Patents, Secrets and the Diffusion of Inventions

Alexandra K. Zaby*

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Abstract
This paper analyzes the decision of a successful inventor between a patent and risky secrecy in a model of dynamic technology adoption with asymmetric firms. We show that the extent of the inventor's technological headstart is decisive for his patenting behavior. With secrecy the inventor faces the risk of accidental leakage of his invention. If patent protection is very strong a patent delays the diffusion of inventions rather than encouraging it. Welfare considerations show that a patent may be socially desirable if patent protection is moderate.

Keywords: Patenting decision, Secrecy, Disclosure requirement, Diffusion, Technology adoption, Patent height

JEL Classifications: L13, O14, O33, O34

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Universität Tübingen, Wirtschaftswissenschaftliche Fakultät, Mohlstraße 36, D-72074 Tübingen. E-mail: alexandra.zaby@uni-tuebingen.de

1 Introduction

One of the main arguments for the existence of our patent system is that patents enhance the diffusion of inventions. Understanding a patent as a contract between an inventor and society, an exclusive property right is granted to the patentee in exchange for his disclosure of all technological information concerning the protected invention. This diffusion of know-how is thought to outweigh the drawback of the temporary monopoly that is enforced by a patent.

Empirical evidence suggests that inventors facing the decision between a patent and secrecy to appropriate their returns from research rate secrecy as more valuable than a patent (*Arundel* (2001), *Cohen et al.* (2000)) - even though by choosing secrecy they face the risk of an unintended leakage of information to rivals as well as the risk of independent discovery of the invention by others. According to *Cohen et al.* (2000) the major reason for the observed appropriation behavior is the disclosure requirement linked to a patent. This evidence suggests that there has to be a drawback to the disclosure of information that even overcompensates the benefits of being temporary monopolist as patentee. Consequently the intention of our patent system - promoting the diffusion of inventions - may fail due to the fact that inventors refrain from patenting and prefer secrecy. But even if an inventor chooses to patent, the question arises whether a patent indeed promotes the diffusion of inventions. A recent empirical survey by *McCalman* (2005) finds that very strong intellectual property rights (IPR) actually may slow down the speed of diffusion rather than enhance it.

The aim of our paper is to investigate whether our patent system actually meets its goal to promote the diffusion of inventions. To capture the possible impact of strong IPR we distinguish between patents of different protection degrees and introduce the decision of an inventor between the alternative appropriation mechanisms patenting and risky secrecy into a dynamic game of technology adoption. Our model setting builds on *Dutta et al.* (1995). They assume that after a technological breakthrough a new technology has to be further developed and adapted to market conditions. So firms have to decide at which quality level to adopt a new technology. *Dutta et al.* (1995) model the strategic adoption decisions of two rival firms as a process of dynamic vertical product differentiation without considering the possibility of patenting.

Unlike *Dutta et al.* (1995) we assume that the winner of a preceding invention race - the successful inventor - possesses the complete technological knowledge needed to manufacture the basic invention and has the possibility to patent this know-how. To participate in the preceding invention race the competing firm has also invested in research and therefore it can profit from own research findings as well as from a spillover effect that is caused by unintended leakage from the inventor's know-how whenever his invention is not protected by a patent. Yet in the subsequent improvement competition the inventor has a technological headstart compared to the non-inventor. As our analysis will show it is this knowledge asymmetry between the inventor and the non-inventor that drives the patenting decision.

In contrast to recent work by *Denicolò*, *Franzoni* (2004a,b) and *Bessen* (2005) we explicitly incorporate the disclosure requirement of a patent as the loss of the technological headstart of the inventor. With the exception of *Erkal* (2005) a common assumption in the recent economic literature concerning the patenting decision is that the disclosure requirement of a patent causes a disadvantage for the patentee only after the patent expires. Then all profits are driven to zero as everyone skilled in the art is able to produce and market the formerly protected invention. Opposing to this we assume that the patentee is affected by the disclosure requirement from the moment the patent is granted since the disclosed information spurs the research of his rival concerning inventions that lay outside the patent protected range.
To measure the diffusion of inventions we follow a recent paper by *Bessen* (2005). He specifically evaluates whether patent disclosure facilitates the diffusion of inventions given that diffusion may occur by a patent, via imitation or independent invention by a rival. *Bessen* (2005) finds that diffusion is not necessarily more likely with a patent system. Our model setting enables us to compare the speed of diffusion of an invention with and without a patent. The timing of diffusion is measured by the adoption date of the non-inventor. As the inventor himself possesses all know-how necessary to commercialize the invention at any time it must be the adoption date of the non-inventor that allows to draw a conclusion about the speed of diffusion of the relevant information.

The rest of the paper is organized as follows. Section 2 introduces the dynamic model of technology adoption with asymmetric firms and analyzes possible equilibria. In Section 3 we consider the decision between patenting and secrecy comparing the speed of diffusion in both cases. Section 4 investigates patent height as a possible policy measure. Section 5 concludes.

2 A Model of Dynamic Quality Competition

The winner of a preceding invention race, the successful inventor i, and his rival, the non-inventor j, compete in quality improvements of the basic invention. To protect his know-how concerning the invention the inventor can choose between a patent and secrecy. His patenting decision is analyzed in Section 3. To start with we only consider the case where the inventor chooses secrecy, which bears the risk of accidental disclosure via knowledge spillovers. 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. This means that the quality of the invention, x, increases by one unit in every subsequent period without involving any further research costs. Thus the inventor's quality improvement function is given by

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

which states that in order to reach a certain quality level $\bar{x}$ the inventor has to invest $t_i(\bar{x})$ periods of time. To capture the fact that the non-inventor has a technological disadvantage compared to the inventor his quality improvement function is specified by

$$t_j(x) = x + \gamma(1 - \lambda) \tag{2}$$

with $\gamma \geq 0$ as the initial extent of the technological headstart of the inventor and $0 \leq \lambda \leq 1$ as the exogenously given leakage parameter. At the end of the preceding invention race the inventor profits from a headstart in the know-how of technological details concerning the invention. This initial headstart is given by γ. This headstart may be reduced by an unintended leakage of information whenever the invention is not protected by a patent. The spillover of information is measured by the leakage parameter λ. So, given that the inventor chooses secrecy the extent of his effective technological headstart differs from his initial headstart whenever $\lambda > 0$. The extent of the effective technological headstart is defined by $\tilde{\gamma} \equiv \gamma(1 - \lambda)$. In other words, to reach a certain quality the non-inventor has to wait $\tilde{\gamma}$ periods longer than the inventor.

