IOWA STATE UNIVERSITY

Are Intellectual Property Rights Detrimental to Innovation?

Claude Crampes, Corinne Langinier

March 2005

Working Paper # 05009

Department of Economics Working Papers Series

Ames, Iowa 50011

Iowa State University does not discriminate on the basis of race, color, age, national origin, sexual orientation, sex, marital status, disability or status as a U.S. Vietnam Era Veteran. Any persons having inquiries concerning this may contact the Director of Equal Opportunity and Diversity, 3680 Beardshear Hall, 515-294-7612.

Are intellectual property rights detrimental to innovation?*

Claude Crampes† and Corinne Langinier‡

February 2005

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 and increase total R&D expenditures in some industries and be detrimental in others. The model is illustrated by case studies from the information and communication technologies industry (software, hardware, music and videogame industries).

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

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

*We thank the participants of seminars at INRA, Grenoble and Paris I, as well as the participants of the EARIE 2004 and ESEM 2004 conferences for their helpful comments.

†Toulouse University, IDEI and GREMAQ; ccrampes@cict.fr

‡Iowa State University, Ames; langinier@econ.iastate.edu

1 Introduction

The innovation game is a complex dynamic process where no one can truly assert that his brand-new product or her cost-killer method comes from no 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 ancient 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-right 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 the 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 a good 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 game, where the innovator decides on his effort anticipating the reaction function of future entrants.

The trade-off between the advantages for 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 will allow private investors to reap the profits generated by their effort rather than to share

[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 innovators. 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.

those profits with free riders. For candidates to enter (either mere copiers or true improvers), this means that they 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 what they intended to do. 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, so far, 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 of whether it is 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 or when does he behave like a follower of the regulation that constraints any candidate to entry?"

We analyze this problem using an elementary model of technological competition between two firms when there exist spillovers between their profit functions.

Contrary to the patent race literature where firms compete to be the first to make the same discovery (Reinganum, 1989), we consider that some firms make innovations, 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. We, thus, depart from this literature as we study the investment decisions when there is no race. Our approach is closer 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). We simply assume that after an innovation has been made the follower observes it and decides how much to invest in imitation. 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. This was first studied by Gallini (1992) who determined the appropriate protection against imitation as well as the optimal duration of the patent in order to prevent imitation. However, it is not necessarily the case that entry should be prevented. If there exist positive externalities 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

[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.

followers.

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 (2004), who are among those 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.

The paper is organized as follows. The model is exposed in section 2. Section 3 gives the details of the equilibria, with and without exogenous constraint and we investigate the case where the IPRs weaken the leadership of the incumbent. Section 4 focuses on the potential for detrimental effects of IPRs on innovation. In section 5, we illustrate all 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 6 concludes.

2 The Model

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 take into account both the uncertainty about the identity of the winner, and about the date on which the innovation will occur (Reinganum, 1989). Other models 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 do not consider any kind of uncertainty, and we adopt a very simple model with 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), first R&D is 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.[4] However, in this 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

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

(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).[5] 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.

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

2.1 The players

We consider a sequential model with two firms: an innovator (I) and a potential entrant (E). Both have to invest in order to develop their products but firm E is a follower, and thus will be second to choose after observing the choice of firm I. Besides, her choice may be constrained by Intellectual Property Rights (IPRs). Let x_I denote the investment decision of firm I. We assume that there is no uncertainty concerning the innovation and it is introduced and patented at the same time. The potential entrant observes the investment decision made by the innovator (through the innovation that has been brought about) and decides how much to invest in imitation or development. Let x_E denote this imitation or development investment decision. In order to keep the model as general as possible we do not precisely specify the imitation decision; It can be a differentiation decision (how far from the existing product the follower wants her product to be), an improvement decision (how better the follower wants her product compared to the initial product), or an application decision (how many applications the follower wants to introduce in the market). As we are mainly interested in the impact of the investment decision of one firm on the decision of the other firm, we simply consider the following reduced form profit functions for each firm:

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

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

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

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

(respectively, 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).

2.2 The regulation

The follower is however constrained by patent or copyright laws or specific regulations to respect some market boundaries. In our elementary setting these constraints are modelled as investment requirements. If for instance the follower invests to differentiate her product, the government can oblige her to invest at least a minimum level, say $\underline{x}$. Indeed, when he receives a patent, the innovator is being granted the right to protect a defined segment of the market (if we consider horizontal differentiation) or a certain number of applications, or improved versions of his product (if we consider vertical differentiation). 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.[6] 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 small scale which does not deprive the innovator of large benefits or, on the contrary, if she invests large amounts of money, which could represent an improvement detrimental for the incumbent but beneficial for consumers. The exclusion zone is the one that 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. They rather should be functions of the effort of the incumbents. This extension would obviously make the model more complex.

