Are intellectual property rights detrimental to innovation?*

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Abstract

Intellectual property rights are legal constraints that limit entry in industries where incumbents are innovators. The set of legal constraints is the same for all industries, without considering that the externalities created by entry are not necessarily negative for the incumbent or that the incumbent's R&D expenditures can be detrimental to entrants. We show that one unique set of legal rules can foster innovation in some industries but be detrimental in others. The model is illustrated by case studies from the information and communication technologies industry.

Keywords: Innovation, spillover, leadership, R&D regulation

JEL classification: K4 (Legal Procedure); L11 (Market Structure); O31 (Innovation and Invention: Processes and Incentives).

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1 Introduction

The innovation game is a complex dynamic process in which no one can truly assert that his brand-new product or her cost-killer method does not rely on previous research. All innovators benefit from former research efforts, either private or public, either access-free or protected by property rights.[1] In some cases, the innovation is Pareto improving because it does not hurt the benefits of any incumbent, and it can even be a good opportunity to improve the spectrum of services provided by some out-dated product or to decrease its production and/or use cost. But in many cases, the innovation is detrimental for some agents. It can be mildly detrimental when it marginally infringes the claims of some property-rights owner. In this case, the right-owner can tolerate the presence of a competing product if it is sufficiently differentiated, because fighting commercially or legally against entry would cost more than the decrease in revenues. The innovation can strongly hurt the benefits of an incumbent when it is a mere copy of the incumbent's product (and should not be called an 'innovation'). It can even result in the exclusion of a former seller when the innovation is a drastic improvement of a product or process. Because today's entrants are tomorrow's incumbents, innovators can rationally anticipate the threat of lost revenues due to entry and can play strategically. For instance, an innovator who cannot benefit from protection against copying has an incentive to underinvest. Symmetrically, an innovator who expects complementary discoveries that will increase his benefits has an incentive to overinvest.[2] This explains why the conventional framework for the economic analysis of intertemporal competition between an innovator and his potential competitors is a sequential

[1] The 'cumulativeness' of innovations is analyzed in Scotchmer (1991). The well-known sentence, "We are like dwarfs on the shoulders of giants so that we can see more than they, and things at a greater distance, not by virtue of any sharpness of sight on our part, or any physical distinction, but because we are carried high and raised up by their giant size," is commonly attributed to Bernard de Chartres, a philosopher of the 12th century... and it has been copied by many scientists.

[2] O'Donoghue, Scotchmer and Thisse (1998) study a dynamic game where improvements arise randomly. They show that, if the protection against imitation is perfect, whereas the protection against improvement is not, innovators tend to overinvest or underinvest, depending on the rate at which ideas occur to them. If ideas are too frequent, innovators cannot fully benefit from their innovations and, thus, tend to underinvest. On the other hand, if they are not that frequent, firms tend to overinvest.

game, where the innovator decides on his effort by anticipating the reaction function of future entrants.

The trade-off between the advantages to society of a high-innovation activity and the mostly private cost of the effort to innovate inevitably pushes the government to intervene in the innovation process. The most common intervention consists in the definition of property rights that allows private investors to reap the profits generated by their effort rather than to share those profits with free riders. This means that candidates to enter (either mere copiers or true improvers) will have to step over administrative or economic thresholds in order to be accepted. For example, the novelty requirement may oblige challengers to invest in 'non-imitation' much more than they intended, as they will not be allowed to enter if they do not differentiate their product sufficiently.[3] But this type of requirement has an effect that, to the best of our knowledge, has not been analyzed in the literature on R&D: each time the legal requirement is binding, newcomers do not really react to the investment decisions of the innovator. Their own research expenditures are fixed by law or regulation. In fact, we can even say that the roles are reversed. When the innovator already knows what the followers will have to spend because of legal restrictions, he behaves like a follower. It results that the question, "is it a good incentive for innovators to have strict regulation by means of patents, copyrights and all the variety of intellectual property rights (IPRs)" can partially be restated as "When does the innovator invest more? When is the innovator the leader of the innovation game and when does he behave like a follower of the regulation that constrains any candidate to entry?"

We analyze this problem using a simple framework of technological competition between two firms when spillovers exist between their profit functions. We assume that after an innovation has been made, a follower observes it and decides how much to invest in imitation (or improvement, differentiation). The role of each player is well-defined: the leader innovates and the follower imitates, develops or improves. Furthermore, we implicitly assume that patent protection is not absolute, as imitation is legal within certain limits.[4] However, it is not necessarily the

[3] In Scotchmer and Green (1990), it is argued that a 'strong' novelty requirement that limits the number of patentable improvements can be socially better than a 'weak' novelty requirement, because it gives greater incentives to race and a race accelerates progress.

[4] This was first studied by Gallini (1992) who determined the appropriate protection against imitation, as well

case that entry should be prevented. If positive externalities exist that flow from the innovator (respectively, the follower) to the follower (respectively, the innovator), entry, even an imitation, can boost innovation rather than being detrimental. We explore the incidence of negative and positive externalities on the investment decisions of innovators and followers.

The paper is organized as follows. Section 2 is devoted to the presentation of related literature. The model is exposed in section 3. We first introduce a general setting, and then propose reduced form profit functions. We give the details of the equilibria, with and without exogenous constraint, and we investigate the case where the IPRs weaken the leadership of the incumbent. We also consider the effects of IPRs on innovation. In section 4, we illustrate all of the configurations (i.e., when the innovator benefits or suffers from the entry of a competitor, and on the contrary, when the competitor benefits or suffers from the leadership of the innovator) within the information and communication technologies (ICT) industry; more precisely, in the music industry, the software industry, the hardware industry and the video game industry. Section 5 concludes.

2 Related Literature

Economic models representing research decisions depict complex games. If several firms are engaged in similar research programs, they will probably race to be first to find the innovation (and to patent it). Most of the patent race models in the patent literature take into account both the uncertainty about the identity of the winner and the date on which the innovation will occur (Reinganum, 1989). In our framework, we do not consider any kind of uncertainty, and instead of assuming that firms compete to be the first to make the same discovery, we consider that some firms innovate, whereas other firms follow the innovators. Consequently, these firms do not compete for the same discoveries, and they play very different roles in the dynamic process of innovation. Our approach is close to the 'cumulative' approach, in which innovation builds upon previous discoveries, but we do not adopt a random dynamic structure like in Scotchmer (1991) and O'Donoghue, Scotchmer and Thisse (1998).

as the optimal patent duration in order to prevent imitation.

On the other hand, in another stream of the literature, some papers investigate how the externalities between the results of research will affect the investment decisions of the firms. They consider a two-stage game where, first, firms do research, and second, they compete in quantities, as has been initiated by d'Aspremont and Jacquemin (1988).

We first consider general payoff functions, and then we use reduced form profit functions. These profit functions are to be viewed as the profit faced by the decision makers at the first stage of a two-stage game where the second stage equilibrium has been solved. For instance, in d'Aspremont and Jacquemin (1988), firms first engage in cost-reducing R&D and then compete in quantities on a homogeneous good market. In Motta (1992), R&D is first aimed at increasing the quality of products, then firms compete in a differentiated goods market.

