post type; the assumption that  $\alpha < 1$  implies that, indeed, there is a positive probability that firm 2 is ex-post. Therefore, from condition (4) it follows that firm 1 is willing to accept contract  $C_E$  only if  $E(L_E) > E(L_C)$ . ■

By signing a contract different from the default one, the first inventor makes lower profits when firm 2 is ex-post. Therefore, as shown in Lemma 2, it is willing to sign contract  $C_E$  provided that, whenever firm 2 is ex-ante, the expected licensing fees are strictly larger than with the default contract. Using this result, we are able to derive three conditions that must be fulfilled by the payments specified in contract  $C_E$ .

**Proposition 3.** *When firm 2 is the proposer at the licensing stage, in any PBE satisfying the D1 criterion, if contract  $C_E$  is signed, then i)  $\bar{L}_E \leq 0$ , ii)  $L_E^B + \bar{L}_E \leq L_C^B$ , and iii)  $L_E^G + \bar{L}_E \leq L_C^G$ .*

Proof. See the appendix. ■

Contract  $C_E$  must specify licensing payments that are smaller or equal than those mandated by the default contract: the upfront payment has to be non-positive, and, in case of infringement, the overall licensing fees that type  $i$  pays have to be such that  $L_E^i + \bar{L}_E \leq L_C^i$ , with  $i = B, G$ . As we show in the appendix, if these conditions were not met, then it would be possible to find an out-of-equilibrium proposal which: a) is not profitable for the ex-post types of firm 2, b) is accepted by firm 1, that, according to the D1 criterion, believes that the proposer is the ex-ante type of firm 2.

We are now able to show that any equilibrium of this game is characterized by the presence of inefficiency. We start by proving that efficient contracts are never signed in equilibrium.

**Proposition 4.** *When firm 2 is the proposer at the licensing stage, in any PBE satisfying the D1 criterion, efficient contracts are never signed.*

Proof. See the appendix. ■

The next result shows that, in case contract  $C_C$  induces under-investment, then any possible equilibrium is still characterized by an under-investment problem. In other words, it is not possible that, when the Court imposes a default contract such that  $\beta L_C^B < \gamma L_C^G$ , then in equilibrium firm 2 chooses a level of R&D greater or equal than  $r^*$ . The same result holds for the opposite case: when  $\beta L_C^B > \gamma L_C^G$ , then in any possible equilibrium of the game firm 2 over-invests.

**Proposition 5.** *When firm 2 is the proposer at the licensing stage, in any PBE satisfying the D1 criterion, firm 2:*

- *under-invests when  $\beta L_C^B < \gamma L_C^G$ ;*
- *over-invests when  $\beta L_C^B > \gamma L_C^G$ .*

Proof. See the appendix. ■

The last result that we show is that any equilibrium of the game is characterized by a non-negligible level of inefficiency. For the sake of simplicity we restrict the analysis to the case where the probability of infringement is exogenous, thus not correlated to the value of the innovation ( $\gamma = \beta$ ); moreover, we assume that the default contract induces under-investment:  $L_C^B < L_C^G$ . For this case we show that there exists an upper-bound to the level of R&D activity that firm 2 chooses in any possible equilibrium of the game. This fact implies that it is not possible that firm 2 chooses a level of R&D arbitrarily close to  $r^*$ .

From the comparison between expressions (1) and (2) it follows that the level of under-investment is proportional to the difference  $(L_E^G - L_E^B)$ . Therefore, in order to define the upper-bound to the level of  $r$  chosen by firm 2, we look for the contract that minimizes such difference and that fulfills the following conditions: conditions i)-iii) defined in Proposition 3, condition (4), according to which firm 1 is willing to sign contract  $C_E$ , and condition  $\pi_E - E(L_E) \geq \pi_C - E(L_C)$ , according to which the ex-ante type of firm 2 benefits from proposing contract  $C_E$ . Notice that these five conditions are necessary in any PBE satisfying the D1 criterion.

In what follows, we let  $\tilde{r}$  be the investment level that firm 2 selects when contract  $\tilde{C} = (L_C^B, \tilde{L}^G, 0)$  is signed, with  $\tilde{L}^G$  being the minimum value of  $L^G$  satisfying the following condition

$$\alpha E(\tilde{L}) + (1 - \alpha)(p\beta L^G + (1 - p)\beta L_C^B) = \alpha E(L_C) + (1 - \alpha)(p\beta L_C^G + (1 - p)\beta L_C^B).$$

In the above expression,  $p$  denotes the probability that the innovation is worth  $V^G$ , given the level of R&D activity that the second innovator chooses when it ignores the existence of firm 1's patent.

