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Abstract

This paper studies the behaviour of firms facing the decision to create a patent fence, defined as a portfolio of substitute patents. We set up a patent race model, where firms can decide either to patent their inventions, or to rely on secrecy. It is shown that firms build patent fences, when the duopoly profits net of R&D costs are positive. We also demonstrate that in this context, a firm will rely on secrecy when the speed of discovery of the subsequent invention is high compared to the competitor's. Furthermore, we compare the model under the First-to-Invent and First-to-File legal rules. Finally, we analyze the welfare implications of patent fences.

Keywords: patent fences, intellectual property rights, secrecy, competition.

JEL: O31, O32, L10

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"You have to evaluate what you have done and say, 'OK, does this have commercial value?' If it has commercial value, you want to build a fence around it."
Neil Howell, molecular biologist, cited in *Science, Next Wave,* October 22nd 2003.

1   Introduction

A number of explanations have been proposed to explain the rapid growth in patenting since the mid 1980s. This worldwide growth has been described, e.g., in Hall (2005) and OECD (2004). Kortum and Lerner (1997) associate this growth with an increased R&D productivity and changes in the management of innovation, while Gallini (2002) suggests that the growth in patenting in the US can be explained by legal changes, what she calls a "pro-patent" shift, that extended patent rights to new subject matters (e.g. business methods and software patents). Regarding Europe, one could think that the creation of the European Patent Office (EPO) in 1978 can partly explain the growth in patenting, since it has considerably reduced the application costs.

Another reason could be that firms patent in a more "strategic" way, in the sense that the patent application is not only driven by the desire to protect innovation rents (see for instance, Rivette and Kline, 2000). Cohen et al. (2000) in a survey at the firm level, found that the most prominent motives for patenting include the prevention of rivals from patenting related invention ("patent blocking"), the use of patents in negotiations and the prevention of suits. However, firms patent for different reasons in "discrete" product industries, in which an invention can be protected by a limited number of patents and in "complex" product industries, where a single patent is not enough to protect an invention. More precisely, firms will patent a coherent group of inventions, which form what is sometimes called a patent "bulk", aimed at protecting one product. The "bulk" can either be a "fence" of substitute patents or a "thicket" of complementary patents (see Reitzig, 2004 and Cohen et al., 2000).

In complex product industries, where innovation is highly cumulative, firms use patents to force rivals into negotiations and, as a consequence, they

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create "thickets" of complementary technologies. This is a similar argument as in Hall and Ziedonis (2001). As a consequence, firms have to face legal challenges in order to acquire rights to outside technologies.

In discrete product industries, firms use patents to block the development of substitutes by rivals. We say that firms create "fences". Firms wishing to protect some patented core invention, may patent substitutes to keep rivals from doing this. Substitute inventions are defined as inventions which resemble one another functionally (following the definition given by Cohen et al, 2000)[1]. As an example of a patent fence, Hounshell and Smith (1988) refer to the case of Nylon. In the 1940's, Du Pont patented over 200 substitutes for Nylon. The patents consisted of a range of molecular variations of polymers with similar properties to Nylon.

While the issue of "thickets" of complementary technologies in cumulative innovations has been extensively analyzed[2], as well as the institutional solutions to overcome this problem (Lerner and Tirole, 2005 and Shapiro, 2001), little attention has been paid to fencing patents so far.

Our contribution in this paper will be to study the incentives of firms to build patent "fences" by allowing different levels of competition and analyze some preliminary welfare implications.

The starting point of our model is that two firms have private informations about two potential substitute innovations. Given their expected profits, both firms choose whether to invest or not to find the first product. We will consider two scenarios. The first model is a simple patent race in which the leader (i.e. the firm that found the invention) patents the product. Then, we are going to extend the model by allowing the leader to choose between patenting the invention or keeping it secret.

After the leader has patented the invention or kept it secret, a second race

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[1]A more precise definition of patent fences can be found in Granstrand (1999):

"*This refers to a situation where a series of patents, ordered in some way, block certain lines or directions of R&D, for example, a range of variants of a chemical sub-process, molecular design, geometric shape, temperature conditions or pressure conditions. Fencing is typically used for a range of possibly quite different technical solutions for achieving a similar functional result.*"

[2]See Scotchmer (2005) for an overview on cumulative innovations.

takes place where both firms choose whether or not to invest in developing a substitute to the first invention. We will assume that the expected time of discovery of the second invention will differ, depending on whether the leader has kept the first innovation secret or not. If the leader has patented the first product, both firms will race at the same speed, as all the information is disclosed in the patent document. However, if the first invention has been kept secret, there is no disclosure to the follower, so that the leader will race faster than the follower.

In addition, the first inventor can collect an interim profit by commercializing the product, only if it has been patented. This comes from an assumption that there is an instantaneous disclosure, if the product based on the invention is commercialized.

In the context of our model, a fence can be defined as a portfolio composed by both patents. As we defined it above, both products are close (non-improving) substitutes. Thus, the fact that a firm produces one or both inventions does not change the profit, if this firm is a monopolist. However, if the firms have to share the market, i.e., if each of them owns a patent, the profits will depend on the degree of competition.

Applying the First-to-File and First-to-Invent legal rules, we find that firms potentially create fences of substitute inventions, when the duopoly profits net of R&D costs are positive. When we allow for secrecy, we show that firms will rely on secrecy, when the speed of discovery of the subsequent invention is high, relative to the competitor's. The intuition behind this result is the following: if competition is strong, the expected duopoly profits are negative, thus the follower will not invest, as this choice is not profitable. Moreover, if the degree of competition is low, it might be profitable for the rival firm to enter the market and for the leader to accommodate as well as collect an interim profit. On the other hand, the leading firm will keep the invention secret when the technological gap between both inventions is high in order to race faster than the follower for the remaining invention.

Moreover, we demonstrate that a patent fence is socially sub-optimal when it is created with certainty.

The issue of substitute inventions is commented upon in Denicolò (2000), whose model describes two-stage patent races with a substitute innovation at each step of the model. In this model, "business stealing" occurs when a firm enters the market and "steals" market shares from the incumbent. It is shown that this indeed reduces investment in the first race and increases it in the second one. This model allows for free entry in both races, which makes the likelihood that the leader (i.e. the firm, which patented the first invention) wins the second innovation tend to zero. Thus, firms can never build fences.

Jensen and Thursby (1996) study an international patent race, where two firms race to develop products that are close substitutes. They focus on the case in which the national authorities set up a "standard" on the market, which requires new products to be compatible with the previous ones, in order to privilege the products developed domestically. As well as in Denicolò (2000), this model does not allow for fence creation, since the domestic invention will be protected by the "product standard".

Trade secrecy has been applied to various situations, for instance, in order to prevent imitation (Gallini, 1992 or Anton and Yao, 2004), to get a head start in cumulative innovations (Scotchmer and Green, 1990)[3] or to mislead rivals (Langinier, 2005). Even though a firm can use a previous invention to find a substitute product in our model, the concept of "patent fence" differs slightly from the notion of "imitation". In our model the leading firm can also decide to invest in a substitute, which is not the case in the imitation models, see for instance Gallini (1992), where only the imitator invests in the second stage. A patent fence can be viewed as an innovator who decides to imitate its own products, in order to avoid a rival firm doing it.

The following paper is organized as follows: section 2 introduces the assumptions of the model. In section 3, we study a simple patent race. The model is then extended to allow for secrecy in First-to-File and First-to-Invent in section 4. In section 5, we discuss the welfare effects of patent

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[3]In their model, the firms actually have the possibility to "suppress" an innovation, but this has the same consequences as keeping it secret.

fences. Section 6 concludes the paper.

2 Basic assumptions

Let us assume that two firms, say A and B, are competing to patent two substitute innovations (in demand), say 1 and 2 in a multiple stages patent race. Allow both products to be non-infringing, otherwise the question of interest disappears. This assumption implies that the patent breadth has to be relatively narrow[4]. We assume our products to be substitutes in demand, but not cumulative innovations (in other words, the products are not improving on each other).

Let us suppose that there is a given number of consumers, willing to pay for the product and indifferent between the different versions. If a firm has a monopoly position on the market, then its profit is normalized to 1. Given that both products are substitutes, the previous assumption means that it does not make a difference in terms of profits, whether a firm owns one or both patents, as long as the rival firm does not have any of them. If the firms have one patent each, they have to share the market. Their duopoly profits are indexed by $\alpha \in [0, 0.5]$ where $\alpha = 0$ corresponds to a Bertrand competition with homogeneous goods and $\alpha = 0.5$ mirrors weak competition, e.g., collusion between the firms. Thus, α can be seen as a measure of agressivity of competition.

Let us also assume, in order to simplify, an infinite patent life, which does not qualitatively change the results.

Following that, we are going to study two models. The first one is a simple patent race in which the inventors do not have the option to keep their inventions secret (section 3). Then, we are going to extend the model to the case, in which the first inventor can keep its invention secret (section 4).

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[4]The patent "breadth" specifies how different another product must be in order not to infringe. See Scotchmer (2005). This assumption corresponds to the "weak novelty requirement" in Scotchmer and Green (1990).

3   A simple patent race model

In the first place, we consider a model in which the first innovator patents the product. The timing of the game is given in figure 1.

