Fences and competition in patent races*

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Abstract

This paper studies the behavior of firms facing the decision to create a patent fence, defined as a portfolio of non-improving substitute patents. We set up a patent race model, where firms can decide either to patent their inventions, or to rely on secrecy and that, for different levels of competition. It is shown that firms create a fence of substitute inventions, when competition is low or at an intermediate level. We also show that in this context, firms will patent their inventions for high and low levels of competition and rely on secrecy when competition is intermediate and the benefit of keeping the invention secret is large. Furthermore, we study the model under the First-to-Invent rule and show that this implies more secrecy in the case of "fencing patents".

Keywords: patent fences, trade secrecy, competition

JEL: O31, O32, L10

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"*It's important to patent other ways of accomplishing the same object,[...]. And so you build up a matrix or pyramid of protection around the idea. That makes it much more invulnerable to challenges by other manufacturers who very often have resources which go far beyond the innovators*". Arthur Bishop, founder of the Bishop Technology Group, 1992[1].

"*[...] getting a single patent is like building a fence with one pole. It doesn't protect much ground. [...] For your best innovations, appropriate patent protection may require a strategy that starts with robust patents and extends to collections of multiple patents - creating a self reinforcing fence surrounding your innovation. However, this approach can become quite expensive, so a careful consideration of the costs involved must be part of the analysis.*" Telaric Ideas, IPR consultants.[2]

"*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 1980's. This worldwide growth has been described, e.g., in Hall et al. (2001) and OECD (2004).

Kortum and Lerner (1997) associate this growth with an increased R&D productivity and changes in the management of innovation.

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 (business methods, 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 the creation of the EPO has considerably reduced the application costs.

[1] Cited on the website from the australian powerhouse museeum: http://www.phm.gov.au

[2] http://www.telaricideas.com/

Another reason could be that firms patent in a more "strategic" way, meaning that the patent application is not only driven by the desire to protect innovation rents (see for instance, Rivette and Kline, 2000). Hall and Ziedonis (2001) find that the increase in patenting in the US semi-conductor industry is associated with the assembly of large patent portfolios, whereas these firms view patents as a weak appropriability mechanism. The authors find that firms create these patent portfolios for defensive reasons, in order to forestall hold-up by rivals and can serve as "bargaining chips". It turns out that these situations create "thickets" of complementary technologies and as a consequence, firms have to face legal challenges in order to acquire rights to outside technologies.

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.

In complex product industries: firms use patents to force rivals into negotiations and firms create "thickets" of complementary technologies. This is a similar argument as in Hall and Ziedonis (2001).

In discrete product industries: firms use patents to block the development of substitutes by rivals. We say that firms create "fences".

More precisely, in this case, firms will patent a coherent group of inventions, which form what is sometimes called a patent 'bulk', aimed at protecting one of them. The 'bulk' can either be a 'fence' of substitute patents or a 'thicket' of complementary patents (see Reitzig, 2004 and Cohen et al., 2000).

Firms wishing to protect some patented core invention, may patent substitutes to keep rivals from doing this. Thus, these firms create a 'fence' around the core invention. Substitute inventions are defined as inventions that resemble one another functionally (following Cohen et al.'s, 2000 definition). An example of a patent fence is given in Hounshell and Smith (1988) and cited in Cohen et al. (2000): in the 1940's, Du Pont patented over 200 substitutes for Nylon, in order to protect its core invention, that consisted in a range of molecular variations of polymers with similar properties to Nylon.

While the issue of complementary technologies in cumulative innovations[3] has been extensively analyzed, as well as the institutional solutions to overcome this problem (Lerner and Tirole, 2005 and Shapiro, 2001), little attention has been paid to non-improving fencing patents so far. By "non-improving fencing patents"[4] we mean patents that are functionally identical (or close substitutes) and owned by the same firm. If the patents are owned by different firms, they can compete on the same market; moreover, each product can be individually protected by a patent. 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."*

Our contribution consists in linking the concept of patent "fence" with competition by allowing the competitors either to patent the inventions or to keep them initially secret.

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. It is shown that this "business stealing" (i.e. a firm has a monopoly position, until a substitute invention is found by another firm) 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 that patented the first invention) wins the second innovation tend to zero. Thus, firms can never build fences and have

[3] See Scotchmer (2005) for an overwiew on cumulative innovations.

[4] See O'Donoghue et al. (1998) for the case of quality improving innovations.

to compete with one substitute each. Moreover, firms cannot use the first invention to build the second one.

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, that require 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, as the domestic invention will be protected by the "product standard".

The starting point, in our model, is that two firms have private informations about a potential innovation for which a substitute can be found. We propose a multiple stage patent race model, where two firms are competing to invent two substitute products. The patent race is modeled following Scotchmer and Green (1990) using a Poisson discovery process. In the context of our model, a fence can be defined as a portfolio composed of both patents. After the first race, the model allows the leader to choose between patenting the invention or keeping it secret. Trade secrecy has been applied to various situations, for instance to prevent imitation (Gallini, 1992 or Anton and Yao, 2004), to get a head start in cumulative innovations (Scotchmer and Green, 1990)[5] 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 usually not the case in the imitation models, see for instance Gallini (1992), where only the imitator invests in the second stage. Moreover, if the leading firm owns both substitutes, it may only market one of them, as, obviously, the cost of producing several products with identical functionality, would be higher than producing simply one of them.