3 Constrained and unconstrained 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.

[6] When $\overline{x} = 0$, entry is totally forbidden since $V_E(0, x_I) = 0$, $\forall x_I$. This would not be true if x_I was not multiplied by x_E in V_E. The entrant could benefit from x_I without any positive effort on his own.

3.1 Different equilibria

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

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

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

$$x_I^m = 1 \tag{5}$$

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

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

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

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

In the absence of 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 $j = E, I$. The variations of the investments are detailed in the following lemma:

Lemma 1: *In the absence of binding requirement,*

1. *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, $\eta_I < 0$).*
2. *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, $-1/2 < \eta_E < 0$).*

The proof of the lemma is straightforward once one take the derivative of (8) and (9) with respect to η_I and η_E.

The intuition of these results is the following. An increase of η_I has two effects on x_I^*: a direct effect that is always positive (for the optimal value x_E^*, the innovator always invests more as η_I increases), and 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 reenforce 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.

Let first investigate how the 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

[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 to allow a direct graphical comparison of the investment levels when the game is sequential and when the game is simultaneous. The same kind of trick 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 alii (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 the interactions between the two firms at all stages.

increase x_I^*) is dominated by the indirect effect. Thus 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 thus 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 reenforce 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 the 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). Thus 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 IPRs weaken the leadership of the incumbent

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 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 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 follower expenditure $\underline{x}$ is fixed before the innovator expenditure x_I.