As the quality of the invention rises costlessly over time the competing firms have to make the strategic decision at which point in time to adopt and market the invention. The first adopter of the new technology earns temporary monopoly profits since his product of relatively low quality is the only version of the new technology available so far. The subsequent adoption of the rival firm constitutes an asymmetric duopoly where the former monopolist realizes

lower profits since his rival now offers a higher quality. At the beginning of the game, $t = 0$, both firms decide when, i. e. at which quality level, to adopt the new technology. Each firm can only adopt once.
The underlying demand structure follows *Shaked*, *Sutton* (1982). Consumers differ in their tastes θ for improvements of the basic invention. Quality preference, $\theta \in [a, b]$ with $b > 2a > 0$, is assumed to be uniformly distributed. 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 adopts a higher quality x_h. Straightforward computation yields the monopoly profit of the early adopter in every period

$$\pi_m = A_m x_l$$

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 $[a, \theta^0]$ and the high quality offered by the late adopter has a market share of $[\theta^0, b]$. Production costs are symmetric and are assumed to be zero.
Standard computation yields the duopoly prices

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

and the corresponding profits per period

$$\begin{aligned} \pi_h &= A_h(x_h - x_l) \\ \pi_l &= A_l(x_h - x_l) \end{aligned}$$

with $A_h \equiv (2b - a)^2/9$ and $A_l \equiv (b - 2a)^2/9$.

2.1 The Late Adopter's Problem

A late adopter has to decide when to adopt the new technology after his rival has already adopted a low quality x_l in t_l. All future profits are discounted with the interest rate $r > 0$. 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. His lifetime profits then amount to

$$F(x_h, x_l) = \int_{t_h(x_h)}^{\infty} e^{-rt} \pi_h dt. \tag{4}$$

Optimization with respect to the quality level x_h yields the optimum differentiation strategy given the early adopter's quality decision, x_l,

$$x_h^* = x_l + \frac{1}{r \cdot \frac{\partial t_h(x_h)}{\partial x_h}}. \tag{5}$$

As stated above the non-inventor will need $\tilde{\gamma}$ additional periods to reach a quality of level x_h so that his entry date as late adopter would be $t_j^h(x_h) = x_h + \tilde{\gamma}$. Due to his technological headstart the inventor would be able to adopt this quality earlier, namely at $t_i^h(x_h) = x_h$. Obviously in both cases the derivative of the quality improvement function with respect to the level of quality equals one, $\partial t_j^h(x_h)/\partial x_h = \partial t_i^h(x_h)/\partial x_h = 1$. Thus the profit maximizing differentiation strategy as defined in equation (5) is $x_h^* = x_l + 1/r$ for both firms. Consequently the optimum level of differentiation is $\Delta_x^* = x_h^* - x_l = 1/r$, independent of the order of adoption. The adoption date for the non-inventor as late adopter would be $t_j^h(x_h^*) = x_l + 1/r + \tilde{\gamma}$ due to his technological disadvantage. By inserting these results into the above profit function (4) and solving the integrals the overall profits of the non-inventor as second adopter can be derived as

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

If the inventor is the late adopter he would optimally adopt at $t_i^h(x_h^*) = x_l + 1/r$ so his overall profits would amount to

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

Note that the inventor loses his technological headstart, $\tilde{\gamma} = 0$, if the leakage parameter reaches its maximum, $\lambda = 1$. In this case both firms are symmetric and thus would realize identical profits as second adopter, $F_i(x_l)\big|_{\tilde{\gamma}=0} = F_j(x_l)\big|_{\tilde{\gamma}=0}$.

2.2 The Early Adopter's Problem

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,

$$L(x_l) = \int_{t_l(x_l)}^{t_h(x_h^*)} e^{-rt}\pi_m\, dt + \int_{t_h(x_h^*)}^{\infty} e^{-rt}\pi_l\, dt. \tag{6}$$

Taking into account the optimum level of differentiation, $\Delta_x^* = 1/r$ and $\partial t_h(x_h^*)/\partial x_l = 1$, optimization with respect to x_l yields the profit maximizing adoption quality for the first adopter

$$x_l^* = \frac{1 - e^{-r(t_h(x_h^*)-t_l)}(1 + A_l/A_m)}{r(1 - e^{-r(t_h(x_h^*)-t_l)})}. \tag{7}$$

Two different cases may occur: the inventor or the non-inventor could be the early adopter. Suppose that the non-inventor j adopts first. Due to his technological disadvantage he needs more time to reach the quality level x_l. Thus as early adopter he would enter the market in $t_{lj}(x_l) = x_l + \tilde{\gamma}$ and the inventor as second adopter would follow in $t_{hi}(x_l) = x_l + 1/r$. To assure that $t_{lj}(x_l) < t_{hi}(x_l)$ let $\tilde{\gamma} < 1/r$. Inserting these adoption dates into equation (6) and solving the integrals yields the overall profits of the non-inventor as early adopter

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

Since the non-inventor faces a technological disadvantage he is able to realize positive profits only after $\tilde{\gamma}$ periods of time have elapsed so that $L_j(x_l) > 0\ \forall\ t > \tilde{\gamma}$ and $L_j(x_l) = 0\ \forall\ x_l \leq \tilde{\gamma}$. If the non-inventor is the early adopter his profit maximizing early adoption quality x_{lj}^* can be derived by inserting $t_{hi}(x_h^*)$ and $t_{lj}(x_l)$ into equation (7),

$$x_{lj}^* = \frac{1 - e^{-1+r\tilde{\gamma}}(1 + A_l/A_m)}{r(1 - e^{-1+r\tilde{\gamma}})}. \tag{8}$$

The case is different if the inventor is the first adopter. He would optimally adopt the basic invention in $t_{li}(x_l) = x_l$ and the non-inventor as second adopter would follow in $t_{hj}(x_l) = x_l + 1/r + \tilde{\gamma}$. Inserting these relations into the profit function (6) and solving the integrals yields the overall profit of the inventor as early adopter

$$L_i(x_l) = \frac{(1 - e^{-1-r\tilde{\gamma}})\,\pi_m + e^{-1-r\tilde{\gamma}}\,\pi_l}{e^{rx_l}\,r} \tag{9}$$

with the corresponding profit maximizing quality level

$$x_{li}^* = \frac{1 - e^{-1-r\tilde{\gamma}}(1 + A_l/A_m)}{r(1 - e^{-1-r\tilde{\gamma}})}. \tag{10}$$

Note that again firms would be symmetric if $\lambda = 1$ due to a complete leakage of know-how. As early adopters they would then choose similar quality levels, $x_{li}^*\big|_{\tilde{\gamma}=0} = x_{lj}^*\big|_{\tilde{\gamma}=0}$ and realize identical profits, $L_i(x_l)\big|_{\tilde{\gamma}=0} = L_j(x_l)\big|_{\tilde{\gamma}=0}$. For all $\tilde{\gamma} > 0$ the profit maximizing quality level of the inventor exceeds that of the non-inventor, $x_{li}^* > x_{lj}^*$, as obviously $\partial x_{li}^*/\partial\tilde{\gamma} > 0$ and $\partial x_{lj}^*/\partial\tilde{\gamma} < 0$.