Given the importance of secrecy as an appropriability mechanism according to Cohen et al.'s (2000) survey, we will try to explain the strategies firms adopt (patent or secrecy) in the process of creating "fencing patents". Af-

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

ter the leader's decision to patent or to rely on secrecy, a second race takes place where again both firms compete for the remaining product. We will assume that the race will differ, whether the leader has kept the first innovation secret or not. If the leader has patented the first product, both firms will race symmetrically as all the information is disclosed. However, if the first invention has been kept secret, there is no disclosure to the follower and we will assume that this creates an asymmetry so that the leader will race faster than the follower. As we defined it above, both products are close non-improving substitutes, which has the consequence that none of the products are more valuable to the consumers or the firms as such. 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, that is, each of them owns a patent, we will make the profit depend on the degree of competition.

We find in this model, that firms create a fence of substitute inventions, when competition is low or at an intermediate level. We also show that in this context, firms will patent their inventions for high and low levels of competition and rely on secrecy when competition is intermediate and the benefit of keeping the invention secret is large. 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 profits. It is also more profitable to patent the invention in order to collect the interim profit. 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 and collect an interim profit. On the other hand, the leading firm will then 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.

The paper is organized as follows: section 2 introduces the assumptions of the model. In section 3 we solve the game. The equilibria are discussed in section 4, which also covers a discussion of the results. In section 5 and 6 we study and compare the results to the first-to-invent rule which applies in the US. In section 7, we discuss the welfare analysis. Eventually, section 8 concludes the paper.

2 The model

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. Let both products be non-infringing, otherwise the question of interest disappears. This assumption implies that the patent breadth[6] has to be relatively narrow[7]. We assume our products to be substitutes in demand but not cumulative innovations (i.e. the products are not improving each other).

We 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, 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, wether 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, and their profits will depend on the index $\alpha \in [0, 0.5]$ where $\alpha = 0$ corresponds to a Bertrand competition with homogeneous goods and $\alpha = 0.5$ mirrors weak competition, for example, a collusion between the firms. α can be seen as a measure of agressivity of competition.

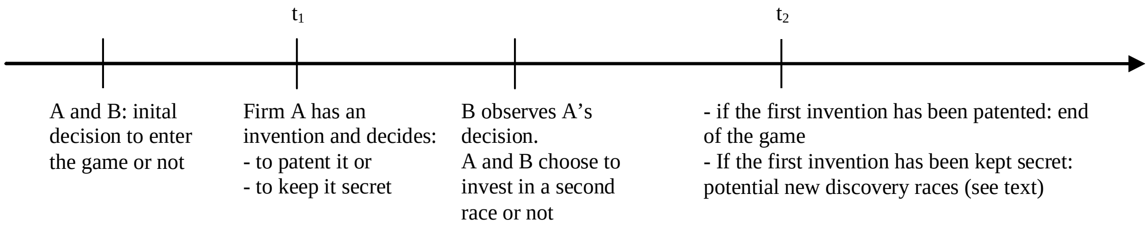
We also assume, for simplicity, an infinite patent life, which does not qualitatively change the results.

Figure 1 shows the timing of the game, which is explained in the following discussion.

[6] The patent "breadth" specifies how different another product must be in order not to infringe. See Scotchmer (2005). Lerner (1994) approximates the patent breadth by the number of subclasses in the International Patent Classification (IPC) into which the patent office assigns the patent.

[7] This assumption corresponds to the "weak novelty requirement" in Scotchmer and Green (1990)

Figure 1: *Timing of the game*



2.1 Stage one

In a first stage, both firms have to decide whether they are going to enter the race (I) or not (N), based on their expected and discounted payoffs. The arrival process of innovations is modeled as in, e.g., 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, so that the aggregate instantaneous probability of success is 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 pay a R&D cost of c per unit of time, during the discovery process, until the first invention is discovered. We assume that they have limited resources so that they can only invest in one innovation at a time.

Thus, one firm is going to get the first invention and be what we call "the leader". For simplicity, we will denote firm A as the leader.

Once firm A has discovered the invention, it has to decide whether to patent the invention or to rely on secrecy. If the leader chooses to patent the invention, we will assume that the invention is fully disclosed, so that the follower can use this information, but the leader collects an interim profit by marketing the product. 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[8] during this period, it will carry a cost and at the same time the leader cannot collect any gain from the discovery.

2.2 Stage two

In the second stage, firms have to make an other investment decision for the remaining invention. This will of course depend on the decision previously made by the leader (patent or secrecy). 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.

If the leader decides to patent the invention (P), both firms choose whether to participate or not for the second invention in the race (based on the choices previously made). In this case, the information on the product is disclosed through the patenting process, so that both firms can race at a speed of λ. However, during the discovery process, the leader is able to collect an interim profit for the commercialization of the first product. The game ends if no firm invests in the second invention. Otherwise, if at least one firm races, the game ends when the second invention is developed and patented.

If the leader chooses to rely on secrecy, both firms again have to choose whether or not to invest in the second invention in this second race. In this scenario, 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 keep the same likelihood parameter as previously: μ. A crucial assumption made in the model is that the follower knows that a discovery took place and which one it is. The alternative setup in which the follower would not be aware that the leader has invented would be very difficult to implement in a multiple stages patent race with a Poisson discovery process. Thus we rely on the previous literature which makes the same assumption

[8]This is a standard assumption in the literature, as it is usually assumed that if the product is commercialized but not patented, reverse engeenering is easy, so that the leader would loose its leading advantage. See Scotchmer and Green (1990) for instance.

(Scotchmer and Green, 1990 or Denicolò, 2000).

If the leader (firm A) discovers the second invention first, the game ends at this point. There is however a 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 chooses to race for the invention already discovered by the leader and kept secret. If the invention is not the same, both firms will patent their respective invention: 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 will take place for the remaining invention, where, again, both firms will have to decide whether they will invest in it or not.