Figure 1: *Timing of the simple patent race*
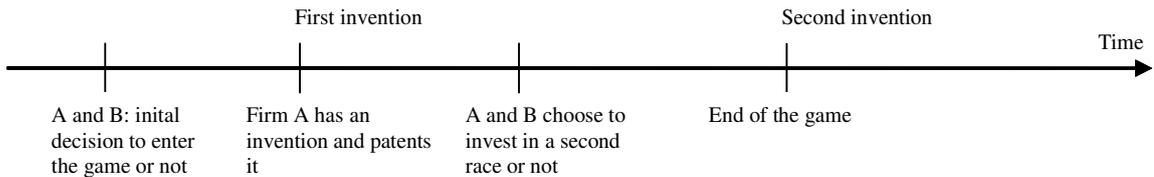
3.1   Stage one

In a first stage, the firms have to decide whether they are going to enter the race by investing in R&D (I) or not (N), based on their expected and discounted payoffs. The arrival process of innovations is modeled as in, Scotchmer and Green (1990) and Denicolò (1996, 2000): assuming an exponential distribution, the probability that a firm is successful at a date τ prior to t is $\Pr[\tau \leq t] = 1 - e^{-\mu t}$, where μ is the instantaneous probability of success for each firm (the Poisson "hit rate" or hazard function). Furthermore, we assume the values of μ to be identical and independent for both firms, as they have the same information at this stage. The aggregate instantaneous probability of success is then the sum of the individual probabilities. It follows that the expected innovation time for each firm is $E(\tau) = 1/\mu$. If the firms choose to invest, they will then pay a R&D cost of c per unit of time during the discovery process, until the first invention is discovered. In this line of thought, we assume that they have limited resources, so that they can only invest in one innovation at a time.

One firm is going to get the first invention, and be what we call "the leader". In order to simplify, we will denote firm A as the leader.

3.2 Stage two

In the second stage, firms have to make another investment decision for the remaining invention. The situations differ in the models we study. We make the assumption that having the first invention is an advantage for the continuation of the game. Thus, we will assume that the leader races faster than before. This is formalized by introducing a larger hazard rate, $\lambda \geqslant \mu$ for the leader. This assumption can be justified by the fact that having an invention can be an advantage for the second race, in the sense that the technologies used for both inventions may be close and that know-how in this specific field is acquired.

Once the first invention is discovered by the leader, it is immediately patented. As the information on the invention is disclosed through the patent document, the follower can use it. As a consequence, both firms race at the same speed (λ) if they decide to invest. However, the leader collects an interim profit by commercializing the product.

3.3 Equilibria

The game is solved by backward induction, thus we will begin with the last stage of the game.

Let us begin at the point where the first innovator, firm A, has patented the invention. Both firms have to choose whether they are going to invest (choice I) or not (choice N) in the second invention.

If both firms invest, each of them will achieve the second innovation with the same probability in the period dt. The expected date of discovery is the same for both firms and has an exponential distribution with parameter 2λ as each firm has an instantaneous probability λ of innovating. In addition, each firm will pay a R&D cost c per unit of time which ends when one of the firms invents.

In dt, with a probability of λ, firm A is the first to discover the invention and gets a flow of profit of $1/r$ forever, where $r > 0$ is the interest rate. We will assume that the expected monopoly profit is positive: $\lambda \frac{1}{r} \geqslant c$, otherwise

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the firms would not enter initially. In the same time interval, with a probability λ, B gets the invention and A will have to share the profit and get α/r. In addition, A will also get the interim profit of the first invention until the second invention is patented. The probability of two discoveries in any interval of size dt is negligible when dt tends to 0.

Thus, A's continuation value is:

$$\int_0^{+\infty} e^{-(2\lambda+r)t} \left[\lambda\left(\frac{1}{r} + \frac{\alpha}{r}\right) + 1 - c\right] dt$$
$$= \frac{\lambda\left(\frac{1}{r} + \frac{\alpha}{r}\right) + 1 - c}{2\lambda + r} \tag{1}$$

The reasoning is similar for B in dt. If A is the first to discover the invention, with a probability of λ, B will get a flow of profit of 0, as it does not own any patent. If B is the first to invent, the value of the final invention will be the duopoly profit, α/r. B does not get any interim profit, but has of course to pay the R&D cost. B's continuation payoff is:

$$\frac{\lambda\left(\frac{\alpha}{r}\right) - c}{2\lambda + r} \tag{2}$$

The other payoffs are derived in the same fashion. Table 1 represents the expected continuation payoff matrix for the sub-game, after the leader has patented. It is assumed that the firms can deviate at any point in time, from investment to non-investment and vice versa, between the patenting decision and the date of discovery of the second invention. However, it can be demonstrated that it is optimal for the firms to take one-time decisions whether to invest or not. In addition, we will only focus on equilibria in pure strategies.

Table 1: Continuation payoffs after A has patented the first invention

		B	
		I	N
A	I	$\frac{\lambda\left(\frac{1}{r}+\frac{\alpha}{r}\right)+1-c}{2\lambda+r}, \frac{\lambda\left(\frac{\alpha}{r}\right)-c}{2\lambda+r}$	$\frac{\lambda\frac{1}{r}+1-c}{\lambda+r}, 0$
	N	$\frac{\lambda\frac{\alpha}{r}+1}{\lambda+r}, \frac{\lambda\frac{\alpha}{r}-c}{\lambda+r}$	$\frac{1}{r}+1, 0$

It is obvious that the results would be symmetric in the case Firm B had been the first patentee.

Remark 1 *In the sub game following A's decision to patent, firm A only invests in the second invention when firm B also does.*

Proof. $\frac{1}{r}+1 > \frac{\lambda\left(\frac{1}{r}\right)+1-c}{\lambda+r}, \forall \lambda \in [0,1], c > 0$ and $r > 0$ ∎

The interpretation is that if B does not invest in the second race, A is better off by not investing, as the expected gain is the same but there is no R&D cost to incur.

Table 2 gives the conditions under which the different choices are Nash equilibria in the sub game. Regarding the notation in the column labelled "decisions", the first letter refers to A's decision in the second race, and the second one refers to B's choice. The notation will always follow this logic hereafter.

Table 2: Conditions for having a Nash equilibrium in the sub game where A patents

Decisions	Conditions
II	$\alpha < 1 - \frac{cr(\lambda+r)}{\lambda^2}$ and $\lambda\frac{\alpha}{r} > c$
NI	$\alpha > 1 - \frac{cr(\lambda+r)}{\lambda^2}$ and $\lambda\frac{\alpha}{r} > c$
NN	$\lambda\frac{\alpha}{r} < c$

Consider now the entry in the game where both firms have to decide whether or not to invest in the initial product. At this stage, each firm has a probability one half of being in position A or B if both firms enter. Scotchmer and Green (1990) showed that there is no possibility of having asymmetric

equilibria of the ex ante entry game (i.e., it is not possible that only one firm enters the race) in their model. This is also the case in this model; both firms make the same decision.

In order to simplify, we will assume that the Poisson hit rates are identical at each stage, $\mu = \lambda$, as this does not affect the results for the moment. The ex ante profits depend on the choices made at the second stage. For each choice at the second stage, firms get the payoff to A (in table 1) with a probability λ, and they get the payoff to B with probability λ. By that means, we can determine a lower bound on α for both firms to enter the race (table 3).

Table 3: Lower bound on α for positive ex ante profits.

Decisions at the second stage	Conditions
II	$\frac{rc(2\lambda+1)-\lambda r-\lambda^2}{2\lambda^2}$
NI	$\frac{r[c(1+\lambda)-\lambda]}{2\lambda^2}$
NN	Entry always optimal

Our analysis will be based on the cases, in which both firms initially enter the race. Thus, we will assume that the ex ante profits are positive (i.e. the conditions in table 3 hold):

A1: $\alpha \geqslant \frac{rc(2\lambda+1)-\lambda r-\lambda^2}{2\lambda^2}$

A2: $\alpha \geqslant \frac{r[c(1+\lambda)-\lambda]}{2\lambda^2}$

The equilibria are summarized in figure 2 for a given r. The solid curve indicate the equilibria of the second race, while the dashed curves indicate the direction to which these curves move when the cost (c) increases. Finally, the shaded areas show where ex-antes profits would be negative if both firms entered (table 3). The regions are labelled according to the optimal choices that apply. "Entry" means that both firms initially enter the race, and the following letters indicate the optimal choice of, respectively, the leader (the winner of the first race) and the follower.

From tables 1 and 2, we derive the following result.

Figure 2: *Equilibria of the patent race*
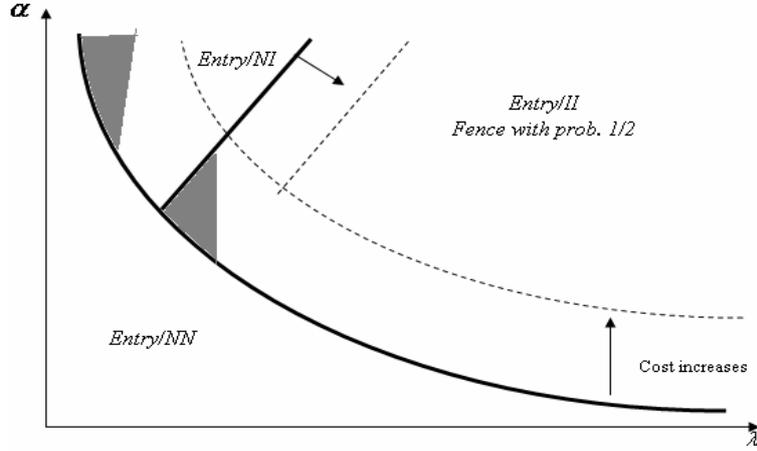
Corollary 2 *If the expected duopoly profits are negative, i.e. $\lambda\frac{\alpha}{r} < c$, none of the firms is going to invest in the second product. If the duopoly profits are positive, there exist a threshold of α function of λ, $\overline{\alpha} = 1 - \frac{cr(\lambda+r)}{\lambda^2}$, so that for $\alpha < \overline{\alpha}$ both firms invest in the second product, whereas for $\alpha > \overline{\alpha}$, only the follower will invest.*

The intuition behind this result is the following: if the expected duopoly profits are negative, the follower is not going to invest. As a consequence, the leader will not invest either, to avoid a duplication of R&D costs which would not increase its profit.

If the duopoly profits are positive, the follower will invest, but the choice of the leader will depend on the degree of competition as well as the expected time of discovery. The leader will only invest if the speed of discovery is high.

Our motivation was to study the process of creating a patent fence surrounding some core invention[5]. We now turn to this question by first defining what can be called a "fence" in this model.

Definition 3 *A fence is created when one of the firms owns patents for both inventions.*

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[5]The "core invention" denotes here the invention that will actually be marketed.

In other words, a fence can potentially be created when the winner of the first race also invests in the second race.

