Losing the Lead: The Patenting Decision in the Light of the Disclosure Requirement

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Abstract

Empirical findings state that the disclosure requirement might be a reason for firms to rely on secrecy rather than patents to protect their inventions. We choose a dynamic framework in which we can explicitly analyze the patenting decision reflecting the trade off between a positive protective effect and a negative effect due to the required disclosure of the protected invention. Despite of a patent the inventor's rival may still enter the market with a non-infringing product. The technological lead of the inventor is measured by a time advantage he has compared to his rival. We show that if his head start exceeds a critical threshold he will not patent and rather rely on risky secrecy.

Keywords: patenting decision, secrecy, disclosure requirement, patent height, vertical product differentiation

JEL Classifications: L13, O14, O33, O34

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1 INTRODUCTION

Firms do not patent every invention. In many cases they rather rely on risky secrecy to appropriate the returns from their research efforts. In their seminal empirical study *Cohen et al.* (2000) find that a major reason for this - at a first glance - surprising behavior is the disclosure requirement that is linked to a patent. With data from the 1993 European Community Innovation Survey (CIS) for up to 2849 R&D-performing firms *Arundel* (2001) explicitly analyzes the relative importance of secrecy versus patents. His findings support the results of *Cohen et al.* (2000): A higher percentage of firms in all size classes rate secrecy as more valuable than patents. Why is it that firms refrain from patenting although they could profit from temporary monopoly power? One possible explanation stated in the empirical literature is the loss of a technological leadership caused by the disclosure of proprietary knowledge. The patentee has to fear that the transfer of enabling knowledge included in the patent description may benefit his rivals instantaneously by facilitating a rapid catch-up. On account of this they could be able to invent around the patent at an earlier point in time, thereby terminating the monopoly of the patentee.

Considerable theoretical attention has been devoted to the study of the patenting decision of R&D-performing firms.[1] A common assumption in this literature is that the disclosure requirement has no impact until a patent expires. Only then the enabling knowledge can be used by the competitors and everyone skilled in the art is able to produce and market the formerly protected invention. This assumption obviously does not reflect the empirical findings stated above: according to the empirical evidence the disclosure requirement has a strong influence on the patenting decision of the innovating firm. To our knowledge so far only few papers follow a more comprehensive approach.

In a vertically differentiated product market *Yiannaka*, *Fulton* (2006) analyze the strategic patent breadth decision of a patentee who can potentially deter the entry of a rival firm. Due to the disclosure requirement of the patent, the market entry costs of the rival are set to zero. While *Yiannaka*, *Fulton* (2006) focus on the patentee's choice of the strength of his patent our focus lies on the patenting decision itself which is not considered in their model.

Anton, *Yao* (2004) take the patenting decision into account and additionally assume that an inventor can decide how much of the invention (*enabling knowledge*) to disclose. Their main result is that small innovations

[1] See for example *Horstmann et al.* (1985), *Gallini* (1992), *Denicolò*, *Franzoni* (2004a,b), *Anton*, *Yao* (2003, 2004), and *Bessen* (2005).

are patented and fully disclosed without being imitated while very large innovations are not protected by a patent due to the problem of imitation. Opposing to this we will explicitly incorporate the disclosure requirement so that the inventor has no choice on how much enabling knowledge he wishes to disclose: if he patents he is obligated to fully disclose his invention. Still we come to the same conclusion as *Anton*, *Yao* (2004) that whenever the technological advance of the inventor is very large, he will rather rely on secrecy instead of patenting.

Langinier (2005) studies the patenting decision of an innovator who has private information on the improvability of his invention. Due to the disclosure requirement a patent allows competitors to improve the innovation without undertaking all of the research already accomplished by the innovator. Eventually an improvement may invalidate the original patented innovation. If the inventor decides to keep his discovery secret, he maintains his technological lead but it is possible that a rival firm independently discovers the invention and decides either to exploit it or to patent it himself. Other than *Langinier* (2005) we assume that the innovator can exploit his innovation and realize positive profits even if he decides to rely on secrecy. A reason for this may be that reverse engineering is prohibitively costly, which for example is the case in industry sectors such as aerospace or precision instruments where products are extremely complex.[2] But even in industries where reverse engineering is a threat for innovating firms, a rival firm will never be able to immediately market a copied product. Instead it will need to invest some amount of time until it is able to produce something similar to the initial innovation. In our model we include this case by assuming that the inventor has a technological lead compared to his rival and that the rival needs a given time span to catch up with the inventor. To capture this temporal lead, we need a dynamic framework. A related paper is that of *Erkal* (2005) who extends the setting of a repeated R&D race as introduced by *Denicolò* (2000). If the winner of a R&D race decides to patent his invention he loses his technological lead and consequently all firms face the same probability of success subsequently. Although this approach incorporates the disclosure requirement in a realistic way, a major drawback of the race setting is that the prize for the winner - the value of the patent - is exogenously determined. As the patent value clearly is one of the main decisive factors concerning the choice between a patent and secrecy, we will analyze this issue in a dynamic framework where the value of patenting is defined endogenously.

[2] *Arundel et al.* (1995) find that the three industry sectors aerospace, precision instruments and telecommunications equipment even rely on the technical complexity of their products as a protection mechanism for their innovations.

Methodically our paper builds on *Dutta et al.* (1995) who model the strategic market entry decisions of two rival firms in a vertically differentiated product market. Due to the dynamic setting in *Dutta et al.* (1995) and their assumption that the quality of an innovation increases costlessly over time, a first adopter can realize monopoly profits offering a low-quality product until the rival firm enters and offers a product with higher quality. Then both compete in an asymmetric duopoly. Both firms strategically choose their optimal adoption dates, that is, the quality at which they decide to cease their research activities and launch the achieved quality as a new product. *Dutta et al.* (1995) do not consider aspects of patent protection. They propose that two alternative equilibria evolve depending on the extent of consumer diversity: a *preemption* equilibrium, where both firms engage in a race for being the first, and a *maturation* equilibrium, where firms postpone adoption to reach a higher quality level.[3]

Extending *Dutta et al.* (1995) we assume that firms are asymmetric in their adoption capabilities.[4] One firm is a successful inventor and possesses the complete technological knowledge about his invention. His rival, the non-inventor, has failed to make the invention, but has accumulated some know-how. Additionally to the adoption decision the inventor faces the choice between a patent and secrecy to protect his discovery. A patent protects a given quality range and offers temporary monopoly power but has the drawback of the disclosure requirement linked to it. As we assume that inventing around is possible, the non-inventor may still enter the market despite of a patent. In this case both firms compete in an asymmetric duopoly.

To analyze the impact of the disclosure requirement on the patenting decision of the inventor, we assume that a patent requires the immediate and full disclosure of all technical details concerning the discovery. This transfer of enabling knowledge benefits the non-inventor instantaneously as it boosts his research so that he may be able to invent around the patent at an earlier point in time. The patenting decision of the inventor therefore has to balance the tradeoff between the benefits of temporary monopoly power on the one hand and the drawback of the complete disclosure of enabling knowledge on the other. We show that the positive effect may be enhanced by stronger property rights while the negative effect is subject to the extent of the tech-

[3]In a succeeding paper *Hoppe*, *Lehmann-Grube* (2001) prove that the *maturation* equilibrium proposed by *Dutta et al.* (1995) actually does not exist since the market coverage condition is not fulfilled (see *Hoppe*, *Lehmann-Grube* (2001), Proposition 1, p. 425) and show that by incorporating research costs this error can be fixed.

[4]Note that due to the assumed asymmetry between firms in our model setting the terms "maturation" and "second mover advantage" cannot be used equivalently as in the symmetric settings of *Dutta et al.* (1995) and *Hoppe*, *Lehmann-Grube* (2001).

nological lead.