2.3 Equilibria

With the alternative strategies of adopting a new technology before or after a rival does so the question arises whether a first or a second mover advantage exists in this game of dynamic quality competition. *Hoppe*, *Lehmann-Grube* (2001) have thoroughly investigated this matter in a setting of dynamic quality competition with symmetric firms. They find that if R&D costs are low technological competition is mainly time-consuming and thus the rival firms engage in a race of being the first to adopt, thereby gaining from the advantage of the first move. Since in our setting R&D is only time-consuming without involving any further costs the only equilibrium should involve preemptive strategies of both firms. But as the subsequent analysis will show, the fact that firms are asymmetric leads to another possible equilibrium which involves maturation of the basic invention.

In the previous section the overall profit functions solely depending on the adoption quality of the first adopter, $L_i(x_l)$, $L_j(x_l)$, $F_i(x_l)$ and $F_j(x_l)$ were derived. Note that the asymmetric adoption capabilities of the firms were taken into account by inserting the specific quality improvement functions $t_i(x)$ and $t_j(x)$ as specified in equations (1) and (2). Therefore the quality level, x_l, that the profits are now dependent on, is equivalent to time, $x_l = t$. Figure 1 depicts these profit functions for two alternative values of the leakage parameter λ. The solid lines are the overall profits of the inventor and the dotted lines represent the non-inventor's alternative profits.

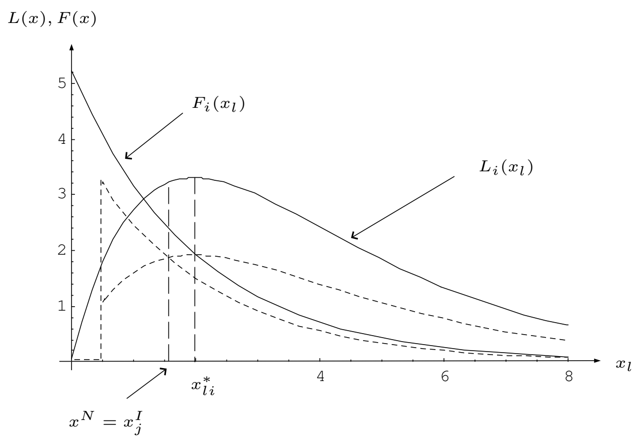

Figure 1: Preemption, $\lambda = 2/3$, x^N depicts the equilibrium low quality, with $a = 2$, $b = 5$, $r = 1/2$, $\gamma = 3/2$

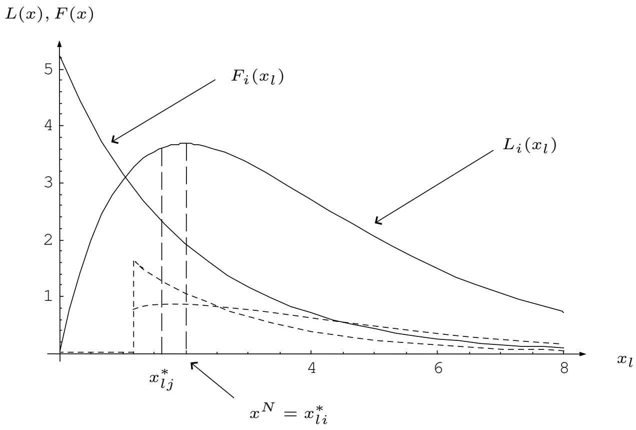

Figure 2: Maturation, $\lambda = 1/5$, x^N depicts the equilibrium low quality, with $a = 2$, $b = 5$, $r = 1/2$, $\gamma = 3/2$

If the effective headstart of the inventor is small due to a high leakage parameter, as in Figure 1, both firms prefer to be the first adopter with quality x^*_{lk}, $k = i, j$, as this would maximize their overall profits $L_k(x^*_{lk})$, $k = i, j$. Since both anticipate that the other will follow this adoption strategy no one is able to realize his profit maximizing quality level. Suppose the inventor i intends to adopt quality x^*_{li} then the non-inventor, j, anticipating this, would adopt at $x^*_{li} - \epsilon$ since this yields higher profits, $L_j(x^*_{li} - \epsilon) > F_j(x^*_{li})$. Now the inventor in turn has an incentive to preempt and so on. Following this argument preemption is the dominant strategy for both firms as long as $L_k(x^*_{lk}) > F_k(x^*_{lk})$, $k = i, j$.
Evidently either firm will stop preempting as soon as it reaches the adoption quality at which early and late adoption yield the same profits, the intersection point x^I_k with $L_k(x^I_k) = F_k(x^I_k)$, $k = i, j$. Therefore the loser of a preemption race will be the firm that reaches its intersection point first when moving backwards from x^*_{lk}, $k = i, j$.

Lemma 1 *The inventor will always be the first adopter if both firms follow a preemption strategy.*

Proof: The intersection point for the non-inventor can be derived by equating his alternative profits, $F_j(x^I_j) = L_j(x^I_j)$. Rearranging terms yields

$$x^I_j = \frac{e^{-r\tilde{\gamma}} A_h - A_l}{erA_m(e^{-r\tilde{\gamma}} - e^{-1})}. \tag{11}$$

Analogously the intersection point for the inventor can be derived as $x_i^I = (A_h - e^{-r\tilde{\gamma}} A_l)/(erA_m(1 - e^{-1-r\tilde{\gamma}}))$. As both firms are symmetric whenever $\tilde{\gamma} = 0$, x_i^I has to be equal to x_j^I if the effective technological headstart equals zero. As obviously $\partial x_j^I/\partial\tilde{\gamma} > 0$ and $\partial x_i^I/\partial\tilde{\gamma} < 0$ it is always true that $x_i^I < x_j^I$ for $\tilde{\gamma} > 0$. Consequently if both firms follow a preemptive strategy the non-inventor reaches his intersection point first and thus always loses the preemption race. ■

Following *Lemma 1* if the effective technological headstart is small as in Figure 1 the inventor will always win the preemption race by adopting the quality x_j^I. The non-inventor has no incentive to preempt this quality since he realizes higher profits as second adopter, $L_j(x_j^I - \epsilon) < F_j(x_j^I)$.