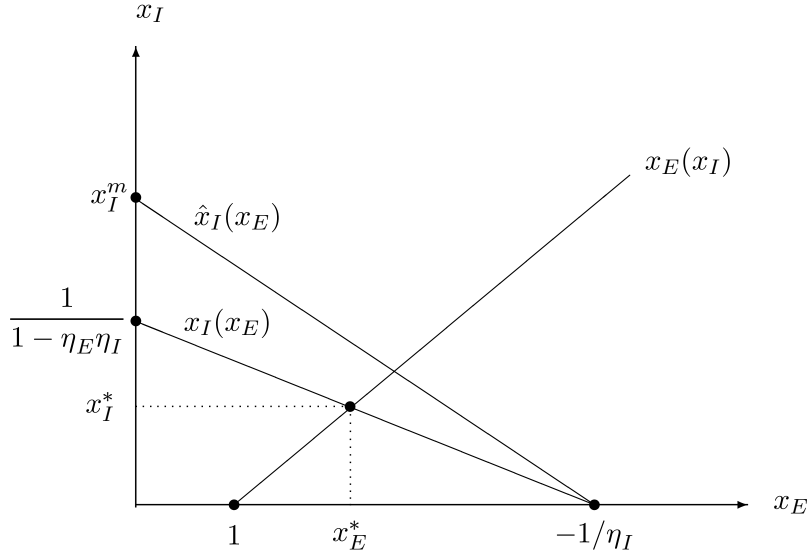

Figure 1: Research efforts when $\eta_E > 0$, and $\eta_I < 0$

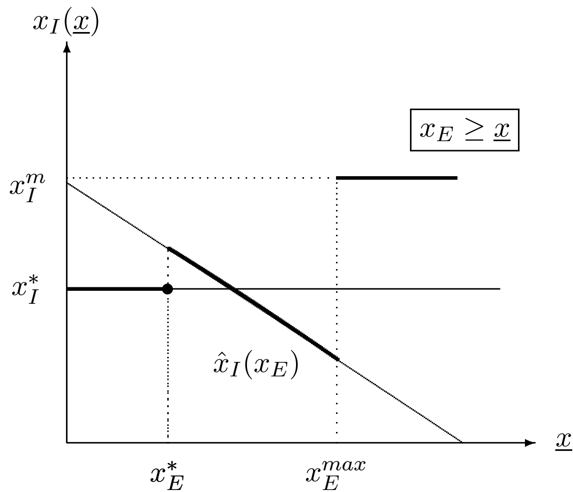

Figure 2: Effect of a minimum requirement on the entrant's expenditures

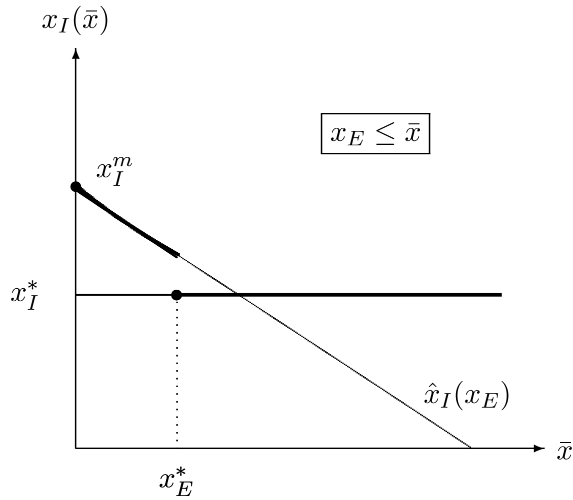

Figure 3: Effect of an upper bound on the entrant's expenditures

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 ($\widehat{x}_I(\overline{x}) \leq x_I^m$).

We can summarize those findings in the following proposition:

Proposition 1 *(imitation case): 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 $\underline{x}_E^{\max}$, or if entry is prohibited $\overline{x} = 0$) allows the innovator to invest at the monopoly level. This level is higher than what he would have invested 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. Thus, from a strict society's viewpoint, it is not clear whether a very tough policy that completely prevents entry is better than a softer requirement that allows to speed up imitation, or eventually improvement. We need to carefully study how the imposition of IPRs affect all the investments.

4 Detrimental effect of IPRs on innovation

We now investigate the effects of IPRs on the total investment chosen by the two firms. From a social viewpoint, the investment made by the initial innovator obviously matters. But the overall investment is of interest as well. 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 in force.

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

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

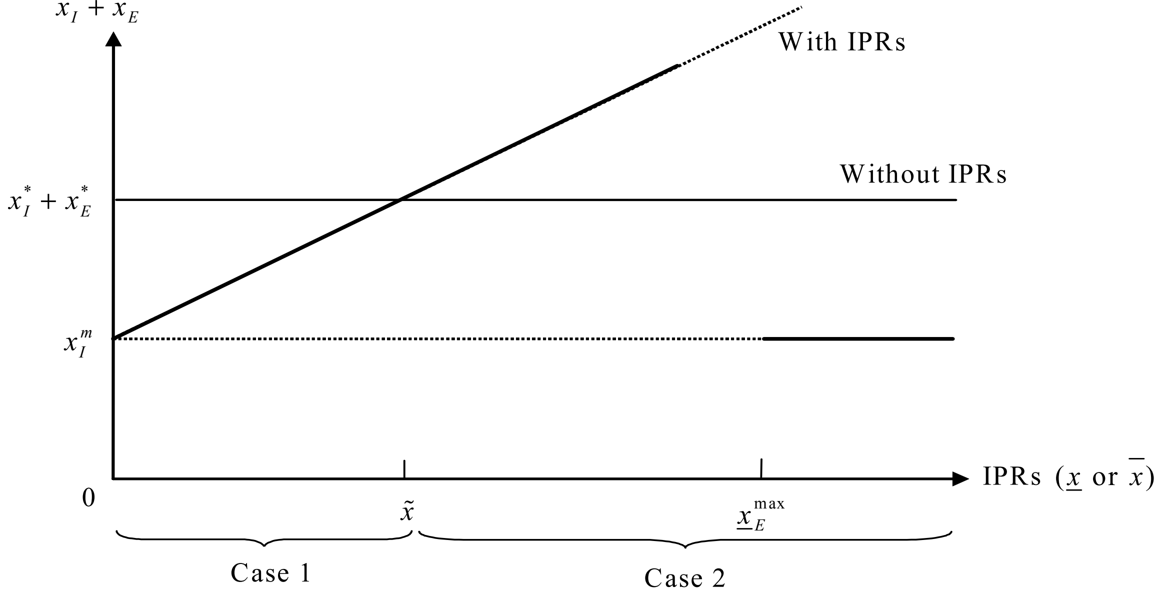

Figure 4: Aggregate investment with and without IPRs

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 first assume that the unconstrained investment of the follower is bigger 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 $x_E^* > \overline{x} > \widetilde{x}$.

