Patent Law and Complementary Innovations*

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The patent system was initially designed to provide incentives to develop stand-alone innovations in fields such as mechanics, chemicals or pharmaceuticals. Its application is therefore problematical in more recent fields such as biotechnology and ICT industries, where innovation patterns are different. A well-known problem concerns cumulative innovations. Patent law must then trade off the rights granted to upstream patent owners with the incentives to develop subsequent innovations (Scotchmer, 1991; O'Donoghue, Scotchmer and Thisse, 1998; Denicolò, 2000). Another issue concerns complementary innovations, which are the focus of the paper.

When final products embody several complementary innovations, the scattering of patents between various owners jeopardizes the commercial exploitation of the products because of negotiation and royalty stacking issues (Merges & Nelson, 1990; Heller & Eisenberg, 1998; Shapiro, 2001). In biotechnology, this is the case of therapeutic proteins or genetic diagnostic tests that require the use of multiple patented gene fragments (Heller & Eisenberg, 1998). It is also very frequent in ICT industries such as electronics, computer hardware and software, where firms have to navigate "patent thickets" (Shapiro, 2001). Shapiro (2001) reports, for example, that in the semi-conductor industry firms receive "thousands of patents each year and manufacturers can potentially infringe on hundreds of patents with a single product". The situation is similar in the U.S. software industry, where there are "potentially dozens or hundreds of patents covering individual components of a product" (FTC, 2003).

I study the problem of the production of complementary innovations in a model of dynamic R&D competition between two firms, and argue that in some cases complementary innovations should not be patentable as such, but bundled with other innovations prior to patenting. To do so I consider two complementary innovations and examine whether they should be patented separately or as a bundle. This approach echoes several papers on cumulative innovations where patentability requirements are defined as the need to develop two or more successive innovations before obtaining a patent (Scotchmer and Green, 1990; Hunt, 1995; O'Donoghue, Scotchmer and Thisse, 1998; Denicolò, 2000).

As regards complementary innovations, the optimal patenting rule depends on a trade-off between the profit loss due to scattered complementary patents, and the possible benefit of patent disclosure. The scattering of complementary patents between different owners creates a double marginalization issue. Since each patentee behaves as a monopolist, the Cournot (1838) theorem predicts that prices do not maximize the firms' profits (Shapiro, 2001; Lerner & Tirole, 2005)[1]. The requirement that complementary innovations be bundled prior to patenting can be a way to prevent this profit loss. However, small innovations are not disclosed when innovations have to be bundled prior to patenting (Scotchmer and Green, 1990). As a result, firms lose the possibility to quit the race after a first innovation has been patented, which leads to R&D cost duplications.

I show that patent disclosure has a positive social effect, although it does not permit a fully efficient coordination between firms. In this context, bundling innovations prior to patenting can be more efficient if innovations can be developed quickly. As I argue in the Conclusion, this condition is consistent with the legal definition of the "inventive step" patentability requirement.

The paper is structured in six sections. First, the model is introduced in Section 2. Section 3 then considers the case in which innovations can be patented separately, while Section 4 focuses on the case in which they must be bundled prior to patenting. Section 5 compares the social outcomes of the two requirements. Finally, Section 6 concludes and discusses the policy implications of the model.

[1] To overcome this problem, patent holders can cooperate to lower their royalties by designing an appropriate cross-licensing agreement. Still, such agreements are not however systematic and their negotiation and monitoring also generate substantial transaction costs.

1 The model

I consider a technology which consists of two complementary innovations. These two innovations are assumed to be pure complements. Both are essential to exploit the technology, and they have no use when isolated from each other. A monopolist exploiting the technology makes a profit π.

The R&D setting is derived from Scotchmer and Green (1990). The timing of each innovation follows the same Poisson discovery process with a hit rate λ per unit of time and per innovation. Thus the expected research time for an innovation is $\frac{1}{\lambda}$. I normalize the R&D cost per unit of time and per innovation to one monetary unit. As a result, the cost of developing an innovation is determined only by the Poisson hit rate of the R&D process, independently of any considerations regarding the price of research inputs. Contrary to the model of Scotchmer and Green (1990), the two innovations that constitute the technology are not cumulative: their development processes are independent and simultaneous.

Two identical firms compete in R&D for developing the technology. The discount rate is denoted by r. I make the general assumption that:

$$\frac{\pi}{2}\lambda - 1 > 0 \tag{1}$$

This assumption guarantees that the technology is worth developing. More precisely, it implies that it would be profitable for a single firm to invest in the development of one of the two innovations if that ensured it a profit equal to one half of the technology's value. The firm would invest 1 at each time period dt, and would expect a profit $\frac{\pi}{2}$ with a probability λ. Its expected profit would thus be equal to $\left(\lambda\frac{\pi}{2} - 1\right) / (r + \lambda)$.

I use the model to compare two different patent policy settings. In a first setting, each innovation is patentable. It is thus possible, although not necessary, that each firm patents a different innovation. The disclosure of a first patent informs the other firm that it can stop trying to develop this innovation, and that it will have to share the rent if it patents the second innovation[2]. In a second setting, only the bundled technology is patentable. Therefore a firm must develop both innovations by its own means in order to obtain a patent. In both cases I assume that patents confer perfect protection against imitation.