The high effective technological headstart as depicted in Figure 2 is due to a low leakage parameter. In this case the non-inventor has no incentive to preempt his rival at all since $F_j(x_{lj}^*) \geq L_j(x_{lj}^*)$. It can be shown that opposing to the change of strategies of the non-inventor from preemption to maturation the inventor's dominant adoption strategy does not change as the effective technological headstart rises.

Lemma 2 *If the technological headstart rises the non-inventor's dominant strategy changes from preemption to maturation while the inventor's dominant strategy always is preemption.*

Proof: The preemption-conditions for the firms can be derived by inserting their profit maximizing quality levels x_{lk}^*, $k = i, j$ as stated in equations (8) and (10) into $L_k(x_{lk}^*) > F_k(x_{lk}^*)$, $k = i, j$. Inserting $\tilde{\gamma} = \gamma(1 - \lambda)$ and solving for γ yields the critical condition for the initial headstart. For the non-inventor it is

$$\gamma < \frac{1}{r(1-\lambda)} \ln\left[e - \frac{A_h}{A_m}\right] \equiv \gamma^p. \tag{12}$$

If and only if $\gamma^p > 0$ both strategies, preemption and maturation, exist for the non-inventor. Preemption prevails whenever $\gamma < \gamma^p$ and as the technological headstart rises above γ^p the dominant adoption strategy of the non-inventor changes to maturation. Rearranging $\gamma^p > 0$ yields a critical condition for consumer diversity[1]

$$\frac{a}{b} > 2 - \frac{3}{2}\sqrt{e-1}. \tag{13}$$

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

Solving the preemption condition of the inventor, $L_i(x^*_{li}) > F_i(x^*_{li})$, for γ results in $\gamma > \ln[e - \frac{4}{9}(2 - \frac{a}{b})^2]/(-r(1-\lambda))$. Due to condition (13), the right hand side of this inequality is always negative so the preemption-condition of the inventor is fulfilled for all $\gamma \geq 0$. ■

According to *Lemma 2* whenever $\gamma \geq \gamma^p$ maturation is the dominant strategy of the non-inventor while the inventor follows a preemptive strategy trying to realize x^*_{li}. Following his dominant strategy the non-inventor either lets the quality of the basic invention mature up to the point in time where he can reach his profit maximizing quality, x^*_{lj}, realizing overall profits $L_j(x^*_{lj})$ or he waits until the inventor enters with his profit maximizing quality x^*_{li}. By entering as second adopter he then would realize overall profits $F_j(x^*_{li})$. The actual maturation strategy of the non-inventor thus depends on the respective height of the profits that he can realize. For simplicity reasons we restrict the strategy of the non-inventor to the case where he prefers to leave the first entry to the inventor by assuming $F_j(x^*_{li}) > L_j(x^*_{lj})$.[2]

With the results stated in *Lemmata 1* and *2* the unique and stable subgame perfect Nash equilibria of this game of dynamic quality competition can be derived. An equilibrium in which both firms preempt each other is defined as a preemption equilibrium while an equilibrium where at least one firm lets the basic invention mature up to a certain quality is defined as a maturation equilibrium. Note that these Nash equilibria exist if and only if the market is completely covered.

Proposition 1 *This dynamic game of quality competition with asymmetric firms has two unique subgame perfect Nash Equilibria given that consumer diversity is sufficiently wide:*

i) a preemption *equilibrium with* $x^p_i = x^I_j$ *and* $x^p_j = x^I_j + \frac{1}{r}$ *whenever* $\gamma < \gamma^p$,

ii) a maturation *equilibrium with* $x^m_i = x^*_{li}$ *and* $x^m_j = x^*_{li} + \frac{1}{r}$ *whenever* $\gamma \geq \gamma^p$

with $\gamma^p = \frac{1}{r(1-\lambda)} \ln\left[e - \frac{A_h}{A_m}\right]$.

Proof: *i) preemption equilibrium* - From *Lemmata 1* and *2* we know that if $\gamma < \gamma^p$ both firms follow a preemption strategy and that in this case the inventor will always win the preemption race. Thus in equilibrium the inventor

[2]The analysis of the case for $F_j(x^*_{li}) \leq L_j(x^*_{lj})$ is available from the author by request.

markets the quality $x_i^p = x_j^I$ whereas the non-inventor optimally differentiates as stated in equation (5) and adopts the quality $x_j^p = x_j^I + 1/r$.

ii) maturation equilibrium - Due to the assumption $F_j(x_{li}^*) > L_j(x_{lj}^*)$ the non-inventor aims at being the second adopter and waits until the inventor adopts his profit maximizing quality x_{li}^*. In this case the inventor is able to reach his profit maximizing quality level $x_i^m = x_{li}^*$ and the non-inventor optimally differentiates by choosing $x_j^m = x_{li}^* + 1/r$. ■

To assure that the market for differentiated quality goods is completely covered for these equilibria 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 (3) and rearranging yields

$$x_l \geq \frac{1-2c}{3cr} \tag{14}$$

with $c \equiv a/b$. In the respective equilibria the low quality takes the values $x_l = \{x_j^I, x_{li}^*\}$. As $\partial x_j^I/\partial\tilde{\gamma} > 0$ and $\partial x_{li}^*/\partial\tilde{\gamma} > 0$ if the market coverage condition holds for the respective minimum values $x_j^I\big|_{\tilde{\gamma}=0}$ and $x_{li}^*\big|_{\tilde{\gamma}=0}$ it is always fulfilled for all values with $\tilde{\gamma} > 0$. Inserting $x_j^I\big|_{\tilde{\gamma}=0}$ into the critical condition (14) and rearranging terms leads to the restriction that consumer diversity has to exceed a critical level, $c \geq 0.2382$, for the market to be covered. Substituting $x_{li}^*\big|_{\tilde{\gamma}=0}$ into the market coverage condition as stated in equation (14) yields the critical level for consumer diversity, $c > 0.2108$. Consequently, if $c > 0.2382$ both unique Nash equilibria exist.