Following proposition 1, let summarize the above findings for the case of imitation ($\eta_E > 0$, and $\eta_I < 0$) in the following proposition:

Proposition 2 *(imitation case): If $\eta_E > 0$, and $\eta_I < 0$, the imposition of IPRs that set a lower bound $\underline{x}$ (respectively, upper bound $\overline{x}$) too high, i.e., $\underline{x} \geq \underline{x}_E^{\max}$ (respectively, too low, i.e., $\overline{x} < \widetilde{x}$), is detrimental to innovation.*

We now assume that the unconstrained investment of the follower is smaller 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 now 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 what he would do 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 under 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 that there is not one single solution that applies to all the 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 smaller than $\underline{x}_E^{\max}$). For more lenient policy, (i.e., $\underline{x}$ close to x_E^*), it can be detrimental.

5 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 $\eta_I > 0$ corresponds 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 η_E and η_I can be both positive, or both negative or can have opposite signs.

5.1 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 at law 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 talents 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 taken by courts in 2001 consist in a tentative 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 $\underline{x} \geq \underline{x}_E^{\max}$ (prospect your own music stars). But for the music industry as a whole, since we 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 the history of the software industry is made 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 ($x_I^* \to 0$)

[9] See www.afternapster.com.

[10] The idea that the four Microsoft's 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 by its marketing policy (mainly forced bundling) rather than on technical grounds; see Gilbert and Katz (2001).

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]

5.2 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.

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

Concerning the other type of IPRs policy, that is, a ceiling requirement $x_E \leq \overline{x}$, it 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.

[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 like we did with figures 2 and 3 that correspond to figure 1.

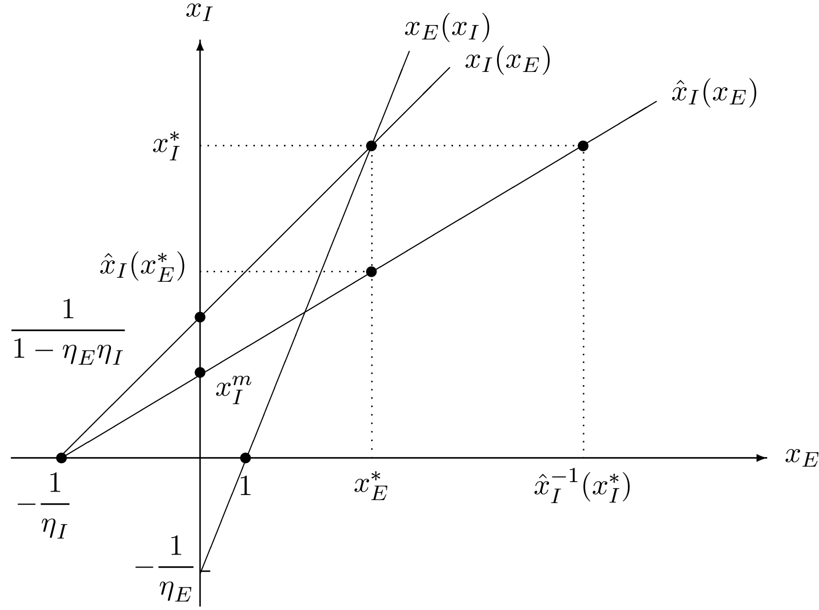

Figure 5: Research efforts in the software industry ($\eta_E > 0, \eta_I > 0$)

This parameter configuration can be observed in the software industry where developers of operating systems (OS) benefit from the expenditures of applications' publishers ($\eta_I > 0$) and, symmetrically, the applications' publishers benefit from the financial effort of the OS developers ($\eta_E > 0$). Consequently if one just wants to increase the OS research expenditure, it is better not to impose any minimum constraint on the effort of the applications' publishers if it is 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 increase 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 leave this type of industry without any restriction to the entrant's decisions[13] and to limit the control to antitrust rules in order to prevent the use of cross licences as market power devices.

5.3 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 ($\eta_I > 0$).