3 Solving the game

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

3.1 The first innovator patents

Begin at the point where the first innovator, say firm A, has patented the invention (choice P). 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, 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. 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:

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

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 this firm does not own any invention. And 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:

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

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 between the patenting decision and the date of discovery of the second invention. However, it can be shown that it is optimal for the firms to take one-time decisions whether to invest or not. Thus, the results would be the same in a version of the model where we allow the firms to deviate from a given strategy before the final date of discovery. In addition, we will only focus on equilibria in pure strategies.

Table 1: Continuation payoffs if A patents 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. $\frac{1}{r}+1 > \frac{\lambda\left(\frac{1}{r}\right)+1-c}{\lambda+r}, \forall\lambda, c \in [0,1]$ 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 interim 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	$\lambda\frac{\alpha}{r} < c$

Remark 2 *If the leader chooses to patent the first product, both firms will invest for the second one, if the intensity of competition is intermediate or high and the expected duopoly profits is positive. However, the leader will drop out as soon as competition becomes low. None of them is going to invest if the expected duopoly profits are negative.*

We find that none of the firms is going to invest for the second invention if the expected duopoly profit is negative, i.e. $\lambda\frac{\alpha}{r} < c$, and none of them is going to deviate as long as this condition is met.

3.2 The first inventor keeps the invention secret

We now turn to the scenario where the first innovator chooses not to disclose its innovation, and thus the follower can not benefit from the knowledge embedded in it. This is formalized by supposing that there is an asymmetry in the instantaneous probabilities that the firms discover the second invention. The leader will race with an instantaneous probability of λ, and the follower will race with a probability of μ, with $\lambda \geq \mu$. 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.

As firm A did not patent the invention, it cannot be commercialized and thus A is not able to collect the interim profit. The fact that A already has an innovation is however common knowledge. This assumption implies that there are spillovers between both firms, for example, labor mobility or industrial espionage.

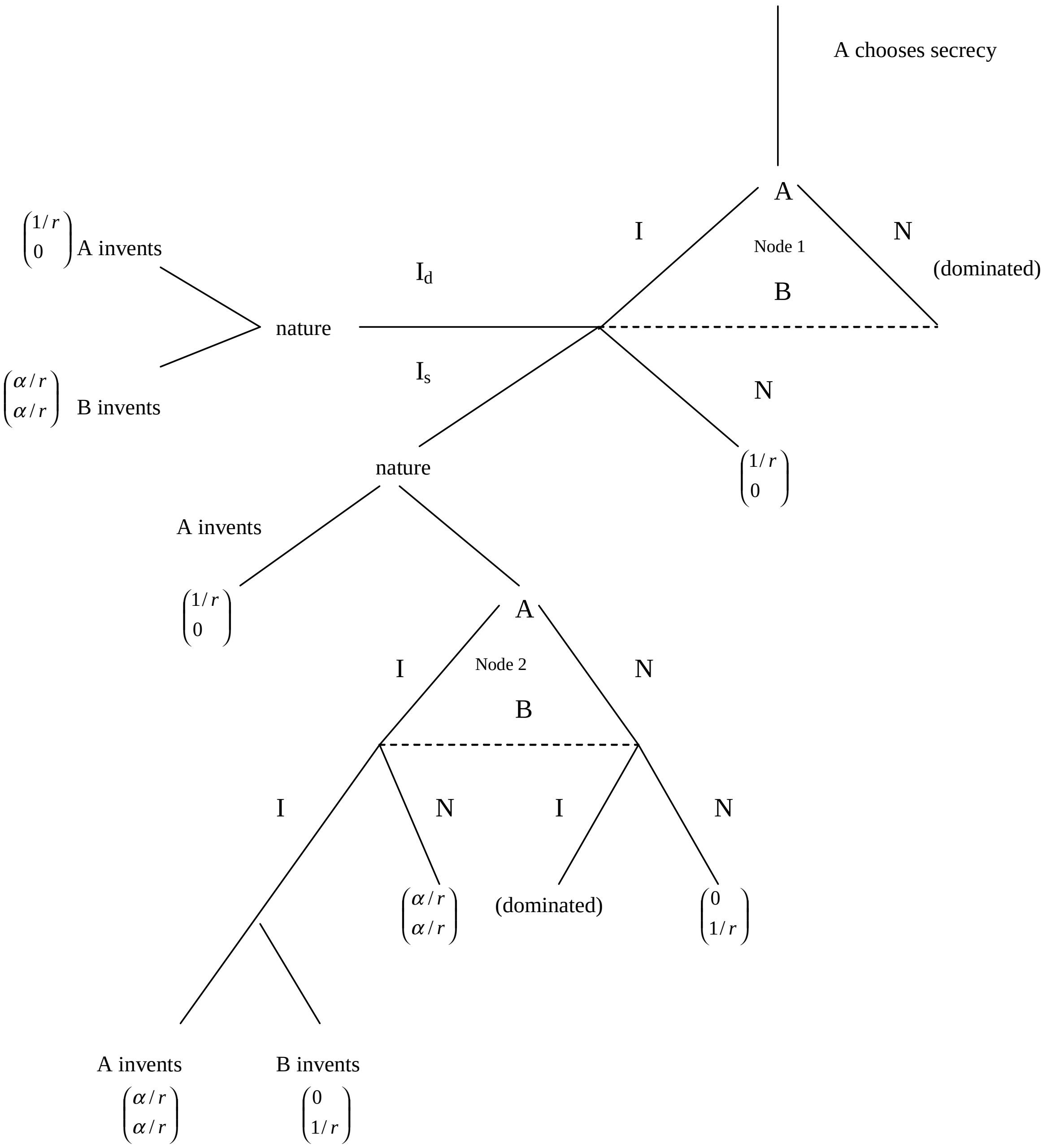
In order to ease the exposition of the assumptions made after A has kept the first invention secret, we represent a part of the timing of the game at this point, in figure 2. The payoffs indicated in the tree represent the discounted future profits, valued at the final discovery date.