When firms are unable to include both innovations in a single patent, they grant separate licenses on their respective patents, which creates a double marginalization problem (Shapiro, 2001). This issue can be captured in a simple way in the context of a competitive industry that produces at zero cost and uses two complementary innovations $i = 1, 2$, each licensed at royalty R_i $(i = 1, 2)$ per unit of output. If the patents are held by different firms, the competitive price is equal to $p = R_1 + R_2$, whereas the price is R when a single firm licenses the innovations as a bundle. Assuming a standard demand function for the product, Shapiro (2001) shows that in a Nash equilibrium, (profit maximizing) uncoordinated licensors set their royalties so that $R_1 + R_2 > R$. As a result, total profits π' are smaller than the profit π a single licensor would have made. This is the standard result of the Cournot (1838) theorem. If patents are held by different firms, each licensor sets its royalty without noticing the fact that high royalties decrease the other licensor's profit. Therefore royalties are beyond the level R that maximizes total profits. In this paper, I denote the profit loss due to double marginalization by $c = \pi - \pi'$, which corresponds to the difference between monopoly and total Cournot profits. Since this cost results from the dispersion of complementary patents between different owners, I refer to it as

[2]Note that the effect of disclosure is not the same with cumulative innovations as with complementary innovations. In the former case, the achievement of one innovation is necessary to enable the development of the other one. In the latter case, firms invest simultaneously in both innovations, and react to the disclosure of a patent by stopping their investment in the underlying innovation.

the scattering cost in the rest of the paper. I moreover assume from now on that it is exogenous.

For simplicity, I focus the analysis on the firms' private surplus, although the double marginalization issue also affects consumers through prices. In Section 4, I use the sum of the innovators' expected profits as a measure of social welfare, the most efficient organization of R&D thus being the one that maximizes total profits. Although biased, this approach to efficiency does not affect my key result. If consumer surplus were taken into account, social efficiency would still require that trivial innovations not be patentable[3].

2 Innovations can be patented separately

Consider first the patent race when innovations can be patented separately. The dynamic game is represented in Figure 1. As a first step, the firms decide simultaneously whether to enter the race or not. Since the two innovations are symmetrical and have identical and independent Poisson hit rates λ, a firm will either invest in R&D for both innovations, or not invest at all. If the firms decide to invest, they have equal chances to be the first one to achieve and patent an innovation.

At Node $n = 1, 2$, firm n has just developed, patented and disclosed a first innovation. In this case both firms must decide either to continue investing for the second innovation, or to give up. I denote by $v_i^n(x_1, x_2)$, firm i's expected payoff at those Node $n = 1, 2$, where $x_i \in \{0, 1\}$ indicates whether firm $i = 1, 2$

[3] Formally, introducing consumer surplus would not change the analysis of investment strategies in Sections 2 and 3. In Section 4, it would imply three modifications in the expression of social surplus. First, the profit π generated by the technology would be replaced with a parameter w equal to the sum of π and the consumer net surplus from the consumption of the good produced with the technology. Second, the private scattering cost c would be replaced with a public scattering cost parameter s equal to the sum of c and the loss of net consumer surplus due to double marginalization. Third the private discount rate r would be replaced with a social discount rate $\widetilde{r}$. Formally, all these changes are equivalent to a variation of the parameter in the total "private" expected surplus. Hence they would not change Propositions 3 and 4.

decides to give up ($x_i = 0$) or to continue investing in the second innovation ($x_i = 1$).

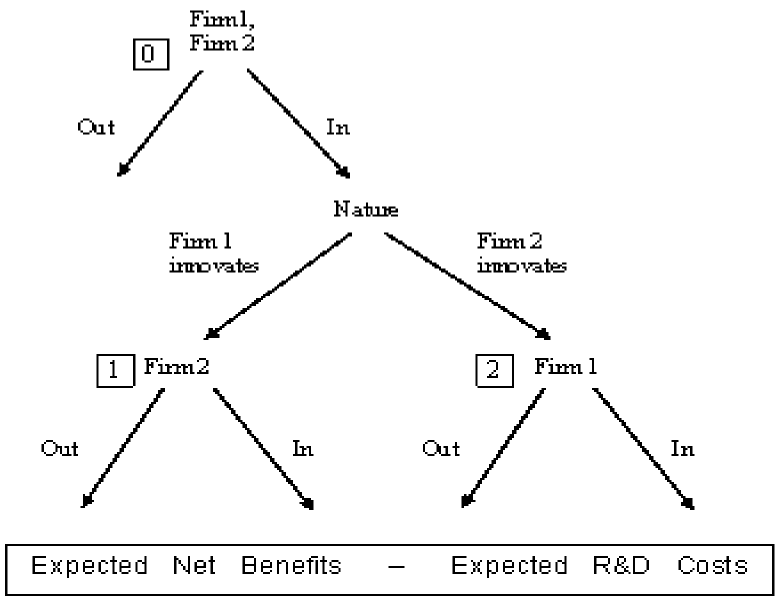

Figure 1: The patent race when innovations can be patented separately

The equilibrium concept is sub-game perfection. I proceed backwards to identify the equilibria in pure strategies. Consider first Node 1. Firm 1 has just patented an innovation, and both firms have to decide whether to continue or not. Table 1 shows the expected payoffs to 1 and 2 at this node.

$\left(v_1^1(x_1,x_2), v_2^1(x_1,x_2)\right)$	$x_2 = 0$	$x_2 = 1$
$x_1 = 0$	$(0,0)$	$\left(\frac{\lambda\left(\frac{\pi-c}{2}\right)}{r+\lambda}, \frac{\lambda\left(\frac{\pi-c}{2}\right)-1}{r+\lambda}\right)$
$x_1 = 1$	$\left(\frac{\lambda\pi-1}{r+\lambda}; 0\right)$	$\left(\frac{\lambda\left(\frac{3\pi-c}{2}\right)-1}{r+2\lambda}, \frac{\lambda\left(\frac{\pi-c}{2}\right)-1}{r+2\lambda}\right)$

Table 1. Firms' expected payoffs after 1 has patented a first innovation

If both firms decide to stay in the race, each firm incurs an R&D cost 1 at each time period dt until the second innovation has been achieved. There is a probability λ that firm 1 achieves the second innovation in time period dt. If this occurs, the payoff to firm 1 is π (since it has already patented the first innovation), while the payoff to firm 2 is 0. But there is also a probability λ that firm 2 innovates before firm 1. In this case, the firms have to share the profit and incur the scattering cost c, leading to symmetrical individual payoffs of $(\pi - c)/2$. Finally the expected payoffs to firms 1 and 2 in time period dt are $\lambda\pi + \lambda(\pi - c)/2 - 1$ and $\lambda(\pi - c)/2 - 1$ respectively. As the time of achievement of the second innovation has exponential distribution with parameter 2λ, the present expected payoffs to firms 1 and 2 are respectively $v_1^1(1,1) = (\lambda(3\pi - c)/2 - 1)/(r + 2\lambda)$ and $v_2^1(1,1) = (\lambda(\pi - c)/2 - 1)/(r + 2\lambda)$.