Proposition 4 *A potential fence is created in the region Entry/II, in which the duopoly profits are positive and the speed of discovery is high.*

Proof. This result follows from corollary 2 and definition 3 ∎

Positive duopoly profits reflect the fact that the degree of competition is low. An increase of the cost of the innovation widens the *NN* region. At the limit, if the cost is such that the duopoly profit is negative for any values of α and λ, non-investment for both firms will be the only outcome.

4 A patent race with secrecy

We now extend the previous model by allowing the winner of the first race to choose between patenting the invention or keeping it secret. If the leader chooses to patent the invention, we will again assume that the invention is fully disclosed and that the follower can use it. The leader also collects an interim profit by marketing the product. Thus, the results will be identical to those in section 3 if the leader chooses to patent the invention.

On the other hand, if the leader chooses secrecy, there is no disclosure at all, which allows the leader to race faster than the laggard, but since the product is not marketed during this stage, the leader cannot collect any profits before the next invention is made[6].

Figure 3 shows the timing of the game, which is detailed in the following discussion.

We will study the model under two alternative legal systems, the First-to-File and First-to-Invent rules. In most countries, if two people independently make the same invention, the patent is awarded to the first one to file a patent application. The United States have a First-to-Invent system, in which the first inventor gets the patent if he can prove earlier inventorship, even if he filed an application later.

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[6]This is a standard assumption in the literature, as it is usually assumed that if the

Figure 3: *Timing of the game in which secrecy is allowed*
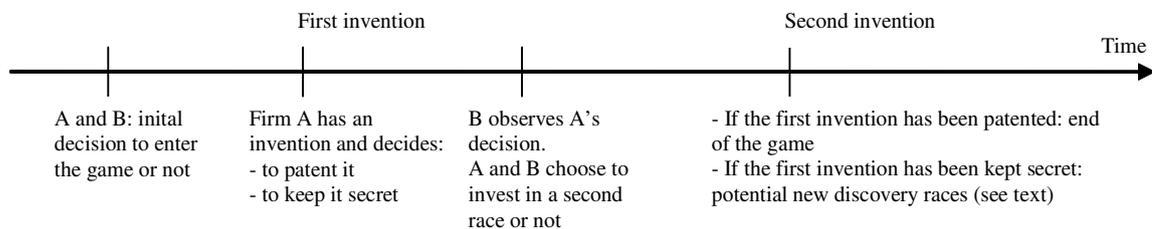
4.1 The model under secrecy in First-to-Invent

Consider the stage in which the first inventor kept the invention secret. A crucial point assumed in the model is that it is common knowledge that A has already innovated (Firm B knows that A has an invention, and which one it is). This assumption implies that there are spillovers between both firms, for example, through labor mobility, industrial espionage, informal communication networks among inventors, or common suppliers (see Mansfield, 1985), and is commonly used in the literature (Scotchmer and Green, 1990 or Denicolò, 2000). As a consequence, the follower can choose whether to invest in the invention already discovered and kept secret, or in the remaining invention.

If the leader chooses to rely on secrecy, both firms have to decide whether or not to invest in the second invention in this race. In this case, as the information on the first invention is not disclosed, the race between the firms is asymmetric. In other words, A will race at a speed λ, whereas B will race at the same speed as in the initial race, μ.

The extend to which λ and μ differ can be interpreted as the technical distance between the products. If λ and μ are close, it could reflect a situation in which two very different technical solutions are found to achieve the same functional result, with more or less the same speed of discovery.

On the other hand, if the gap between λ and μ is high, the time of discovery of the second product, conditional on having discovered the first

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product is commercialized but not patented, reverse engineering is easy, so that the leader would lose its leading advantage. See, e.g., Scotchmer and Green (1990).

one, is low. This implies that the discovery of the second product occurs much more rapidly and suggests that it results from a small variation of the technical characteristics of the first product.

If the leader (firm A) discovers the second invention first, the game ends at this point. There is, however, the risk for the leader that the follower might discover the second invention first.

If the follower (firm B) is the winner of the second race after A's secrecy choice, the end of the game will depend on whether or not the follower has chosen to race for the invention already discovered by the leader and kept secret. If the invention is not similar, both firms will patent their respective inventions: A will patent the invention previously kept secret, and B the second invention. But if the invention is the same in both races, the follower will patent it and a third race can take place for the remaining invention, where, again, both firms will have to decide whether they will invest in it or not.

In order to ease the exposition of the model at this point, we represent a part of the timing in figure 4. The payoffs indicated in the game tree represent the discounted future profits, valued at the final discovery date.

Lemma 5 *It is a dominant strategy for firm A to invest continuously following a secrecy choice.*

Proof. see appendix A ■

If Firm A chooses secrecy, it will always invest in the second race. This comes from the fact that we assume that an invention kept secret cannot be marketed.

4.2   The potential third race

In the case of secrecy, there may be a third stage of the game. This happens if B chooses to invest in the same invention that firm A has kept secret and discovers it before firm A has found the remaining invention. Firm B will patent it and a race for the remaining innovation can arise (node 2). Both firms will race at the same speed as they both have the same stock

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Figure 4: *Timing of the game after A's choice of secrecy*
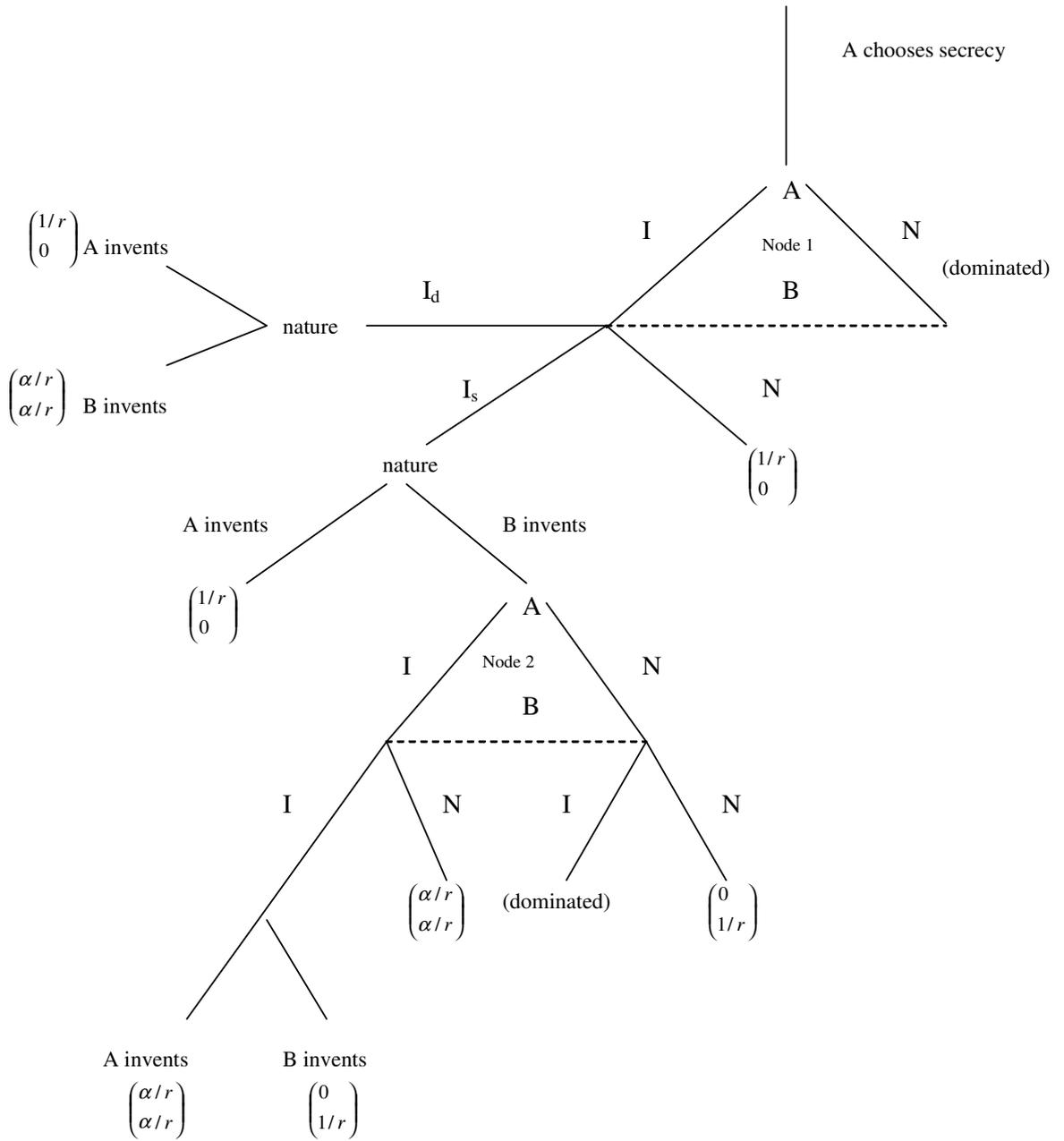
of knowledge. The continuation payoffs look exactly the same as in table 1, except that the payoffs are inverted as, at this stage, B is considered to be the leader (table 3).

Table 3: Continuation payoffs if B patents the invention that A has kept secret

		B	
		I	**N**
A	**I**	$\frac{\lambda\frac{\alpha}{r}-c}{2\lambda+r}, \frac{\lambda\left(\frac{1}{r}+\frac{\alpha}{r}\right)+1-c}{2\lambda+r}$	$\frac{\lambda\left(\frac{\alpha}{r}\right)-c}{\lambda+r}, \frac{\lambda\frac{\alpha}{r}+1}{\lambda+r}$
	N	$0, \frac{\lambda\frac{1}{r}+1-c}{\lambda+r}$	$0, \frac{1}{r}+1$

The interpretations of the results are identical to those in section 3 with the identities of the firms inverted.

4.3   The second race

If B decides to invest in the product already found and kept secret by A (I_s), there is a probability λ that A achieves the invention in the time period dt. In this case, the payoff to A will be $1/r$ and B will get 0.