The rest of the paper is organized as follows. Section 2 extends the model of *Dutta et al.* (1995) to asymmetric firms and analyzes the subgame equilibria for the case that the inventor decides to keep his invention secret (Section 2.1) and for the case that he patents (Section 2.2). In Section 2.3 we derive the subgame perfect Nash equilibrium of the considered three stage game, considering alternative intensities of patent protection. Section 3 concludes. All Proofs can be found in the Appendix.

2 THE MODEL

The patenting decision of a successful inventor and the market entry decisions of the two considered firms are modeled in a three stage game. On the first stage the inventor, henceforth denoted by subscript i, chooses the protection method for his discovery. His strategy, σ_i, can either be to protect it by a patent, $\sigma_i^1 = P$, or to keep his invention secret, $\sigma_i^1 = S$. Note that the superscript denotes the stage of the game for which a strategy is relevant. On the second stage firms choose whether to market a product of low quality, $\sigma_u^2 = x_l$, $u = i, j$, or a product of high quality, $\sigma_u^2 = x_h$, $u = i, j$. On the third stage firms compete in prices in an asymmetric duopoly. The extent of the inventor's technological head start is assumed to be common knowledge. We will solve this three stage game by backward induction, setting off with the last stage where firms compete in prices, given their quality choices and the method of protection. Before we proceed with the analysis, we need to take a closer look at the dynamic nature of product quality.
Following *Dutta et al.* (1995) and *Hoppe*, *Lehmann-Grube* (2001) we assume that investing more time in research activities suffices to improve the quality of the new technology over time. More precisely, the quality of the invention, x, increases by one unit in every subsequent period without involving any further research costs. Thus, the inventor's research time is given by

$$t_i(x) = x, \tag{1}$$

implying that in order to reach a certain quality level $\bar{x}$ the inventor has to invest $t_i(\bar{x}) = \bar{t}$ periods of time. By this the adoption date $\bar{t}$ defines the adopted quality level, $\bar{t} = \bar{x}$. Extending *Dutta et al.* (1995) we assume that at the date of the invention ($t = 0$) the inventor has a technological lead compared to his rival. This initial lead is measured by $\tilde{\gamma}$ and it will be reduced by an unintended leakage of information as long as the invention is not protected by a patent. The spillover of information is measured by an exogenously given leakage parameter λ.[5] This means that whenever the inventor chooses secrecy the extent of his technological lead at any point in time $t > 0$ will differ from his *initial* headstart whenever $\lambda > 0$. We define the extent of his *effective* technological lead as $\gamma \equiv \tilde{\gamma}(1-\lambda)$. Without spillovers the non-inventor would have to invest $\tilde{\gamma}$ periods more than the inventor to reach a certain quality, but due to the spillover of information his research time is shortened by $\lambda\tilde{\gamma}$. Thus the non-inventor's research time can be specified by

$$t_j(x) = x + \tilde{\gamma} - \lambda\tilde{\gamma} = x + \gamma. \tag{2}$$

Following *Dutta et al.* (1995) we assume for simplicity that costs of production are zero.

The demand side is modeled using the idea of the natural-oligopoly model of *Shaked*, *Sutton* (1982). At most two firms can earn positive profits. Consumers differ in their tastes θ for improvements of the basic invention and are uniformly distributed with unit density $f(\theta) = 1$ in the interval $[a, b]$ where $b > 2a > 0$. This assumption assures a minimum level of consumer heterogeneity so that it is potentially possible for both firms to enter the market and earn positive profits. Each consumer will buy one unit of the product in every period as long as his net utility, $U = \theta x - p$, is greater than zero.

The early adopter offers a low quality x_l. All consumers with a quality preference $\theta \geq p_l/x_l$ will buy one unit of the product with quality x_l from the temporary monopolist in every period until the rival firm offers a higher quality x_h. Straightforward computation yields the monopoly profit that the early adopter realizes in every period until his rival enters the market

$$\pi_m = A_m x_l \tag{3}$$

with $A_m \equiv b^2/4$. The adoption of the high quality x_h in t_h by the rival firm constitutes an asymmetric duopoly. By definition $x_h > x_l$. Then the consumer indifferent between buying high or low quality is situated at $\theta^0 = (p_h - p_l)/(x_h - x_l),\ h,\ l = i,\ j\,;\ i \neq j$. The market share for the firm offering the low quality is $[a, \theta^0]$ while the high quality offered by the late adopter has a market share of $[\theta^0, b]$. Standard computation delivers the duopoly prices

$$\begin{aligned} p_l &= (x_h - x_l)(b - 2a)/3 \\ p_h &= (x_h - x_l)(2b - a)/3 \end{aligned} \tag{4}$$

[5] We assume that λ remains unchanged over time and does not increase even if the invention is marketed. In a more realistic setting, one could assume that $\lambda(t)$ is increasing over time with $\lambda'(t) > 0$ and $\lim_{t\to\infty} \lambda = 1$. This would not change the qualitative nature of our results but would make the analysis much more complex.

and the corresponding profits per period

$$\pi_h = A_h(x_h - x_l) \tag{5}$$
$$\pi_l = A_l(x_h - x_l) \tag{6}$$

with $A_h \equiv (2b-a)^2/9$ and $A_l \equiv (b-2a)^2/9$.
To assure that the market for differentiated quality goods is completely covered, the consumer with the lowest taste parameter has to realize a positive net utility from buying the low quality good, $ax_l - p_l \geq 0$. Inserting p_l as stated in equation (4), rearranging terms yields

$$x_l \geq x_h/(aA_l^{-1/2}+1) \tag{7}$$

as market coverage condition.

Now that we derived the pricing decisions of the firms given their quality choices, we proceed to the second stage where firms choose their qualities. Two scenarios are possible: (i) the inventor offers the low quality, $\sigma_i^2 = x_l$, while the non-inventor offers the high quality, $\sigma_j^2 = x_h$ or (ii) the non-inventor offers the low quality, $\sigma_j^2 = x_l$ while the inventor offers the high quality $\sigma_i^2 = x_h$.[6] Both cases are considered in the following analysis.
A late adopter has to decide when to adopt the new technology after his rival has already adopted a low quality x_l. Starting with his entry into the market in t_h with a high quality x_h the late adopter earns duopoly profits π_h per period. Assuming that all future profits are discounted with the interest rate $r > 0$ the lifetime profits of either firm as follower amount to

$$F_u(x_h, x_l) = \int_{t_u(x_h)}^{\infty} e^{-rt}\pi_h dt, \qquad u = i,\, j. \tag{8}$$

Inserting π_h as defined in equation (5) optimization with respect to the quality level x_h yields the optimum differentiation strategy given the early adopter's quality decision, x_l,

$$x_h^* = x_l + \frac{1}{r\,\frac{\partial t_u(x_h)}{\partial x_h}}, \qquad u = i,\, j. \tag{9}$$

As stated above the non-inventor will need γ additional periods to reach the quality x_h, so that his entry date as late adopter would be $t_j(x_h) =$

[6]The firms will only attempt to enter simultaneously if a technological lead is absent, $\gamma = 0$. Then the preemption equilibrium analyzed by *Dutta et al.* (1995) emerges. See p. 13 of this paper for further details.

$x_h + \gamma$. Due to his technological lead the inventor would be able to adopt this quality earlier, namely at $t_i(x_h) = x_h$. Obviously, in both cases the derivative of the research time function with respect to the level of quality equals one, $\partial t_u(x_h)/\partial x_h = 1$, $u = i,\, j$. This reduces the profit maximizing differentiation strategy as defined in equation (9) to $x_h^* = x_l + 1/r$ for both firms and gives us a constant optimum level of differentiation, $x_h^* - x_l = 1/r$, which is independent of the order of adoption. We can now derive the possible adoption dates by inserting this differentiation level into the respective research time functions (1) and (2). We get $t_i(x_h^*) = x_l + 1/r$ and $t_j(x_h^*) = x_l + 1/r + \gamma$ so that the respective lifetime profits amount to

$$F_j(x_l) = e^{-1-r(x_l+\gamma)}\pi_h/r$$

if the non-inventor is the late adopter (case(i)) and

$$F_i(x_l) = e^{-1-rx_l}\pi_h/r$$

if the inventor is the late adopter (case (ii)).