**Proposition 6.** *When firm 2 is the proposer at the licensing stage, and  $\gamma = \beta$ ,  $L_C^B < L_C^G$ , in any PBE satisfying the D1 criterion, the investment level of firm 2 is smaller or equal than  $\tilde{r}$ .*

Proof. See the appendix. ■

Below, we provide an example where the upper-bound  $\tilde{r}$  coincides with  $r_C$ . This fact implies that, in this case, the only PBE satisfying the D1 criterion is the one shown in Proposition 2; therefore, also when firm 2 is the proposer, firms are unable to improve upon the default contract.<sup>14</sup>

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<sup>14</sup>See the appendix for additional details on the computation of the example.

**Example 1.** Assume that firm 2's idea is  $\{p(r) = \min\{r, 1\}, c(r) = \eta r^2/2, V^B, V^G\}$  with  $\eta$  positive and large enough, and the probability of infringement is  $\beta$ . Moreover, assume that  $L_C^i = \rho V_C^i$ , with  $i = B, G$  and  $\rho \in (0, 1)$ , and that  $\alpha \rightarrow 1$ . In this case, for any  $\rho \in (0, 1/2\beta)$ ,  $\tilde{L}^G = \rho V^G$ , and therefore:  $\tilde{C} = (L_C^B, L_C^G, 0) = C_C$  and the upper-bound  $\tilde{r}$  equals  $r_C$ .

Before concluding this section, it is useful to discuss briefly the reason why, in the general setting that we have considered throughout the paper, we are not able to exclude the existence of equilibria different from that described in Proposition 2. Consider an equilibrium where a contract  $C_E$  that satisfies the conditions stated in Proposition 3 is signed, and suppose that, at the licensing stage, firm 2 makes an out-of-equilibrium proposal  $(L_E^B, L_E^G, \bar{L}_E - \varepsilon)$ . In this case, we cannot apply the same reasoning used in the proof of Proposition 3: not only the ex-ante type, but also the ex-post types of firm 2 benefit when firm 1 accepts this proposal. Therefore, in this case, the out-of-equilibrium beliefs that satisfy the D1 criterion cannot be computed without specifying the functional forms of the cost and probability functions. Clearly, the same problem arises for each out-of-equilibrium proposal with at least one payment lower than those specified by contract  $C_E$ .

## 4 Discussion and policy implications

This final section is devoted to discussing some of the assumptions we have made, and to considering the policy implications of our results.

### Partial verifiability of the timing of the investment

The main results of our paper rest on the assumption that neither the first innovator nor the Court are able to verify the timing of firm 2's investment. Even though this assumption is strongly based on practical grounds, it is nevertheless worth discussing it more in detail.

Suppose that, in case firm 2 negotiates ex-post the licensing agreement, then, with some positive probability, parties observe a verifiable signal that the second innovator had already chosen  $r$ . Obviously, if this evidence emerges before firms have signed the licensing contract, then our analysis applies unaltered. Therefore, we only need to care about the scenario where the evidence arises once the contract has been signed. In this case, by stipulating a large penalty  $P$  that firm 2 pays in case the signal is observed, the second innovator might be induced to negotiate ex-ante the licensing contract. In what follows, we argue that if the signal is not perfect then it is not always the case that "penalty contracts" induce the second innovator to contract between  $t = 0$  and  $t = 1$ . For the sake of simplicity, in the discussion we assume that the second innovation always infringes firm 1's patent,  $\beta = \gamma = 1$ .

Suppose that firm 2 negotiates ex-post the licensing agreement, and let  $\lambda$  be the probability that parties will observe the signal that firm 2 had, indeed, already sunk investment; with probability  $(1 - \lambda)$ , no evidence about the timing of firm 2's investment will be observed. When firm 2 negotiates ex-ante the licensing agreement, then with probability  $\varepsilon$  parties will observe a (false) signal indicating that firm 2 had already chosen  $r$ ; with probability  $1 - \varepsilon$ ,

no evidence about the timing of the choice of  $r$  will emerge. We assume that  $\lambda > \varepsilon > 0$ , that is, the verifiable signal is imperfect even though it is not useless.

Consider efficient proposals that consist of an upfront payment  $\bar{L}$  and a penalty  $P$  payable whenever the signal is observed. Within this set of contracts, we focus on those where  $\bar{L} = 0$ ; these are the contracts that have the maximum potential in terms of inducing the second innovator to negotiate ex-ante the licensing agreement. Let  $\pi^*$  be the joint profits of the two firms when the investment is efficient.

The largest penalty,  $\bar{P}$ , that the ex-ante type is willing to accept during the negotiations is implicitly defined by the condition  $\pi^* - \varepsilon\bar{P} = \pi_C - E[L_C]$ : type  $\omega_A$  is indifferent between signing the penalty contract (pay  $\varepsilon\bar{P}$ , and then invest efficiently), and the default one. Consider now firm 1. The larger the probability that firm 2 is of an ex-ante type the more the first innovator is willing to sign a contract different from  $C_C$ . Therefore, the lowest penalty,  $\underline{P}$ , that firm 1 is willing to accept during the negotiations is implicitly defined by the condition  $\varepsilon\underline{P} = E[L_C]$ : firm 1 is indifferent between the penalty contract and  $C_C$ , given that it holds the belief  $\mu_A = 1$ . Notice that any  $P \in [\underline{P}, \bar{P}]$  is such that  $L_C^B < \varepsilon P < L_C^G$ , otherwise either firm 1 or the ex-ante type of firm 2 would prefer  $C_C$  to the penalty contract.