There is also a probability μ that B achieves the invention, in which case the payoff to A and B will be $V_{A;3}^{S/ij}$ and $V_{B;3}^{S/ij}$, where $V_{A;3}^{S/ij}$ and $V_{B;3}^{S/ij}$ are given in table 3 and depend on the decisions taken at node 2, with $i,j = \{I, N\}$ and the superscript S denotes "secrecy".

If B chooses to invest in the product that has not been discovered by A (I_d), B finds it with probability μ. In this case, both firms have to share the market and each of them gets a profit α/r. With probability λ, firm A finds the invention and gets the monopoly profit $1/r$, whereas firm B gets 0.

The date of achieving this invention has an exponential distribution with parameter $(\lambda + \mu)$. The net present values of the payoffs are given in table 4.

Table 4: Payoffs depending on B's choice to invest or not in the second invention

	I_s	I_d	N
Payoff to A	$\frac{\lambda\frac{1}{r}+\mu V_{A;3}^{S/ij}-c}{\lambda+\mu+r}$	$\frac{\mu\frac{\alpha}{r}+\lambda\frac{1}{r}-c}{\lambda+\mu+r}$	$\frac{\lambda\frac{1}{r}-c}{\lambda+r}$
Payoff to B	$\frac{\mu V_{B;3}^{S/ij}-c}{\lambda+\mu+r}$	$\frac{\mu\frac{\alpha}{r}-c}{\lambda+\mu+r}$	0

Lemma 6 *We now briefly summarize what the optimal best responses of firm B will be in the second race after firm A has kept the first invention secret:*

* *Firm B will choose to invest in a different invention than the one already discovered by firm A (I_d) if the expected duopoly net of R&D costs are positive ($\mu\frac{\alpha}{r} > c$), and if the expected duopoly profits of the second race are greater than the expected payoffs in the potential third race ($\mu\frac{\alpha}{r} > \mu V_{B;3}^{S/ij}$).*

* *Firm B will choose to invest in the same invention than the one already discovered by firm A (I_s) if the expected payoffs net of R&D costs of the potential third race are positive ($\mu V_{B;3}^{S/ij} > c$), and if the expected payoffs in the potential third race are greater than the expected duopoly profits of the second race ($\mu V_{B;3}^{S/ij} > \mu\frac{\alpha}{r}$).*

* *Firm B will choose not to invest in any invention, if both the expected duopoly profits of the second race and the expected payoffs of the potential third race (net of R&D costs) are negative ($\mu\frac{\alpha}{r} < c$ and $\mu V_{B;3}^{S/ij} < c$).*

Proof. These results are obtained by a simple comparison of the payoffs in table 4. See Appendix B for more details. ■

4.4   The decision to patent versus secrecy

Given the optimal responses of firm B to secrecy (section 4.3) and patenting (section 3), what is the optimal choice of firm A?

At this stage of the game, the leader has to decide either to keep the first invention secret and race faster than the follower for the second invention,

or to patent and market the invention, which has the consequence that it discloses its private information.

The Nash equilibrium of this sub-game is derived by comparing the payoffs to A when it has patented the first invention and when it has relied on secrecy.

Lemma 7 *Firm A chooses between patenting and secrecy, only in the region in which:*

* *The expected duopoly profits net of R&D costs are positive ($\lambda \frac{\alpha}{r} > c$).*

* *The difference between λ and μ is "high" (the threshold between "low" and "high" being the condition $\overline{\alpha}$ reported in corollary 2).*

This region corresponds to the "Entry/II" region in figure 2.

In all the other regions, patenting is always preferred to secrecy.

Proof. See Appendix C. Table 6 in Appendix C summarizes the different conditions, under which A is going to patent its first invention based on the decisions made at later stages. ■

This result can be explained as follows. If the expected duopoly profits (net of R&D costs) are negative, a single product will be patented, as it has been demonstrated in section 3. If the expected duopoly profits are positive, but the difference between λ and μ is low, secrecy is not attractive, as the expected time of discovery is the same under both regimes, although firm A cannot collect the interim profit if it chooses secrecy.

4.5   The first race

At this stage (not represented in figure 4), we determine whether firms will initially enter the race, which they will do only if their *ex ante* profits are non-negative. Each of them has probability μ of finding the first invention, and thus to be in the position of A (denoted earlier as the leader). With probability μ, they are in position B (the follower). They both have to incur the R&D cost for the first invention. The payment of this cost ends when the first invention is discovered, which event has an exponential distribution

with parameter 2μ. Thus, the *ex ante* profits, identical for both firms in the first race, are given by:

$$\pi = \frac{\mu V_{A;2}^{y/ij} + \mu V_{B;2}^{y/ij} - c}{2\mu + r}$$

With $V_{k;2}^{y/ij}$ being the future expected payoffs of firm $k = \{A; B\}$, discounted to the beginning of the second race, depending on the choices $i, j = \{I, I_s, I_d, N\}$ and $y = \{P, S\}$. For simplicity we will assume that these initial payoffs are positive, so that the firms will always enter the race initially. Thus, we will suppose that α is such that $\pi \geq 0$. The conditions on α for both firms to enter the race initially are reported in appendix D.

4.6   Description and discussion of the equilibria

We now characterize the equilibria of the game in the space $(\lambda; \alpha)$. Given that $\lambda \geqslant \mu$, we represent λ on the interval $[\mu; 1]$. We consider two different cases, for different values of the initial hazard rate (μ), shown in figures 5 and 6. In order to simplify, we omit the "Entry" notation, so that the different areas in the graphs are labeled with reference to the optimal choices, after the first invention has been found, with the same notation as in the rest of the paper. The different regions are defined mathematically in appendix E.

First and foremost, note that in the "south-west" area (P/NN) in both figures, it is always optimal for the leader to patent the first invention, and then for both firms not to invest. The fact, that none of the firms invest after the first invention has been patented, is a consequence of competition being tough. For firm B the prospect of duopoly profits does not justify an investment in R&D, and then firm A has no reason to invest either.

Figure 5 shows the equilibria for $\mu = 0.1$. In the upper-left corner (P/NI), the first innovator patents the first invention, as the technological advance of keeping this invention secret is too low (i.e., the gap between λ and μ is small). In addition, the leader will not invest for a second invention, whereas the follower will stay in. The explanation for this, given that the degree of competition and the hazard rate are low, is that it is more profitable for

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the leader to share the profits in the future than to pay the cost of getting involved in a second race.

In the area $S/II_s/II,$ the leader relies on secrecy, as the difference between λ and μ is high. Then, both firms invest for the second and the possible third race, as competition is low and the instantaneous probability to be successful (λ identical for both firms in the third race) is high.

However, the follower will drop out of the second race as soon as competition becomes stronger (S/IN), and the leader continues to invest; the reason is that, if a single invention is patented, the follower would invest in the second one. Moreover, since an invention kept secret cannot be marketed, it is optimal for the leader to continue to invest in a second race, even if the follower drops out at this point.

Alternatively, when λ is intermediate, it is more profitable for the leader to patent the first invention in order to collect the interim profit *(P/II)*. Both firms will invest in a second race, and they have the same probability to succeed.

Notice that, if the follower chooses to invest,it will always target the same invention under secrecy. The choice to invest in the same invention, which has already been discovered by firm A or in the other one, will determine if a third race is going to take place in the case firm B wins the second race. A third race can only occur if firm B chooses I_s.

Proposition 8 *If $c \leqslant 0.5$, firm B will never choose to invest in a different invention than the one previously discovered by firm A.*

Proof. See Appendix F. ∎

The intuition for this result is the following. Whether firm B chooses I_s or I_d before the second race, the expected time of discovery, function of μ, is the same. But if it chooses I_d, firm B can get the duopoly profit if it wins the second race. Thus, if the cost is low (i.e. $c \leqslant 0.5$) firm B has nothing to loose by choosing I_s (or not invest at all, if the expected payoffs net of R&D costs are negative).

Figure 5: *Equilibria of the game:* $c = 0.2$, $\mu = 0.1$, $r = 0.3$
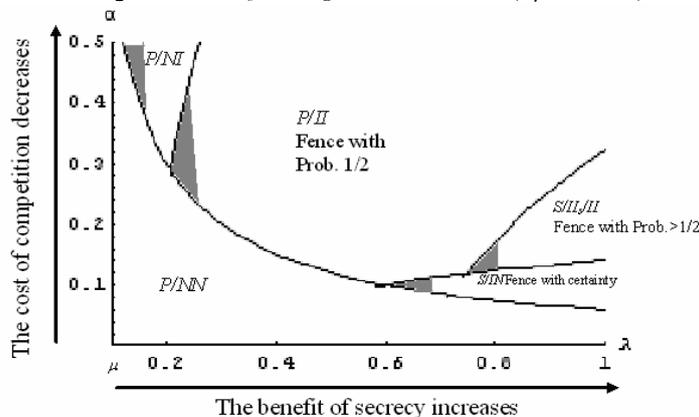
Figure 6: *Equilibria of the game:* $c = 0.2$, $\mu = 0.2$, $r = 0.3$
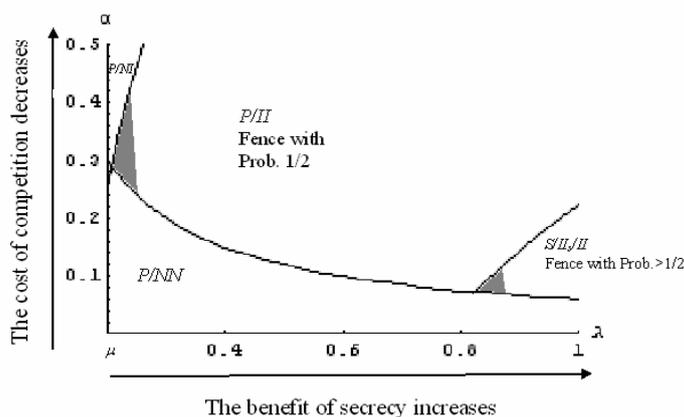
Consider now figure 6 with $\mu = 0.2$. The situation is somewhat different, as the benefit of having the first invention is lower for a given value of λ.