The results derived so far allow an interesting conclusion about the influence of the risk of leakage, λ, on the equilibrium strategies of the firms.

Corollary 1 *As the leakage parameter rises the non-inventor's incentive to follow a preemptive strategy increases.*

Proof: From *Lemma 2* we know that the non-inventor's dominant strategy is preemption as long as $\gamma < \gamma^p$. As $\partial\gamma^p/\partial\lambda > 0$ the propensity for preemption increases as the leakage parameter rises. ■

In other words, as the asymmetry between the firms declines due to a rise of the unintended spillover of technical know-how, the non-inventor's incentive to follow a maturation strategy decreases. This result is consistent with the findings of *Hoppe*, *Lehmann-Grube* (2001): As the firms tend toward symmetry they engage in a race for being the first.

3 The Patenting Decision

Patent protection has three possible dimensions: length, breadth and height.[3] Whereas patent length defines the duration of a patent, patent breadth constitutes the extent of protection against imitations - the broader the patent is, the less similar imitations are allowed to be. Patent breadth is thus relevant for horizontally differentiated products. Patent height is determined by the stringency of the novelty requirements used by examiners in the patent office. An innovation is sufficiently novel if it exceeds the quality range that is protected by the patent, so obviously patent height is relevant for vertically differentiated products. While patent length as well as patent breadth have been thoroughly investigated in the literature[4] patent height to our knowledge has so far only been considered by *van Dijk* (1996). In our model setting the firms compete in improvements of a basic invention, consequently patent breadth is not of concern.

The inventor has an incentive to patent in every situation where he is not able to adopt his profit maximizing quality level, x^*_{li}. As the precedent analysis showed this is the case in a preemption equilibrium. Thus $x^S_i = x^p_i$ describes the secrecy equilibrium quality that induces an incentive to patent. 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, the length of a patent, τ_ϕ, is assumed to exceed the time that the non-inventor would need to develop a quality that lies outside the protected quality range, $\tau_\phi > t_j(\phi + \epsilon)$. This makes patent height the only dimension of patent protection relevant for the subsequent analysis.

Two patent types can be distinguished according to their height: *protective* patents and *delaying* patents. Note that with a patent the inventor will always be the first adopter so that x^*_h as stated in equation (5) always is the optimum differentiation strategy of the non-inventor. Then patents of height $\phi \in \left]x^S_i, x^*_{hj}\right[$ are *protective* since they accommodate the optimum differentiation strategy of the non-inventor while having the positive effect of protecting the quality range $[x^S_i, \phi]$. Patents of height $\phi \geq x^*_{hj}$ are *delaying* patents since additionally to the protective effect they affect the differentiation strategy of the non-inventor: he is forced to postpone adoption further into the future. For the extreme case of $\phi \geq b$ market entrance even is de-

[3] *Matutes et al.* (1996) introduce patent scope as an additional dimension of patent protection. Where height protects a certain quality range of further developments of a basic invention, scope protects further developments, e. g. applications, of a basic invention that cannot be ranked in terms of quality relative to the basic technology.

[4] See *Denicolò* (1996) for a survey.

terred for the non-inventor by a *delaying* patent. Thus the strength of patent protection rises with the height of a patent.

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 $\partial L_i/\partial x_i > 0$ for $x_i < x_{li}^*$, the inventor will always profit from this *protective effect* of a patent. In the case that an invention is patented the choice variables of the firms carry the superscript ϕ. With a patent the inventor will adopt the quality that corresponds to the height of the patent $x_i^\phi = \phi$ if $\phi \leq x_{li}^*$, and he will adopt the quality $x_i^\phi = x_{li}^*$ whenever $\phi > x_{li}^*$ since this maximizes his profits. The *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_{li}^ϕ due to patent protection and his equilibrium profits without a patent,

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

This positive *protective effect* is opposed by the negative effect arising from the disclosure requirement of a patent. Understanding a patent in the sense of *Denicolò*, *Franzoni* (2004a) as a contract between the inventor and society, the inventor is granted an exclusive property right in exchange for the disclosure of all technological information concerning the protected invention. By the required disclosure the leakage parameter is set to unity, $\lambda = 1$, so that the inventor loses his initial technological headstart, $\tilde{\gamma} = 0$. Consequently, as the non-inventor is now able to enter at an earlier point in time, $t_j^\phi(\bar{x}) = \bar{x}$, instead of $t_j^S(\bar{x}) = \bar{x} + \tilde{\gamma}$, the duration of the monopoly of the patent holder is narrowed. This negative patenting effect corresponds to the difference between the profit of the inventor if an effective technological headstart exists, $\tilde{\gamma} > 0$, and his profit when both firms face symmetric adoption abilities, $\tilde{\gamma} = 0$,

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

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

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

Whenever Δ_ϕ is positive, the *protective effect* overcompensates the *disclosure effect* so that the inventor has an incentive to patent since this increases his overall profits. Inserting the profit function $L_i(\cdot)$ as defined in equation (9) and taking into account that Δ_ϕ is additively separable into the profit change in the temporary monopoly and the profit change in the subsequent duopoly yields

$$\Delta_\phi = \Delta_M + \Delta_D \tag{18}$$

with

$$\begin{aligned} \Delta_M &\equiv A_m((e^{-rt_i^\phi} - e^{-rt_j^\phi})x_i^\phi - (e^{-rt_i^S} - e^{-rt_j^S})x_i^S)/r & (19) \\ \Delta_D &\equiv A_l(e^{-rt_j^\phi} - e^{-rt_j^S})/r^2. & (20) \end{aligned}$$

While the adoption date of the non-inventor in an equilibrium with secrecy, t_j^S, is dependent on the extent of the technological headstart, in case of a patent it is dependent on patent height with $\partial t_j^\phi/\partial\phi > 0$. Obviously, if patent height is chosen so that the adoption date of the non-inventor is the same with and without a patent $t_j^\phi = t_j^S$, namely $\phi = x_i^S + \tilde{\gamma}$, the overall patent effect solely consists of the patent effect in monopoly, $\Delta_\phi = \Delta_M$. Additionally using the established equilibrium interrelations $t_j^\phi = t_i^\phi + 1/r$ and $t_j^S = t_i^S + 1/r + \tilde{\gamma}$ equation (18) can be rewritten as

$$\Delta_\phi\big|_{t_j^\phi = t_j^S} = \frac{A_m\left((e-1)\,x_i^\phi - (e^{1+r\tilde{\gamma}} - 1)\,x_i^S\right)}{e^{rt_j^S}\,r}. \tag{21}$$

With this functional form of the overall patent effect it is possible to derive a critical level for the technological headstart that determines whether the inventor patents his basic invention or not. Recall that this dynamic game of technology adoption has two unique equilibria if patents are absent: a preemption equilibrium and a maturation equilibrium. As one would expect the patenting behavior is different in the respective cases.