We show now that if the signal is of poor quality, namely if  $\lambda$  is close enough to  $\varepsilon$  and such that  $\lambda P < L_C^G$  for any  $P \in [\underline{P}, \bar{P}]$ , then penalty contracts do not induce firm 2 to negotiate ex-ante. Consider firm 2 choosing whether to negotiate the licensing contract ex-ante or ex-post. In the former case, it obtains  $\pi^* - \varepsilon P$ . In the latter case, if  $V^B$  occurs, then firm 2 signs the default contract since  $\lambda P > L_C^B$ ; if  $V^G$  occurs, it signs the penalty contract, because  $\lambda P < L_C^G$ . This fact implies that, when negotiating ex-post, firm 2 obtains a pay-off greater or equal to  $\pi^* - p(r^*)\lambda P - (1 - p(r^*))L_C^B$ .<sup>15</sup> Therefore, a sufficient condition to ensure that firm 2 prefers to come ex-post is  $\pi^* - p(r^*)\lambda P - (1 - p(r^*))L_C^B \geq \pi^* - \varepsilon P$ , that is  $\lambda \leq \varepsilon/p(r^*) - (1 - p(r^*))L_C^B/(p(r^*)P)$ ; when this latter condition is met, penalty contracts do not provide enough incentives to firm 2 to contract ex-ante.

There are additional arguments according to which penalty contracts cannot restore efficiency. Firstly, when the signal is imperfect, such contracts might induce a moral hazard problem. Suppose that the signal about the timing of firm 2's investment is verified by means of the Court; in this case, firms might have incentives to exert efforts (e.g. hiring highly qualified and expensive lawyers) in order to influence the decision taken by the Court. In other words, when the probabilities  $\lambda$  and  $\varepsilon$  are, to some extent, affected by the efforts exerted by the two firms, then there is another argument against the use of penalty contracts: they might induce an additional inefficiency due to the fact that parties waste resources in trying to induce the Court to take a more favorable decision. Another reason why penalty contracts might have a limited capacity in restoring efficiency is related to the fact that penalties cannot be unbounded. Firms' limited liability imposes an upper bound to the level of  $P$  that might be specified in the contract. Moreover, in many legislations large penalties are not enforceable in front of the Court (see Edlin and Schwartz, 2003 for a discussion on this point).

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<sup>15</sup>This amount is the expected payoff of firm 2 when it chooses  $r^*$ ; however, the second innovator can obtain a larger pay-off by choosing  $\hat{r} \equiv \arg \max p(r) (V^G - \lambda P) + (1 - p(r)) (V^B - \beta L_C^B) - c(r)$ .

## Licensing terms affecting the commercial value

A simplifying assumption that we employ all through the paper is that the profits that firm 2 obtains from using/commercializing its innovation are exogenously given, and they are not affected by the licensing terms; namely, we assume that  $V^B$  and  $V^G$  are exogenous parameters. This assumption allows us to focus on how the licensing terms affect the R&D incentives of the second innovator. The literature that studies patent licensing for commercialization/production purposes focuses on contracts that stipulate royalties, lump-sum payments or a combination of the two. The main message of this literature is that, absent asymmetric information between parties and unless agents are risk averse, lump-sum payments ensure efficiency since they do not distort production decisions (see Macho-Stadler et al., 1996). In our setting, given that parties are risk neutral and that, once the state of the world (either  $V^B$  or  $V^G$ ) has materialized there are no additional instances of asymmetric information, then lump-sum payments contingent on the state of the world (namely a payment  $L_j^B + \bar{L}_j$  in case of  $V^B$  and  $L_j^G + \bar{L}_j$  in case of  $V^G$ ) ensure efficiency at the commercialization/production stage.<sup>16</sup> Thus, contracts  $(L_j^B L_j^G, \bar{L}_j)$  on which we focus in the paper ensure efficient production/commercialization decisions also in case  $V^B$  and  $V^G$  are affected by the licensing terms. Moreover, it would be easy to verify that in case the default contract includes royalties that distort production decisions, parties would always find it beneficial to renegotiate it with a “production efficient” contract  $(L_j^B L_j^G, \bar{L}_j)$ .