The early adopter anticipates the optimum differentiation strategy of his rival, x_h^*. His overall profit consists of two parts: the monopoly profits he realizes from his adoption in t_l until the second firm enters in t_h and the subsequent duopoly profits. Thus the lifetime profits of either firm if it is the leader amount to

$$L_u(x_l) = \int_{t_u(x_l)}^{t_u(x_h^*)} e^{-rt}\pi_m\,dt + \int_{t_u(x_h^*)}^{\infty} e^{-rt}\pi_l\,dt, \qquad u = i,\, j. \quad (10)$$

Inserting π_m and π_l defined by equations (3) and (6) and taking into account the optimum level of differentiation, $x_h^* - x_l = 1/r$, as well as the fact that $\partial t_u(x_h^*)/\partial x_l = 1$, optimization of (10) with respect to x_l yields the profit maximizing adoption quality for the first adopter

$$x_u^* = \frac{1 - e^{-r(t_w(x_h^*)-t_u)}(1 + A_l/A_m)}{r(1 - e^{-r(t_w(x_h^*)-t_u)})}, \qquad u, w = i,\, j; \qquad i \neq j. \quad (11)$$

Recall that two scenarios are possible: either the inventor takes the lead (i) or the non-inventor is the first adopter (ii). Let us first consider scenario (i). The inventor's research time as first adopter amounts to $t_i(x_l) = x_l$ and the non-inventor as second adopter would follow in $t_j(x_l) = x_l + 1/r + \gamma$. Inserting these relations into the profit function (10) and solving the integrals yields the overall profit of the inventor as early adopter

$$L_i(x_l) = \frac{(1 - e^{-1-r\gamma})\,\pi_m + e^{-1-r\gamma}\,\pi_l}{r\,e^{rx_l}} \quad (12)$$

with the corresponding profit maximizing quality level

$$x_i^* = \frac{1 - e^{-1-r\gamma}(1 + A_l/A_m)}{r(1 - e^{-1-r\gamma})}. \tag{13}$$

This changes in scenario (ii). As early adopter the non-inventor j could enter the market in $t_j(x_l) = x_l + \gamma$ and the inventor as second adopter would follow with $x_h^* = x_l + 1/r$ in $t_i(x_h^*) = x_l + 1/r$.[7] Inserting these adoption dates into equation (10) and solving the integrals yields the overall profits of the non-inventor as early adopter

$$L_j(x_l) = \frac{(e^{-r\gamma} - e^{-1})\,\pi_m + e^{-1}\,\pi_l}{r\,e^{rx_l}}$$

with the corresponding profit maximizing quality level

$$x_j^* = \frac{1 - e^{-1+r\gamma}(1 + A_l/A_m)}{r(1 - e^{-1+r\gamma})}. \tag{14}$$

Since the non-inventor faces a technological disadvantage he is able to realize positive profits only after γ periods of time have elapsed, so that $L_j(x_l) > 0 \;\forall\; t > \gamma$ and $L_j(x_l) = 0 \;\forall\; t \leq \gamma$.

The actual quality choices of the inventor and his rival depend on the inventor's protection decision on the first stage, $\sigma_i^1 = \{P, S\}$. If he chooses to patent a given range of quality levels is protected with the consequence that the non-inventor can only enter the market with a quality that exceeds the protected range. This positive aspect of the patent is accompanied by the drawback that the inventor loses his technological lead due to the disclosure requirement. If he chooses secrecy he maintains his head start but misses the benefits of patent protection. Proceeding we will first have a look at the subgame *secrecy* before considering the subgame *patent*. By comparing the outcomes for the inventor in both cases we can finally derive the subgame perfect Nash equilibrium of the three stage game.

2.1 Quality choices if the invention is kept secret

So far we derived the lifetime profit functions for the possible scenarios solely depending on the adoption quality of the first adopter, $L_i(x_l)$, $L_j(x_l)$, $F_i(x_l)$ and $F_j(x_l)$. Note that the asymmetric adoption capabilities of the firms

[7] To assure that $t_j(x_l) < t_i(x_h^*)$ we assume that $\gamma < 1/r$ holds throughout the rest of the paper.

were taken into account by inserting the respective research time functions $t_i(x)$ and $t_j(x)$ as specified in equations (1) and (2). Therefore - due to our assumption that quality is proportional to time - the quality level x_l can be replaced by time, $x_l = t$. In Figures 1 and 2 these profit functions are plotted for two alternative values of the technological lead γ, where the dashed lines represent the possible lifetime profits of the inventor and the solid lines represent those of the non-inventor.

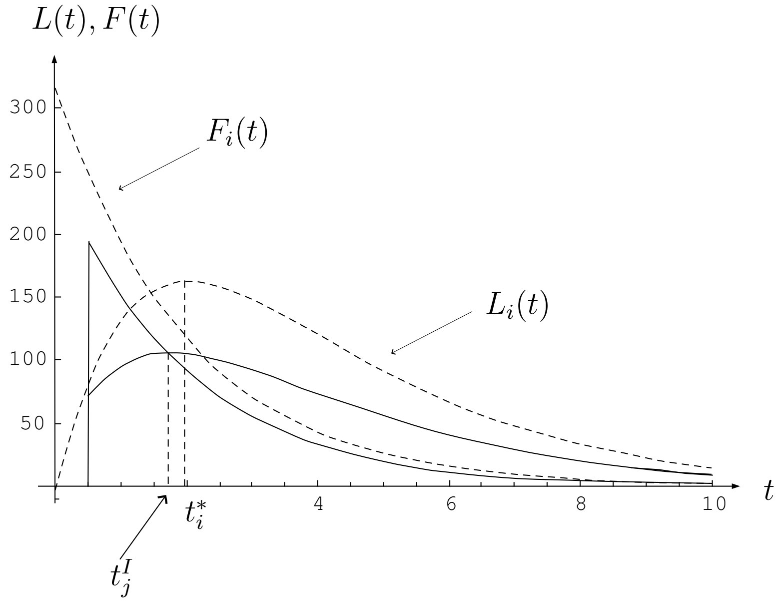

Figure 1: Preemption, with $\gamma = 0.5$ $a = 6$, $b = 25$, $r = 0.5$

Whenever $L_u > F_u$, firms prefer to be the first adopter ($\sigma_u^2 = x_l$) and whenever $F_u > L_u$ firms prefer to wait until a rival has entered and then enter as second adopter ($\sigma_u^2 = x_h$).[8]

As we will see, alternative values of the technological lead yield different equilibrium outcomes. Let us first consider the case depicted in Figure 1, where the technological lead of the inventor, γ, is small. A reason for this could either be a small initial headstart or a high leakage of information or a combination of both. With γ low, both firms prefer to be the first adopter at their profit maximizing entry date $t_u^* \equiv t(x_u^*)$, $u = i, j$, as this would maximize their overall profits $L_u(t_u^*)$, $u = i, j$. Since both anticipate that the

[8]Note that the potentially higher profits at the far left of the F_u-curves cannot be reached since neither firm will enter as first adopter as long as $F_u > L_u$. Thus no firm can become a follower if none decides to be the leader.

other will follow the adoption strategy *adopt first* ($\sigma_u^2 = x_l$) in the area where $L_u > F_u$, no one is able to actually reach his profit maximizing quality level. The argumentation for this is straightforward. Suppose the inventor i intends to adopt quality x_i^* in t_i^*. Then the non-inventor, j, anticipating this, would adopt at $t_i^* - \epsilon$ as this yields higher profits for him, $L_j(t_i^* - \epsilon) > F_j(t_i^*)$. Now the inventor in turn has an incentive to preempt. Following this argument the behavior of both firms will be preemptive as long as $L_u(t - \epsilon) > F_u(t)$ $\forall\ t < t_u^*$, $u = i, j$. So evidently either firm will stop preempting its rival as soon as it reaches the adoption date at which early and late adoption yield the same profits, which is the intersection point t_u^I with $L_u(t_u^I) = F_u(t_u^I)$, $u = i, j$. Therefore, the loser of the race for being the first will be the firm that reaches its intersection point first when moving backwards from t_u^*, $u = i, j$. A comparison of the intersection points of the inventor and the non-inventor leads to the following Lemma.