Remark 3 *It is a dominant strategy for firm A to invest continuously following a secrecy choice, provided $\lambda\frac{1}{r} \geqslant c$, which means that the expected monopoly profit has to be positive.*

Proof. see appendix A ■

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 (I_s) and discovers it before firm A has found the remaining invention.

Figure 2: *Timing of the game after A's choice of secrecy*



Firm B will patent it and a race for the remaining innovation has to be made (node 2). Both firms will race at the same speed as they both have the same stock 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

A	**I**	**N**
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	$0, \frac{\lambda\frac{1}{r}+1-c}{\lambda+r}$	$0, \frac{1}{r}+1$

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 $V_{B;3}^{S/ij}$,given in table 3 depending on the decisions taken at node 2, $i, j = \{I, N\}$.

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

B

	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

We now examine the decision of B to participate in the second race after A has kept the first innovation secret. 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 gives 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 are given in table 5, 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	**$\mathbf{I}_s$ preferred to $\mathbf{I}_d$**	**$\mathbf{I}_s$ 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	**$\mathbf{I}_d$ preferred to $\mathbf{I}_s$**	**$\mathbf{I}_d$ preferred to N**
II	$\alpha > 1 - \frac{cr}{r+\lambda}$	$\mu\frac{\alpha}{r} > c$
IN	I_d never optimal	
NN	I_d never optimal	

Conditions for N to be optimal

Choices at node 2	**N preferred to $\mathbf{I}_s$**	**N preferred to $\mathbf{I}_d$**
II	$\alpha < 1 - \frac{cr}{r+\lambda}$	$\mu\frac{\alpha}{r} < c$
IN	N always optimal	
NN	N always optimal	

3.3 The decision to patent versus secrecy

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.

Table 6 summarizes the different conditions under which A is going to patent its first invention, based on the decisions made at latter stages. To make the different choices comparable, the conditions on the parameters that we derived before have to be the same. As the potential third race in the secrecy case and the second race in the patenting case are symmetric, they are only comparable for symmetric choices. 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 same 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**
$S/II_s/II$	P/II	$\alpha < -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu)}{\lambda(r+\lambda)}$
$S/II_s/IN$	P/NI	$\alpha < \frac{\lambda^2-r^2(1+c)-r[\mu+c(\lambda+\mu)]}{r0.5\mu-\lambda(\lambda+r)}$
S/II_d	P/II	$\alpha < -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu-c\mu)}{(\lambda-\mu)(r+\lambda)}$
S/II_d	P/NI	$\alpha < -\frac{(r+cr-\lambda)(r+\lambda)+r\mu}{\lambda(r+\lambda)-r\mu}$
S/IN	P/II	$\alpha < 1 - \frac{r[r+\lambda(c+2)]}{\lambda(\lambda+r)}$
S/IN	P/NI	$\alpha < 1 - \frac{r(c+1)}{\lambda}$
S/IN $S/II_s/NN$ S/II_d	P/NN	Never Nash equilibria (alternative choice preferred)

3.4 The first race

At this stage (not represented in figure 2), we determine if firms will initially enter the race, which they will do only if their *ex ante* profits are nonnegative. Each of them has probability μ of finding the first invention, and thus to be in the position of A (which we called 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 exponential distribution with parameter 2μ. Thus, the *ex ante* profit for firm $k = \{A; B\}$ in the first race is given by:

$$\pi_k = \frac{\mu V_{k;1}^{y/ij} + \mu V_{k;1}^{y'/i'j'} - c}{2\mu + r}$$

With $V_{k;1}^{y/ij}$ being the future expected payoffs, discounted to the present, depending on the choices $i, j, i', j' = \{I, N\}$ and $y, y' = \{P, S\}$ .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 $\pi_k \geq 0$.

4 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 3 and 4. 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 B.

First and foremost, note that in the "south-west" area (P/NN), 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.

Figure 3 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 product, whereas the follower will stay in. The explanation, given that the degree of competition and the hazard rate are low, is that it is more profitable for the leader to share the profits than to pay the cost and get 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) is high.

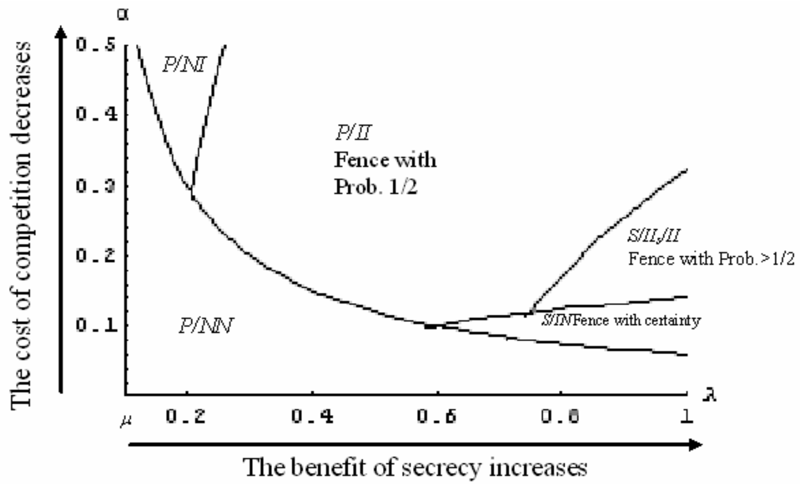
However, the follower will drop out of the second race as soon as competition becomes stronger (S/IN), and the leader continues to invest; the reason is that if a single invention is patented, the follower would invest in the second one. Moreover, a crucial assumption of the model is that an invention kept secret cannot be marketed. Thus, 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.