## Legal expenses

In the paper, we focus on the effects of the inability of the patent holder to observe the timing of the R&D investment of the second innovator, ruling out other sources of asymmetric information. In particular, we assume that at the commercialization stage ( $t = 2$ ) both the value of second innovation and the fact that there is infringement of the patent is observed by both firms. In this setting, the presence of positive costs of litigation does not alter our results if, consistently with our assumption of symmetric information at  $t = 2$ , firms may negotiate a pretrial settlement. Since going to Court is inefficient and, at commercialization stage there is symmetric information, then, in equilibrium, independently of the bargaining protocol firms reach an amicable settlement, and never resort to Court. Let  $T_1 \geq 0$  and  $T_2 \geq 0$  be the costs of litigation borne by firm 1 and 2 respectively. Consider the case in which firm 1 is the proposer of both the licensing agreement and the pretrial settlement. If at  $t = 2$  firms have not signed a licensing contract, then, in case of infringement, firm 1 proposes to settle and license the patent in front of the payment  $L_C^i + T_2$ , when  $V^i$ , with  $i = B, G$ , is the observed value of the innovation. Therefore, in this case Proposition

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<sup>16</sup>The literature on licensing has shown that the choice of royalty contracts can be a useful device in order to signal the value of the innovation (see Gallini and Wright, 1990, and Macho-Stadler et al., 1996). In the setting that we are considering, the verifiability of  $V^B$  and  $V^G$ , and therefore, the fact that firms can contract contingent on the value of the innovation rules out the usefulness of royalty contracts as a signaling device.

1 changes as follows: in equilibrium firms never resort to Court and licensing occurs under contract  $(L_C^B + T_2, L_C^G + T_2, 0)$ . When firm 2 is the proposer of both the licensing agreement and the pretrial settlement, then Proposition 2 can be re-written as follows: there exists a PBE satisfying the D1 criterion where firms never resort to Court and licensing occurs under contract  $(L_C^B - T_1, L_C^G - T_1, 0)$ .

## Policy implications

Practitioners and legal scholars have pointed out the difficulties related to the negotiations of IPRs. In this paper, we argue that there is an additional reason that may complicate licensing negotiations, thus increasing the risk of hold-up of future innovations. When the patent-holder is unable to observe the timing of the R&D investment of a follow-on inventor, then the possibilities of reducing the risk of hold-up of future innovations through licensing are severely limited. This fact has an important policy implication. 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 licensing is unlikely to solve the hold-up problem: the simple inability of the patent-holder to know whether the follow-on innovator is truly ex-ante prevents parties from signing contract that restore the R&D incentives. In this sense our result complements the analysis provided by Bessen and Maskin (2009). These authors show that in a context where patent licensing is inefficient because of an adverse selection problem, then a regime without patents might be preferable.

## 5 Appendix

### Proof of Proposition 3.

*Proof of part i)*

Let  $\beta$  be the probability that firm 1 accepts contract  $C_E$ , and suppose that, contrarily to the statement of Proposition 3 part *i*), in equilibrium parties sign a contract  $C_E$  with  $\bar{L}_E > 0$ . In order to prove that this cannot be the case, we show that there is an out-of-equilibrium proposal  $C_D = (L_E^B + \varepsilon, L_E^G + \varepsilon, \bar{L}_E - \varepsilon)$ , with  $\varepsilon$  positive but negligible, which is profitable for type  $\omega_A$  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  $\omega_A$  (Claim 1);

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

In what follows, we let  $\tau$  to denote the probability that firm 1 accepts the out-of-equilibrium proposal  $C_D$ .

Claim 1: According to divinity criterion D1, firm 1 assigns 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  $C_E$ .

Consider the ex-ante type of firm 2. The equilibrium proposal  $C_E$  is accepted with probability  $\beta$  by firm 1, and then the equilibrium pay-off is  $\beta(\pi_E - E(L_E)) + (1 - \beta)(\pi_C - E(L_C))$ . The out-of-equilibrium proposal  $C_D$  is accepted with probability  $\tau$  by the first innovator, thus ensuring a pay-off  $\tau(\pi_D - E(L_D)) + (1 - \tau)(\pi_C - E(L_C))$ . Therefore, type  $\omega_A$  benefits from proposing contract  $C_D$  rather than  $C_E$  provided that:

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

Re-arranging the above condition we have:

$$\tau \geq \beta \frac{(\pi_E - E(L_E) - \pi_C + E(L_C))}{(\pi_D - E(L_D) - \pi_C + E(L_C))} \equiv \tau_A.$$

Therefore, when  $\tau \geq \tau_A$  type  $\omega_A$  benefits from the out-of-equilibrium proposal  $C_D$ . Note that the licensing fees that firm 2 pays under contracts  $C_D$  and  $C_E$  are the same in case of infringement (they are equal to  $L_E^i + \bar{L}_E$ ,  $i = B, G$  under both contracts), and are strictly smaller under contract  $C_D$  in case of non-infringement ( $\bar{L}_E - \varepsilon$  rather than  $\bar{L}_E$ ); therefore,  $\pi_D - E(L_D) > \pi_E - E(L_E)$ ; this fact implies that  $\tau_A < \beta$ .