Our setting is close in spirit to the literature about knowledge externalities.[5] However, in that literature, spillovers are, in general, positive externalities, as they indicate the transmission of useful information. They can be included in the final cost reduction and be symmetric (d'Aspremont and Jacquemin, 1988) or asymmetric (De Bondt and Henriques, 1995), or they can intervene in each firm's final R&D investment (Kamien, Muller and Zang, 1992).[6] Most of the findings in these studies depend on the size of those spillovers: they can be small or large compared to a certain cut-off value (that is model-dependent). Here, we do not specify where the externalities intervene and, thus, we consider that spillovers can be either positive or negative.

Many economists recognize the need to reform the patent system (see, for instance, Gallini, 2002), and there are also strong advocates against IPRs. Boldrin and Levine (2005), who are among the latter, argue that markets for ideas are not so different from other markets, and thus there is no need for IPRs. Some of our results are consistent with their findings, even though we use a very different modeling approach.

We now describe the game: the players, the timing of the game, the set of strategies of each player, and their payoffs. We then explore the effect of the regulation on the strategies chosen.

[5] See De Bondt (1996) for a description of spillovers.

[6] See Amir (2000) for an extensive comparison of the models of d'Aspremont and Jacquemin (1988) and Kamien, Muller and Zang (1992).

3 The Model

We first present a general setting, and we then introduce reduced form profit functions in order to get simple and tractable findings.

3.1 General Setting

We consider a two period model with two firms: an innovator (firm I) and a potential entrant (firm E). The timing of the game is as follows. In the first period, firm I undertakes an investment x_I to innovate. We assume that there is no uncertainty concerning the innovation and, once discovered, it is introduced and patented at the same time. Therefore, by the end of the first period, the innovator gets a monopoly payoff that depends on the initial investment. In the second period, firm E observes the investment decision made by the innovator (through the new innovation) and then decides to invest x_E. This investment decision can be a differentiation decision (how far from the existing product the follower wants her product to be), an improvement decision (how much better the follower wants her product to be compared to the initial product), or an application decision (how many applications she wants to introduce into the market). However, the choice of firm E may be constrained by Intellectual Property Rights (IPRs). For instance, firm E may have to invest more than initially planned to meet the legal requirement and not infringe upon the initial innovation. Then, once firm E has developed her product, both firms are engaged in a duopoly competition where the duopoly payoffs depend on the initial investment made by each of the firms. If firm E does not enter the market, firm I keeps her monopoly position in the second period. To simplify, we assume that the game ends after two periods, as it may be that the patent does not last more than two periods and, therefore, competitors enter the market after expiration or, alternatively, the second period can represent the discounted payoffs from all of the future stream of payoffs. The discounted payoff functions of both firms when they have to make their investment decisions are $V_I(x_I, x_E)$ and $V_E(x_I, x_E)$, where we assume that $V_i(.)$ is twice differentiable and that $\partial^2 V_i / \partial x_i^2 \leq 0$. As we are mainly interested in investigating the impact of IPRs on investment decisions, we do not explicitly model the duopoly competition that takes place. Our model is general enough to depict situations where firms compete in prices or quantities in differentiated markets. The investment decisions of each firm can affect the costs of production and/or the demand.

3.1.1 The regulation

As the leader holds a patent on his innovation, firm E is constrained by patent or copyright laws or specific regulations to respect certain market boundaries. For instance, in a setting of horizontally differentiated goods, the follower cannot enter the market with a product that is too close to the existing patented innovation without infringing upon it. Therefore, she must put some effort into differentiating her product. Hence, we consider that the constraint imposed by IP laws is expressed in terms of investment decisions. In order to meet the differentiation requirement imposed by IPRs for not infringing, she must invest at least a minimum level $\underline{x}$. Note that this requirement is not only restricted to differentiation. It can also be that the follower cannot enter with a very small improvement of the patented innovation, or with applications that are protected by the patent. Symmetrically, it can be the case that there exists some upper limit $\overline{x}$ that the entrant is not allowed to exceed because it would be viewed as an obvious infringement of the innovator's rights. For instance, in copyrights, the U.S. law enunciates the doctrine of "fair use." As long as the follower uses only some part of the protected material, it is not seen as an infringement, but only a fair use of it. However, if the follower replicates the entire protected material, it is an infringement. Hence, making small efforts to use part of the innovation is not an infringement, whereas making too much effort can be.

Consequently, the entrant has to respect the constraints $x_E \leq \overline{x}$ and / or $x_E \geq \underline{x}$. In centrally planned systems, we would have $\underline{x} = \overline{x}$, so that entrants would have no choice at all, since all R&D decisions are controlled by one unique principal. An alternative restriction could be an exclusion zone $x_E \notin [\underline{x}, \overline{x}]$. This would mean that entry is accommodated only if the challenger operates on a small scale that does not deprive the innovator of large benefits or, on the contrary, invests large amounts of money, which could represent an improvement detrimental to the incumbent, but beneficial for consumers. The exclusion zone best corresponds to the patent system. However, in order to keep the model as simple as possible, we only consider the two following elementary restrictions: either $x_E \leq \overline{x}$ or $x_E \geq \underline{x}$, and we analyze the consequences of a change in $\overline{x}$ or $\underline{x}$ on the investment decisions. In a more realistic model, those values should not be fixed from the very beginning of the game. Rather, they should be functions of the efforts of the incumbents. This extension would obviously make the model more complex.

3.1.2 Equilibria

The resolution of the game is done backwards. Without more specification on the demand side, we do not derive the profits resulting from price or quantity competition, and we only concentrate on the sequential investment decisions.

In the absence of any IPRs constraint, firm E chooses x_E that maximizes $V_E(x_I, x_E)$ for any given x_I. Therefore, $x_E(x_I)$ is the best response function of firm E. The total differentiation of the first order condition gives that

$$sign(\frac{dx_E}{dx_I}) = sign(\frac{\partial^2 V_E}{\partial x_I \partial x_E}).$$

Let us define $\partial^2 V_E/\partial x_I \partial x_E \equiv \eta_E$. Whenever $\eta_E > 0$ (respectively, $\eta_E < 0$), the best response of firm E is increasing (respectively, decreasing) with the investment of the leader and, therefore, an increase in x_I will trigger an increase (respectively, a decrease) in x_E. Hence, η_E can be seen as a spillover effect, as its sign will determine whether it negatively impacts firm E or not.

The leader then chooses x_I that maximizes $V_I(x_I, x_E(x_I))$, which gives the level of investment undertaken by firm I in this common leader-follower setting, namely x_I^*. Therefore, at the equilibrium, the level of investment of firm E is $x_E^* = x_E(x_I^*)$.

In the extreme case of a very strong IPRs regime where entry is prohibited, firm I gets monopoly payoffs during the two periods and, accordingly, invests x_I^m.

However, in the presence of a IPRs regime that does not prohibit entry but imposes constraints on the follower, firm E might not be able to freely choose her level of investment. Indeed, if the policy is such that the entrant must enter with a differentiated product, it may force firm E to invest more than $x_E(x_I)$, especially if $x_E(x_I) < \underline{x}$. In this case, firm E has no choice but to invest $\underline{x}$, as long as $V_E(x_I, \underline{x}) > 0$. The leader does not have a leadership position anymore, as she chooses x_I that maximizes $V_I(x_I, \underline{x})$. The chosen investment is therefore $x_I(\underline{x})$. Firm I does not choose her investment as a leader anymore, but as a follower, as he responds to $\underline{x}$. We also define $\partial^2 V_I/\partial x_I \partial x_E \equiv \eta_I$, where η_I can be positive or negative, and can also be seen as a spillover effect.