Lemma 1 *If both firms follow the strategy* adopt first *($\sigma_i^2 = \sigma_j^2 = x_l$), the inventor will always win the preemption race ($\sigma_i^{2*} = x_l$ and $\sigma_j^{2*} = x_h$).*

This means that in a situation where the technological lead of the inventor is low, his equilibrium choice will be the adoption date t_j^I since then the non-inventor has no incentive to continue the race for being the first as $L_j(t_j^I - \epsilon) < F_j(t_j^I)$.[9] Following *Dutta et al.* (1995) we will characterize this equilibrium as a preemption equilibrium since both firms engage in a race for being the first.

Obviously the incentive for the preemptive behavior that leads to this equilibrium can be ascribed to the fact that the profit maximizing adoption date as first adopter, t_u^*, lies on the right of the intersection point t_u^I. If the order of both points is reversed, the strategy of the firms changes from adopt first, $\sigma_u^2 = x_l$, to wait, $\sigma_u^2 = x_h$, $u = i, j$. The position of the dates t_u^* and t_u^I, $u = i, j$, crucially depends on the extent of the technological lead, γ, as the following Lemma points out.

Lemma 2 *If the technological lead is smaller than the threshold $\hat{\gamma}$ both firms follow the strategy* adopt first*, $\sigma_u^2 = x_l\ \forall\ \gamma \leq \hat{\gamma}$, $u = i, j$. As the technological lead rises above the critical value $\hat{\gamma}$ the non-inventor's strategy changes from*

[9] In this subgame equilibrium the low quality takes the value $x_l = x_j^I$. We can assure that the market is covered by constraining the domain of consumer diversity, $c \in [0.2384, 0.5[$ with $c \equiv a/b$. As $\partial x_j^I / \partial \gamma > 0$, if the market coverage condition holds for the minimum value $x_j^I\big|_{\gamma=0}$ it is always fulfilled if $\gamma > 0$. Inserting $x_j^I\big|_{\gamma=0}$ into the critical condition (7) and rearranging terms leads to the restriction for consumer diversity: it has to exceed a critical level that can be approximated as $c \geq 0.2384$, for the market to be covered.

adopt first *to* wait *while the inventor's strategy remains unchanged,* $\sigma_j^2 = x_h \wedge \sigma_i^2 = x_l \; \forall \; \gamma > \hat{\gamma}$.

So while the inventor himself is always best off by adopting at his profit maximizing entry date t_i^*, in case of a high technological lead the non-inventor may have the incentive to wait and be the second adopter. This situation is depicted in Figure 2.

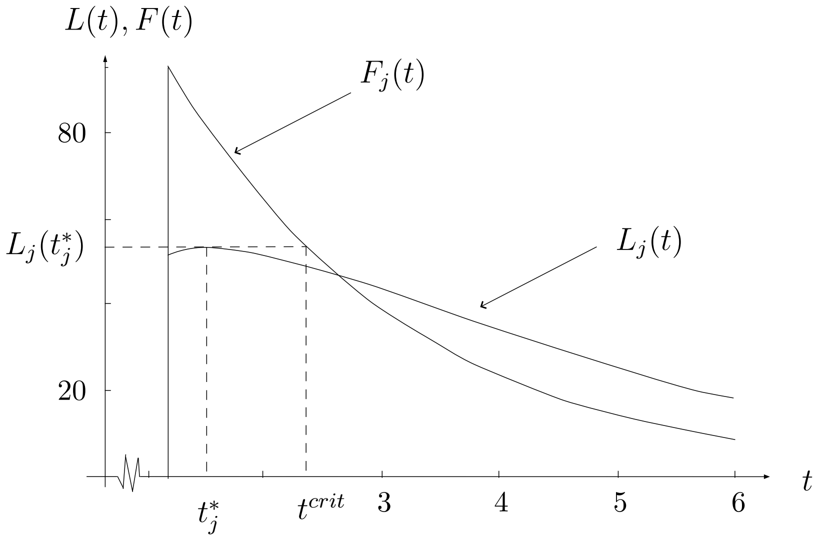

Figure 2: Alternative payoff functions of the non-inventor with $\gamma = 1.2$, $a = 6$, $b = 25$, $r = 0.5$

Since we know from Lemma 2 that the strategy and thus the relative positions of the adoption dates t_i^* and t_i^I are not changed by an increase of the technological lead, for clearness only the alternative payoff functions of the non-inventor are plotted. As we can see in Figure 2 the profit maximizing strategy of the non-inventor is *wait* as long as $t \leq t^{crit}$ holds due to $F_j(t) \geq L_j(t) \; \forall \; t \leq t^{crit}$. For any date after t^{crit} the non-inventor could gain from adopting at t_j^* since $L_j(t_j^*) > F_j(t) \; \forall \; t > t^{crit}$.
Let us think about the strategy of the inventor. To maximize his profits he will try to reach t_i^*. As we know that $t_i^*\big|_{\gamma=0} = t_j^*\big|_{\gamma=0}$ and obviously $\partial t_i^*/\partial\gamma > 0$ and $\partial t_j^*/\partial\gamma < 0$, the profit maximizing adoption date of the inventor always exceeds that of the non-inventor, $t_i^* > t_j^*$ for $\gamma > 0$. Let us first suppose that $t_i^* \leq t^{crit}$. Then the non-inventor will wait long enough for the inventor to reach t_i^*. Since both cannot gain from deviating this

constitutes another subgame equilibrium.[10] Following *Dutta et al.* (1995) we will denote this a maturation equilibrium as the behavior of the firms results in so called staggered innovations (*Dutta et al.* (1995), p. 564): the inventor unilaterally adopts at t_i^* while his rival has no incentive to preempt him. Instead, he will wait to develop the technology further and will then enter the market with a product of higher quality. Now let us suppose $t_i^* > t^{crit}$ so that the non-inventor is better off adopting at t_j^* before the inventor reaches his profit maximizing adoption date since $L_j(t_j^*) > F_j(t) \ \forall \ t > t^{crit}$. Recall from Lemma 2 that $t_i^I < t_i^*$ is always fulfilled and that $L_i(t) > F_i(t) \ \forall \ t > t_i^I$. Consequently, the inventor will preempt his rival by adopting at $t_j^* - \epsilon$ since $L_i(t_j^* - \epsilon) > F_i(t_j^*)$. Thus, this situation leads to another possible preemption equilibrium.[11]

As the preceding argumentation showed we have to deal with two critical conditions to find out which of the possible equilibria will emerge. Subject to the extent of the technological lead γ the non-inventor's strategy can either be *adopt first* or *wait* and - if his dominant strategy is *wait* - he will either wait long enough for the inventor to reach t_i^* or not. The following Lemma sorts this out analytically.