Proposition 2 *In this dynamic game of technology adoption the decision between patenting and keeping the basic invention secret crucially depends on the extent of the initial headstart of the inventor:*

i) in a preemption equilibrium the inventor will patent his basic invention whenever $\gamma \leq \gamma_\phi^p$.

ii) in a maturation equilibrium the inventor will never patent.

Where

$$\gamma_\phi^p \equiv \frac{1}{r(1-\lambda)} \ln\left[\frac{1}{2eA_l}(\alpha_0 - \sqrt{\alpha_0^2 - 4eA_l(A_h + A_m(e-1)rex_i^\phi)})\right] \tag{22}$$

with $\alpha_0 \equiv A_l + eA_h + A_m(e-1)rx_i^\phi$.

Proof: *i) preemption equilibrium* - The inventor will patent whenever $\Delta_\phi\big|_{t_j^\phi=t_j^S} \geq 0$. Inserting $\tilde{\gamma} = \gamma(1-\lambda)$, solving for γ and rearranging terms yields $\gamma \leq \gamma_\phi^p$ as stated in equation (22). A preemption equilibrium requires $\gamma < \gamma^p$ (*Proposition 1*) so that if $\gamma_\phi^p < \gamma^p$ holds, patenting and secrecy may occur. Obviously $\partial\Delta_\phi\big|_{t_j^\phi=t_j^S}/\partial x_i^\phi > 0$ and consequently $\partial\gamma_\phi^p/\partial x_i^\phi > 0$. Then a function $\Omega^p \equiv \gamma^p - \gamma_\phi^p > 0$ must be monotonically decreasing in x_i^ϕ reaching its minimum as x_i^ϕ reaches its maximum. Inserting $x_i^\phi = x_{li}^*$ into $\Omega^p(\cdot) > 0$ and rearranging terms yields

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

which is equal to the necessary condition for a preemption equilibrium as stated in equation (13). So for all $x_i^\phi \leq x_{li}^*$ it is true that $\gamma_\phi^p < \gamma^p$. So that patenting and secrecy may occur in a preemption equilibrium.

If $t_j^\phi > t_j^S$ ($t_j^\phi < t_j^S$) the inventor patents more (less) whenever $\phi > A_l/(A_m r)$ since then $\partial\Delta_\phi/\partial t_j^\phi > 0$. If $\phi < A_l/(A_m r)$ the inventor patents less (more) if $t_j^\phi > t_j^S$ ($t_j^\phi < t_j^S$) since in this case $\partial\Delta_\phi/\partial t_j^\phi < 0$.

iii) maturation equilibrium - In a maturation equilibrium the inventor realizes $x_i^m = x_{li}^*$ so that the *protective effect* of a patent as stated in equation (15) is smaller than or equal to zero. Consequently, the overall patenting effect can never be positive so the inventor never patents in a maturation equilibrium. ■

Figure 3 illustrates[5] these results for $\phi = x_{li}^*$, $t_j^\phi = t_j^S$ and $\lambda = 0$ so that $\tilde{\gamma} = \gamma$. As stated in *Proposition 1* this game of technology adoption has a preemption equilibrium whenever $\gamma < \gamma^p$ which means that all parameter constellations below the γ^p-curve in Figure 3 lead to an adoption quality $x_i^p = x_j^I$ of the inventor if the basic invention is not patented. As $\Delta_\phi\big|_{t_j^\phi=t_j^S} = \Delta_M$ the γ_ϕ^p-curve defines all combinations of a/b and γ for which the *protective* and the *disclosure effect* compensate each other and thus the patent effect equals zero. Clearly this curve lies within the area that constitutes a preemption equilibrium so that the patenting decision depends on the extent of the technological headstart. If the technological headstart is small the *protective effect* dominates the *disclosure effect* and the inventor profits from patenting his basic invention. This is the case in the hatched area of Figure 3. In

[5] Note that for Figure 3 the range of consumer diversity, a/b, is chosen such that market coverage and thus the existence of both unique Nash equilibria is ensured.

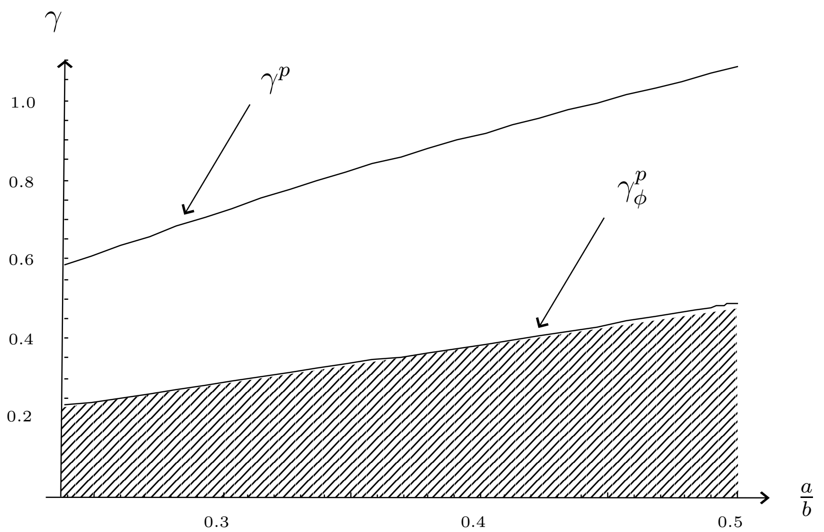

Figure 3: Patenting behavior in a preemption equilibrium, $r = 0.5$, $\lambda = 0$

the extreme case of $\gamma = 0$ the inventor will always patent his invention in a preemption equilibrium since this protects him from a preemptive adoption by his competitor with the *disclosure effect* being absent. If the technological headstart exceeds the critical value γ^p_ϕ, as is the case between the $\gamma^p_\phi-$curve and the γ^p-curve, the *disclosure effect* outweighs the *protective effect* and the inventor prefers to keep his invention secret. Note that as $\partial\gamma^p_\phi/\partial\lambda > 0$ the inventor's propensity to patent rises as the leakage parameter increases. In Figure 3 this would result in a rise of the $\gamma^p_\phi-$curve. As a consequence the hatched area where the inventor profits from patenting would increase.