3.2 Reduced Form Profit Functions

In order to obtain tractable and simple results, and because we are mainly interested in the impact of regulation on investment decisions, we consider the following reduced form profit function for each firm:

$$V_I(x_I, x_E) = -\frac{(x_I)^2}{2} + x_I + \eta_I x_I x_E, \tag{1}$$

$$V_E(x_E, x_I) = -\frac{(x_E)^2}{2} + x_E + \eta_E x_I x_E, \tag{2}$$

where η_i $(i = I, E)$ represents a spillover effect that can take positive or negative values, with $|\eta_i| < 1$, and $\eta_E \eta_I < \min\{1 + \eta_E, 1/2\}$. As $\eta_I = \frac{\partial^2 V_I(.)}{\partial x_E \partial x_I}$ and $\eta_E = \frac{\partial^2 V_E(.)}{\partial x_E \partial x_I}$, when η_I (respectively, η_E) is positive, the innovator (respectively, the follower) benefits from the effort of the follower (respectively, the innovator). On the contrary, a negative value of η_I (respectively, η_E) corresponds to a negative externality borne by the innovator (respectively, the follower).

Note that in this simple setting, if the initial innovator does not invest (i.e., $x_I = 0$), the entrant can still invest in a new product. In this extreme case, the entrant does not imitate and, therefore, regulation is irrelevant.

3.2.1 Different Equilibria

In this section, we compare three types of equilibria: the unchallenged monopolist equilibrium, the leader-follower equilibrium without legal constraint on the decision set of the entrant and the leader-follower equilibrium with a binding constraint.

The best unconstrained choice of the follower is

$$x_E(x_I) = 1 + \eta_E x_I, \tag{3}$$

since she knows x_I at the time she makes her decision.

Anticipating the reaction function (3), the best choice of the innovator is

$$x_I^* = \arg\{-x_I + 1 + \eta_I[x_E(x_I) + x_I \frac{dx_E(x_I)}{dx_I}] = 0\}. \quad (4)$$

We consider three alternative cases:

1. The benchmark case in which entry is prohibited or technically impossible (either because $\overline{x} = 0$ or $\underline{x}$ is too high), so that $x_E \equiv 0$. Let

$$x_I^m = 1 \quad (5)$$

denote the investment in R&D made by the unchallenged monopoly.

2. The second case corresponds to constrained choices by the follower, either because $x_E(x_I) < \underline{x}$ or $x_E(x_I) > \overline{x}$. Depending on the value of the exogenous requirement, solving (4), we see that the patentholder will choose

$$\text{either} \quad \underline{x}_I = 1 + \eta_I \underline{x} \quad \text{or} \quad \overline{x}_I = 1 + \eta_I \overline{x}. \quad (6)$$

Let $\widehat{x}_I(x_E)$ be the best choice of the innovator when he anticipates $dx_E/dx_I \equiv 0$. In particular, we have $\widehat{x}_I(\underline{x}) = \underline{x}_I$ and $\widehat{x}_I(\overline{x}) = \overline{x}_I$.

When the constraint is a minimum requirement $x_E \geq \underline{x}$, it can be the case that $\underline{x}$ is so high that the follower prefers to stay out. For the entrant, the threshold is given by the pairs (x_E, x_I) such that the average profit is zero: $\frac{V_E}{x_E} = 1 - \frac{x_E}{2} + \eta_E x_I = 0$. Combining this relation with the incumbent's response to this type of regulation $\underline{x}_I = 1 + \eta_I \underline{x}$, we obtain the critical value

$$x_E^{\max} = \frac{2(1 + \eta_E)}{1 - 2\eta_E \eta_I},$$

such that for $\underline{x} \geq x_E^{\max}$, the follower does not enter.

3. We now turn to the case where the follower observes the value of x_I and can choose x_E without any restriction. She therefore reacts according to $\frac{dx_E(x_I)}{dx_I} = \eta_E$. Using this information, from (4) we can write x_I^* as a best anticipation to x_E,

$$x_I(x_E) = \frac{1 + \eta_I x_E}{1 - \eta_E \eta_I}. \quad (7)$$

In the absence of a binding requirement, the equilibrium levels of investment in the sequential game are[7]

$$x_I^* = \frac{1+\eta_I}{1-2\eta_E\eta_I}, \tag{8}$$

$$x_E^* = \frac{1+\eta_E(1-\eta_I)}{1-2\eta_E\eta_I}. \tag{9}$$

These equilibrium levels vary with the spillover parameters in a non-trivial manner.[8] The investment of each firm i, x_i^* for $i = E, I$ depends on its "own" spillover parameter, i.e., η_i as well as on the spillover parameter of the other firm, i.e., η_j for $j \neq i$ and $j = E, I$. By taking the derivatives of (8) and (9) with respect to η_I and η_E, we obtain the following variations.

- The investment of the innovator is increasing (respectively, decreasing) with η_I if $\eta_E > -1/2$ (respectively, $\eta_E < -1/2$); it is increasing (respectively, decreasing) with η_E if $\eta_I > 0$ (respectively, $\eta_I < 0$).

- The investment of the entrant is always increasing with η_E; it is increasing (respectively, decreasing) with η_I if $\eta_E < -1/2$ or $\eta_E > 0$ (respectively, $-1/2 < \eta_E < 0$).

An increase of η_I has two effects on x_I^*. A direct effect that is always positive as, for the optimal value x_E^*, the innovator always invests more as η_I increases. An indirect effect, due to the effect of the investment of the innovator on the investment of the entrant through the best response function of the entrant, $x_E(x_I) = 1 + \eta_E x_I$, that can reinforce or, on the contrary, dominate the direct effect. On the other hand, an increase of η_E has only an indirect effect on x_I^* through the investment of the entrant.

[7] Solving (3) and (4) gives the same result as solving the system of equations (3) and (7). We use the latter method, which has the advantage of allowing a direct graphical comparison of the investment levels when the game is sequential and when the game is simultaneous. The same kind of algebraic procedure can be used to solve the Stackelberg equilibrium, where a leader and a follower compete in quantities to sell an homogenous product.

[8] Amir et ali. (2001) show that the equilibrium R&D level is decreasing in the spillover parameter. But, in their model, the parameter is defined at the production stage as information sharing to decrease costs, while in our model, the spillover parameters are shortcuts for all interactions between the two firms at all stages.

Let us first investigate how investment decisions change after an increase of η_I for a given η_E. For low values of η_E, i.e., $\eta_E < -1/2$, the direct effect of an increase of η_I on x_I^* (that should increase x_I^*) is dominated by the indirect effect. By reducing his investment, the innovator forces the entrant to invest more and, thus, he benefits more through the spillover effect. In other words, the profit of the innovator increases due to the increase of the investment of the entrant, that has been triggered by the innovator.