Consider now figure 4 with $\mu = 0.2$. The situation is somewhat different as the benefit of having the first invention is lower. The increase in μ has lowered the P/NN region, which is the area where none of the firms will invest in the second race, after the fist invention has been patented.

The leader will keep the invention secret for intermediate levels of competition (α) to keep the leading advantage, as 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 behavior of the follower does not depend

Figure 3: Equilibria of the game: $c = 0.2$, $\mu = 0.1$, $r = 0.3$



on μ, as all information is disclosed, but on λ. 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 4. The S/IN region from figure 3 disappears, and on the other hand, the "P/II" region increases in figure 4. In this region it becomes more profitable for the leader to patent and collect the interim profit.

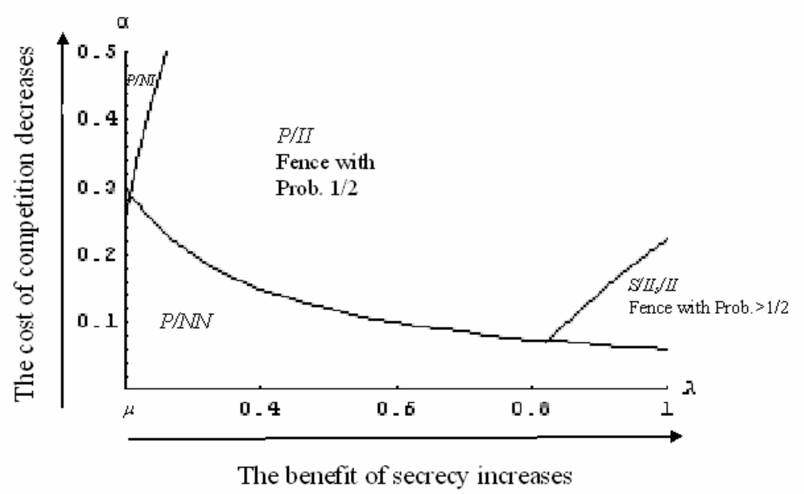
The explanation is that, if the technological gap ($\lambda - \mu$) becomes smaller, the follower will invest more and the leader will rely on secrecy less often.

Our motivation was to study the process of creating a patent fence surrounding some core invention[9]. We now turn to this question by first defining what can be called a "fence" in this model.

Definition 4 *A patent fence (of non-improving substitutes) is defined as a portfolio of close substitute patents owned by the same firm.*

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

Figure 4: Equilibria of the game: $c = 0.2$, $\mu = 0.2$, $r = 0.3$



In our model, a fence is created when one of the firms owns patents for both inventions. In other words, 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.

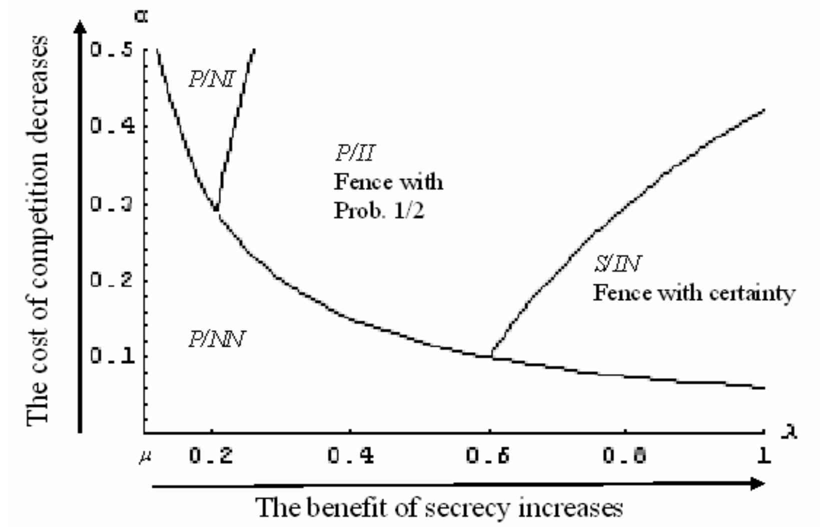
The above analysis and the conditions derived in tables 1 to 6, enable us to make the following proposition:

Proposition 5 *Potential fences of substitute inventions are created for intermediate and low levels of competition. When firms wish to build fences, they patent the first invention when the technological gap (i.e. the difference between λ and μ) is intermediate. On the other hand, they keep it secret when competition is intermediate and the benefit of secrecy is large.*

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. It is also more profitable for the leader to patent the invention in order to collect the interim profit.

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.