If firm 2 gives up, its continuation payoff is $v_2^1(x,0) = 0$, $x \in \{0,1\}$. Firm 1 still incurs an R&D cost of 1 at each time period dt. It achieves the second innovation with a probability λ, for a payoff π. Since firm 1 remains alone, the time of achievement of the second innovation has now an exponential distribution with parameter λ, leading to a continuation payoff of $v_1^1(1,0) = (\lambda\pi - 1)/(r + \lambda)$.

Lemma 1 *Assume that a firm has patented a first innovation.*

Then if $\frac{\pi - c}{2} \geq \frac{1}{\lambda}$ *both firms continue to invest in R&D to develop the second innovation.*

If $\frac{\pi - c}{2} < \frac{1}{\lambda}$ *the firm that patented the first innovation keeps investing in R&D to develop the second innovation, while the other firm stops investing in R&D.*

Proof. See Appendix 1. ■

Lemma 1 summarizes the outcomes of the subgame at Nodes 1 and 2 (see Figure 1). The firm that patents an innovation first will always keep investing in R&D in order to develop the second innovation. It is never profitable for it to stop investing and rely on the other firm to complete the technology, since it would then have to share profits which it could appropriate entirely by achieving the last innovation. Under these conditions the other firm will stay in the race only if $\frac{\pi - c}{2} \geq \frac{1}{\lambda}$, and will otherwise give up. This implies that a high scattering cost is not incurred. Since only one firm continues to invest in the development of the second innovation, the scattering cost is replaced with longer innovation delays.

Consider now Node 0 on Figure 1. At this node, no innovation has been developed yet and the firms have to decide whether to invest in R&D or not, in order to develop the technology. I assume that firms cannot avoid competition by agreeing ex ante to coordinate their R&D investments. I also assume that a firm cannot wait for its competitor to patent a first innovation before investing and trying to patent the second innovation[4]. I therefore look for the conditions under which it is profitable for both firms to invest simultaneously in both research lines, and show that this is the case when parameter λ is high enough.

To identify the conditions under which the firms can expect a positive profit from a patent race, I must calculate their payoffs in two different cases, depending on what would happen after a first innovation had been patented (Nodes 1 and 2). Let V_c denote the expected profit of a firm at Node 0 when both firms keep investing after a first innovation has been patented. Conversely, let V_a denote the expected profit at Node 0 when a firm gives up after a first innovation has been patented. To simplify the presentation, I calculate these payoffs for firm 1.

Let us first consider the case where both firms continue investing at Nodes 1 and 2. If the firms invest at Node 0, there is a probability 2λ that firm 1 achieves one of the innovations in time period dt (so that the firms arrive at

[4]This assumption simplifies the analysis. It is realistic since the other firm could counter this strategy effectively by relying on secrecy rather patenting to protect its first innovation.

Node 1). Then the expected payoff to firm 1 is $v_1^1(1,1)$, as given in Table 1. There is an equal probability 2λ that firm 2 achieves one of the innovations in time period dt (so that the firms arrive at Node 2). In this case, the payoff to firm 1 is $v_1^2(1,1)$. Since each firm invests in parallel in two research lines, the time of achievement of the first innovation has an exponential distribution with parameter 4λ. The present expected payoff to firm 1 if it enters is finally

$$V_c = \frac{2\lambda v_1^1(1,1) + 2\lambda v_1^2(1,1) - 2}{r + 4\lambda}. \tag{2}$$

Let us assume now that the firm that did not innovate gives up at Nodes 1 and 2. If the firms invest at Node 0, there is a probability 2λ that firm 1 achieves one of the innovations in time period dt (so that the firms arrive at Node 1). The expected payoff to firm 1 is then $v_1^1(1,0)$. There is an equal probability 2λ that firm 2 achieves one of the innovations in time period dt (so that the firms arrive at Node 2). In this case, the payoff to firm 1 is $v_1^2(0,1) = 0$. Since the time of achievement of the first innovation has an exponential distribution with parameter 4λ, the present expected payoff to firm 1 if it enters is finally

$$V_a = \frac{2\lambda v_1^1(1,0) - 2}{r + 4\lambda}. \tag{3}$$

Lemma 2 *There exist* $\overline{\pi}_c(\lambda) = \frac{c}{2} + \frac{2}{\lambda} + \frac{r}{2\lambda^2}$, $\overline{\pi}_a(\lambda) = \frac{2}{\lambda} + \frac{r}{\lambda^2}$ *and* $f(\lambda) = c + \frac{2}{\lambda}$ *such that:*

- *if* $\lambda > Max\{\overline{\pi}_c(\lambda), f(\lambda)\}$, *both firms continue after the first patent.*
- *if* $\overline{\pi}_a(\lambda) < \lambda < f(\lambda)$, *one firm gives up after the first patent.*
- *if* $\lambda < Min\{\overline{\pi}_c(\lambda), \overline{\pi}_a(\lambda)\}$, *the firms do not start the R&D race.*