For higher values of η_E, i.e., $\eta_E \in (-1/2, 0)$, the direct effect of an increase of η_I dominates the indirect effect, and therefore the innovator invests more. The higher the investment of the innovator, the lower the investment of the entrant, as the best response function of the entrant is a downward sloping function of the investment of the innovator (as $\eta_E < 0$).

For positive values of η_E, the indirect effect reinforces the direct effect, as the best response function of the entrant slopes upward. Thus, both innovator and entrant invest more as η_I increases.

We now examine how investment decisions are affected by an increase in η_E for a given η_I. The investment of the entrant is always increasing with η_E for any given x_I. Furthermore, as long as $\eta_I < 0$ (respectively, $\eta_I > 0$), the indirect effect of an increase of η_E on the investment of the innovator is always negative (respectively, positive). Therefore, the innovator decreases (respectively, increases) his investment.

It follows that the comparison of the optimal investments of the innovator given by (5), (6), and (8) depends on the sign of the spillover parameters η_E and η_I.

3.2.2 Traditional Model of Imitation

Even though the roles of each player are well-determined at the beginning of the game (firm I is the leader, firm E is the follower), the imposition of IPRs induces the leader to behave like a follower.

Let us consider the case where the follower benefits from the research of the innovator ($\eta_E > 0$), but the presence of the imitator is harmful to the innovator ($\eta_I < 0$). This case corresponds to the traditional model of imitation, where imitation (respectively, innovation) creates a negative (respectively, positive) externality on the innovator's profit (respectively, the imitator's profit). From (3), $x_E(x_I)$ is increasing, and from (4) and (7), $x_I(x_E)$ and $\widehat{x}_I(x_E)$ are decreasing.

Because $\eta_I < 0$, when facing the threat of imitation, we can see in Figure 1 that the innovator has a natural incentive to invest less than when there is no such threat ($x_I^* < x_I^m$). But this is the unconstrained equilibrium of the sequential game. As an innovator, firm I is protected against too large ($x_E \leq \overline{x}$) or too small an investment ($x_E \geq \underline{x}$) of the follower. Do these limits help the innovator to keep a high level of investment?

The requirement to invest at least $\underline{x}$ is binding only when $\underline{x} > x_E^*$. It has an adverse effect on the innovator's profit, who is obliged to increase his R&D investment ($\widehat{x}_I(\underline{x}) > x_I^*$) at least as long as $\underline{x}$ is not too large. For a large requirement $\underline{x}$, the effort of the incumbent is less than x_I^*. And if $\underline{x} \geq x_E^{\max}$, since the incumbent expects no entry, he plays like a monopolist by spending x_I^m.

As can be seen in figures 1 and 2, when $x_E \geq \underline{x}$ is imposed, the R&D expenditure of the innovator, expressed as a function of $\underline{x}$, is discontinuous at point x_E^*. This is because imposing such a constraint is like changing the timing of the game. The regulated value of the expenditure of the follower $\underline{x}$ is fixed before the innovator's expenditure x_I.

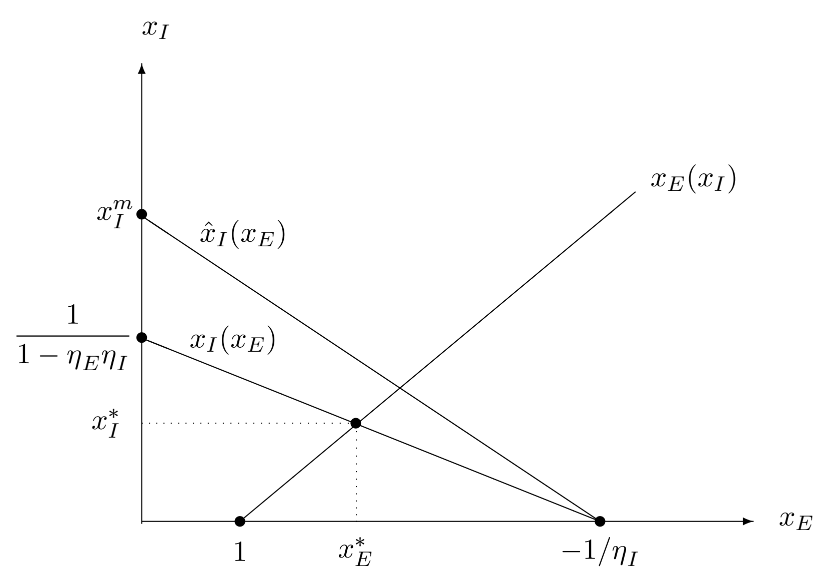

Figure 1: Research efforts when $\eta_E > 0$, and $\eta_I < 0$

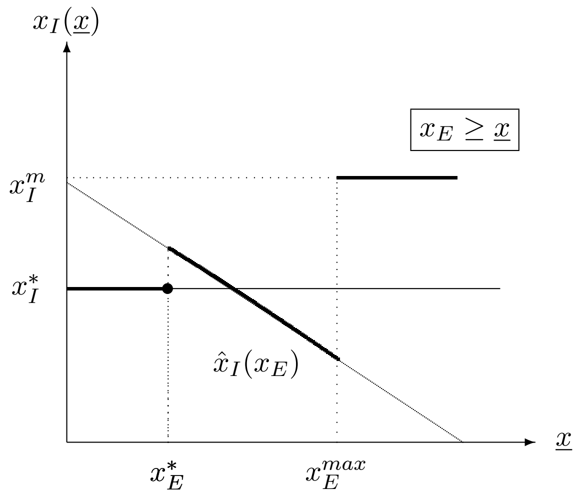

Figure 2: Effect of a minimum requirement on the entrant's expenditures

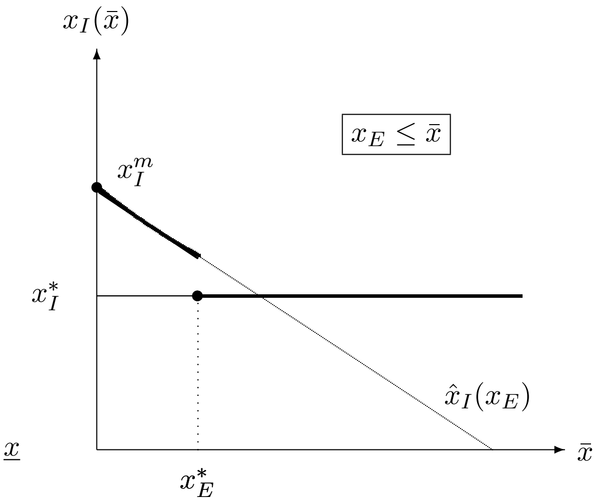

Figure 3: Effect of an upper bound on the entrant's expenditures

Symmetrically, from figures 1 and 3, we see that the upper limit $x_E \leq \overline{x}$ has a positive effect on the investment of the innovator ($\widehat{x}_I(\overline{x}) > x_I^*$ for $\overline{x} < x_E^*$), but it cannot give the innovator an incentive to invest more than when there is no imitator at all ($\widehat{x}_I(\overline{x}) \leq x_I^m$).

To summarize, if $\eta_E > 0$, and $\eta_I < 0$, the imposition of IPRs that set a lower bound $\underline{x}$ (respectively, upper bound $\overline{x}$) on the investment of the imitator may induce the innovator to behave as a follower. His optimal investment is a non-monotonic function of $\underline{x}$ (respectively, $\overline{x}$).