Figure 5: Equilibria in First-to-Invent: $c = 0.2, \mu = 0.1, r = 0.3$



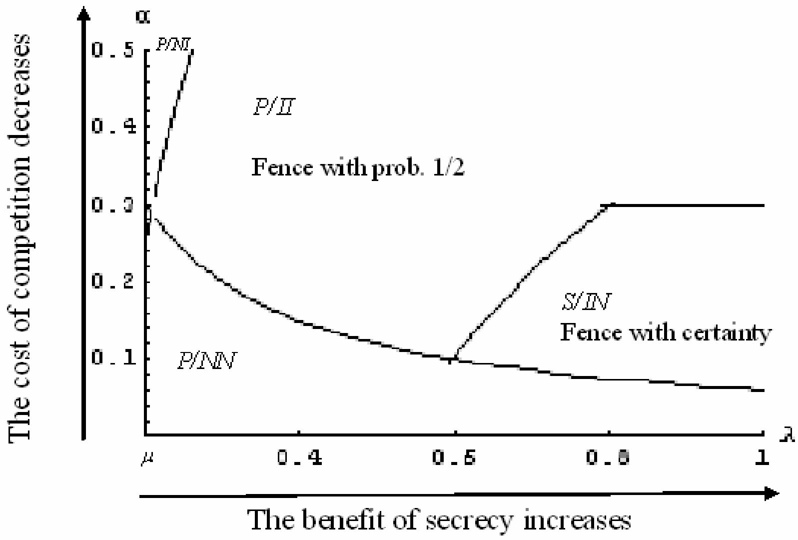
What would happen if the parameters had different values? If the cost c is high, the P/NN region would increase, and none of the firms would ever invest in a second invention. On the other hand, if the cost is too low, the firms would always invest in both products.

It is obvious, that if μ is very high, the leader will always patent the first invention as secrecy does not lead to an important advantage. Similarly, if we fix a low μ, the leader will always rely on secrecy, and the follower will never invest in the following races.

5 Fences in first-to-invent

Our analysis was based on the first-to-file system. We now examine how the alternative legal rule that applies in the United States affects the creation of patent fences. The only difference in the game appears at node 2 in figure 2, when firm B wants to patent the invention that the leader has kept secret. If the invention is duplicated by firm B, the patent will nevertheless be granted to firm A, according to the US patent system. Thus, the only part of the

Figure 6: Equilibria in First-to-Invent: $c = 0.2, \mu = 0.2, r = 0.3$



game affected is the potential third race, for which firm A, instead of B, will be the leader. At this stage, the continuation values are similar to those in table 1.

However, the conditions under which firm B invests after a secrecy choice from firm A differ (table 7). As expected, the follower will never choose to invest in the invention already found by firm A under the First-to-Invent legal rule. Even if B finds the invention, the patent will be granted to firm A.

Table 7: Conditions for B to invest in the second race resulting from a secrecy choice by A (first-to-invent)

Conditions for I_d to be optimal

<table>
<tr><th>Choices at node 2</th><th>I_d preferred to I_s</th><th>I_d preferred to N</th></tr>
<tr><td>II</td><td rowspan="3">I_d always optimal</td><td rowspan="3">$\mu\frac{\alpha}{r} > c$</td></tr>
<tr><td>IN</td></tr>
<tr><td>NN</td></tr>
</table>

Conditions for N to be optimal

Choices at node 2	**N preferred to $\mathbf{I}_s$**	**N preferred to $\mathbf{I}_d$**
II	$\alpha < \frac{cr(2\lambda+r+\mu)}{\lambda\mu}$	$\mu\frac{\alpha}{r} < c$
IN	$\alpha < \frac{cr(\lambda+r+\mu)}{\lambda\mu}$	
NN	$c > 0$	

The conditions under which firm A keeps the first invention secret differ only when firm B invests in the same invention in the second stage. This comes from the fact that the only part of the game affected (with respect to the first-to-file rule) is the potential third race. But as shown above, the follower will never make this choice. In the analytical analysis, the conditions for the leader to rely on secrecy are the same than in table 6, with the difference that the choices implying a duplicative investment by the follower (I_s) disappear.

Figures 5 and 6 describe the equilibria with the same parameter values as in figures 3 and 4. Scotchmer and Green (1990) found that the first-to-invent rule implies more secrecy than the first-to-invent rule in a similar framework, but with cumulative innovations. This is also the case here. 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 patent the invention for low λ, 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 and makes the follower drop out of the race.

6 Comparing First-to-file and First-to-invent

Figures 7 and 8 compares the first-to-invent rule (figures 5 and 6) with the first-to-file rule (figure 3 and 4) in two ways. First, we show the parameter

Figure 7: Comparison First-to-File/First-to-Invent: $c = 0.2, \mu = 0.1, r = 0.3$

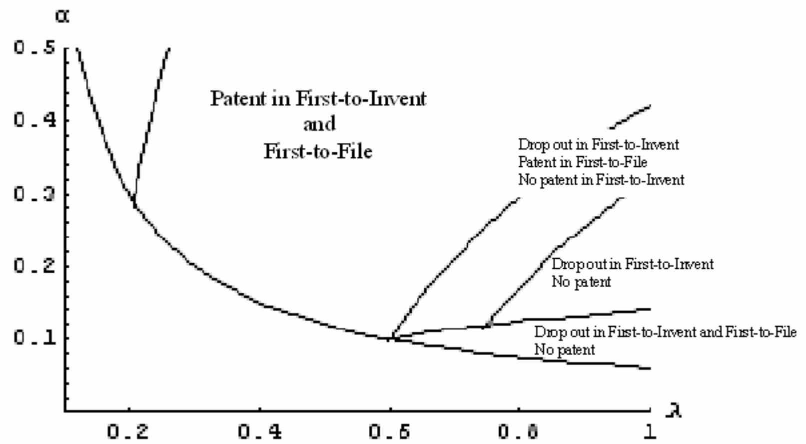
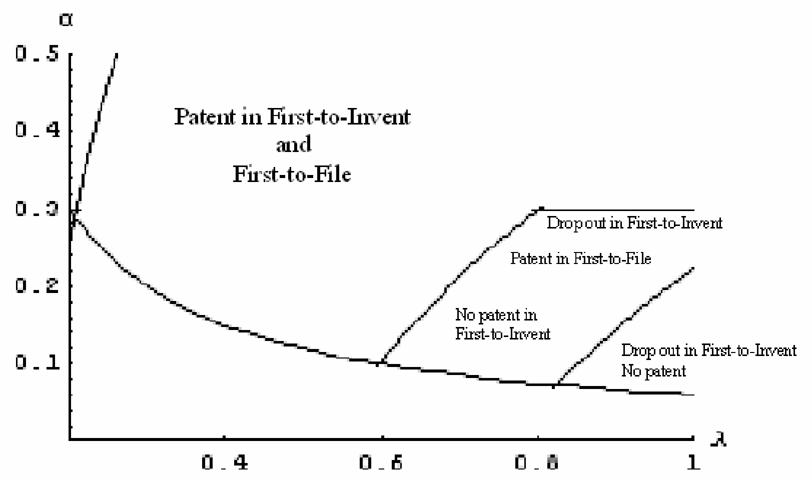