Proof. See Appendix 2. ■

Lemma 2 is illustrated in Figure 2 for a particular value of r, without loss of generality. Given the discount rate and scattering cost parameters r and c, the firms start an R&D race if the expected profit π is large enough and if the expected time of development $1/\lambda$ is short enough. After the first innovation has been patented and disclosed, both firms continue if the expected market profit π is large enough. The possible scattering cost c then has a negligible impact on the incentive power of π. By contrast, the scattering cost c really matters when the market profit π is low. In that case the firm that has not innovated yet prefers to quit the race rather than competing in R&D for $(\pi - c)/2$. The innovator then develops the second innovation alone. It avoids the scattering cost but must expect a longer delay until the complete technology is developed. It is worth to noting here that the fact of one firm giving up after the first patent has been disclosed, extends the range of parameters for which the firms will invest in R&D, for $\overline{\pi}_a < \overline{\pi}_c$ when $\lambda > \sqrt{r/c}$. In that respect, patent disclosure increases the social surplus.

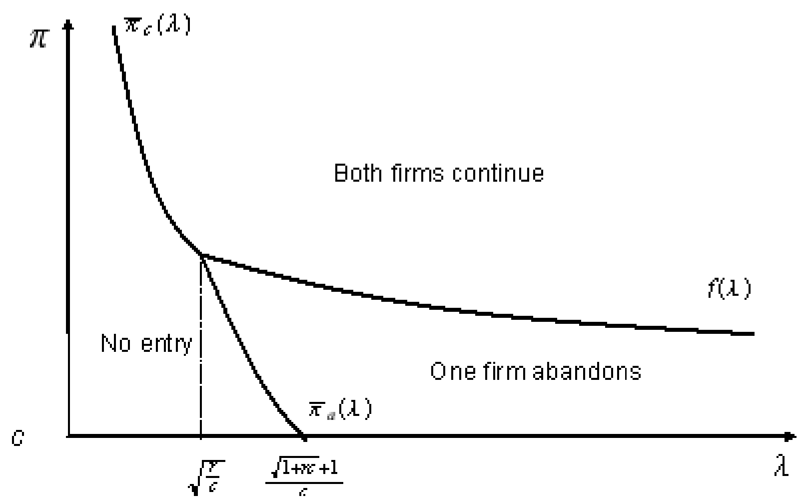

Figure 2: Equilibria when the innovations can be patented separately

Proposition 3 deals with the social impact of patent disclosure, measured as the difference between the firms' aggregate profits when a firm gives up and when both firms continue after the first patent.

Proposition 3 *Equilibria in which a firm gives up always maximize the firms' expected surplus. Equilibria in which both firms continue maximize the firms' expected surplus iff* $\pi \geq g(\lambda)$*, where* $g(\lambda) = c + \frac{c\lambda}{r} + \frac{1}{\lambda}$*. If* $\pi < g(\lambda)$*, the firms' expected surplus would be greater if one firm gave up.*

Figure 3 indicates the difference between the equilibrium surplus (in bold) and the other scenario for each equilibrium. It shows firstly that the equilibrium in which a firm gives up after the first patent is always welfare improving. This confirms and generalizes Lemma 2's finding that the possibility to give up after the first patent disclosure extends the range of parameters (to $\overline{\pi}_a < \pi < \overline{\pi}_c$) for which firms will invest. In other cases (e.g. $\overline{\pi}_c < \pi < f(\lambda)$), the firms would start the R&D race anyway, but would maximize the total expected payoffs if a single firm developed the second innovation alone. This is because, given the low value of π, avoiding the scattering cost is more important than delaying the second innovation.

The social efficiency of equilibria in which both firms continue after the first patent is more ambiguous. The firms' decision to continue is efficient when profits are large ($\pi > g(\lambda)$). The scattering cost is then negligible and it is more efficient if the technology is completed quickly. If the market profit is not large enough and/or the innovation takes time to develop ($f(\lambda) < \pi < g(\lambda)$), it would be more efficient for a firm to give up after the first patent. However the firm that did not innovate prefers to continue, which reduces the payoff that firms can expect at the beginning of the race. This is equivalent to a patent race pattern where firms invest in excess to appropriate an innovation rent.

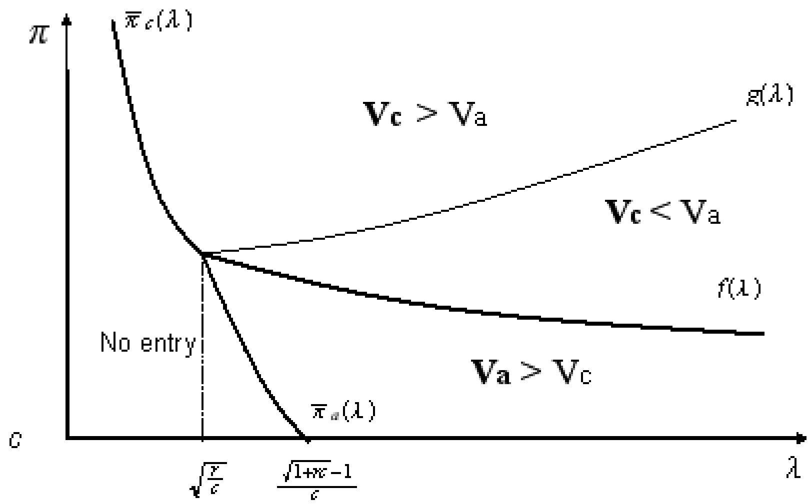

Figure 3: Disclosure and social surplus

3 Innovations must be bundled prior to patenting

Consider now the patent race when innovations must be bundled prior to patenting. In this case, a firm that has achieved one innovation does not disclose it because it is not protected against imitation. As a result, a firm has to achieve the technology entirely on its own in order to obtain a patent. There is no scattering cost and the payoff to the patentee is always π.