This case is the benchmark for the defenders of intellectual property rights: all efforts by the innovator are good for imitators, whereas the former suffers from the activity of the latter.

A very tough IPRs policy that prohibits entry (if, for instance, entry becomes prohibitively costly, i.e., $\underline{x}$ larger than $x_E^{\max}$, or if entry is prohibited $\overline{x} = 0$) allows the innovator to invest at the monopoly level. This investment level is higher than it would have been if a lenient IPRs policy was enforced (i.e., for $\underline{x} < x_E^{\max}$) or if entry was just restricted ($\overline{x} > 0$). So, from the innovator's viewpoint, a very tough IPRs policy induces more innovation by preventing imitation. However, IPRs that permit entry (restricted or not) can increase the total sum of the investments made by firms. Therefore, from a strict society viewpoint, it is not clear whether a very tough policy that completely prevents entry is better than a softer requirement that allows speedier imitation, or eventually improvement. We need to carefully study how the imposition of IPRs affects all of the investments.

3.3 Effect of IPRs on Innovation

We now investigate the effects of IPRs on the total investment level chosen by the two firms. In the absence of a formal demand side, it is difficult to draw robust welfare conclusions, and we do not pretend to do so. Our goal is not to study the impact of regulation on the entire society, but rather its impact on the behavior of innovators and imitators. The investment made by the initial innovator matters, as it gives an indication of initial innovation, but the overall investment can be of interest, as well. In fact, if investments are not mere duplicates or copies of existing innovations, both types of investments matter.

We show that because the spillover effects can be either positive or negative, the overall investment $(x_I + x_E)$ can be reduced when IPRs are enforced.

It is straightforward to derive the sum of the investments in the unconstrained case and constrained case. When there is no constraint on the follower, the sum is

$$x_I^* + x_E^* = \frac{2 + \eta_E + \eta_I - \eta_E \eta_I}{1 - 2\eta_E \eta_I}.$$

When IPRs are in force, the follower is constrained to invest a given x_E (either $\overline{x}$ or $\underline{x}$), and the sum of the investments becomes

$$\widehat{x}_I(x_E) + x_E = 1 + (1 + \eta_I)x_E.$$

If the constraint is active, whatever the value of η_I, this is an increasing function of the legal cutoff value imposed by the government. When the constraint prevents entry (either $\overline{x} = 0$ or $\underline{x} > x_E^{\max}$), the investment is just the monopoly investment of the leader $x_I^m = 1$.

Let $\widetilde{x}$ be the value of x_E such that $x_I^* + x_E^* = \widehat{x}_I(\widetilde{x}) + \widetilde{x}$; that is

$$\widetilde{x} = \frac{1 + \eta_E}{1 - 2\eta_E \eta_I}.$$

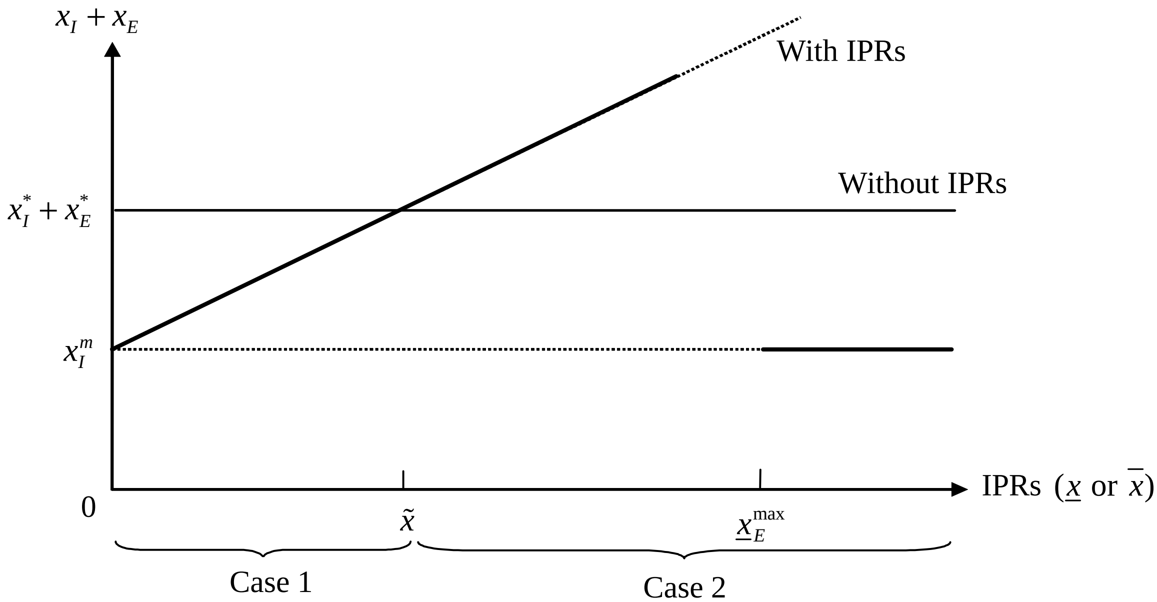

Figure 4: Aggregate investment with and without IPRs

Using figure 4, we now consider different scenarios, depending on whether the unconstrained investment of the follower, x_E^*, is smaller or higher than the cutoff value $\widetilde{x}$.

Let us first assume that the unconstrained investment of the follower is higher than the cutoff value, i.e., $x_E^* > \widetilde{x}$ (case 2 in figure 4). This happens when the spillover coefficients have opposite signs.

- If IPRs impose a minimum constraint ($\underline{x}$) and the regulation is tight enough, i.e., $\underline{x} > x_E^*$, the constraint is binding and the follower must invest $\underline{x}$. Under a policy $\underline{x} < \underline{x}_E^{\max}$, IPRs increase total R&D expenditures. However, if $\underline{x} \geq \underline{x}_E^{\max}$, IPRs are detrimental to innovation, as $x_I^m < x_I^* + x_E^*$.
- If IPRs impose a maximum constraint, and if $\overline{x} < x_E^*$, the constraint is binding. For any

policy such that $\overline{x} < \widetilde{x}$, IPRs are detrimental to innovation. Otherwise, IPRs encourage R&D expenditure when $x_E^* > \overline{x} > \widetilde{x}$.

We now assume that the unconstrained investment of the follower is less than the cutoff value, i.e., $x_E^* < \widetilde{x}$ (case 1 in figure 4). One can easily check that this inequality holds when η_E and η_I have the same sign. Thus, we have two different configurations of parameters for which $x_E^* < \widetilde{x}$. We investigate whether IPRs are detrimental to innovation when the IPRs policy imposes either a minimum or a maximum threshold to the follower.