Consider now the ex-post types of firm 2. When  $\varepsilon$  is negligible, then  $\bar{L}_E - \varepsilon > 0$ , which implies that, irrespectively of firm 1's choice, type  $\omega_N$  cannot profit from proposing neither contract  $C_D$  nor contract  $C_E$ . Consider now the ex-post types  $\omega_G$  and  $\omega_B$ . Contracts  $C_D$  and  $C_E$  specify the same payment for these types of firm 2:  $L_E^i + \bar{L}_E$ ,  $i = B, G$ . If  $L_E^i + \bar{L}_E > L_C^i$ , then proposing contracts  $C_D$  or  $C_E$  is not profitable irrespectively of the probability of firm 1 accepting the proposal. In case,  $L_E^i + \bar{L}_E \leq L_C^i$  type  $i = B, G$  prefers proposing  $C_D$  rather than  $C_E$  provided that firm 1 accepts the former proposal with a probability greater than  $\beta$ , namely for  $\tau \geq \beta \equiv \tau_i$ ,  $i = B, G$ .

Notice that since  $\tau_A < \tau_i$ ,  $i = B, G$ , then the D1 criterion imposes the belief  $\mu_A = 1$  when contract  $C_D$  is offered. ■

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

Proof of Claim 2. From Lemma 2 we know that  $E(L_E) > E(L_C)$ ; therefore it is possible to find  $\varepsilon$  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 parts ii) and iii)*

Part ii) of Proposition 3 can be proved by contradiction, following the same lines as for part i). In particular, it can be verified that there exists an out-of-equilibrium proposal  $C_{D'} = (L_E^B - \varepsilon, L_E^G, \bar{L}_E)$ , with  $\varepsilon$  positive but negligible, such 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  $\omega_A$ ;
- II. given the beliefs defined in I., accepting  $C_{D'}$  is a best response for firm 1.

Part *iii*) of Proposition 3 can be proved by contradiction following the same lines as for part *i*). In particular, it can be verified that there exists an out-of-equilibrium proposal  $C_{D''} = (L_E^B, L_E^G - \varepsilon, \bar{L}_E)$ , with  $\varepsilon$  positive but negligible, such 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  $\omega_A$ ;
- II. given the beliefs defined in I., accepting  $C_{D''}$  is a best response for firm 1. ■

#### Proof of Proposition 4.

Consider the expected licensing fees that firm 1 obtains with contract  $C_E$  and with  $C_C$ . In case  $V^G$  realizes, firm 1 obtains an expected fee  $\gamma L_E^G + \bar{L}_E$  under contract  $C_E$  and  $\gamma L_C^G$  under contract  $C_C$ ; in case  $V^B$  realizes, it obtains  $\beta L_E^B + \bar{L}_E$  and  $\beta L_C^B$ , respectively. Next we show that if the proposed contract  $C_E$  is efficient, namely if  $\beta L_E^B = \gamma L_E^G$ , then firm 1 prefers to reject the proposal since in case of acceptance it obtains a pay-off smaller or equal to  $\min\{\beta L_C^B, \gamma L_C^G\}$  when either  $V^B$  or  $V^G$  realize. Suppose that  $V^B$  occurs. The inequality  $\beta L_E^B + \bar{L}_E \leq \beta L_C^B$  can be re-written as  $\bar{L}_E \leq \beta(L_C^B - L_E^B)$ ; from Proposition 3 we know that  $\bar{L}_E \leq L_C^B - L_E^B$ ,  $\bar{L}_E \leq 0$ , and therefore: in case  $L_C^B - L_E^B > 0$ , the inequality  $\bar{L}_E \leq \beta(L_C^B - L_E^B)$  is obviously verified for any  $\beta \geq 0$ ; in case,  $L_C^B - L_E^B \leq 0$ , then  $L_C^B - L_E^B \leq \beta(L_C^B - L_E^B)$  for any  $\beta \leq 1$ , and therefore inequality  $\bar{L}_E \leq \beta(L_C^B - L_E^B)$  is verified also in this case. Consider now the inequality  $\beta L_E^B + \bar{L}_E \leq \gamma L_C^G$ ; given that  $C_E$  is such that  $\gamma L_E^G = \beta L_E^B$ , then we can re-write it as  $\bar{L}_E \leq \gamma(L_C^G - L_E^G)$ . Proposition 3 shows that  $\bar{L}_E \leq L_C^G - L_E^G$ ,  $\bar{L}_E \leq 0$ , and therefore: in case  $L_C^G - L_E^G > 0$ , then condition  $\bar{L}_E \leq \gamma(L_C^G - L_E^G)$  is obviously verified for any  $\gamma \geq 0$ ; in case,  $L_C^G - L_E^G \leq 0$ , then  $L_C^G - L_E^G \leq \gamma(L_C^G - L_E^G)$  for any  $\gamma \leq 1$ , and therefore inequality  $\bar{L}_E \leq \gamma(L_C^G - L_E^G)$  is verified also in this case. Hence, we have shown that  $\beta L_E^B + \bar{L}_E \leq \min\{\beta L_C^B, \gamma L_C^G\}$ . By using the same arguments, one can easily verify that also condition  $\gamma L_E^G + \bar{L}_E \leq \min\{\beta L_C^B, \gamma L_C^G\}$  is met. ■