In these conditions the patent race is a 'two hits' one, as represented in Figure 4. The firms initially invest in each innovation simultaneously (Node 0). Thus a firm incurs the R&D cost of two research lines until it has achieved the first innovation (Nodes 1 and 21 for firm 1, and Nodes 2 and 12 for firm 2), or alternatively until the other firm has patented the whole technology. In the first case, the firm continues to incur the R&D cost of one research line until it or the other firm has patented the technology. In the second case, the R&D race ends with the patent.

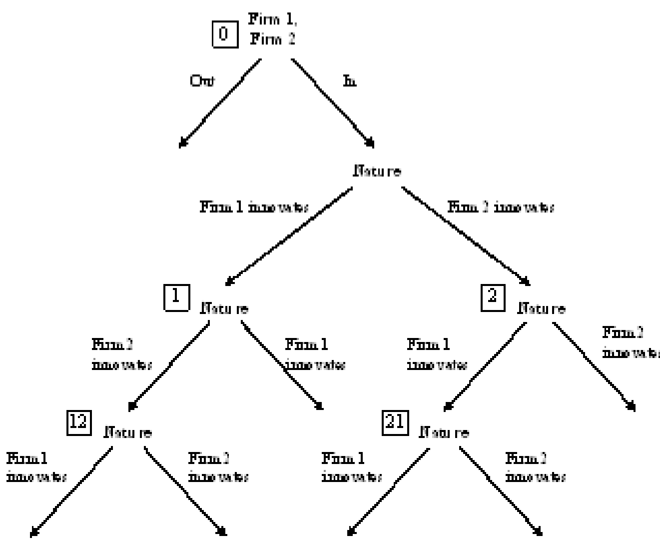

Figure 4: The patent race when the innovations must be bundled prior to patenting

Let us calculate the firms' payoffs when innovations are bundled prior to patenting. Let u_i^n denote the expected payoff of firm $i = 1, 2$ at Node $n \in \{1, 2, 12, 21\}$. At Node 12, the expected payoffs of the firms are equal: $u_1^{12} = u_2^{12} = u^{12}$. Each firm has already achieved one innovation and the first firm that will achieve the second innovation will win the race. (A similar argument can be made for Node 21.) Each firm incurs an R&D cost 1 at each time period dt until the complete technology has been achieved. There is a probability λ that firm 1 achieves a second innovation in time period dt. In this case firm1's payoff is π and firm 2's payoff is 0. Symmetrically, there is a probability λ that firm 2 achieves a second innovation. Its payoff is π and that of firm 1 is 0. Since the time of achievement of the most recent innovation has exponential distribution with parameter 2λ, the present continuation payoff to each firm is $u^{12} = (\lambda\pi - 1) / (r + 2\lambda)$.

I can now compute the continuation payoffs to firms 1 and 2 at Node 1. At this Node, only firm 1 has already achieved an innovation. I will thus denote by u_1^1 the expected payoffs to firm 1, and by u_2^1 the expected payoff to the firm that has not innovated yet, namely firm 2. Firm 1 incurs an R&D cost 1 at each time period dt in order to achieve the second innovation, while firm 2 incurs the R&D cost of two parallel research lines. The probability that firm 1 achieves its second innovation in time period dt is λ. If it succeeds the race ends, implying that its payoff is π and firm 2's payoff is 0. On the other hand the probability that firm 2 achieves an innovation in time period dt is 2λ. The firms will then be at Node 12 and their payoffs will be u^{12}. The time of achievement of the next innovation has exponential distribution with parameter 3λ. The firms' expected payoffs after one firm has achieved a first innovation can thus be expressed as follows:

$$u_1^1 = \frac{\lambda\pi + 2\lambda u^{12} - 1}{r + 3\lambda}$$

$$u_2^1 = \frac{2\lambda u^{12} - 2}{r + 3\lambda}$$

The last step consists in calculating the payoffs to the firms at Node 0, if they enter the race. At this stage no innovation has been achieved yet, so that both firms invest in both research lines. Therefore each firm incurs a cost 2 in time period dt. One firm, say firm 1, may achieve an innovation with a probability 2λ at each time period dt. In this case its payoff is u_1^1. There is also a probability 2λ that firm 2 achieves an innovation in time period dt. The payoff to firm 1 is then $u_1^2 = u_2^1$. As there is a probability 4λ that either firm 1 or firm 2 achieves an innovation in time period dt, the expected entry payoff to each firm is $U = \frac{2\lambda u_1^1 + 2\lambda u_2^1 - 2}{r+4\lambda}$. After some calculations this writes:

$$U = 2\frac{6\pi\lambda^3 - r^2 - 16\lambda^2 - 8r\lambda + \pi r\lambda^2}{(r+2\lambda)(r+3\lambda)(r+4\lambda)} \tag{4}$$

Firms enter the patent race only if $U \geq 0$, which can be expressed as a condition on π:

$$U \geq 0 \quad \Leftrightarrow \quad \pi \geq \frac{(r+4\lambda)^2}{\lambda^2 (r+6\lambda)} \equiv \overline{\pi}_b(\lambda) \tag{5}$$

4 Optimal patentability requirement

The last step consists in comparing the social effects of the patent races under the two policy settings. I consider as optimal the policy that yields the greatest expected production surplus. The welfare comparison thus takes into account the expected total costs of the R&D, the delay of achievement of the whole technology, and the possible scattering cost. I show that for sufficiently large values of the Poisson hit rate λ, a strong patentability requirement is optimal. Propositions 1 and 2 state that this result holds when the innovations can be calculated separately, irrespective of the firms' continuation strategies.