The leader will keep the invention secret for intermediate levels of competition in order to keep the leading advantage, since the follower is going to invest in any case. The leader will patent when the leading advantage is low or intermediate. If the leader patents, the behaviour of the follower does not depend on μ, but on λ, as all information is disclosed. Thus, not surprisingly, firms will invest when λ is high.

If we now compare both figures, two differences appear when we increase the initial hazard rate (μ) in figure 6. The S/IN region from figure 5 dis-

appears and, on the other hand, the "P/II" region increases in figure 6. In this region, it becomes more profitable for the leader to patent and collect the interim profit.

The explanation is that, if the technological gap $(\lambda - \mu)$ becomes smaller, the follower will invest more often and the leader will rely on secrecy less often.

Potential fences are raised as soon as one of the firms invests in both inventions. The areas, where potential fences appear, are reported in the graphs.

The above analysis and the conditions derived in tables 1 to 6 enable us to make the following proposition:

Proposition 9 *Potential fences of substitute inventions are created when the duopoly profits net of R&D costs are positive. When the winner of the first race wishes to build a fence, it keeps the first invention secret when the speed of discovery of the second invention (λ) is large relative to the competitor's (μ).*

Proof. See Appendix G ∎

The intuition behind this result is the following: when the leader patents the first invention, it is not worth investing in the second invention for the follower if the competition is strong, as the costs are larger than the expected duopoly profits.

On the other hand, if the degree of competition is low, it might be profitable for the rival firm to enter the market and for the leader to collect the interim profit.

An interpretation of this result could be the following. If the difference between λ and μ is a measure of the technological gap between the inventions, as it has been discussed in section 4.1 (the higher the difference between λ and μ, the smaller the technological gap), this would mean that, if a firm develops small variations of a product, the different versions would be kept secret and patented once the last product has been discovered, creating a fence with patents which have similar properties.

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Figure 7: *Equilibria in First-to-Invent:* $c = 0.2, \mu = 0.1, r = 0.3$
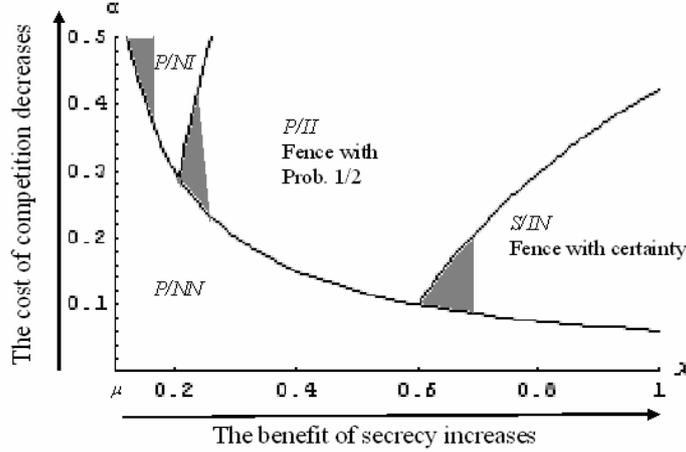
What would happen if the parameters had different values? If the cost c is high, then the *P/NN* region would increase, and none of the firms would ever invest in a second invention. On the other hand, if the cost is low, the firms would always invest in both products.

The effects of a variation of the parameter μ are summarized in the following proposition.

Proposition 10 *If the speed of discovery of the follower under secrecy (μ) increases, the leader will keep the first invention secret for less parameter values.*

Proof. See appendix H ∎

This result is rather intuitive: secrecy is only desirable if λ is high compared to μ. If the difference between the two hazard rates decreases, the leader will rely on secrecy in a lower number of cases.

4.7   Fences in First-to-Invent

Our analysis has so far been based on the first-to-file system. Let us now examine how the alternative legal rule applied in the United States affects the creation of patent fences.

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Figure 8: *Equilibria in First-to-Invent:* $c = 0.2, \mu = 0.2, r = 0.3$
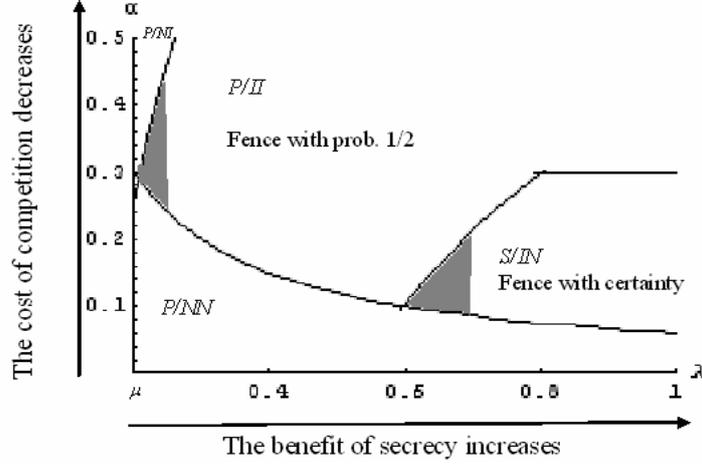
The only difference in the timing of the game appears at node 2 in figure 4. Even if B finds the second invention first, the patent will be granted to firm A. Thus, the payoffs in the potential third race are the same as in table 1, as firm A will be the leader after the second race (meaning that firm A has one patent and firm B does not have any). A simple comparison of the payoffs in table 4 (by replacing the payoffs of the second race with those in table 1) indicates that the follower will never choose to invest in the invention already found by firm A under the First-to-Invent legal rule.

Lemma 11 *Under the First-to-Invent legal rule, the follower will invest in the invention that has not yet been found (I_d) if the duopoly profits under secrecy net of R&D costs are positive ($\mu \frac{\alpha}{r} > c$), and will choose non-investment otherwise.*

Proof. This result is obtained by a simple comparison of the payoffs in table 4. ∎

This result can be explained as follows. If the follower chooses the same invention (I_s), the patent will be granted to firm A, whichever firm wins the second race. The follower would then have to invest in the third race to be able to get, at the best, the duopoly profit. On the other hand, if firm B

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chooses I_d, it will then earn the duopoly profit after the second race, if it is the first to find the second product.

Figures 7 and 8 describe the equilibria with the same parameter values as in figures 5 and 6. We see from the graph that the leader patents the first invention for a wider range of values of α and λ in the First-to-File system. In the present case, the follower never invests if the leader keeps the invention secret. Thus, the leader will only patent the invention for λ close to μ, where the benefit of secrecy is low in order to collect the interim profit. However the leader will keep the invention secret when the benefit of secrecy is large, as the high λ makes the cost of the second invention very low as well as it makes the follower drop out of the race. A more detailed comparison between First-to-File and First-to-Invent is presented in the next section.

5   Welfare analysis

A recent NRC (2004) report raises concerns about the social benefits of low quality patent[7]:

> "*Granting patents for inventions that are not new, useful and non-obvious unjustly rewards the patent holder at the expense of consumer welfare.*" (NRC, 2004, p. 38)

This section aims at studying the welfare effects of patent fences in two ways. First, by comparing "strong" and "weak" novelty requirements and, then, by comparing the First-to-File and First-to-Invent legal rules.

5.1   Comparing strong and weak novelty requirements

This section examines ex ante social welfare by comparing "strong" and "weak" novelty requirement. The "strong" novelty requirement is here meant to be a protection which follows the statutory definition of a patentable invention regarding the inventive step, whereas the "weak" novelty requirement refers to a situation in which the novelty step is not respected.

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[7]The term "patent quality" refers here to the statutory definition of a patentable invention: novelty, non-obviousness, usefulness

Social welfare is defined as the sum of producer surplus, consumer surplus, and a non-appropriable value of the first innovation. For a variety of reasons investors may not always be able to appropriate for themselves the entire social benefit of their innovations. Let $s \geqslant 0$ be the non appropriable value of the innovations. It represents the increase in social welfare which firms in other industries and their consumers may enjoy due to either knowledge or demand spillovers. Due to the fact that both inventions are substitutes, we will assume that there is a non-appropriable part to the first invention only. The second invention does not add anything to the stock of knowledge of the society.

Let $d(\alpha) \geqslant 0$ be the measure of deadweight loss reduction, due to competition in the second race. We assume that this function is decreasing in α such that $d'(\alpha) < 0$. The function has a lower bound: $d(0.5) = 0$, which means that if competition is weak (for instance, if firms collude), there will be no deadweight loss reduction. In order to reduce the notation, we will omit the α argument in the function in the continuation of the text.

The private returns from the innovations are 1 in the case of monopoly, and 2α in the case of duopoly. The aggregated R&D cost is c or $2c$ depending on whether one firm or both of them are participating in the race.

As Green and Scotchmer (1995) and Denicolò (2000) have pointed out, the social benefit from an innovation includes the option value of investing to obtain the second innovation, since a firm is favoured in the second race if it already has the first invention. This implies that an early invention is valued more than a later one. If the first innovation is patented, and both firms invest in the second race, the expected social welfare, evaluated at the beginning of the first race is:

$$W^{P/II} = P(\mu) \left[\frac{1+s}{r} + \left(\frac{\lambda}{2\lambda + r} \right) \left(\frac{2\alpha - 1 + d}{r} \right) - 2c \right] - 2c \qquad (3)$$

Where $P(\mu) \equiv 2\mu/(2\mu + r)$ represents the adjusted probability of innovating in the first race, as in Denicolò (2000). The social welfare in the first race is measured as the sum of the private (monopoly) profit and the

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non-appropriable part.

In equation (3), the social welfare of the second race depends on which firm wins this race. If the winner of the second race is the same as in the first one, which occurs with probability λ, the private profit remains unchanged, and there is no reduction of the deadweight loss. Thus, the (net) social value of the second invention is 0. With probability λ the winner of the second race is the follower. In this case, the private return of the second invention will be $2\alpha - 1$ (which is likely to be negative), but there is a reduction of the deadweight loss, measured by $d(\alpha)$.

The other welfare functions are reported in appendix I.

Since the follower will not invest in the same invention as the leader under the First-to-Invent legal rule, equations (20) and (21) in appendix G have to be taken out of the analysis in this case.