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

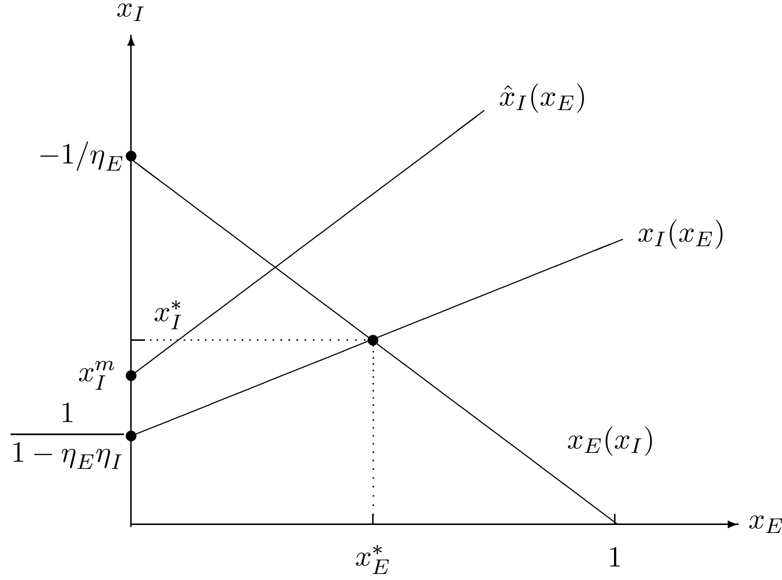

Figure 6: Research efforts in the hardware industry $(\eta_E < 0, \eta_I > 0)$

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 her to increase her research effort. A minimal requirement $x_E \geq \underline{x}$ above x_E^* is a good incentive to develop the innovator's effort since $\widehat{x}_I(\underline{x}) > x_I^m$ for all $\underline{x} > x_E^*$.

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 to increase the investment of the innovator 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 users basis. They face a trade-off to let 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 advantage in letting "clones" be in the market. For instance Sun Microsystem, has encouraged clones of its computer workstation to build its technology's user base (Conner, 1995). Those consumers who favour 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 to the imitator.

5.4 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.

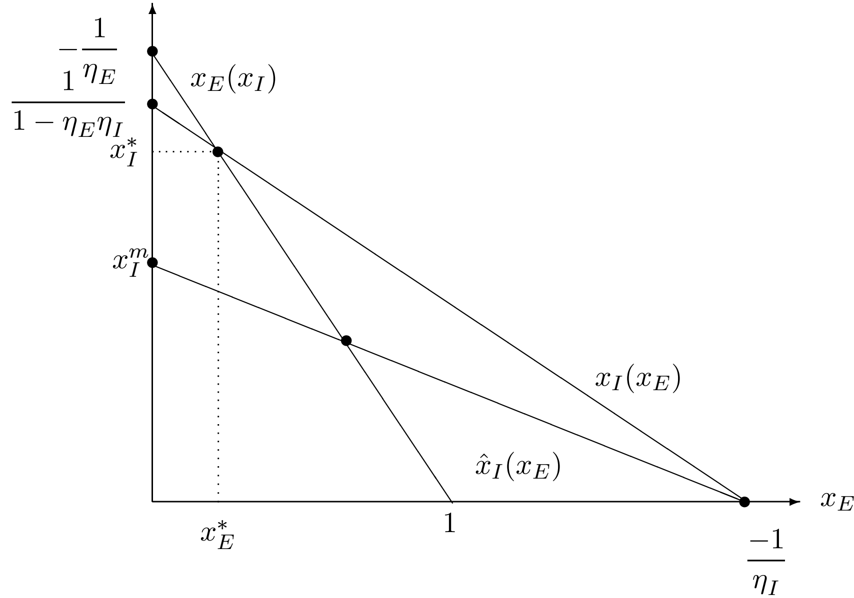

Figure 7: Research efforts in the video-game industry ($\eta_E < 0, \eta_I < 0$)

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

The introduction of a minimum requirement on x_E has the effect to create 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 fix a minimal threshold for the investment by imitators is always detrimental for the efforts of the innovator.

When η_E is very small ($\eta_E < -1/2$), the innovator is inclined to overinvesting ($x_I^* > x_I^m$) because he knows that this is armful to imitators who will invest less. Consequently, if the government fixes $\underline{x} > x_E^*$, this dissuasive policy does not work any longer. 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 $\underline{x}$ the lower the incentive to spend money on the initial innovation: $\underline{x}$ is like 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 just restricted, the innovator does not

invest more. Here again competition induces firms to invest more compared to what a monopoly would do.

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 presence of competitors. The competition between Nintendo and Sega is relevant for 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 between Microsoft and Nokia in the mobile phones market is another illustration of this case of technological competition.[15]

6 Conclusion

In the innovation game, each player in his 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 candidates to innovation and innovators are simultaneously facing actual and would-be providers of complement and substitute products, not just one like in our model.

Several extensions and development of the model can be considered. Let us mention three of them: i) to explicit 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), knowledge spills over after the end of 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.

[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.