Lemma 3 *If $\gamma > \hat{\gamma}$ so that the non-inventor's optimum strategy is* wait *($\sigma_j^2 = x_h$) he will wait beyond t_i^* only if the technological lead exceeds the threshold $\hat{\hat{\gamma}}$, $t_i^* \leq t^{crit}$ iff $\gamma > \hat{\hat{\gamma}}$.*

The situation thus is the following: as the technological lead rises the nature of the non-inventor's payoff functions is changed. This alternates the order of the decisive dates t_j^I, t_i^* and t_j^* and as a consequence leads to different equilibrium outcomes. The following Proposition characterizes the three alternative unique equilibria of the subgame *secrecy* as described above.

Proposition 1 *If the inventor chooses to keep his invention secret ($\sigma_i^1 = s$), his optimum strategy is to adopt first, regardless of the extent of his head start, $\sigma_i^{2*}\big|_{\sigma_i^1=s} = x_l \ \wedge \ \sigma_j^{2*}\big|_{\sigma_i^1=s} = x_h$. Depending on the extent of his technological lead, γ, and given that consumer diversity is sufficiently wide the subgame* secrecy *then has three alternative Nash equilibria*

[10] Following the same argument as in Footnote 9 the critical value that consumer diversity has to fulfill to assure market coverage can be approximated as $c > 0.2108$. This is fulfilled by the assumption that $c \in [0.2384, 0.5[$.

[11] In this subgame equilibrium the low quality takes the value $x_l = x_j^* - \epsilon$. Other than in the above cases here $\partial(x_j^* - \epsilon)/\partial\gamma < 0$. Substituting $x_l = x_j^* - \epsilon$ into the market coverage condition as stated in equation (7) yields a critical condition for the technological lead subject to the level of consumer diversity, $\gamma < \frac{1}{r} ln \left[\frac{3e(5c-1)}{16c^3-16c^2+19c-3}\right] \equiv \gamma^c$. We assume that $\gamma < \gamma^c$ holds throughout the rest of our analysis.

(i) a preemption *equilibrium with* $x_l = x_j^I$ *whenever* $0 < \gamma < \hat{\gamma}$,

(ii) a preemption *equilibrium with* $x_l = x_j^* - \epsilon$ *whenever* $\hat{\gamma} \leq \gamma < \hat{\hat{\gamma}}$

(iii) a maturation *equilibrium with* $x_l = x_i^*$ *whenever* $\gamma \geq \hat{\hat{\gamma}}$.

Note that without a technological lead ($\gamma = 0$) both firms are symmetric and the preemption equilibrium as analyzed by *Dutta et al.* (1995) emerges. Then both firms try to simultaneously adopt at $t^I = t_j^I = t_i^I$ and firm i (j) is successful with probability p ($1-p$). For all $\gamma > 0$ our results differ from those derived by *Dutta et al.* (1995), but are consistent with the findings of *Hoppe*, *Lehmann-Grube* (2001) who propose that with costless R&D symmetric firms will engage in a race for being the first. In our model it is the asymmetry between firms that leads to the existence of a maturation equilibrium. This type of equilibrium will only occur if the asymmetry between firms is rather high, $\gamma \geq \hat{\hat{\gamma}}$. Contrarily, as the asymmetry between firms vanishes, $\gamma \rightarrow 0$, they engage in a race for being the first adopter, as *Hoppe*, *Lehmann-Grube* (2001) propose.

2.2 Quality choices if the innovation is patented

If the inventor patents his basic invention, the non-inventor is deterred from adopting the new technology up to a certain quality level that is characterized by the height of the patent, ϕ. To isolate the strategic effects of patent height we assume that the length of a patent, τ_P, exceeds the time that the non-inventor would need to develop a quality that lies outside the protected quality range, $\tau_P > t_j(\phi + \epsilon)$. This makes patent height the only dimension of patent protection relevant for the subsequent analysis.

To avoid confusion henceforth choice variables will carry the superscript S if the inventor chooses secrecy and the superscript P if he patents his invention. The inventor has an incentive to patent in every situation where he is not able to adopt his profit maximizing quality level, x_i^*. This is due to the fact that $\partial L_i / \partial x > 0 \; \forall \; x < x_i^*$, so that the inventor will profit from a patent that allows him to choose a higher product quality whenever $x_i^S < x_i^*$. As the precedent analysis has shown, this is the case in any preemption equilibrium. Let $x_i^S = \{x_j^I, x_j^* - \epsilon\}$ denote these subgame equilibrium outcomes we derived above.

We distinguish two patent types according to their protectional degree: *protective* patents and *delaying* patents. Patents of height $\phi \in \,]x_i^S, x_i^*[$ are *weak protective* patents since they accommodate the optimum differentiation strategy of the non-inventor, $x_h^* \equiv \sigma_j^{2*}\big|_{\sigma_i^{2*}=x_l}$, while having the positive effect of protecting the quality range up to $[a, \phi]$. Patents of height $\phi \in [x_i^*, x_h^*[$ are *strong protective* patents as they allow the inventor to reach his profit maximizing quality x_i^*, still admitting the non-inventor to follow his best differentiation strategy. The strongest protectional degree is reached with *delaying* patents. They are of height $\phi \geq x_h^*$ so that additionally to the protective effect they affect the differentiation strategy of the non-inventor: he is forced to postpone adoption further into the future.[12]

Given that the inventor patents his invention, three alternative Nash equilibria are possible in the subgame *patent* depending on the strength of protection. They are summarized in the following Proposition.

Proposition 2 *If the inventor chooses to patent his invention ($\sigma_i^1 = P$) the subgame* patent *has three alternative unique and stable Nash Equilibria where the inventor always is the first adopter, $\sigma_i^{2*}\big|_{\sigma_i^1=P} = x_l \;\wedge\; \sigma_j^{2*}\big|_{\sigma_i^1=P} = x_h$.*

(i) With weak protective patents *the inventor adopts the quality $x_l^P = \phi$ and the non-inventor can follow his profit maximizing strategy with $x_h^P = x_h^*$.*

(ii) With strong protective patents *the inventor adopts the quality $x_l^P = x_i^*$ and the non-inventor can follow his profit maximizing strategy with $x_h^P = x_h^*$.*

(iii) With delaying patents *the inventor adopts the quality $x_l^P = x_i^*$ and the non-inventor is forced to wait until he reaches the quality $x_h^P = \phi + \epsilon$ which exceeds his optimum entry date.*

Now finally we can derive the subgame perfect Nash equilibrium of the three stage game by comparing the inventor's alternative payoffs subject to the chosen protection mechanism.

2.3 The patenting decision

The inventor will choose to patent his invention whenever this yields higher profits than he could realize by keeping the invention secret. As a patent has

[12]In the extreme case of $\phi \geq b$ market entrance would be deterred for the non-inventor by a *delaying* patent. In this case the inventor will always patent since this assures him monopoly profits without any disadvantage from disclosure. Consequently this case is not of interest for the analysis of the patenting decision and we exclude it by assuming $\phi < b$ throughout the rest of the paper.