The possibility for firms to create a fence is only possible if the novelty requirement is weak. Several studies report that the novelty and non-obviousness criterion are not respected, resulting in "low-quality patents" (Lunney, 2001; Hall et al., 2003). We now turn to this question, by studying whether the policy makers should allow this weak novelty step, or require a strong novelty step that does not allow a firm to patent an invention being a substitute from an existing patented product. On the one hand, a weak novelty step allows some extent of competition, given that firms can patent substitute inventions, which is welfare improving. But on the other hand, firms will be able to create fences to increase the scope of protection of their inventions. In addition to anti-trust concerns (which are also raised in the case of broad patents), this situation implies a "waste of R&D" due to the duplication.

The welfare function under the strong novelty requirement is equivalent to the $W^{P/NN}$ function in our model; after one invention has been patented, the patentee benefits from the monopoly rent, and none of the firms invest to find a substitute. This function can be compared to all the other welfare functions in order to find out which is the optimal policy.

Consider first the choice S/IN, the case in which the leader keeps the first invention secret and then invests to find the substitute, whereas the rival

firm does not. In this situation we will have a fence with certainty.

$$W^{P/NN} - W^{S/IN} = \frac{1+s+\lambda c}{\lambda + r} > 0 \qquad (4)$$

The comparison of both functions clearly shows that a single product is socially preferable to a fence that will be built with certainty. The first reason is that the inventor keeps the initial invention secret which implies costs both for the consumer (the product is introduced on the market at a latter stage) and for the firm (no interim profits in the case of secrecy, duplication of R&D expenses without any increase in profits). The second reason is that, in this situation, there will not be any deadweight loss reduction.

If we compare the single-patent welfare function to the cases in which the leader applies for a first patent and a substitute patent is allowed, we get:

$$W^{P/NN} - W^{P/II} = 2c - \frac{\lambda(2\alpha - 1 + d)}{(2\lambda + r)r} \qquad (5)$$

$$W^{P/NN} - W^{P/NI} = c - \frac{\lambda(2\alpha - 1 + d)}{(\lambda + r)r} \qquad (6)$$

Equation (5) and (6) show that, a single patent is preferable to the case where the policy maker allows for a substitute, if the expected social welfare gain of duopoly is smaller than the aggregate cost of an additional invention.

For the remaining cases following a choice of secrecy by the leader, we have:

$$W^{P/NN} - W^{S/II_d} = \frac{(1+s)(\mu + r) - \mu(2\alpha + s + d)}{r(\lambda + \mu + r)} + 2c \qquad (7)$$

$$W^{P/NN} - W^{S/II_s/II} = \frac{1 + s + 2c(\lambda + 2\mu + r)}{\lambda + \mu + r} - \frac{\lambda\mu(2\alpha - 1 + d)}{(\lambda + \mu + r)(2\lambda + r)r} \qquad (8)$$

$$W^{P/NN} - W^{S/II_s/NI} = \frac{1 + s + 2c(\lambda + 1.5\mu + r)}{\lambda + \mu + r} - \frac{\lambda\mu(2\alpha - 1 + d)}{(\lambda + \mu + r)(\lambda + r)r} \qquad (9)$$

The signs of equations (7) to (9) depend crucially on the size of s and the shape of the $d(\cdot)$ function. If s is high, and/or d is low, the single patent solution is the optimal policy, because s being high, an early disclosure (i.e. the single patent solution) is socially optimal, compared to a late disclosure (i.e.,the case where the first product is kept secret).

The implications of these results are twofold. Equation (4) shows that a single patent is socially preferable to a fence which would be built with certainty. The only case in which the weak novelty requirement is socially optimal, is when the deadweight loss compensates the decrease of the expected duopoly profit and/or when the non-appropriable part (s) is low.

5.2   Comparing First-to-File and First-to-Invent

Scotchmer and Green (1990) found that the First-to-Invent rule implies more secrecy than the First-to-File rule in a similar framework, though with cumulative innovations.

Define $\alpha^{S/II_s/II}$, α^{S/II_d} and $\alpha^{S/IN}$ as the critical values under which firm A keeps the first invention secret, with the superscript referring to the choices after the first invention has been discovered. The values of these thresholds have been calculated in section 4.4 and result from the comparison by A of the payoffs under secrecy and patenting.

Lemma 12 *The first innovator's threshold for keeping the first invention secret is lowest if the subsequent choices are II_d and highest if the choices are IN: $\alpha^{S/IN} > \alpha^{S/II_s/II} > \alpha^{S/II_d}$.*

Proof. See appendix J. ■

This result means that the leader has a higher incentive to keep the first invention secret, if it can prevent the follower from investing in the second race. This incentive is lower if secrecy makes the follower choose to invest in a different invention. In the First-to-Invent system, the inequality simply becomes: $\alpha^{S/IN} > \alpha^{S/II_d}$, as the follower never chooses to invest in the same invention.

Proposition 13 *The leader's incentive for keeping the first invention secret is:*

* *larger or equivalent under the First-to-Invent legal rule than in the First-to-File system, if the expected duopoly profits under secrecy net of R&D costs are negative ($\mu\frac{\alpha}{r} < c$)*

* *larger or equivalent under the First-to-File system than in the First-to-Invent system, if the expected duopoly profits under secrecy net of R&D costs are positive ($\mu\frac{\alpha}{r} > c$)*

Proof. Follows from lemma 10 and lemma 11. ∎

If $\mu\frac{\alpha}{r} < c$, firm B will always choose not to invest after secrecy under the First-to-Invent legal rule, which is the region where secrecy is largest. Under the First-to-File legal rule, the secrecy thresholds will be lower, as firm B can also choose to invest in the same invention.

Scotchmer and Green (1990) argue that disclosure accelerates discovery, so that patenting is always preferable. The implications are, however, different in our model. As it has been shown in the previous sub-section, there might be a wasteful duplication and then, secrecy can be better than patents if it makes the follower drop out. It is however not clear in this model whether the overall incentives to patent are greater under the First-to-File or First-to-Invent legal rule.

From the previous discussion, we can make the following proposition:

Proposition 14 *After secrecy, the follower will drop out of the race for more parameter values under First-to-Invent than under First-to-File.*

In this case, as well as in Scotchmer & Green (1990), a shake-out (i.e. the follower drops out of after the first invention has been discovered by the leader) will occur for more parameter values with First-to-Invent. Again, the conclusions we can draw are different. Scotchmer & Green (1990) argue that a shake-out may be socially beneficial. In our model, given that we allow for different levels of competition between firms racing for substitute inventions, the deadweight loss is likely to be reduced if both firms compete on the same

market. The previous sub-section showed that the conclusion will depend on the size of the deadweight loss reduction.

6   Conclusion

This paper has studied the behaviour of firms facing the decision to create a patent fence, in the context of multiple stage patent races. We allowed firms to choose between patenting their inventions or relying on secrecy for different levels of competition.

We define a "patent fence" as a set of substitute patents owned by the same firm. Then, under a "weak novelty requirement" and applying the First-to-File and First-to-Invent rules, it is shown that firms try to create such fences of substitute inventions, when the duopoly profits net of R&D costs are positive. We also show that in such a setup, firms will rely on secrecy when the speed of discovery of the second invention is large, relative to the competitor's.

We also demonstrate that the First-to-Invent rule does not unnecessarily imply more secrecy than the First-to-File system in this context. However, under secrecy, the follower will drop out of the race more often under the First-to-Invent legal rule, which is consistent with the previous results for the case of cumulative innovations.

Finally, the welfare analysis shows that equilibrium outcomes where fences occur with certainty are socially sub-optimal. The weak novelty requirement (i.e. allowing patents for substitute products) is desirable, only if the deadweight loss is higher than the expected loss of private profits.

A recent staff survey at the European Patent Office (EPO) shows that "*examiners at the European Patent Office (EPO) are losing confidence in its ability to ensure the quality of the patents it issues*" and that "*the pressure to process files encourages them to approve marginal cases*" (Pressured staff 'loose faith' in patent quality, *Nature 429, 493*, 03 June 2004). In contrast with the US Patent Office (USPTO), the EPO has a "post-grant" opposition system allowing any third party to attack a patent once it has been granted, if the invention lacks novelty or an inventive step. Future work in that line

of research could be to check how efficient this opposition system is in trying to improve the quality of the European patents.

References

[1] Anton, J. J. and Yao, D. A. (2004), "Little Patents and Big Secrets", *The RAND Journal of Economics*, 35(1), 1-22.

[2] Cohen, W.M., Nelson, R.R., Walsh, J.P. (2000), "Protecting their intellectual assets: Appropriability conditions and why U.S. manufacturing firms patent (or not)", *NBER Working Paper* 7552.

[3] Denicolò, V. (1996), "Patent races and optimal patent breadth and length", *The Journal of Industrial Economics*, 44(3), 249-265.

[4] Denicolò, V. (2000), "Two-stage patent races and patent policy", *The RAND Journal of Economics*, 31(3), 488-501.

[5] Gallini, N. (1992), "Patent Policy and Costly Imitation", *The RAND Journal of Economics,* 23(1), 52-63.

[6] Gallini, N. (2002), "The Economics of Patents: Lessons from Recent US Patent reform", *Journal Of Economic Perspectives,* 16(2), 131-154.

[7] Granstrand, O. (1999), "The Economics and Management of Intellectual Property: Towards Intellectual Capitalism", *eds.. Edward Elgar Publishing.*

[8] Green, J.R. and Scotchmer, S. (1995), "On the Division of Profit in Sequential Innovation", *The RAND Journal of Economics*, 26(), 20-33.

[9] Hall (2005), "Exploring the Patent Explosion", *Journal of Technology Transfer*, forthcoming.

[10] Hall, B.H., Graham S., Harhoff D. and Mowery D.C. (2003), "Prospects for Improving U.S. Patent Quality via Postgrant Opposition", in: Adam

B. Jaffe, Josh Lerner and Scott Stern (eds.), *Innovation Policy and the Economy*, Vol. 4, pp. 115-143.

[11] Hall, B.H. and Ziedonis, R.H. (2001), "The patent paradox revisited: an empirical study of patenting in the US semiconductor industry, 1979-1995", *The RAND Journal of Economics*, 32 (1), 101-128.