Proposition 4 (i) *The requirement that innovations be bundled prior to patenting prevents the development of innovations with a low value (e.g. such that* $Min\{\overline{\pi}_a(\pi);\overline{\pi}_c(\pi)\} \leq \pi < \overline{\pi}_b(\pi)$*) that would be developed if they were patentable separately.*

(ii) *Suppose* $\frac{\pi-c}{2} > \frac{1}{\lambda}$ *so that all firms continue their R&D after a first patent. In that case,* $\overline{\lambda}_c > 0$ *always exists so that patenting separate innovations is optimal if* $\lambda < \overline{\lambda}_c$ *and patenting bundled innovations is optimal otherwise.*

(iii) Suppose now that $\frac{\pi - c}{2} < \frac{1}{\lambda}$ *so that one firm abandons R&D after a first patent. If* $r \geq \frac{2}{c}$*, then* $\overline{\lambda}_a > 0$ *exists so that patenting separate innovations is optimal if* $\lambda < \overline{\lambda}_a$ *and patenting bundled innovations is optimal if* $\lambda > \overline{\lambda}_a$ *. If* $r < \frac{2}{c}$*, patenting separate innovations is optimal.*

Proof. See Appendix 3. ■

Proposition 4 firstly states that requiring that innovations be bundled prior to patenting may prevent the achievement of some innovations that would be developed if they were patentable separately. This result concerns innovations which take a long time to develop. It is due to the inefficient R&D cost duplications that could be prevented by means of patent disclosure. Conversely, the other parts of the Proposition show that bundling innovations prior to patenting may be more efficient when innovations can be developed rapidly.

Consider firstly the case in which the second firm stays in the race after a first innovation has been patented. Proposition 4 establishes the existence of a threshold value of the R&D Poisson hit rate λ above which only the complete technology should be patentable. Since a low λ means that the expected time to achieve the innovation is long, it follows that each innovation should be patentable separately if it takes a long time to achieve. In contrast innovations that can be developed quickly should be combined with complementary innovations prior to patenting.

Bundling innovations prior to patenting can be welfare-improving because it makes it possible to avoid the scattering cost. This benefit must however be balanced with additional R&D costs. If there is no disclosure, the firm that did not innovate continues to invest in both innovations, which is socially wasteful. When developing an innovation takes a long time (low λ), it is worth taking the risk of incurring a scattering cost if it can save R&D costs. Innovations should thus be patentable separately. When innovations can be developed rapidly (high

λ), R&D cost duplications are negligible and there is no need to incur the scattering cost. Innovations should thus be bundled prior to patenting.

Consider now the case in which the value of the technology is low while the scattering cost is high, so that a second firm gives up after the first patent. In that case the scattering cost is never incurred and the efficient policy depends on a trade-off between R&D duplications and short delay on the one hand, and R&D limitation (since a firm gives up) and longer delay, on the other. Since the flow of R&D is normalized to 1, the outcome of this trade-off depends on the discount rate r. Proposition 4 states that if $r > 2/c$ there is a threshold value of the R&D Poisson hit rate λ above which only the complete technology should be patentable. In that case the opportunity cost of postponing the development of the complete technology is high. It is thus worthwhile allowing R&D duplications in order to accelerate this development when the cost of these duplications is acceptable, that is, when the R&D process is rapid (high λ). If $r < 2/c$, delays matter less and separate patenting should prevail to avoid cost duplications.

5 Conclusion and policy implications

This paper compares two R&D race settings in which two firms invest to develop two complementary innovations. In the first setting, each innovation is patentable separately, while in the second setting they must be bundled prior to patenting. Both policies have some advantages. When innovations are patentable separately, the disclosure of interim patents extends the range of profitable innovations and improves the efficiency of R&D investments. A firm abandons the race after the first patent if the expected market profit is low, which limits R&D cost duplications and avoids the cost generated by scattered patents. When innovations must be bundled prior to patenting, the scattering cost is always avoided but the absence of patent disclosure generates useless R&D duplications. Compared with separate patents, this policy generally improves the efficiency of R&D when the expected development delay is short, although it may also slow down the development of the lowest value innovations.

From a policy perspective, discrimination between trivial innovations and innovations that take a long time to develop is possible, by enforcing a severe "inventive step" requirement. In Europe, an innovation can be patented only if (*i*) it is new, (*ii*) it has an industrial application and (*iii*) it constitutes an inventive step, meaning that it must solve an objective technical problem. In U.S. patent law, an innovation must be new, useful and non-obvious to be patentable. The latter requirement means that the innovation should not be viewed as obvious by someone skilled in the technology of the particular field, and is practically equivalent to the European "inventive step" test.

The idea that a lenient enforcement of these requirements can lead to the inefficient patenting of elementary pieces of technology has been expressed by several authors in the legal literature. Barton (2003) takes the surprising example of coffee cup holders to argue that a weak application of the non-obviousness standard in the U.S. has led to the granting of too many complementary patents on one object. In a paper on the intellectual property protection of software, Lemley (1995) develops a comparable argument in the case of software where he states that patents could protect "either the idea of a program or [each] of its subroutines".

The present paper upholds policy arguments that emphasize the importance of a severe application of this patentability requirement as a means to limit the size of "patent thickets" and to promote innovation in sectors where complementary innovations are frequent (Jaffe, 2000; Barton, 2003; FTC, 2003). It applies in particular to the current European debate on the patentability of computer driven inventions. Software innovations have generally been patentable in the U.S. since 1995, and obtaining software patents has been an easy task since then (Lemley, 2001; Barton, 2003; FTC, 2003). In contrast, the European Patent Office has been more severe in applying patentability requirements (Graham et alii, 2002)[5]. A European Directive aimed at updating and clarifying the rules for software patentability should therefore ensure that the current severity of the EPO regarding patent applications is maintained.