So far only *protective* patents have been considered. Intuitively, increasing the height of a patent should also increase the propensity to patent, especially in the case of *delaying* patents since they prolong the temporary monopoly of the patent holder. The following Corollary states the interdependence between patent height and the propensity to patent.

Corollary 2 *In a preemption game of technology adoption the inventor's propensity to patent rises as patent height increases.*

Proof: *i) protective patents* Obviously with patent protection the inventor will adopt the quality that corresponds to the height of the patent $x^\phi_i = \phi$ if $\phi \in]x^S_i, x^*_{li}]$ since this maximizes his profits. From equation (17) it is easy to derive $\partial\Delta_\phi/\partial\phi\big|_{\phi\le x^*_{li}} > 0$. Consequently an increase of patent height increases the propensity to patent. For $x^*_{li} < \phi < x^*_{hj}$ the propensity to patent remains unchanged by a further increase of patent height, since the inventor will always choose $x^\phi_i = x^*_{li}$ for all $\phi > x^*_{li}$ so that $\partial\Delta_\phi/\partial\phi\big|_{\phi > x^*_{li}} = 0$.

ii) delaying patents In this case a patent delays the adoption date of the non-inventor due to $\phi > x^*_{hj}$. Then the adoption date of the non-inventor is $x^\phi_j > x^*_{hj}$ while the inventor's adoption date is not influenced by an increase of patent height beyond x^*_{li}. From equation (17) we can derive $\partial\Delta_\phi/\partial x^\phi_j = e^{-1-rx_{li}}A_l/r$ which is obviously greater than zero. Consequently the inventor's propensity to patent rises if patent height increases beyond x^*_{hj}. In the extreme case of $\phi \ge b$ the non-inventor is completely deterred from adopting so the inventor will always patent, since this assures him monopoly profits without having any disadvantage from disclosure. ■

Note that as the inventor never patents in a maturation equilibrium a change of the height of a patent has no influence on his patenting behavior.

After investigating the patenting behavior of a successful inventor the question whether the patent-enforced disclosure of technical know-how does indeed spur the diffusion of inventions is still left unanswered. To derive an answer we need to compare the speed of diffusion with and without a patent. The results are summarized in the following Proposition.

Proposition 3 *A patent enforces the diffusion of inventions only if the protected quality range does not exceed the effective headstart of the inventor,* $x^\phi_{li} - x^S_{li} < \tilde{\gamma}$.

Proof: Let $\text{Diff}_\phi = t^\phi_{hj}$ be the speed of diffusion if the inventor decides to patent and $\text{Diff}_S = t^S_{hj}$ the speed of diffusion if he keeps his invention secret. A patent will increase the speed of diffusion whenever $\text{Diff}_S > \text{Diff}_\phi$ holds. From equations (2) and (5) we know that $t^S_{hj} = x^S_{li} + 1/r + \tilde{\gamma}$ whereas in case of a patent with $\lambda = 1$ the speed of diffusion is $t^\phi_{hj} = x^\phi_{li} + 1/r$. Inserting into the above inequality and rearranging terms yields $x^\phi_{li} - x^S_{li} < \tilde{\gamma}$. ■

In other words a patent spurs the diffusion of technical know-how if and only if the protected range, $[x^S_{li}, x^\phi_{li}]$, is smaller than the technological headstart of the inventor when he chooses secrecy. Note that the critical condition for a diffusion-enhancing patent may be weakened by three factors a) a rise of patent height, b) a decrease of the initial technological headstart γ or c) an increase of the leakage parameter, λ.

Corollary 3 *Delaying patents slow down the speed of diffusion.*

Proof: With delaying patents patent height increases above x^*_{hj}, $\phi > x^*_{hj}$, so that the protected quality range rises. This leads to a weakening of the critical condition stated in *Proposition 3*. Consequently the speed of diffusion of an invention is higher with secrecy than with a patent. ∎

This result is in line with the empirical evidence found by *McCalman* (2005). He finds that very strong IPR may actually retard the speed of diffusion.

4 Patenting and Welfare

The analysis of the patenting decision of an inventor leaves the question whether a patent is socially desirable or not. As the height of a patent is left to policy decisions, investigating this question might lead to careful implications on the design of this parameter. Naturally, a first step has to be the determination of a social welfare function in the underlying model of dynamic technology adoption. In the subsequent welfare considerations only the preemption case with the inventor as early adopter will be considered since in a maturation equilibrium the inventor never patents. Recall that this means that the inventor will enter the market as monopolist in t_l adopting the product at a low quality whereas the non-inventor enters at t_h adopting a high quality. This unambiguousness allows us to drop the subscripts i and j. Consumers thus face monopoly and subsequently duopoly so that consumer surplus amounts to

$$\begin{aligned} \text{CS} &= \int_{t_l}^{t_h} e^{-rt} \int_{p_m/x_l}^{b} (\theta x_l - p_m)\, d\theta\, dt \\ &+ \int_{t_h}^{\infty} e^{-rt} \left(\int_{a}^{\theta^0} (\theta x_l - p_l)\, d\theta + \int_{\theta^0}^{b} (\theta x_h - p_h)\, d\theta \right) dt \end{aligned}$$

where the first summand depicts the consumer's surplus during monopoly and the second summand their surplus during duopoly. The producer's surplus consisting of the overall profits of the two firms over time equals

$$\text{PS} = \int_{t_l}^{t_h} e^{-rt} \pi_m dt + \int_{t_h}^{\infty} e^{-rt} (\pi_l + \pi_h)\, dt.$$

Inserting equilibrium prices, quality levels and profits derived in the previous sections, solving the integrals, summing up and collecting terms yields the social welfare function

$$W = \frac{1}{8\,r}\,[\,3\,b^2\,e^{-rt_l} + (b^2 - 4a^2)\,e^{-rt_h}]. \tag{23}$$

The derivatives of this function with respect to the adoption dates t_h and t_l are both negative so that an early date of the first technology adoption as well as a small level of differentiation are socially desirable. As stated in the following Proposition a patent may be welfare enhancing although it delays the date of the first adoption.