the drawback of the disclosure requirement linked to it, he has to consider the tradeoff between a positive and a negative patenting effect.
The positive *protective effect* of a patent can be described by the difference between the inventor's profit when he is able to choose the higher quality x_i^P due to patent protection and his equilibrium profits without a patent,

$$\Delta^+ = L_i(x_i^P)|_{\gamma>0} - L_i(x_i^S)|_{\gamma>0}. \tag{15}$$

This positive *protective effect* is opposed by the negative *disclosure effect.* Due to the disclosure requirement linked to a patent the inventor loses his lead which means that technically speaking γ is set to zero. Consequently, as the non-inventor is now able to enter at an earlier point in time, $t_j^P(x) = x$, instead of $t_j^S(x) = x+\gamma$, the duration of the monopoly of the patent holder is narrowed. This negative patenting effect can be measured by the difference between the profit of the inventor with and without a technological lead,

$$\Delta^- = L_i(x_i^P)|_{\gamma>0} - L_i(x_i^P)|_{\gamma=0}. \tag{16}$$

Combining the *protective* and the *disclosure effect* yields the overall effect that patenting has on the profit of the inventor, $\Delta_P = \Delta^+ - \Delta^-$. Inserting equations (15) and (16) this patent effect can be derived as

$$\Delta_P = L_i(x_i^P)|_{\gamma=0} - L_i(x_i^S)|_{\gamma>0}. \tag{17}$$

Whenever the patent effect Δ_P is positive, the *protective effect* overcompensates the *disclosure effect* and the inventor has an incentive to patent as this increases his overall profits.
Figure 3 depicts the patent effect for strong protective patents, $\phi \geq x_i^*$. In the region left of $\hat{\gamma}$ a preemption equilibrium would result if the inventor chose secrecy. From Proposition 1 we know that then he would realize quality $x_i^S = x_j^I$. By patenting the inventor could increase his profits since he would be able to choose $x_i^P = x_i^* > x_j^I$ due to the *protective effect* of the patent.
Obviously the patent effect increases as the technological lead decreases. The intuition for this is straightforward: a decrease of the technological lead will attenuate the disclosure effect of a patent, while the protective effect is left unchanged - this must lead to a rise of the patent effect Δ_P, which is equivalent to a move to the left on the Δ_P- curve in Figure 3. Note that an increase of the unintended leakage of information measured by λ leads to the same effect as $\partial\gamma/\partial\lambda < 0$.
As we can see the patent effect Δ_P takes positive as well as negative values as it crosses zero exactly once. The intersection point of the Δ_P- curve with the x-axis defines a critical value of the technological lead, γ^P. For $\gamma = \gamma^P$

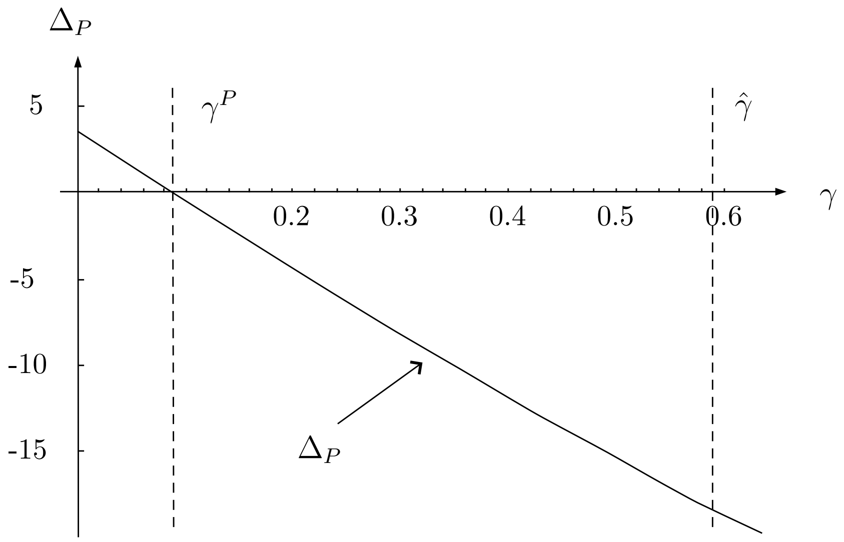

Figure 3: Δ_P for $a = 6$, $b = 25$, $r = 0.5$ and $\phi = x_i^*$

the *protective* and the *disclosure effect* compensate each other and the patent effect equals zero. If the technological lead is small, $\gamma < \gamma^P$, the *protective effect* dominates the *disclosure effect* and the inventor profits from patenting his basic invention. If the technological lead exceeds the critical value γ^P the *disclosure effect* outweighs the *protective effect* so that the patent effect is negative and the inventor prefers to keep his invention secret.
The following Proposition generalizes these findings, finally stating the subgame perfect Nash equilibrium of the considered three stage game.

Proposition 3 *If the inventor is not able to reach his profit maximizing quality level x_i^* with secrecy, he will patent his invention if his technological lead is small, $\sigma_i^1 = P$ iff $\gamma \leq \gamma^P$, and he will keep his invention secret if his technological lead is high, $\sigma_i^1 = S$ iff $\gamma > \gamma^P$.*

This Proposition states that the disclosure requirement plays a decisive role for the patenting decision of an inventor. If his invention incorporates a substantial amount of proprietary knowledge the drawback of a patent as appropriation mechanism is immense. The amount of unintended disclosure will weaken this result: as the spillover of information, λ, rises, the propensity to patent increases since the effective technological lead, $\gamma = \tilde{\gamma}(1 - \lambda)$, declines without patent protection. Intuitively an increase of the strength of protection should cause the same effect of increasing the inventor's propensity to patent. The following Corollary confirms this analytically.

Corollary 1 *The inventor's propensity to patent increases if the height of a weak protective patent,* $\phi =]x_i^S, x_i^*[$*, or a delaying patent,* $\phi > x_h^*$*, increases. It remains unchanged if the height of a strong protective patent,* $\phi = [x_i^*, x_h^*]$*, increases.*

The intuition is clear for protective patents. A change of patent height has no impact on the *disclosure effect* of a patent, but naturally it influences the *protective effect*. A rise of ϕ would result in an upward shift of the Δ_P- curve in Figure 3. By this the critical value γ_P would move to the right so that the area in which the inventor decides to patent would grow larger.
The *protective effect* can only increase if a weak patent's protectional range rises, since then the inventor is able to reach a higher quality level. With a strong protective patent the inventor already realizes his profit maximizing quality level and a further increase of patent height has no influence on the *protective effect* of a patent, leaving the propensity to patent unchanged. The case is different for delaying patents. They postpone the non-inventor's entry date further into the future so that the profit of the inventor rises due to a longer duration of his monopoly. This again leads to an increase of the *protective effect* of a patent resulting in a rise of the propensity to patent.

3 CONCLUDING REMARKS

Although recent empirical literature finds that the disclosure requirement is a major reason for firms to refrain from patenting, the impact of the disclosure requirement on the patenting decision has drawn sparse attention in the theoretical literature so far. Our aim was to provide a simple framework in which the decision of an inventor between a patent and secrecy could be analyzed taking into account the effects of the disclosure requirement.
To capture the fact that the inventor has a technological lead compared to a rival who has not yet successfully invented, we extended the model of dynamic quality competition introduced by *Dutta et al.* (1995) to asymmetric firms. In this framework we analyzed the tradeoff the inventor faces by dividing the patent effect into two parts, a *protective* and a *disclosure effect*. The literature so far mostly assumes that a disclosure effect applies only after a patent expires, and that before this date the disclosure requirement has no negative consequences for the patentee. We contribute to the literature by assuming that the disclosure requirement affects the patentee from the moment he decides to patent as he loses his technological lead immediately. Our main

result is that the decision of an inventor between a patent and secrecy depends on the extent of his technological lead. If the inventor's headstart is large, then the negative effect of patenting - the required disclosure of enabling information - outweighs its positive effect: the inventor will choose secrecy. If the inventor's lead is small the opposite occurs and he decides to patent his invention, accepting the fact that this means losing his technological lead.