#### Proof of Proposition 5.

From the proof of Proposition 4 we know that  $\beta L_E^B + \bar{L}_E \leq \beta L_C^B$ , and  $\gamma L_E^G + \bar{L}_E \leq \gamma L_C^G$ . Suppose that the default contract induces under-investment,  $\beta L_C^B < \gamma L_C^G$ . In this case when  $V^B$  occurs, under contract  $C_E$  firm 1 obtains an expected payment  $\beta L_E^B + \bar{L}_E \leq \min\{\beta L_C^B, \gamma L_C^G\}$ . Therefore, since from Lemma 2  $E(L_E) > E(L_C)$ , then it has to be that  $\gamma L_E^G + \bar{L}_E > \beta L_C^B$ . This last inequality implies that contract  $C_E$  induces under-investment:  $\gamma L_E^G + \bar{L}_E > \beta L_E^B + \bar{L}_E$ , since  $\beta L_E^B + \bar{L}_E \leq \beta L_C^B$ . Finally, since any contract  $C_E$  and the default contract induce under-investment, then in equilibrium firm 2 under-invests independently of whether contract  $C_E$  is signed with probability 1 or less.

Using a similar reasoning, it is possible to prove that when  $\beta L_C^B > \gamma L_C^G$ , then any  $C_E$  that parties are willing to sign yields over-investment. ■

**Proof of Proposition 6.**

In this proof, we focus on the set of contracts and system of beliefs that satisfy the following five conditions:

- i)  $\bar{L}_E \leq 0$ ;
- ii)  $L_E^B + \bar{L}_E \leq L_C^B$ ;
- iii)  $L_E^G + \bar{L}_E \leq L_C^G$ ;
- iv)  $\mu_A E(L_E) + \mu_B (L_E^B + \bar{L}_E) + \mu_G (L_E^G + \bar{L}_E) + \mu_N \bar{L}_E \geq \mu_A E(L_C) + \mu_B L_C^B + \mu_G L_C^G$  ;
- v)  $\pi_E - E(L_E) \geq \pi_C - E(L_C)$ .

Conditions i) – iii) have been defined in Proposition 3, while conditions iv) and v) ensure that contract  $C_E$  is weakly preferred to default one by firm 1 and by the ex-ante type of firm 2 respectively. Notice that this set is non-empty, as proved in Proposition 2.

In what follows, we look for the contract  $C_E = (L_E^B, L_E^G, \bar{L}_E)$  and the system of beliefs that minimize the difference  $(L_E^G - L_E^B)$ . Assume that there exists a contract  $C_E$  different from  $C_C$  that, for some system of beliefs, satisfies all the five conditions. Notice that in order to satisfy simultaneously condition iv) and v) (and be different from  $C_C$ ) contract  $C_E$  must induce a more efficient level of  $r$  than  $C_C$ ; moreover, since  $r_E > r_C$  (and  $r^* > r^E$ ) then at most one of the conditions iv) and v) can be binding. We now solve the minimization problem by proving the following claims.

*Claim 1: When looking for the contract and system of beliefs that satisfy conditions i)–v), and that minimize  $(L_E^G - L_E^B)$ , we can restrict, without loss of generality, to contracts such that  $\bar{L}_E = 0$  and  $L_E^B = L_C^B$ .*

*Proof.* 1)  $\bar{L}_E = 0$ . Consider a contract  $C_E = (L_E^B, L_E^G, \bar{L}_E)$  that satisfies conditions i) – v), and suppose that, contrarily to the statement of Claim 1,  $\bar{L}_E < 0$ ; moreover, assume that under contract  $C_E$  condition v) is not binding. In this case, the following contract  $C_{E'} = (L_E^B - \varepsilon, L_E^G - \varepsilon, \bar{L}_E + \varepsilon)$  still satisfies conditions i) – v) for some  $\varepsilon > 0$  and induces the same level of investment as  $C_E$  since  $L_E^G - \varepsilon - (L_E^B - \varepsilon) = L_E^G - L_E^B$ . It is easy to verify that contract  $C_{E'}$  satisfies conditions ii), iii). Consider condition iv). Contract  $C_{E'}$  induces the same investment as contract  $C_E$  and since with respect to this latter under contract  $C_{E'}$ , firm 1 obtains an  $\varepsilon$  more as upfront payment and an  $\varepsilon$  less only in case of infringement, then firm 1 obtains a larger pay-off than under  $C_E$ ; therefore, condition iv) is satisfied. When condition v) is not binding, then there exists some  $\varepsilon$  such that condition v) is verified also under contract  $C_{E'}$ . When condition v) is binding under contract  $C_E$  (and therefore condition iv) is not binding), then it is possible to find a couple  $\Delta > 0, \varepsilon > 0$  with  $\Delta > \varepsilon$  such that contract  $C_{E''} = (L_E^B - \Delta, L_E^G - \Delta, \bar{L}_E + \varepsilon)$  simultaneously satisfy conditions iv) and v), and induces the same level of investment as  $C_E$ . Notice that such  $\Delta$  and  $\varepsilon$  do exist since contract  $C_{E''}$  (and  $C_E$ ) is more efficient than  $C_C$ . Finally, it is easy to verify that contract  $C_{E''}$  satisfies conditions ii) and iii). Concluding, when contract  $C_E$  with  $\bar{L}_E < 0$  satisfies conditions i) – v) then it is possible to find a new contract that induces the same investment as  $C_E$ , that satisfies conditions i) – v), and that specifies an upfront payment  $\bar{L}_E + \varepsilon$ , with  $\varepsilon > 0$ . Therefore, without loss of generality we can set  $\bar{L}_E = 0$ .