Proposition 4 *Patenting the basic invention increases (decreases) social welfare if a technological headstart exists, $\gamma > 0$, and $\phi < \phi^W$ ($\phi \geq \phi^W$). Where*

$$\phi^W = x^I + \tilde{\gamma} - \frac{1}{r}\,ln\left[\frac{4a^2 - b^2(1 + 3e^{1+r\tilde{\gamma}})}{4a^2 - b^2(1 + 3e)}\right].$$

In the absence of a technological headstart, $\gamma = 0$, a patent is welfare decreasing.

Proof: If the inventor decides to patent, his date of adoption depends on the height of the patent, $t_i^\phi = \phi$, as does the adoption date of the non-inventor, $t_j^\phi = \phi + 1/r$. Substituting these adoption dates into equation (23) yields $W^\phi = [\,3\,b^2\,e^{-r\phi} + (b^2 - 4a^2)\,e^{-r(\phi+1/r)}]/(8\,r)$. If the inventor refrains from patenting his adoption strategy is $t_i^S = x^I$ and the non-inventor reacts by adopting in $t_j^S = x^I + 1/r + \gamma$. Substituting these adoption times into equation (23) results in the welfare realized when the basic invention is not patented, $W^S = [\,3\,b^2\,e^{-rx^I} + (b^2 - 4a^2)\,e^{-r(x^I+1/r+\tilde{\gamma})}]/(8\,r)$. Then the effect patenting has on social welfare amounts to $\Delta_\phi^W = W^\phi - W^S$. Inserting W^ϕ and W^S as derived above and rearranging terms yields

$$\Delta_\phi^W = 3\,b^2(e^{-r\phi} - e^{-rx^I}) + (b^2 - 4a^2)(e^{-1-r\phi} - e^{-r(x^I+1/r+\tilde{\gamma})}). \tag{24}$$

This patent effect on welfare is zero, $\Delta_\phi^W = 0$, for a patent height of ϕ^W as stated in the above Proposition. In the absence of a technological headstart, $\tilde{\gamma} = 0$, this critical patent height is $\phi^W = x^I$. A patent of this height would have no *protective effect* at all so the inventor would never patent. Therefore minimum patent height must be $\phi^{min} = x^I + \epsilon$. Since $\partial\Delta_\phi^W/\partial\phi < 0$ the patent effect on social welfare will be positive for all patent heights with $\phi < \phi^W$. As $\partial\phi^W/\partial\tilde{\gamma} > 0$, an increase of the technological headstart would raise the critical level of the patent height that induces a welfare effect of zero, ϕ^W. Thus for all $\tilde{\gamma} > 0$ there is a multitude of possible patent heights

$\phi \in [x^I + \epsilon,\, \phi^{\mathrm{W}}[$ that offer a *protective effect* and enhance social welfare. ■

Recalling *Proposition 2* and the fact that the inventor may refrain from patenting if his technological headstart exceeds a critical level γ^p_ϕ, it is crucial to investigate whether patents actually occur for patent heights that are welfare enhancing. Note that ϕ^{W} as stated in the above *Proposition 4* always exceeds $x^I + \tilde{\gamma}$ since the term in square brackets is smaller than one so that the term $ln[\cdot]$ always has a negative value. Then $\bar{\phi} = x^I + \tilde{\gamma} < \phi^{\mathrm{W}}$ is a welfare enhancing patent height. As stated in Section 3 the inventor will patent as long as the overall effect of patenting, Δ_ϕ, as stated in equation (18), is positive. Note that $\bar{\phi} = x^I + \tilde{\gamma}$ may lead to both cases, patenting and secrecy, depending on the extent of the technological headstart (see *Proposition 2*). Consequently patent height is indeed a tractable measure to induce a welfare enhancement. But adjusting patent height for welfare reasons is a very complex matter - not only the counter effects of a patent on social welfare have to be considered but also the effects on the inventor's patenting decision: The attempt to enhance social welfare by decreasing patent height may lead to a situation where the inventor completely refrains from patenting.

5 Concluding Remarks

This paper has examined the patenting decision of a successful inventor as well as the speed of diffusion of inventions with and without patent protection. In understanding a patent as a contract between an inventor and society (*Denicolò*, *Franzoni* (2004a)) we divided the effect a patent has on the profits of an inventor 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. Before this date the disclosure requirement has no negative consequences for the patentee. We extended this view to include the realistic case that the disclosure requirement affects the patentee from the moment a patent is granted as he loses a technological headstart.
The main contribution of this paper is that we derive a critical level of asymmetry between the firms as the decisive factor concerning the patenting behavior of a successful inventor. Building on *Dutta et al.* (1995) the patenting decision was endogenized in a dynamic model of technology adoption. We derived two unique Nash equilibria, *preemption* and *maturation.* The patenting behavior differs in both cases. If both firms follow preemptive strategies in improving the basic invention, a patent will only benefit the inventor if his headstart does not exceed a critical level. If the technological headstart is higher, the *disclosure effect* of a patent absorbs its positive *protective effect*

completely - a patent would decrease the profits of the patentee so that he prefers secrecy. In a *maturation* equilibrium this is always the case.

Our findings are strongly supported by empirical evidence. On the one hand we find a possible theoretical explanation for the observed behavior of firms preferring risky trade secrets rather than patents as appropriation mechanism for their inventions. On the other hand our finding that the speed of diffusion may be retarded by strong IPR is supported by the empirical work of *McCalman* (2005).
Thus weakening patent protection by decreasing a patent's height may have positive effects concerning the speed of diffusion as well as the height of social welfare. But possibly a decrease of patent height may have a negative influence on the patenting decision of the inventor. If he refrains from patenting due to the lower patent height a policy attempt would be in vain. Thus any policy implications have to be considered with great care, cautiously taking into account specific market conditions.

References

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

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. (1996): Patent Races and Optimal Patent Breadth and Length. *The Journal of Industrial Economics* 44, 249–265.

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.

van Dijk, T. (1996): Patent Height and Competition in Product Improvements. *The Journal of Industrial Economics* XLIV, 151–167.

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.

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

Matutes, C., Regibeau, P., Rockett, K. (1996): Optimal Patent Design and the Diffusion of Innovations. *RAND Journal of Economics* 27, 60–83.

McCalman, P. (2005): International Diffusion and Intellectual Property Rights: An Empirical Analysis. *Journal of International Ecnomics* 67, 353–372.

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