[12] Hounshell, J.A. and Smith, J.K. (1988), "Science and Corporate Strategy", *eds. Cambridge University Press.*

[13] Jensen, R. and Thursby, M. (1996), "Patent Races, Product Standards, and International Competition", *International Economic Review,* 37 (1), 21-49.

[14] Kortum and Lerner, J. (1997), "Stronger Protection or Technological Revolution: What is behind the Surge in Patenting?", *NBER working paper* 6204.

[15] Langinier, C. "Using patents to mislead rivals", Forthcoming in *Canadian Journal of Economics.*

[16] Lerner, J. and Tirole, J. (2004), "Efficient Patent Pools », *American Economic Review*, 94 (3), 691-711.

[17] Lunney, G. S., Jr. (2001), "e-Obviousness.", *Michigan Telecommunications Technology Law Review* 7: 363-422.

[18] Mansfield, E. (1985), "How Rapidly Does New Industrial Technology Leak Out?", *Journal of Industrial Economics*, 34(2), 217-223.

[19] National Research Council (NRC), 2004, "A Patent System for the 21st Century", Washington, DC.: National Academies Press.

[20] OECD (2004), "Compendium of Patent Statistics", *OECD.*

[21] Reitzig, M. (2004), "The private value of 'thickets' and 'fences': towards an updated picture of the use of patents across industries", *Economics of Innovation and New Technology*, 13(5), 457-476.

[22] Rivette, K.G. and Kline, D. (2000), "Rembrandts in the Attic", *Boston: Harvard Business School Press.*

[23] Scotchmer, S. (2005), "Innovation and Incentives", *eds. MIT Press.*

[24] Scotchmer, S. and Green, J. (1990), "Novelty and disclosure in patent law", *The RAND Journal of Economics*, 21(1), 131-146.

[25] Shapiro, C. (2001), "Navigating the patent thicket: cross licenses, patent pools, and standard-setting", in: Jaffe, A., Lerner, J., Stern, S. (2001), *Innovation Policy and the Economy*, vol. 1, eds., MIT Press.

Appendix

A Proof of lemma 4

Following Scotchmer and Green (1990)'s line of proof, we show that it is a dominant strategy for A to invest at each moment of time after having kept the first invention secret, until the discovery of a second one.

I. If Firm B invests in the product which has not been found by firm A (choice I_d)

1. If A also invests (left hand side of inequality 16):

In the time period dt, A has a probability of λ of achieving the final patent worth $1/r$.

There is also a probability μ that B achieves the patent worth α/r.

In addition, there is a probability of $(1 - \lambda dt - \mu dt)$ that neither firm invents in dt.

2. If A does not invest (right hand side inequality 16)

There is also a probability μ that B achieves the patent worth α/r in the time period dt

In addition, there is a probability of $(1 - \mu dt)$ that firm B does not invent in dt.

If B also invests in the period dt, A should invest if:

$$\left[\lambda\frac{1}{r} + \mu\frac{\alpha}{r} - c\right]dt + (1 - \lambda dt - \mu dt)\,P_A e^{-rdt} \geq \mu\frac{\alpha}{r}dt + (1 - \mu dt)\,P_A e^{-rdt} \tag{10}$$

Where P_A is A's continuation value if neither firm invents.

After dividing by dt and letting dt go to 0, we get:

$$P_A \leq \frac{\lambda - cr}{\lambda r}$$

If A and B invest continuously, then the continuation value to A is: $\frac{\lambda\frac{1}{r} + \mu\frac{\alpha}{r} - c}{\lambda + \mu + r}$. The inequality is then satisfied

$$P_A \leq \frac{\lambda\frac{1}{r} + \mu\frac{\alpha}{r} - c}{\lambda + \mu + r} \leq \frac{\lambda - cr}{\lambda r} \tag{11}$$

II. If B invests in the product which has been found by firm A (choice I_s)
Inequality (16) becomes:

$$\left[\lambda\frac{1}{r} + \mu V_{A;3}^{S/ij} - c\right]dt + (1 - \lambda dt - \mu dt)\,P_A e^{-rdt} \geq \mu V_{A;3}^{S/ij} dt + (1 - \mu dt)\,P_A e^{-rdt} \tag{12}$$

Where $V_{A;3}^{S/ij}$ is the continuation payoff to firm A, depending on the choices made in the third race (see text and table 3).

This reduces to the same result as before: $P_A \leq \frac{\lambda - cr}{\lambda r}$.

Under these conditions, the continuation value to A is: $\frac{\lambda\frac{1}{r} + \mu V_{A;3}^{S/ij} - c}{\lambda + \mu + r}$ The inequality is then satisfied

$$P_A \leq \frac{\lambda\frac{1}{r} + \mu V_{A;3}^{S/ij} - c}{\lambda + \mu + r} \leq \frac{\lambda - cr}{\lambda r} \tag{13}$$

III. If B does not invest.
Then the relevant inequality becomes:

$$\left(\lambda\frac{1}{r} - c\right)dt + (1 - \lambda dt)\,P_A e^{-rdt} \geq P_A e^{-rdt} \tag{14}$$

Again, this reduces to the same result: $P_A \leq \frac{\lambda - cr}{\lambda r}$.

If A invests continuously and B does not invest, then the continuation value to A is $\frac{\lambda/r - c}{\lambda + r}$. The inequality is then satisfied:

$$P_A \leq \frac{\lambda \frac{1}{r} - c}{\lambda + r} \leq \frac{\lambda - cr}{\lambda r} \tag{15}$$

Provided $\lambda \frac{1}{r} \geq c$ i.e., that the expected monopoly profit is positive.

B Conditions for Firm B to invest after secrecy

Firm B compares the payoffs under investment in the same invention, the second invention and non-investment. This gives a lower bound for α, above which B is going to participate in the race.

I_d is the optimal choice if it is preferred to N and I_s. This creates two conditions:

$\mu \frac{\alpha}{r} > c$ and $\frac{\alpha}{r} > V_{B;3}^{S/ij}$

In the same way, I_s is the optimal choice if it is preferred to N and I_d:

$\mu V_{B;3}^{S/ij} > c$ and $V_{B;3}^{S/ij} > \frac{\alpha}{r}$

The results, for the different possible choices in the third race.

Table 5: Conditions for B to invest in the second race resulting from a secrecy choice by A

Conditions for I_s to be optimal

Choices at node 2	I_s preferred to I_d	I_s preferred to N
II	$\alpha < 1 - \frac{cr}{r+\lambda}$	$\alpha > \frac{rc(r+2\lambda+\mu)-\mu(r+\lambda)}{\mu\lambda}$
IN	I_s always optimal	$\alpha > \frac{r[c(r+\lambda)\mu]}{\mu\lambda}$
NN	I_s always optimal	$\mu(1+r) > cr$

Conditions for I_d to be optimal

Choices at node 2	I_d preferred to I_s	I_d preferred to N
II	$\alpha > 1 - \frac{cr}{r+\lambda}$	
IN	I_d never optimal	$\mu\frac{\alpha}{r} > c$
NN	I_d never optimal	

Conditions for N to be optimal

Choices at node 2	N preferred to I_s	N preferred to I_d
II	$\alpha < \frac{rc(r+2\lambda+\mu)-\mu(r+\lambda)}{\mu\lambda}$	
IN	$\alpha < \frac{r[c(r+\lambda)\mu]}{\mu\lambda}$	$\mu\frac{\alpha}{r} < c$
NN	$\frac{\mu}{r}(1+r) < c$	

C   Patent or secrecy?

To make the different choices comparable, the conditions on the parameters that we derived before have to be the same. Since the potential third race in the secrecy case as well as the second race in the patenting case are symmetric, they are only comparable for symmetric choices (see tables 1 and 3). For instance, the case where both firms invest in the potential third race after a secrecy choice from A, denoted *S/II/II,* is only comparable with the *P/II* choice, as the conditions on α are the similar in both cases. The case in which firm B does not invest after A's secrecy choice (*S/IN*) has to be compared to all the possible choices in the patenting case, as the conditions are not totally symmetric and could overlap for some more restricted conditions.

Table 6: Conditions for the leader to rely on secrecy.

Choices	Alternative choices	Conditions
(1) $S/II_s/II$	P/II	$\alpha < -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu)}{\lambda(r+\lambda)}$
(2) $S/II_s/IN$	P/NI	Never Nash equilibria (alternative choice preferred)
(3) S/II_d	P/II	$\alpha < -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu-c\mu)}{(\lambda-\mu)(r+\lambda)}$
(4) S/II_d	P/NI	Never Nash equilibria (alternative choice preferred)
(5) S/IN	P/II	$\alpha < 1 - \frac{r[r+\lambda(c+2)]}{\lambda(\lambda+r)}$
(6) S/IN	P/NI	Never Nash equilibria (alternative choice preferred)
(7) S/IN $S/II_s/NN$ S/II_d	P/NN	Never Nash equilibria (alternative choice preferred)

We now justify why the choices (4), (6) and (7) can never be optimal.

(2) The comparison between the continuation payoffs under the choices $S/II_s/IN$ and P/NI gives the following condition for firm A to invest: $\alpha < \frac{\lambda^2-r^2(1+c)-r[\mu+c(\lambda+\mu)]}{r0.5\mu-\lambda(\lambda+r)}$. This condition does not bind, as the lower bound of the P/NI region is given by $\frac{cr}{\lambda}$ which is larger than $\frac{\lambda^2-r^2(1+c)-r[\mu+c(\lambda+\mu)]}{r0.5\mu-\lambda(\lambda+r)}$.

(4) The comparison between the continuation payoffs under the choices S/II_d and P/NI gives the following condition for firm A to invest: $\alpha < -\frac{(r+cr-\lambda)(r+\lambda)+r\mu}{\lambda(r+\lambda)-r\mu} < 0$. The condition on α is negative and cannot be met.