Figure 8: Comparison First-to-File/First-to-Invent: $c = 0.2, \mu = 0.2, r = 0.3$



region for which the leader will patent the first invention or not. Scotchmer and Green (1990) argue that disclosure accelerates discovery, so that patenting is always preferable. We find the same result: the First-to-Invent rule induces secrecy for more parameter values than the First-to-File rule in the case of "fencing patents". The implications are, however, different. As there might be a wasteful duplication, secrecy can be better than patents if it makes the follower drop out.

Secondly, we examine the parameter values for which the follower will drop out of the race. There, as well as in Scotchmer & Green (1990), a shake-out will occur for more parameter values with First-to-invent. Again, the conclusions that we can make 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 the firms which race for substitute inventions, the deadweight loss is likely to be reduced if both firms compete on the same market.

Making conclusions about the social benefits of one or the other legal rule is not obvious is this model. On the one hand, if there is an investment for both products, that is a duplication, this can be viewed as a waste of R&D as the substitute invention does not add anything (or at least very little[10]) to the society's stock of knowledge. On the other hand, the fact that more than one firm is on the same market implies more competition and reduces the welfare loss due to a monopoly distortion. The next section aims at exploring this issue.

7 Welfare analysis

This section examines social welfare at the beginning of the first race. 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

[10] One could think of a situation in which one of the inventions has an application on another market.

social benefit of their innovations. Let $s \geqslant 0$ be the non appropriable value of the innovations. It represents the increase in social welfare that 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 $d'(\alpha) < 0$ and if competition is weak, the function has a lower bound: $d(0.5) = 0$. 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 wether 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 favored 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 non-appropriable part.

In (3), the social welfare in the second race depends on which firms wins this race. If the winner of the second race is the same than in the first one, which occurs with probability λ, the private does not change, 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 $d(\alpha)$.

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

$$W^{P/NI} = P(\mu)\left[\frac{1+s}{r} + P(\lambda)\left(\frac{2\alpha-1+d}{r}\right) - c\right] - 2c \tag{4}$$

$$W^{P/NN} = P(\mu)\left(\frac{1+s}{r}\right) - 2c \tag{5}$$

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[11]:

$$W^{S/IN} = P(\mu)P(\lambda)\left(\frac{1+s}{r} - c\right) - 2c \tag{6}$$

$$W^{S/II_d} = P(\mu)\left[\frac{\lambda}{\lambda+\mu+r}\left(\frac{1+s}{r}\right) + \frac{\mu}{\lambda+\mu+r}\left(\frac{2\alpha+s+d}{r}\right) - 2c\right] - 2c \tag{7}$$

$$W^{S/II_s/II} = P(\mu)\left[\frac{\lambda}{\lambda+\mu+r}\left(\frac{1+s}{r}\right) + \frac{\mu}{\lambda+\mu+r}\left(\frac{W^{P/II}+2c}{P(\mu)}\right) - 2c\right] - 2c \tag{8}$$

$$W^{S/II_s/IN} = P(\mu)\left[\frac{\lambda}{\lambda+\mu+r}\left(\frac{1+s}{r}\right) + \frac{\mu}{\lambda+\mu+r}\left(\frac{W^{P/NI}+2c}{P(\mu)}\right) - 2c\right] - 2c \tag{9}$$

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

Since the follower will not invest in the same invention as the leader under the First-to-Invent legal rule, equations (8) and (9) have to be taken out of the analysis in this case.

In a similar analysis, with cumulative innovations, Erkal (*forthcoming*) finds that patenting is the socially optimal choice, whenever the payoffs under patenting are higher than under secrecy. This is not always the case here. The results strongly depend on the sign of $2\alpha - 1 + d$ (i.e., if the loss of the firms' profits under duopoly are compensated by the gain in the consumer surplus), and on the shape of $d(\cdot)$ and the size of s, as well as the technological gap between both inventions $(\lambda - \mu)$. Thus, a more precise welfare analysis regarding the optimality of either patenting or secrecy would require to specify the size of the deadweight loss from monopoly, relative to the cost of duplication.

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 that is 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. This might raise anti-trust concerns and implies a "waste of R&D".