2)  $L_E^B = L_C^B$ . Consider a contract  $C_E = (L_E^B, L_E^G, 0)$  that satisfies conditions  $i) - v)$ , and suppose that, contrarily to the statement of Claim 2,  $L_E^B < L_C^B$ . Moreover, assume that under contract  $C_E$  condition  $v)$  is not binding. In this case, the following contract  $C_{E'} = (L_E^B + \varepsilon, L_E^G + \varepsilon, 0)$  still satisfies conditions  $i) - v)$  for some  $\varepsilon > 0$  and induces the same investment as  $C_E$  since  $L_E^G + \varepsilon - (L_E^B + \varepsilon) = L_E^G - L_E^B$ . It is immediate to check that contract  $C_{E'}$  satisfies condition  $i)$ . Condition  $iii)$  is satisfied for some  $\varepsilon > 0$  given that the same condition  $iii)$  could not be binding under the initial contract  $C_E$ ; in fact, it cannot be simultaneously that  $L_E^B < L_C^B$  and  $L_E^G = L_C^G$  otherwise contract  $C_E$  would be less efficient than  $C_C$  ( $L_E^G - L_E^B > L_C^G - L_C^B$ ), and then conditions  $iv)$  and  $v)$  could not be satisfied simultaneously. Condition  $iv)$  is satisfied: contract  $C_{E'}$  induces the same investment as  $C_E$  and firm 1 obtains an  $\varepsilon$  more in case of infringement. Finally, in case condition  $v)$  is not binding under contract  $C_E$ , then there exists an  $\varepsilon$  such that condition  $v)$  is satisfied also under contract  $C_{E'}$ . Consider the case where condition  $v)$  is binding under contract  $C_E$ ; then contract  $C_{E''} = (L_E^B + \varepsilon, L_E^G + \varepsilon, -\varepsilon)$  satisfies conditions  $i) - v)$  for some  $\varepsilon > 0$  and induces the same investment as  $C_E$ . It is easy to verify that conditions  $i)$  and  $iii)$  are satisfied. Since contract  $C_{E''}$  (and  $C_E$ ) is more efficient than  $C_C$  then there exists an  $\varepsilon$  such that  $iv)$  and  $v)$  are verified simultaneously. Concluding, when contract  $C_E = (L_E^B, L_E^G, 0)$  with  $L_E^B < L_C^B$  satisfies conditions  $i) - v)$ , then it is possible to find a new contract that induces the same investment as  $C_E$ , that satisfies conditions  $i) - v)$ , and that specifies a payment  $L_E^B + \varepsilon$ , with  $\varepsilon > 0$ , contingent on infringement and  $V^B$ . Therefore, without loss of generality we can set  $L_E^B = L_C^B$ . ■

Claim 2: *Let  $C_E$  be the contract (with the corresponding beliefs) that satisfies conditions  $i) - v)$  and minimizes  $(L_E^G - L_E^B)$ . Firm 1 is indifferent between accepting or rejecting contract  $C_E$  (condition  $iv)$  is binding).*

Proof. Consider a contract  $C_E = (L_C^B, L_E^G, 0)$  that satisfies conditions  $i) - v)$ , and suppose that, contrarily to the statement of Claim 3, condition  $iv)$  is not binding. In this case it is possible to find an  $\varepsilon > 0$  such that contract  $C_{E'} = (L_C^B, L_E^G - \varepsilon, 0)$  satisfies conditions  $i) - v)$  and induces a larger investment since  $L_E^G - \varepsilon - L_C^B < L_E^G - L_C^B$ . It is immediate to check that conditions  $i) - iii)$  are satisfied by contract  $C_{E'}$ . Condition  $v)$  is satisfied since firm 2 pays a smaller fee when there is infringement and the innovation is worth  $V^G$ .