Appendix

Proof of Lemma 1: Using $t = x_l$, the intersection point for the non-inventor can be derived by equating his alternative profits, $F_j(x_j^I) = L_j(x_j^I)$. Rearranging terms yields

$$x_j^I = \frac{e^{-r\gamma}A_h - A_l}{erA_m(e^{-r\gamma} - e^{-1})}\,. \tag{A1}$$

Analogously the intersection point for the inventor can be derived as

$$x_i^I = \frac{A_h - e^{-r\gamma}A_l}{erA_m(1 - e^{-1-r\gamma})}. \tag{A2}$$

Clearly $x_i^I\big|_{\gamma=0} = x_j^I\big|_{\gamma=0}$. As obviously $\partial x_i^I/\partial\gamma < 0$ it would be true that $x_i^I < x_j^I$ for $\gamma > 0$ if $\partial x_j^I/\partial\gamma > 0$ holds. Then, if both firms follow the strategy *adopt first* ($\sigma_u^2 = x_l$, $u = i,\, j$) the non-inventor reaches his intersection point first and thus always loses the preemption race.
To determine the sign of $\partial x_j^I/\partial\gamma > 0$, we need to take a closer look. Carrying out the differentiation we get

$$\frac{\partial x_j^I}{\partial\gamma} = \frac{A_h - eA_l}{e^{-r\gamma}A_m(e - e^{r\gamma})^2}\,. \tag{A3}$$

This derivative is positive as long as $A_h - eA_l > 0$ holds. Resubstituting $A_h = (2b-a)^2/9$ and $A_l = (b-2a)^2/9$ and setting $a/b = c$ we get $(c-2)^2 - e(1-2c)^2 > 0$. This function is positive for $c \in]-0.1529,\, 0.8490\,[$. Consequently the derivative $\partial x_j^I/\partial\gamma$ is always positive as due to the assumption $b > 2a > 0$ the domain of c is $c\ \in]0, 0.5[$. □

Proof of Lemma 2: From *Lemma 1* we know that L_u and F_u, $u = i,\, j$ have exactly one intersection point. First suppose that two situations are possible for both firms: (a) $x_u^I < x_u^*$ and (b) $x_u^I \geq x_u^*$, $u = i,\, j$. In situation (a) the dominant strategy for firm u is *adopt first* ($\sigma_u^2 = x_l$) since as $\partial F_u/\partial x < 0$ and $\partial L_u/\partial x > 0\ \forall\ x < x_u^*$ it is always true that $L_u(x) > F_u(x)\ \forall\ x > x_u^I$. In situation (b) the dominant strategy for u is *wait* ($\sigma_u^2 = x_h$) since as both curves have only one intersection point, x_u^I, and $\lim_{x\to 0} F_u(x) = \infty$, it is always true that $F_u(x) > L_u(x)\ \forall\ x < x_u^I$. By inserting x_j^I and x_j^* from equations (A1) and (14) into inequality (a) we get a critical condition for the non-inventor's adoption decision,

$$\gamma < \frac{1}{r}\ln\left[e - \frac{A_h}{A_m}\right] \equiv \hat{\gamma}. \tag{A4}$$

If and only if $\hat{\gamma} > 0$ both strategies, *adopt first* and *wait*, exist for the non-inventor. Rearranging $\hat{\gamma} > 0$ yields a critical condition for consumer diversity[13]

$$\frac{a}{b} > 2 - \frac{3}{2}\sqrt{e-1}. \tag{A5}$$

Whenever $\gamma < \hat{\gamma}$ the non-inventor's dominant strategy is *adopt first* since $x_j^I < x_j^*$ holds. For $\gamma \geq \hat{\gamma}$ the intersection point is to the right of the profit maximizing quality x_j^* and thus the non-inventor's dominant strategy is *wait*. The case is different for the inventor: Inserting x_i^I and x_i^* from equations (A2) and (13) into inequality (a) and rearranging terms yields the critical condition $\gamma > \ln[e - \frac{4}{9}(2-\frac{a}{b})^2]/(-r)$. Due to condition (A5), the right hand side of this inequality is always negative so that inequality (a) is fulfilled for all $\gamma \geq 0$. Consequently the inventor's dominant strategy always is *adopt first*. □

Proof of Lemma 3. We get t^{crit} by solving $F_j(t^{crit}) = L_j(t_j^*)$ as

$$t^{crit} = \frac{1}{r}\left(1 - ln\left[\frac{A_m}{A_h}(e - e^{\gamma r})\right] + \frac{A_l}{A_m(1-e^{1-\gamma r})}\right) \tag{A6}$$

Our aim is to prove that a critical $\hat{\hat{\gamma}}$ exists for which $t^{crit} \leq t_i^* \,\forall\, \gamma \leq \hat{\hat{\gamma}}$ and $t^{crit} > t_i^* \,\forall\, \gamma > \hat{\hat{\gamma}}$ holds. If a function $\Omega = t^{crit} - t_i^*$ is monotonically increasing in γ and has negative (positive) values for low (high) γ's then there must exist one critical γ for which $\Omega = 0$.
Solving $\partial\Omega/\partial\gamma > 0$ for c yields

$$c > \frac{1}{2} - \frac{1}{3}\left[\frac{(e-e^{\gamma r})(-1+e^{1+\gamma r})^2}{e(1+e^2+e^{2\gamma r}-4e^{1+\gamma r}+e^{2+2\gamma r})}\right]^{1/2}. \tag{A7}$$

By numerical simulations we can show that this condition is always met whenever the market coverage condition for a preemption equilibrium with $x_l = x_j^* - \epsilon$ as stated in Footnote 11 is fulfilled. This leaves us to analyze the functional values for a high (low) γ. As we analyze the situation where the non-inventor chooses the strategy *wait* ($\sigma_j^2 = x_h$) we consider the region $\gamma \geq \hat{\gamma}$. Then $\Omega(\hat{\gamma})$ must be the minimum of the function Ω. Inserting $\gamma = \hat{\gamma}$ we get

$$\Omega(\hat{\gamma}) = \frac{A_l e(A_h^2 - 2A_h A_m e + A_m^2(e^2-1))}{A_h A_m(A_m + A_h e - A_m e^2)r}. \tag{A8}$$

[13]Note that this condition corresponds to the preemption-condition for symmetric firms as stated by *Dutta et al.* (1995).

The denominator of this function is negative for $-0.3 < c < 4.3$, its nominator is positive for $0.03 < c < 3.97$. As the considered domain for consumer diversity is $c \in [0.2384, 0.5[$ (see Footnotes 9, 10 and 11), the function indeed is negative for a low value of γ, $\Omega(\hat{\gamma}) < 0$. This leaves us to show that $\Omega(\gamma) > 0$ for some $\gamma > \hat{\gamma}$. As we assumed that $\gamma < 1/r$ let us check the arbitrarily chosen functional value of $\gamma = 3/(4r)$. We get

$$\Omega\left(\frac{3}{4r}\right) = -\frac{4(1-2c)^2(e^{5/2}-e)}{9r(e^{3/4}-e-e^{5/2}+e^{11/4})} - \frac{1}{r}\, ln\left[\frac{9(e-e^{3/4})}{4(c-2)^2}\right]. \tag{A9}$$

This expression is positive for all $c \geq 0.24$ which completes our proof. □

Proof of Proposition 1: (i) preemption equilibrium - From *Lemmata 1* and *2* we know that if $\gamma < \hat{\gamma}$ both firms engage in a race for being the first and that the inventor will always win this preemption race. Thus in equilibrium the inventor markets the quality $x_l = x_j^I$ whereas the non-inventor optimally differentiates as stated in equation (9) and adopts the quality $x_h = x_j^I + 1/r$.