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 the voice applications. Nowadays, when we want to obtain traffic information or to 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. This is the objective of the Voice XML, pushed by the main firms of the telecom industry within World Wide Web Consortium (W3C), an Internet standards body.[16] All the industry members expect lower costs (saving on live operators) and higher demand (due to easier and more rapid information).

ii) Like in many other sequential decision processes, the participants to the innovation game suffer sort of intertemporal schizophrenia. When they are candidates to entry they would like to face doors wide open. 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 incumbent.[17]

iii) In the ICT industries, there are strong incentives to integrate horizontally and vertically and to take the control of allies and start-ups. These are driven by the sake of internalization. For example, in November 2002, Comcast (a cable operator) merged with AT&T Broadband to create a giant of the US media and communication industry (22m

[16] See the Economist, December 14, 2002, p. 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 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." From the Wall Street Journal Europe, December 20-22, 2002.

subscribers). The objective of the merger was to stop customers leaving: during the nine first months of 2002, some 0.6m left (most of them from AT&T Broadband) to satellite TV which is cheaper. Joining the efforts of the two companies would eventually allow to diversify into activities more profitable than cable TV broadcasting and to propose services that satellite rivals cannot match, namely broadband internet access, interactive television and national cable-telephone.[18]

[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 (the Comcast's president) says." From the Financial Times, December 20, 2002.

References

[1] Amir R. (2000), "Modelling Imperfectly Appropriable R&D via Spillover," *International Journal of Industrial Organization*, 18, 1013-32.

[2] Amir R., I. Evstigneev and J. Wooders (2001), "Non Cooperative Versus Cooperative R&D with Endogenous Spillover Rates," CORE Discussion Papers 2001/50, Louvain-la-Neuve, Belgium.

[3] d'Aspremont C. and A. Jacquemin (1988), "Cooperative and Non Cooperative R&D in Duopoly with Spillover," *American Economic Review*, 78, 1133-1137.

[4] Boldrin M. and D. Levine (2002), "Why Napster is right."

[5] Boldrin M. and D. Levine (2004), "The economics of ideas and intellectual property."

[6] Bulow J., J. Geanakoplos and P. Klemperer (1985), "Multimarket oligopoly: Strategic Substitutes and Complements," *Journal of Political Economy*, 93, 488-511.

[7] Conner K. (1995), "Obtaining Strategic Advantage from Being Imitated: When Can Encouraging 'Clones" pay?," *Management Science*, 41, 2, 209-225.

[8] De Bondt R. (1996), "Spillover and Innovative Activities," *International Journal of Industrial Organization*, 15, 1-28.

[9] De Bondt R. and I. Enriques (1995), "Strategic investment with asymmetric spillovers," *Canadian Journal of Economics*, 3, 656–674.

[10] Gallini N. (1992) "Patent Policy and Costly Imitation," *Rand Journal of Economics*, 23, 52-63.

[11] Gallini N. (2002) "The Economics of Patents: Lessons from Recent U.S. Patent Reform," *Journal of Economic Perspectives*, 16, pp 131-154.

[12] Gilbert R. and M. Katz (2001), "An Economist's Guide to US v. Microsoft," *Competition Policy Center*, CPC01-09, University of California, Berkeley.

[13] Kamien M.I, E. Muller and I. Zang (1992), "Research Joint Ventures and R&D Cartels," *American Economic Review*, 82, 1293-1306.

[14] Leibovitz S. and S. Margolis (2001), "Winners, Losers & Microsoft: Competition and Antitrust in High Technology," Independent Institute.

[15] Motta M. (1992), "Cooperative R&D and Vertical Product Differentiation," *International Journal of Industrial Organization*, December, vol 10 n°4, p. 643-662.

[16] O'Donoghue T., S. Scotchmer and J.J. Thisse (1998), "Patent Breadth, Patent Life, and the Pace of Technological Progress," *Journal of Economics and Management Strategy* 7:1-32.

[17] Reinganum J. (1989) "The Timing of Innovation," Handbook of Industrial organization, R. Schmalensee and R. Willig, volume 1, 850-908.

[18] Scotchmer S. (1991), "Standing on the Shoulders Of Giants: Cumulative Research and the Patent Law," *Journal of Economic Perspectives,* 5, 29-41.

[19] Scotchmer S. and J. Green (1990), "Novelty and Disclosure in Patent Law," *Rand Journal of Economics*, 21, 131-146.

[20] Shapiro C. and H. Varian (1999), *Information Rules, a Strategic Guide to the Network Economy*, Harvard Business School press.

[21] Tirole J. (1988), "The Theory of Industrial Organization," MIT Press, MA.