(6) The comparison between the continuation payoffs under the choices S/IN and P/NI gives the following condition for firm A to invest: $\alpha < 1 - \frac{r(c+1)}{\lambda}$. This condition does not bind, as the upper bound of the P/NI region is given by $1 - \frac{cr(\lambda+r)}{\lambda^2}$ which is larger than $1 - \frac{r(c+1)}{\lambda}$, provided that the expected monopoly profits net of R&D costs are positive, i.e., $\frac{\lambda}{r} > c$

(7) A simple comparison of the payoffs in tables 1 and 4 shows that the choices P/NN are preferred to any alternative choices.

D   The first race

The ex-ante entry conditions under patenting have been computed in section 3 and are identical when we allow for secrecy. We now just need to find these conditions when the leader chooses secrecy, conditional on the subsequent choices.

Table 7: Lower bound on α for positive ex ante profits under secrecy

Choices	Conditions
II_s	$\frac{-\mu[\lambda(2\lambda-\mu)+r(\lambda+\mu)]+cr[r+2r\mu+2(\lambda+2\lambda\mu+\mu^2)]}{2\lambda\mu^2}$
II_d	$\frac{cr(r+\lambda+3\mu)-\mu\lambda}{2\mu^2}$
IN	$\frac{cr(r+\mu)}{\mu-cr}$

E   Description of the equilibria

Here, we derive the conditions for the different possible choices taken by the firms to be optimal. We use the successive discounted payoffs and associated conditions, that we found in the text for them to be equilibria in the considered sub-games, presented in tables 1 to 6.

(1) *P/II* is the optimal choice if:
(i) $\alpha < 1 - \frac{cr(\lambda+r)}{\lambda^2}$ Firm A invests in the second race (tables 1 and 2)
(ii) $\lambda\frac{\alpha}{r} > c$ Firm B invests in the second race (tables 1 and 2)
(iii) $\alpha > -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu)}{\lambda(r+\lambda)}$ Firm A patents (tables 5 and 6)
(iv) $\alpha > 1 - \frac{r[r+\lambda(c+2)]}{\lambda(\lambda+r)}$ Firm A patents (tables 5 and 6)
(v) $\alpha > -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu-c\mu)}{(\lambda-\mu)(r+\lambda)}$ Firm A patents (tables 5 and 6)

(2) *P/NI* is the optimal choice if:
(i) $\alpha > 1 - \frac{cr(\lambda+r)}{\lambda^2}$ Firm A does not invest in the second race (tables 1 and 2)
(ii) $\lambda\frac{\alpha}{r} > c$ Firm B invests in the second race (tables 1 and 2)

(3) *P/NN* is the optimal choice if:
(i) $\lambda\frac{\alpha}{r} < c$: The firms do not invest in the second race (tables 1 and 2).

(4) *S/II$_s$/II* is the optimal choice if:

(i) $\alpha < 1 - \frac{cr(\lambda+r)}{\lambda^2}$ Firm A invests in the potential third race (tables 1, 2,3)

(ii) $\lambda\frac{\alpha}{r} > c$ Firm B invests in the potential third race (tables 1, 2,3)

(iii) $\alpha < 1 - \frac{cr}{r+\lambda}$ Firm B invests in the second race (tables 4 and 5)

(iv) $\alpha > \frac{rc(r+2\lambda+\mu)-\mu(r+\lambda)}{\mu\lambda}$ Firm B invests in the second race (tables 4 and 5)

(v) $\alpha < -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu)}{\lambda(r+\lambda)}$ Firm A keeps the first invention secret (table 6)

(6) *S/IN* is the optimal choice if:

(i) $\alpha < 1 - \frac{cr(\lambda+r)}{\lambda^2}$ Firm B does not invest in the second race (tables 4 and 5)

(ii) $\lambda\frac{\alpha}{r} < c$ Firm B does not invest in the second race (tables 4 and 5)

(iii) $\alpha < 1 - \frac{r(c+1)}{\lambda}$ Firm A keeps the first invention secret (table 6)

(7) *S/II$_d$* is the optimal choice if:

(i) $\alpha > 1 - \frac{cr(\lambda+r)}{\lambda^2}$ Firm B invests in the second race (tables 4 and 5)

(ii) $\lambda\frac{\alpha}{r} > c$ Firm B invests in the second race (tables 4 and 5)

(iii) $\alpha < -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu-c\mu)}{(\lambda-\mu)(r+\lambda)}$ Firm A keeps the first invention secret (table 6)

F Proof of proposition 7

According to the results in table 7, I_d is preferred to I_s if $\alpha > 1 - \frac{cr}{r+\lambda}$. The intercept of this curve in the space (λ, α) is $1-c$ and the function is strictly increasing: $\frac{\partial}{\partial\lambda}(1 - \frac{cr}{r+\lambda}) = \frac{cr}{(r+\lambda)^2} > 0$. Thus, if $c \leqslant 0.5$, firm B will never choose I_d.

G Proof of Proposition 8

The proposition consists of two parts:

1) *Potential fences of substitute inventions are created when the duopoly profits are positive:*

This result is straightforward and is obtained from tables 1 to 6.

2) *When firms wish to build fences, they keep the first invention secret when the benefit of secrecy (the speed of discovery) is large relative to the competitor's.*

We have to show that firms keep their first inventions secret when λ is large relative to μ. Table 6 shows the conditions under which secrecy is preferred to patenting by reporting an upper bound on α. To prove our statement, we just need to show that these boundaries (1, 3 and 5 in table 6) are upward slopping. $\forall \lambda \in [\mu; 1], \mu \in [0, 1], r > 0$, and $c > 0$, we compute the first order derivatives and show that they are positive in the space (λ, α):

(1) $\frac{\partial}{\partial \lambda} \left\{ -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu)}{\lambda(r+\lambda)} \right\} = \frac{r\left[r^2+2r\lambda+(2+c)\lambda^2\right]+(r+\lambda)^2\mu}{\lambda^2(r+\lambda)^2} > 0$

(3) $\frac{\partial}{\partial \lambda} \left\{ -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu-c\mu)}{(\lambda-\mu)(r+\lambda)} \right\} = \frac{-2+r[-c\mu+r+(2+c)\lambda]+(r+\lambda)^2\mu}{(r+\lambda)} + \frac{-c\mu+(1+c)r^2+2cr\lambda-2\lambda^2}{(r+\lambda)^2(\lambda-\mu)} >$

0

(5) $\frac{\partial}{\partial \lambda} \left\{ 1 - \frac{r[r+\lambda(c+2)]}{\lambda(\lambda+r)} \right\} = r\left[\frac{1+c}{(r+\lambda)^2} + \frac{1}{\lambda^2}\right] > 0$

H Proof of proposition 9

We need to show that the conditions for firm A to keep the invention secret are decreasing with respect to μ. We take the conditions in table 6:

(1) $\frac{\partial}{\partial \mu} \left\{ -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu)}{\lambda(r+\lambda)} \right\} = \frac{-r(r+2\lambda)}{(r+\lambda)(\lambda-\mu)} < 0$

(3) $\frac{\partial}{\partial \mu} \left\{ -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu-c\mu)}{(\lambda-\mu)(r+\lambda)} \right\} = \frac{-1}{\lambda} < 0$

Condition (5) does not depend on μ and is thus constant when μ varies.

I Welfare functions

Regarding the cases in which the first invention is patented, we have:

$$W^{P/NI} = P(\mu) \left[\frac{1+s}{r} + P(\lambda)\left(\frac{2\alpha-1+d}{r}\right) - c\right] - 2c \qquad (16)$$

$$W^{P/NN} = P(\mu)\left(\frac{1+s}{r}\right) - 2c \qquad (17)$$

Where $P(\lambda) \equiv \lambda/(\lambda+r)$

Under secrecy, the first invention is not disclosed before the second invention has been discovered, so that the social benefits are delayed to the date when the inventions are patented and commercialized. We have[8]:

$$W^{S/IN} = P(\mu)P(\lambda)\left(\frac{1+s}{r} - c\right) - 2c \tag{18}$$

$$W^{S/II_d} = P(\mu)\left[\frac{\lambda}{\lambda + \mu + r}\left(\frac{1+s}{r}\right) + \frac{\mu}{\lambda + \mu + r}\left(\frac{2\alpha + s + d}{r}\right) - 2c\right] - 2c \tag{19}$$

$$W^{S/II_s/II} = P(\mu)\left[\frac{\lambda}{\lambda + \mu + r}\left(\frac{1+s}{r}\right) + \frac{\mu}{\lambda + \mu + r}\left(\frac{W^{P/II} + 2c}{P(\mu)}\right) - 2c\right] - 2c \tag{20}$$

$$W^{S/II_s/IN} = P(\mu)\left[\frac{\lambda}{\lambda + \mu + r}\left(\frac{1+s}{r}\right) + \frac{\mu}{\lambda + \mu + r}\left(\frac{W^{P/NI} + 2c}{P(\mu)}\right) - 2c\right] - 2c \tag{21}$$

J   Proof of lemma 11

We want to show that $\alpha^{S/IN} > \alpha^{S/II_s/II} > \alpha^{S/II_d}$, where the α are the critical values in table 6 under which firm A will rely on secrecy.

We have:

$\alpha^{S/IN} - \alpha^{S/II_d} = \frac{r(r+2\lambda)\mu}{\lambda(r+\lambda)(\lambda-\mu)} > 0$

$\alpha^{S/II_d} - \alpha^{S/II_s/II} = \frac{\mu}{\lambda} > 0$

$\alpha^{S/II_s/II} - \alpha^{S/II_d} = \frac{\mu[r(r+\lambda+\mu)+\lambda(\mu-\lambda)]}{\lambda(r+\lambda)(\lambda-\mu)} > 0$

Thus, $\alpha^{S/IN} > \alpha^{S/II_s/II} > \alpha^{S/II_d}$

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[8]$W^{S/II_s/NN}$ is not reported here, since the choice corresponding to this welfare function is always dominated (the leader will always prefer patenting, see table 6).