- If the IPRs policy imposes a minimum constraint ($\underline{x}$), and if the regulation is tight, i.e., $\underline{x} > x_E^*$, the constraint is binding and the follower must invest more than he would absent the IPRs. But, under a policy such that $\underline{x} < \widetilde{x}$, IPRs are detrimental to innovation, as the sum of the investments with IPRs is lower than the sum in absence of any policy ($\widehat{x}_I(\underline{x}) + \underline{x} < x_I^* + x_E^*$). However, if $\underline{x} \geq \widetilde{x}$ but $\underline{x} < \underline{x}_E^{\max}$, the converse is true, and IPRs boost innovation. This is no longer the case for $\underline{x} > \underline{x}_E^{\max}$, since the minimum legal requirement is so high that the follower does not enter, and the leader invests only x_I^m. This is the case depicted by the bold lines in Figure 4.

- If the policy imposes an investment cap ($\overline{x}$), and if $\overline{x} < x_E^*$, the constraint is binding and the follower must spend $\overline{x}$. For any policy, IPRs are detrimental to innovation. Indeed, the sum of the investments with IPRs is lower than the sum without IPRs ($\widehat{x}_I(\overline{x})+\overline{x} < x_I^*+x_E^*$). At best, the cap is not binding and the total investment is the same.

The conclusion is no one single solution applies to all cases. We can just observe that the imposition of a ceiling investment ($\overline{x}$) is likely to reduce the sum of the investments, except if the cap $\overline{x}$ is close to x_E^*. The imposition of a floor investment ($\underline{x}$) is more likely to be beneficial to society, especially when the IPRs are strict enough ($\underline{x}$ high enough but lower than $\underline{x}_E^{\max}$). For more lenient policy (i.e., $\underline{x}$ close to x_E^*), it can be detrimental.

However, these results should be tempered. As we do not specify whether the follower invests in imitation or in improvement, x_E can purely be business stealing (mere imitation), and can create no social value, whatsoever. In this case, a social planner should not be concerned with the sum of the investments.

4 Industry-Specific Externalities

We now detail four configurations that we classify according to the relevance of both signs of the spillover parameters for a specific branch of the information and communication technologies (ICT) industry. The ICT industry presents the largest spectrum of possibilities, which probably explains why IPRs are so controversial in this sector. For instance, $\eta_E > 0$ and $\eta_I > 0$ correspond to an industry where both externalities are positive: the more the innovator (respectively, the follower) invests, the higher the profit of the follower (respectively, the innovator). This corresponds to the externalities that arise in the computer industry as a whole, when firm I represents the microprocessor producers and firm E the software publishers. They both benefit from the effort of the other. We successively consider the four cases where both η_E and η_I can be positive, negative or can have opposite signs.

4.1 The Music Industry

The music industry is a good illustration of the situation where $\eta_E > 0$ and $\eta_I < 0$ (see figures 1 to 3). At the beginning of 2000, Napster developed a program to download MP3 files. In less than six months, the music industry *i*) incurred a sharp decrease in revenues evaluated at \$ 20m and *ii*) sued Napster to obtain the withdrawal of the program needed for downloading. Music companies argued that given the copy (imitation) activity encouraged by Napster-like firms, their expenditures in new talent research and recording activity would drop dramatically (say, from x_I^m to x_I^* in Figure 1). The demand for withdrawal and the decision made by courts in 2001 consisted in a tentative decision to go back to x_I^m. Napster has now disappeared, but it has been replaced by several newcomers.[9] From the figures, we see that if the public objective is to keep the effort of firm I as high as possible, the best policy is either to fix $\overline{x} = 0$ (no entry) or $\underline{x} \geq x_E^{\max}$ (prospect your own music stars). But for the music industry as a whole, since we

[9] See www.afternapster.com.

are in case 2 of figure 4, $\overline{x}$ should be larger than $\widetilde{x}$ or $\underline{x}$ should be less than $\underline{x}_E^{\max}$.

This configuration of the spillover parameters also illustrates that innovation can be severely damaged by dramatic improvements. All of the history of the software industry is made up of first movers excluded from the market by a drastically improved version of their product: Word, Excel, Explorer and Outlook have replaced, respectively, WordPerfect, Lotus 1-2-3, Netscape and Eudora as dominant applications.[10] This exclusion appears in the model when η_I is close to -1. From (8) and (9) we see that this results in the bankruptcy of the innovator ($x_I^* \to 0$) and its replacement by the follower ($x_E^* \to 1 = x_E^m$). In this case, it would be socially inefficient to protect firm I.[11]

4.2 The Software Industry

We now consider the case where the innovator benefits from the research of the follower, and, reciprocally, the follower benefits from the efforts of the innovator ($\eta_E > 0$ and $\eta_I > 0$). Following the 'conventional' definition of Bulow, Geanakoplos and Klemperer (1985), the investment decisions of the firms are strategic complements.

If the follower is allowed to freely enter the market, the investment made by the innovator is non-ambiguously higher than the investment of the innovator without entry. We see from figure 5 that $x_I^* > x_I^m$. In this case, the expected presence of the follower boosts innovation: the innovator has high incentives to invest more, since he will later benefit from the efforts of the follower.

Now if $x_E^* < \underline{x}$, we also have $x_I(\underline{x}) > x_I^m$ by transitivity.[12] But $x_I(\underline{x})$ can be larger or smaller than x_I^*, depending on the slopes of $\widehat{x}_I(x_E)$ and $x_I(x_E)$ and on the value of $\underline{x}$. If the minimum investment requirement $\underline{x}$ is larger than but close to x_E^*, the R&D expenditure of the innovator is lower than without the $\underline{x}$ requirement.

[10] The idea that the four Microsoft products are technically better than their predecessors is developed in Leibowitz and Margolis (2001). Some authors challenge this idea and consider that Microsoft won the battle with its marketing policy (mainly forced bundling), rather than on technical grounds; see Gilbert and Katz (2001).

[11] On Napster, see Boldrin and Levine (2002).

[12] This is because $x_I(x_E)$ is an increasing function. The reader can easily draw the graphs of $x_I(\underline{x})$ and $x_I(\overline{x})$ corresponding to figure 5, as we did with figures 2 and 3 that correspond to figure 1.

Because of the discontinuity in the innovator's investment due to the legal restriction imposed on the follower, if the government wants to foster R&D efforts by imposing a minimal constraint on followers, this constraint has to be very stringent, namely, $x_E \geq \widehat{x}_I^{-1}(x_I^*) = \frac{1+2\eta_E}{1-2\eta_E\eta_I}$.

The other type of IPRs policy, that is, a ceiling requirement $x_E \leq \overline{x}$, would not be a good idea, either, since the effort of firm I is increasing with x_E. At most, the innovator will invest x_I^*. At worst (when $\overline{x} < x_E^*$), he will invest $\widehat{x}_I(\overline{x}) < x_I^*$.

A very tough IPRs policy has a negative impact on investments as a monopoly always invests less than competitive firms. In this case, it is clear that competition boosts innovation. Furthermore, the total sum of investments is always higher under IPRs policies that allow entry.