The analysis carried out in this paper has several limitations that could be addressed by extending the model. Such limits primarily concern the strategies that innovators can develop to reduce the costs resulting from patent scattering. In some cases, firms can circumvent disclosed patents to avoid buying a license. Ex ante agreements such as cross-licensing and patent pools are another possible strategy to mitigate scattering costs, and warrant further analysis. Finally, it may be especially interesting to study grant back clauses designed ex ante to prevent scattering costs after complementary innovations have been developed and patented.

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6 Appendix

6.1 Appendix 1: Proof of Lemma 1

Let firm 1 be the firm that patented the first innovation. The Proof is derived directly from Table 1.

(i) I show first that *continuing* is always a dominant strategy for firm 1.

If firm 2 continues, then firm 1 will continue if $\frac{\lambda\left(\frac{3\pi-c}{2}\right)-1}{r+2\lambda} > \frac{\lambda\left(\frac{\pi-c}{2}\right)}{r+\lambda}$ or $r(\pi\lambda-1)+\lambda\left(\frac{\pi}{2}\lambda-1\right)+\frac{c}{2}\lambda^2 > 0$, which is always true when inequality (1) holds.

If firm 2 gives up, then firm 1 will continue if $\frac{\lambda\pi-1}{r+\lambda} > 0$. This is always true under inequality (1).

(ii) I show afterwards that the best response of firm 2 to firm 1's *continuation* strategy depends on the sign of $\frac{\pi-c}{2}-\frac{1}{\lambda}$.

If firm 1 continues, then firm 2 will also continue if $\frac{\lambda\left(\frac{\pi-c}{2}\right)-1}{r+2\lambda} > 0$, which is true if $\frac{\pi-c}{2} \geq \frac{1}{\lambda}$.Hence if inequality (1) holds, firm 2 will give up.

6.2 Appendix 2: Proof of Lemma 2

- Putting the expressions of $v_1^1(1,1)$ and $v_1^2(1,1)$ into equation (2) gives $V_c = 2\dfrac{2\lambda^2\left(\pi - \frac{c}{2}\right) - r - 4\lambda}{(r+2\lambda)(r+4\lambda)}$, and $V_c > 0$ if $\pi > \frac{c}{2} + \frac{2}{\lambda} + \frac{r}{2\lambda^2} \equiv \overline{\pi}_c$.

- From equation (3) and the expression of $v_1^1(1,0)$ in Table 1; I have $V_a = \dfrac{2\left(\pi\lambda^2 - 2\lambda - r\right)}{(r+\lambda)(r+4\lambda)} = 2(r+\lambda)^{-1}(r+4\lambda)^{-1}\left(\pi\lambda^2 - 2\lambda - r\right)$, and $V_a > 0$ if $\pi > \frac{2}{\lambda} + \frac{r}{\lambda^2} \equiv \overline{\pi}_a$.

- I now study $\overline{\pi}_c - \overline{\pi}_a$

  $\overline{\pi}_c - \overline{\pi}_a = \frac{c}{2} + \frac{2}{\lambda} + \frac{r}{2\lambda^2} - \frac{2}{\lambda} - \frac{r}{\lambda^2} = \frac{c}{2} - \dfrac{r}{2\lambda^2}$

  This is positive iff $\lambda > \sqrt{\frac{r}{c}} \equiv \lambda_{ca}$

- We moreover know that a firm gives up after the first innovation is patented iff $\pi < c + \frac{2}{\lambda} \equiv f(\lambda)$.

  I now study the sign of $\overline{\pi}_a - f(\lambda)$.

  I have $\overline{\pi}_a - f(\lambda) = \frac{r}{\lambda^2} - \frac{c}{2}$.

  This expression is positive iff $\lambda < \lambda_{ca}$. Hence $\overline{\pi}_a > f(\lambda)$ if $\lambda < \lambda_{ca}$.

  I study finally the sign of $\overline{\pi}_c - f(\lambda)$.

  I have $\overline{\pi}_c - f(\lambda) = \frac{r}{2\lambda^2} - \frac{c}{2}$.

  This expression is positive iff $\lambda < \lambda_{ca}$. Hence $\overline{\pi}_c > f(\lambda)$ if $\lambda < \lambda_{ca}$.

6.3 Appendix 3: Proof of Proposition 3

It is more efficient that both firms continue after the first patent iff $V_c - V_a > 0$.

$V_c - V_a = 2\dfrac{\left(\pi r\lambda - r - cr\lambda - c\lambda^2\right)\lambda}{(r+\lambda)(r+2\lambda)(r+4\lambda)}$ is positive if $(\pi - c)r\lambda - r - c\lambda^2 > 0$ or, which is equivalent, if $\pi > c + \frac{c\lambda}{r} + \frac{1}{\lambda} \equiv g(\lambda)$.

The function $g(\lambda)$ is firstly decreasing on $]0, \lambda_{ca}]$ and then increasing on $[\lambda_{ca}, \infty)$

6.4 Appendix 4: Proof of Proposition 4

We prove successively points (ii), (iii) and (i).

(ii) When $\frac{\pi-c}{2} > \frac{1}{\lambda}$, bundling innovations prior to patenting is optimal iff $U > V_c$. I have $U - V_c = (-2)(r+3\lambda)^{-1}(r+2\lambda)^{-1}(r+4\lambda)^{-1}\left(r+4\lambda+\pi r\lambda - cr\lambda - 3c\lambda^2\right)$ λ.

This expression is positive iff $r+4\lambda+\pi r\lambda - cr\lambda - 3c\lambda^2 < 0$ or, put differently, iff $\pi < c + \frac{3c\lambda}{r} - \frac{4}{r} - \frac{1}{\lambda} \equiv \widetilde{\pi}_1(\lambda)$, where $\widetilde{\pi}_1(\lambda)$ is a continuous and increasing function of λ from $]0,+\infty)$ *to* $(-\infty,+\infty)$.