(ii) maturation equilibrium - From *Lemma 2* we know that in the case $\gamma \geq \hat{\gamma}$ the non-inventor waits to be the second adopter. In this case the inventor is able to reach his profit maximizing quality level $x_l = x_i^*$ and the non-inventor optimally differentiates by choosing $x_h = x_i^* + 1/r$. □

Proof of Proposition 2: As a patent protects a certain quality range it enables the inventor to choose a higher quality level than with secrecy, $\phi > x_i^S$. As $\partial L_i/\partial x > 0 \ \forall \ x < x_i^*$, the inventor will always profit from this *protective effect* of a patent. With a *weak protective* patent, $\phi < x_i^*$, the inventor will adopt the quality that corresponds to the height of the patent $x_i^P = \phi$. With a *strong protective*, $\phi \geq x_i^*$, or *delaying*, $\phi > x_h^*$, patent he will adopt the quality $x_i^P = x_i^*$ since this maximizes his profits. The non-inventor maximizes his profits by optimally differentiating. This is possible for *weak* and *strong protective* patents. If the protectional degree of a patent is very high (*delaying* patent) the entry of the non-inventor is postponed into the future. As $\partial F_j(x)/\partial x < 0$ he will enter as soon as he can reach a quality level that lies outside the protected range, $x_j^P = \phi + \epsilon$. □

Proof of Proposition 3:[14] If the patent effect Δ_P is monotonically decreasing in γ and takes positive as well as negative values, then there must exist

[14]For expository reasons we carry out parts of this proof for $x_i^S = x_j^I$. Following equal arguments all the same can be shown for $x_i^S = x_j^* - \epsilon$.

exactly one critical value γ^P which is decisive for the inventor's patenting decision.

First note that $\Delta_P\big|_{\gamma=0} > 0$ since $L_i(x_i^P)\big|_{\gamma=0} > L_i(x_i^S)\big|_{\gamma=0}$ due to $x_i^P > x_i^S$ and $\partial L_i(\cdot)/\partial x > 0 \ \forall \ x < x_i^*$. We thus know that the patent effect, Δ_P, can take positive values. Next let us look at $dL_i(x_i^S)\big|_{\gamma>0}/d\gamma > 0$. Differentiating we get

$$\frac{dL_i(\cdot)\big|_{\gamma>0}}{d\gamma} = \frac{\partial L_i(\cdot)\big|_{\gamma>0}}{\partial\gamma} + \frac{\partial L_i(\cdot)\big|_{\gamma>0}}{\partial x_i^S}\frac{\partial x_i^S}{\partial\gamma} \ . \tag{A10}$$

It is easy to show that the first term on the right hand side of (A10) is greater than zero. The same is true for the second term since $\partial L_i(\cdot)\big|_{\gamma>0}/\partial x_i^S$ $\forall \ x_i^S < x_i^*$ and $\partial x_i^S/\partial\gamma > 0 \ \forall \ x_i^S = x_j^I$ (see the proof of *Lemma 1*). Then the total differential $dL_i\big|_{\gamma>0}/d\gamma$ is positive and consequently the patent effect is monotonically decreasing in γ as $\partial L_i(x_i^P)\big|_{\gamma=0}/\partial\gamma = 0$.

This leaves us to show that Δ_P can take negative values. For $\gamma = \hat{\hat{\gamma}}$ a maturation equilibrium will result with $x_i^S = x_i^*$ (see *Proposition 1*). In this case a patent is needless for the inventor, as he is able to reach his profit maximizing quality with secrecy. Thus the patent effect should be negative. To begin with, presume a *strong protective* patent. Then

$$\lim_{\gamma\to\hat{\hat{\gamma}}} \Delta_P = L_i(x_i^*)\big|_{\gamma=0} - L_i(x_i^*)\big|_{\gamma=\hat{\hat{\gamma}}} < 0 \tag{A11}$$

since we know from (A10) that $dL_i(\cdot)\big|_{\gamma>0}/d\gamma > 0$ as long as $\partial x_i^S/\partial\gamma > 0$ which is the case for $x_i^S = x_i^*$. This is all the same true if patent height decreases, $x_i^* > \phi = x_i^P$, as this leads to a decrease of the first term on the right hand side of equation (A11) due to $\partial L_i(x_i^P)\big|_{\gamma=0}/\partial\phi > 0$. By this we know that the patent effect, Δ_P, can take positive as well as negative values. Thus, due to the fact that Δ_P is monotonically decreasing in γ there must exist one single critical value γ^P. □

Proof of Corollary 1: (i) protective patents With *weak protective* patents the inventor will adopt the quality that corresponds to the height of the patent $x_i^P = \phi$ since this maximizes his profits. From equation (17) it is easy to derive $\partial\Delta_P/\partial\phi\big|_{\phi<x_i^*} > 0$. Consequently an increase of patent height increases the propensity to patent. For *strong protective* patents the propensity to patent remains unchanged by a further increase of patent height, since the inventor will always choose $x_i^P = x_i^*$ for all $\phi \geq x_i^*$ so that $\partial\Delta_P/\partial\phi\big|_{\phi>x_i^*} = 0$.

(ii) delaying patents In this case a patent delays the adoption date of the non-inventor due to $\phi > x_h^*$. Then the adoption date of the non-inventor is $x_j^P = \phi + \epsilon$ while the inventor's adoption date is not influenced by an increase of patent height beyond x_i^*. From equation (17) we can derive $\partial \Delta_P / \partial x_j^P > 0$. Consequently the inventor's propensity to patent rises if patent height increases beyond x_h^*. $\square$

References

Anton, J. J., Yao, D. A. (2003): Patents, Invalidity, and the Strategic Transmission of Enabling Information. *Journal of Economics and Management Strategy* 12, 151–178.

Anton, J. J., Yao, D. A. (2004): Little Patents and Big Secrets: Managing Intellectual Property. *RAND Journal of Economics* 35, 1–22.

Arundel, A. (2001): The Relative Effectiveness of Patents and Secrecy for Appropriation. *Research Policy* 30, 611–624.

Arundel, A., van de Paal, G., Soete, L. (1995): Innovation Strategies of Europe's Largest Industrial Firms. Results of the PACE Survey for Information Sources, Public Research, Protection of Innovations and Government Programmes. *Final Report, MERIT, PACE Report, Brussels* .

Bessen, J. (2005): Patents and the Diffusion of Technical Information. *Economics Letters* 86, 121–128.

Cohen, W., Nelson, R., Walsh, J. (2000): Protecting Their Intellectual Assets: Appropriability Conditions and Why U. S. Manufacturing Firms Patent (or Not). *NBER working paper* 7552.

Denicolò, V. (2000): Two-Stage Patent Races and Patent Policy. *RAND Journal of Economics* 31, 488–501.

Denicolò, V., Franzoni, L. A. (2004a): The Contract Theory of Patents. *International Review of Law and Economics* 23, 365–380.

Denicolò, V., Franzoni, L. A. (2004b): Patents, Secrets and the First-Inventor Defense. *Journal of Economics & Management Strategy* 13, 517–538.

Dutta, P., Lach, S., Rustichini, A. (1995): Better Late Than Early: Vertical Differentiation in the Adoption of a New Technology. *Journal of Economics & Management Strategy* 4, 563–589.

Erkal, N. (2005): The Decision to Patent, Cumulative Innovation, and Optimal Policy. *International Journal of Industrial Organization* 23, 535–562.

Gallini, N. T. (1992): Patent Policy and Costly Imitation. *RAND Journal of Economics* 23, 52–63.

Hoppe, H., Lehmann-Grube, U. (2001): Second-Mover Advantages in Dynamic Quality Competition. *Journal of Economics & Management Strategy* 10, 419–433.

Horstmann, I., MacDonald, G. M., Slivinsky, A. (1985): Patents as Information Transfer Mechanisms: to Patent or (maybe) not to Patent. *Journal of Political Economy* 93, 837–858.

Langinier, C. (2005): Using Patents to Mislead Rivals. *Canadian Journal of Economics* 28, 520–545.

Shaked, A., Sutton, J. (1982): Relaxing Price Competition Through Product Differentiation. *Review of Economic Studies* XLIX, 3–13.

Yiannaka, A., Fulton, M. (2006): Strategic Patent Breadth and Entry Deterrence with Drastic Product Innovations. *International Journal of Industrial Organization* 24, 177–202.