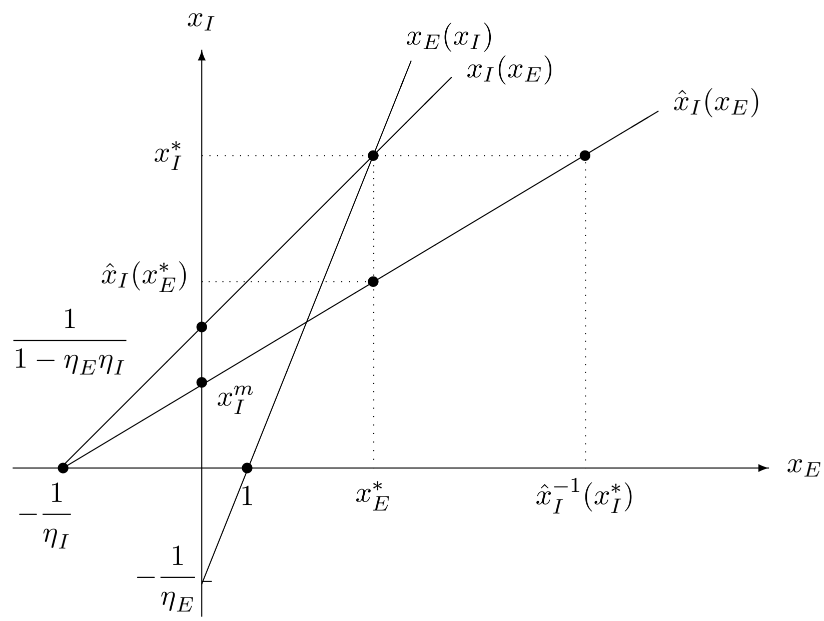

Figure 5: Research efforts in the software industry ($\eta_E > 0, \eta_I > 0$)

This parameter configuration can be observed in the software industry, where operating system (OS) developers benefit from the expenditures of application publishers ($\eta_I > 0$) and, symmetrically, the application publishers benefit from the financial efforts of the OS developers ($\eta_E > 0$). Consequently, if one just wants to increase OS research expenditures, it is better not to impose any minimum constraint on the efforts of the application publishers rather than imposing a mild constraint. Indeed, a constraint $x_E \geq \underline{x}$, where $\underline{x}$ is slightly above x_E^*, would have the adverse effect of decreasing x_I. Alternative solutions to increasing x_I are to encourage joint venture and to organize a merger between the OS and application producers. But the simplest obvious policy is to have no restriction on entrants' decisions[13] and to limit the control to antitrust rules in order to prevent the use of cross-licenses as market power devices.

4.3 The Hardware Industry

Consider now that the follower does not benefit from the innovator ($\eta_E < 0$), while the latter benefits from the entrant's effort ($\eta_I > 0$).

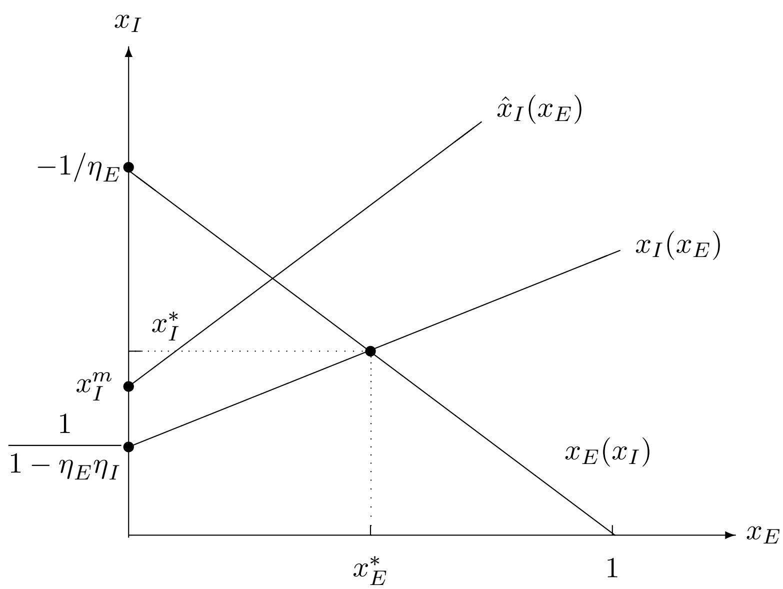

Figure 6: Research efforts in the hardware industry ($\eta_E < 0, \eta_I > 0$)

Because of the negative externality that she suffers from the innovator ($\eta_E < 0$), the follower is somewhat reluctant to invest. By contrast, the innovator would like the follower to increase her research effort. A minimal requirement $x_E \geq \underline{x}$ above x_E^* is a good incentive to increase the innovator's effort, since $\widehat{x}_I(\underline{x}) > x_I^m$ for all $\underline{x} > x_E^*$.

[13] It means that an OS producer should not be allowed to prevent the use of its OS to develop applications. The difficulty arises from the fact that OS producers can also be applications developers.

An IPRs policy that prevents entry induces the innovator to invest more only if the negative externality of the follower is very large (i.e., $\eta_E < -0.5$). Otherwise, competition tends to increase innovation. However, a policy that restricts entry (i.e., $\underline{x} > x_E^*$) allows the investment of the innovator to increase, as well as the total sum of the investments, as long as $\underline{x} < x_E^*$ (see figure 4, case 2).

In industries with strong network externalities, innovators benefit from a large user base. They face a trade-off on letting imitators enter. On one hand, they benefit from additional users, but on the other hand, they lose in unit sales. A good example is the hardware industry, where innovators (brand firms) may have an advantage in letting "clones" be in the market. For instance, Sun Microsystems, has encouraged clones of its computer workstation in order to build its technology's user base (Conner, 1995). Those consumers who favor higher quality have a preference for the branded hardware. As the innovator invests in providing cheaper computer workstations, the demand for clones decreases and, thus, it hurts the imitator ($\eta_E < 0$). On the other hand, the introduction of clones allows the user base to grow, so the innovator gains from letting the imitator be in the market ($\eta_I > 0$). Thus, imitation boosts innovation. It is even more dramatic if the imitation is restricted: the innovator invests more than without the minimum or maximum requirement imposed on the imitator.

4.4 The Video Game Industry

The most likely case is when the follower suffers from the innovator ($\eta_E < 0$) and the latter also suffers from the former ($\eta_I < 0$). In this case, the investment decisions of the two firms are strategic substitutes, like in standard competition games.

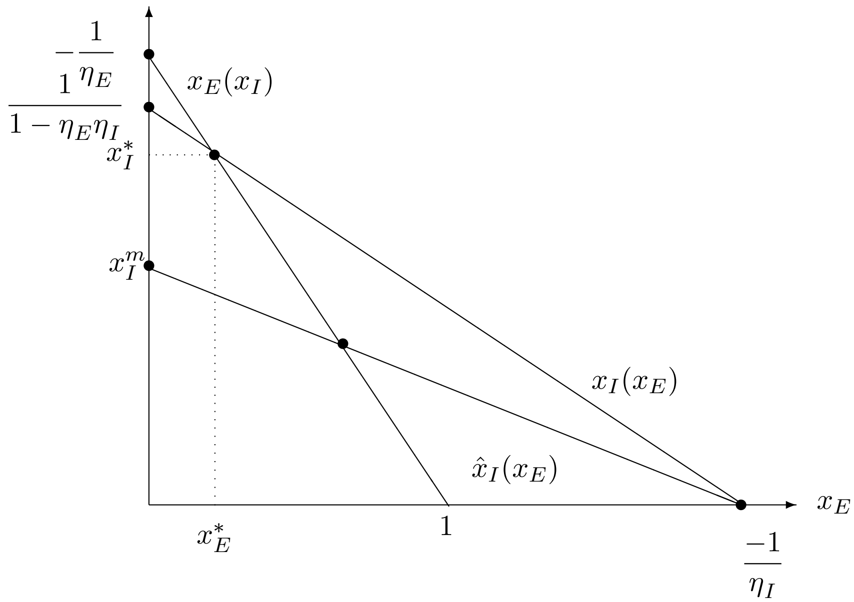

Figure 7: Research efforts in the video-game industry ($\eta_E < 0, \eta_I < 0$)

As compared with the case where the innovator does not suffer from imitation and invests x_I^m, we see that the presence of the imitator has the effect of increasing (respectively, decreasing) the innovator's efforts if $\eta_E < -1/2$ (respectively, $\eta_E > -1/2$).