One can check that $\widetilde{\pi}_1(\lambda_{ac}) - f(\lambda_{ac}) = \frac{3c}{r}\sqrt{\frac{r}{c}} - \frac{4}{r} - \dfrac{3}{\sqrt{\frac{r}{c}}} = -\frac{4}{r} < 0$. Hence $\widetilde{\pi}_1(\lambda_{ac}) < f(\lambda_{ac})$. Since on $[\lambda_{ac},\infty)$, $\widetilde{\pi}_1(\lambda)$ is increasing towards $+\infty$ while $f(\lambda)$ is decreasing towards c, it follows that there always exists a threshold value $\widetilde{\lambda}_2 > \lambda_{ac}$ such that $\widetilde{\pi}_1(\lambda) < f(\lambda)$ if $\lambda_{ac} < \lambda < \widetilde{\lambda}_1$ and $\widetilde{\pi}_1(\lambda) > f(\lambda)$ if $\widetilde{\lambda}_1 < \lambda$.

When $\frac{\pi-c}{2} > \frac{1}{\lambda}$, we can thus define $\overline{\lambda} \equiv \widetilde{\pi}_1(\lambda)$ so that for each set (π, r) bundling innovations prior to patenting is optimal if $\lambda > \overline{\lambda}$.

(iii) When ,$\frac{\pi-c}{2} < \frac{1}{\lambda}$ bundling innovations prior to patenting is optimal iff $U > V_a$.

I have $U - V_a = 4(r+\lambda)^{-1}(r+2\lambda)^{-1}(r+3\lambda)^{-1}(r+4\lambda)^{-1}\left(\pi r\lambda^2 - r^2 - 2\lambda^2 - 4r\lambda\right)\lambda$. This expression is positive iff $\pi r\lambda^2 - r^2 - 2\lambda^2 - 4r\lambda > 0$ or, put differently, iff $\pi > \dfrac{r^2+2\lambda^2+4r\lambda}{r\lambda^2} = \dfrac{r}{\lambda^2} + \dfrac{4}{\lambda} + \dfrac{2}{r} \equiv \widetilde{\pi}_2(\lambda)$.

$\widetilde{\pi}_2(\lambda)$ is a continuous and decreasing function of λ from $]0,+\infty)$ to $\left]\dfrac{2}{r},+\infty\right)$. Moreover one can check that $\widetilde{\pi}_2(\lambda) - f(\lambda) = \frac{2}{\lambda} + \frac{r}{\lambda^2} + \frac{2}{r} - c$ and $\widetilde{\pi}_2(\lambda_{ac}) > f(\lambda_{ac})$. Since on $[\lambda_{ac},\infty)$, $\widetilde{\pi}_2(\lambda)$ is decreasing towards $\dfrac{2}{r}$ while $f(\lambda)$ is decreasing towards c, it follows that there exists a threshold value $\widetilde{\lambda}_2 > \lambda_{ac}$ such that $\widetilde{\pi}_1(\lambda) < f(\lambda)$ iff $\frac{c}{2} > \frac{1}{r}$.

In that case, there exists a threshold $\overline{\lambda} \equiv \widetilde{\pi}_2(\lambda)$ above which bundling innovations prior to patenting is optimal for all $\frac{\pi}{2} \geq \frac{1}{r}$, which is always the case since $\frac{\pi}{2} > \frac{c}{2}$ and $\frac{c}{2} > \frac{1}{r}$. Otherwise, independent patenting always prevails.

(i) We need to prove that $\overline{\pi}_b(\lambda) > \overline{\pi}_c(\lambda)$ when $\frac{\pi-c}{2} > \frac{1}{\lambda}$, while $\overline{\pi}_b(\lambda) > \overline{\pi}_a(\lambda)$ when $\frac{\pi-c}{2} \leq \frac{1}{\lambda}$, or put differently that

$$\overline{\pi}_b(\lambda) > Min\left\{\overline{\pi}_a(\lambda), \overline{\pi}_c(\lambda)\right\} \tag{6}$$

Proving that $\overline{\pi}_b(\lambda) > \overline{\pi}_a(\lambda)$ when $\frac{\pi-c}{2} \leq \frac{1}{\lambda}$ is straightforward. Indeed we have $\overline{\pi}_b(\lambda) - \overline{\pi}_a(\lambda) = \frac{4}{6\lambda+r} > 0$.

The proof that $\overline{\pi}_b(\lambda) > \overline{\pi}_c(\lambda)$ when $\frac{\pi-c}{2} > \frac{1}{\lambda}$ can be derived from the Proof of point (ii). We know that $U < V_c$ when $\pi > \widetilde{\pi}_1(\lambda)$, where $\widetilde{\pi}_1(\lambda)$ is a continuous and increasing function of λ from $]0, +\infty)$ *to* $(-\infty, +\infty)$. We also know that $\widetilde{\pi}_1(\lambda_{ac}) < f(\lambda_{ac}) = \overline{\pi}_c(\lambda_{ac})$. Since $\overline{\pi}_c(\lambda)$ is decreasing while $\widetilde{\pi}_1(\lambda)$ is increasing it follows that $\overline{\pi}_c(\lambda) > \widetilde{\pi}_1(\lambda)$ when $\lambda < \lambda_{ac}$. Thus $\pi = \overline{\pi}_c(\lambda)$ implies that $V_c = 0$ while $U < 0$ when $\lambda < \lambda_{ac}$. It follows that $\overline{\pi}_b(\lambda) > \overline{\pi}_c(\lambda)$ when $\lambda < \lambda_{ac}$. Oberving that $\lambda < \lambda_{ac} \Leftrightarrow \frac{\pi-c}{2} > \frac{1}{\lambda}$ we have thus proved that $\overline{\pi}_b(\lambda) > \overline{\pi}_c(\lambda)$ when $\frac{\pi-c}{2} > \frac{1}{\lambda}$.