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 invests to find a substitute. This function has to 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.

$$W^{P/NN} - W^{S/IN} = \frac{1 + s + \lambda c}{\lambda + r} > 0 \tag{10}$$

The comparison of both functions clearly shows that a single product is socially preferable to a fence that will be built with certainty. The fist 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:

$$W^{P/NN} - W^{P/II} = 2c - \frac{\lambda\,(2\alpha - 1 + d)}{(2\lambda + r)r} \tag{11}$$

$$W^{P/NN} - W^{P/NI} = c - \frac{\lambda\,(2\alpha - 1 + d)}{(\lambda + r)r} \tag{12}$$

Equation (11) and (12) 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:

$$W^{P/NN} - W^{S/II_d} = \frac{(1 + s)(\mu + r) - \mu(2\alpha + s + d)}{r\,(\lambda + \mu + r)} + 2c \tag{13}$$

$$W^{P/NN} - W^{S/II_s/II} = \frac{1 + s + 2c(\lambda + 2\mu + r)}{\lambda + \mu + r} - \frac{\lambda\mu(2\alpha - 1 + d)}{(\lambda + \mu + r)\,(2\lambda + r)\,r} \tag{14}$$

$$W^{P/NN} - W^{S/II_s/NI} = \frac{1 + s + 2c(\lambda + 1.5\mu + r)}{\lambda + \mu + r} - \frac{\lambda\mu(2\alpha - 1 + d)}{(\lambda + \mu + r)\,(\lambda + r)\,r} \tag{15}$$

The signs of equations (13) to (15) 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.

The implications of these results are twofold. Equation (10) shows that a single patent is socially preferable to a fence that 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.

8 Conclusion

This paper intended to study the behavior 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 to rely on secrecy, allowing for different levels of competition. This index of competition can take different forms. The polar cases are, on the one hand "Bertrand competition", which drives the duopoly profits to zero, and on the other hand, a weak type of competition, which could take the form of a collusion between the firms.

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 rule, it is shown that firms try to create such fences of substitute inventions, when competition is low or at an intermediate level. We also show that in such a setup, firms will patent their inventions for weak or low levels of competition and rely on secrecy when competition is intermediate, and the technological gap between the inventions is high.

We also showed that the First-to-invent rule implies more secrecy in this context, which is consistent with the case of cumulative innovations.

Finally, the welfare analysis shows that fences 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, coming from the duopolistic market structure.

Future work, from an empirical point of view, could be to test some of the results of the model, among which, the relation between the competition level and the creation of patent fences.

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Appendix

A Proof of Remark 3

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 that 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:

$$\left[\lambda\frac{1}{r} + \mu\frac{\alpha}{r} - c\right] dt + (1 - \lambda dt - \mu dt)\, P_A e^{-rdt} \geq \mu\frac{\alpha}{r}dt + (1 - \mu dt)\, P_A e^{-rdt} \tag{16}$$

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

$$P_A \leq \frac{\lambda \frac{1}{r} + \mu \frac{\alpha}{r} - c}{\lambda + \mu + r} \leq \frac{\lambda - cr}{\lambda r} \tag{17}$$

II. If B invests in the product that has been found by firm A (choice I_s)

Inequality (16) becomes:

$$\left[\lambda \frac{1}{r} + \mu V_{A;3}^{S/ij} - c\right] dt + (1 - \lambda dt - \mu dt)\, P_A e^{-rdt} \geq \mu V_{A;3}^{S/ij} dt + (1 - \mu dt)\, P_A e^{-rdt} \tag{18}$$

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

$$P_A \leq \frac{\lambda \frac{1}{r} + \mu V_{A;3}^{S/ij} - c}{\lambda + \mu + r} \leq \frac{\lambda - cr}{\lambda r} \tag{19}$$

III. If B does not invest.

Then the relevant inequality becomes:

$$\left(\lambda \frac{1}{r} - c\right) dt + (1 - \lambda dt)\, P_A e^{-rdt} \geq P_A e^{-rdt} \tag{20}$$

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

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

$$P_A \leq \frac{\lambda \frac{1}{r} - c}{\lambda + r} \leq \frac{\lambda - cr}{\lambda r} \tag{21}$$

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

B 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)

(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)
(iii) $\alpha > \frac{\lambda^2-r^2(1+c)-r[\mu+c(\lambda+\mu)]}{r0.5\mu-\lambda(\lambda+r)}$ Firm A patents (table 6)
(iv) $\alpha > 1 - \frac{r(c+1)}{\lambda}$ Firm A patents (table 6)

(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) $\alpha > \frac{r[c(r+\lambda)\mu]}{\mu\lambda}$Firm B invests in the second race (tables 4 and 5)
(vi) $\mu(1+r) > cr$Firm B invests in the second race (tables 4 and 5)
(vii) $\alpha < -\frac{r^2+\lambda(\mu-\lambda)+r(\lambda+c\lambda+\mu)}{\lambda(r+\lambda)}$ Firm A keeps the first invention secret (table 6)

(5) $S/II/IN$ is the optimal choice if:

(i) $\alpha > 1 - \frac{cr(\lambda+r)}{\lambda^2}$ Firm B does not invest in the potential third race (tables 1 and 2)
(ii) $\lambda\frac{\alpha}{r} > c$ Firm A invests in the potential third race (tables 1 and 2)
(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) $\alpha > \frac{r[c(r+\lambda)\mu]}{\mu\lambda}$Firm B invests in the second race (tables 4 and 5)
(vi) $\mu(1+r) > cr$Firm B invests in the second race (tables 4 and 5)
(iv) $\alpha < \frac{\lambda^2-r^2(1+c)-r[\mu+c(\lambda+\mu)]}{r0.5\mu-\lambda(\lambda+r)}$ 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) $\alpha < \frac{r[r+\lambda(c+2)]}{\lambda(\lambda+r)}$ Firm A keeps the first invention secret (table 6)
(iv) $\alpha < 1 - \frac{r(c+1)}{\lambda}$ 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)
(iv) $\alpha < -\frac{(r+cr-\lambda)(r+\lambda)+r\mu}{\lambda(r+\lambda)-r\mu}$ Firm A keeps the first invention secret (table 6)