The introduction of a minimum requirement on x_E has the effect of creating a downward jump in x_I at the point x_E^*. But contrary to the former case, an additional increase in $\underline{x}$ provokes a decrease in $x_I(\underline{x})$. Therefore, to set a low threshold for investments by imitators is always detrimental to the efforts of the innovator.

When η_E is very small ($\eta_E < -1/2$), the innovator is inclined to overinvest ($x_I^* > x_I^m$), because he knows that this is harmful to imitators who will invest less. Consequently, if the government fixes $\underline{x} > x_E^*$, this dissuasive policy no longer works. On the contrary, we observe that $x_I(\underline{x})$ is less than x_I^m for $\underline{x} > x_E^*$. The requirement $\underline{x}$, that can be viewed as the investment that measures the novelty of an improvement on the initial innovation, provides a negative incentive to innovate. The higher the $\underline{x}$, the lower the incentive to spend money on the initial innovation: $\underline{x}$ serves as a barrier that protects the innovator.

Thus, a tough IPRs policy allows the innovator to invest more only if the follower's negative externality is very strong ($\eta_E < -1/2$). When entry is only restricted, the innovator does not invest more. Here again, competition induces firms to invest more than a monopoly would.

In industries where the leader and the follower have different standards, the more the leader invests in an innovation that promotes his standards, the less the follower benefits from it ($\eta_E < 0$). On the other hand, the more the follower invests in an innovation that is compatible with her own standard, the lower the profit of the leader ($\eta_I < 0$). Innovators invest more in the presence of competition. The competition between Nintendo and Sega is relevant to this specific case. Indeed, every time Nintendo invents a new game, Sega loses consumers. Then Sega invests to produce a more powerful game that will be detrimental to Nintendo.[14] If the government intervenes and forces Sega to artificially differentiate its product, for instance, it will reduce innovations instead of boosting them. In fact, each firm will compete in different markets.

The present fight for digital dominance in the mobile phone market between Microsoft and Nokia is another illustration of this case of technological competition.[15]

5 Conclusion

In the innovation game, each player in turn appears as the leader. The strategies are so intricate that the game is a complex combination of simultaneous, sequential and collusive behaviors. Each player should also take into account the likelihood of positive and negative externalities. In the short run, the sign of the spillover coefficients can be forecasted reasonably well, but in the medium run, it is much harder. An additional difficulty is that all actual innovation candidates and innovators are simultaneously facing multiple actual and would-be providers of complement and substitute products; instead of one as in our model.

Several extensions and developments of the model can be considered. Let us mention three: i) to explicitly explore the origin of spillovers, ii) to allow several moves by the players and iii) to consider the possibility of mergers.

i) The spillover effect at work in the former sections can have several origins and different materializations: technological, legal, marketing. In d'Aspremont and Jacquemin (1988),

[14] Concerning the study of standards, as well as the competition between Nintendo and Sega, see Shapiro and Varian (1999).

[15] See *The Economist*, November 21, 2002.

knowledge spills over after the R&D process, i.e., spillover relates to R&D outputs. By contrast, in Kamien et al. (1992), knowledge spills over during the R&D process, i.e., spillover relates to R&D inputs. In our model, we cannot distinguish between the two types of spillover.

One case where the net value of the spillover coefficients of each firm (taking into account all the positive and negative externalities resulting from technological constraints and market conditions) is most likely positive is when firms have to decide on an industry-wide standard.

For example, since 1999, hundreds of firms in the telecom industry support Voice XML (for Voice eXtensible Mark-up Language) as a common language for all voice applications. Nowadays, when we want to obtain traffic information or check bank accounts by phone without the intervention of a live operator, we are limited to pushing some buttons or using a predefined vocabulary. These flaws obviously impair the profitability of this type of activity. To develop it necessitates drastic progress in speech recognition technology. This is the objective of the Voice XML, pushed by the main firms of the telecom industry within the World Wide Web Consortium (W3C), an Internet standards body.[16] All of the industry members expect lower costs (saving on live operators) and higher demand (due to easier and more rapid information).

ii) As in many other sequential decision processes, the participants in the innovation game suffer a sort of intertemporal schizophrenia. When they are candidates to entry, they would like to face wide open doors. Later, the winners of the race will argue that doors should be kept tightly closed. Let us remain within our model, where the decision variables are investment in R&D, not legal arrangements that are exogenous. Because of the aforementioned evolution of the players' interests, a complete description of the innovation game should require that entrants internalize their expected behavior as future incumbents.[17]

[16] See *The Economist*, December 14, 2002, pp. 28-29. In the past, W3C developed HTML (for Hypertext Mark-up Language), used to design Web pages.

[17] "Sony, the world's largest consumer-electronics maker is under constant assault from a host of new competitors, with Samsung leading the pack. The one clear advantage Sony has had is its strong brand image, which is

iii) In the ICT industries, there are strong incentives to integrate horizontally and vertically and to take control of allies and start-ups. These are driven for the sake of internalization. For example, in November 2002, Comcast (a cable operator) merged with AT&T Broadband to create a US media and communication industry giant (22m subscribers). The objective of the merger was to stop customers from leaving: during the nine first months of 2002, some 0.6m left (most of them from AT&T Broadband) to go to satellite TV which is cheaper. Joining the efforts of the two companies would eventually allow them to diversify into activities more profitable than cable TV broadcasting and to propose services that satellite rivals could not match, namely broadband internet access, interactive television and national cable-telephone.[18]

still the global electronics brand to beat. But now, that edge is being blunted.(...). Samsung has quickly gained technical prowess and is learning the Sony-pioneered art of turning gadgets into fashion accessories. Now it is building a brand. In 2002, Samsung has spent more than $900 million world-wide on branding activities such as television ads and retail promotions, compared with $700 million last year." Sony must now "introduce new products first in markets where Samsung is strongest," says Sony President Kunitake Ando. "They've learned so much from us. ... Now they're becoming a much bigger influence on our strategy." (*Wall Street Journal Europe*, December 20-22, 2002)

[18] Additionally, "Comcast has a foot in the content business through the QVC home shopping channel, its Hello!-style entertainment channel, E!, and the Golf Channel. Its latest project is G4, a channel for video games. With its enlarged customer base, Comcast will become a powerful partner for those looking to launch new services. 'The beauty of having 21.5m customers is for ourselves or other companies or entrepreneurs to enable their business plans,' Mr. Robert (Comcast's president) says." (*The Financial Times*, December 20, 2002)

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