Claim 3: *When looking for the contract and system of beliefs that satisfy conditions  $i) - v)$ , and that minimize  $(L_E^G - L_E^B)$ , we can restrict, without loss of generality, to systems of beliefs such that  $\mu_A = \alpha$ .*

Consider a contract  $C_E = (L_C^B, L_E^G, 0)$  that satisfies conditions  $i) - v)$ , and suppose that  $\mu_A < \alpha$ . Notice that under contract  $C_E$  firm 1 obtains the same pay-off as under contract  $C_C$  when firm 2 is of type  $\omega_B$  and  $\omega_N$  and strictly less when firm 2 is of type  $\omega_G$  (it has to be that  $L_E^G < L_C^G$ , otherwise we have the default contract); therefore, condition  $iv)$  is satisfied provided that  $E(L_E) > E(L_C)$ . However, if condition  $iv)$  is satisfied when  $\mu_A < \alpha$ , then it is possible to find an  $\varepsilon > 0$  such that contract  $C_{E'} = (L_C^B - \varepsilon, L_E^G - \varepsilon, 0)$  satisfies condition  $iv)$  for  $\mu_A = \alpha$ ; obviously, contract  $C_{E'}$  also satisfies the remaining four conditions and induces the same level of investment as  $C_E$ . Concluding, when contract

$C_E = (L_C^B, L_E^G, 0)$  satisfies conditions  $i) - v)$ , for some  $\mu_A < \alpha$ , then it is possible to find a new contract that induces the same investment as  $C_E$ , that satisfies conditions  $i) - v)$ , and that specifies a payment  $L_C^B - \varepsilon$ , and  $L_E^G - \varepsilon$  with  $\varepsilon > 0$ , contingent on infringement and  $V^B$  and  $V^G$  respectively. Therefore, without loss of generality we can set  $\mu_A = \alpha$ ,  $\mu_B = (1 - \alpha)(1 - p)\beta$ ,  $\mu_G = (1 - \alpha)p\beta$ ,  $\mu_N = (1 - \alpha)(1 - \beta)$ . ■

Claims 1, 2, and 3 together, imply that the upper-bound to the level of investment is induced by the contract  $\tilde{C} = (\tilde{L}^G, L_C^B, 0)$ , where  $\tilde{L}^G$  is the minimum value of  $L^G$  satisfying the following condition

$$\alpha E(\tilde{L}) + (1 - \alpha)(p\beta L^G + (1 - p)\beta L_C^B) = \alpha E(L_C) + (1 - \alpha)(p\beta L_C^G + (1 - p)\beta L_C^B).$$

■

### Details for Example 1.

Assume that firm 2's idea is  $\{p(r) = \min\{r, 1\}, c(r) = \eta r^2/2, V^B, V^G, \beta, \beta\}$ , with  $\eta > 0$  and large enough. Moreover, assume that  $L_C^i = \rho V_C^i$  with  $i = B, G$  and  $\rho \in (0, 1)$ , and that  $\alpha \rightarrow 1$ .

With simple calculations we find:  $r^* = (V^G - V^B)/\eta$ ,  $r_C = (V^G - V^B)(1 - \rho\beta)/\eta$ ,  $E(L_C) = r_C\beta\rho V^G + (1 - r_C)\beta\rho V^B$ .

In order to determine  $\tilde{r}$  we proceed as follows. Using the result of Proposition 6, we consider a contract that specifies a payment  $\rho V^B (= L_C^B)$  in case of infringement and  $V^B$  and  $xV^G$  in case of infringement and  $V^G$ , with  $x$  to be determined. Given this contract firm 2 (when informed about the existence of the patent) selects  $r$  to maximize  $rV^G(1 - \beta x) + (1 - r)V^B(1 - \beta\rho) - \eta r^2/2$ ; simple calculations allow us to compute the optimal investment level  $r(x) = (V^G(1 - \beta x) - V^B(1 - \beta\rho))/\eta$ , and  $E(L(x)) = r(x)\beta xV^G + (1 - r(x))\beta\rho V^B$ . The value of  $x$  that induces  $\tilde{r}$  is the the lowest  $x$  that solves the following condition:

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

This equation has two roots:  $x_1 = \rho$  and  $x_2 = ((V^G - V^B)(1 - \beta\rho) + \beta\rho V^B)/(V^G\beta) + \eta p(1 - \alpha)/(\alpha V^G\beta^2)$ ; taking  $\alpha \rightarrow 1$ ,  $x_2$  reduces to:  $x_2 = ((V^G - V^B)(1 - \beta\rho) + \beta\rho V^B)/(V^G\beta)$ , with  $x_1 < x_2$  iff  $\rho < 1/(2\beta)$ . Therefore:

- When  $\rho < 1/(2\beta)$ ,  $\tilde{r} = r_C$ , 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  $r_C$ .
- When  $\rho \geq 1/(2\beta)$ ,  $\tilde{r} = \rho\beta(V^G - V^B)/\eta$ . ■

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