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Losing the Lead? An Empirical Investigation of the Decision to Patent

Diana Heger* and Alexandra K. Zaby†

Abstract

This paper presents a theoretical model on firms' patenting decision in vertically differentiated markets. The model's prediction regarding patenting and rival's market entry decision are then tested empirically. We find that in industries which are characterized by easy-to-use knowledge spillovers the technological lead of the inventor is reduced to such an extent that the propensity to patent increases. Furthermore, the intensity of patent protection has a delaying impact on rival's market entry.

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

JEL Classifications: L13, O14, O33, O34

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†This paper

1 Introduction

The fact that not every innovation is patented has long since been discussed in economic literature (see e.g. Horstmann et al. (1985)). Empirical evidence points in the same direction: With data from the 1993 European Community Innovation Survey (CIS), Arundel (2001) explicitly analyzes the relative importance of secrecy versus patents and finds that a higher percentage of firms in all size classes rate secrecy as more valuable than patents. In their seminal empirical study Cohen et al. (2000) find that a major reason for the firm's decision not to patent is the disclosure requirement that is linked to a patent. Thus it is the loss of a technological leadership caused by the required disclosure of proprietary knowledge which drives the propensity not to patent: The patentee has to fear that the transfer of enabling knowledge included in the patent application may benefit his rivals instantaneously by facilitating a rapid catch-up.

This paper empirically investigates the disclosure requirement's significance for the propensity to patent and the competitor's market entry decision subsequent the firm's patenting decision. It thereby builds on the theoretical model presented in Zaby (2009). In line with patent law, Zaby assumes that a patent requires the immediate and full disclosure of all technical details concerning a patented discovery.¹ This transfer of enabling knowledge benefits a noninventor instantaneously so that due to the disclosure effect the profits of the innovator will decrease. This negative effect of patenting is opposed by a positive protective effect. Overall the patenting decision of an inventor thus 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. Naturally, the positive effect may be enhanced by stronger property rights while the negative effect is subject to the impact of the disclosure requirement.

In Zaby (2009) the patenting decision of a successful inventor is introduced into a market with vertically differentiated products. She considers two firms which are asymmetric in their capabilities to adopt a new technology: one firm is a successful inventor and possesses the complete technological knowledge about its invention. Its rival, the non-inventor, has failed to invent so far, but has accumulated some know-how. Assuming that the quality of the invention increases costlessly over time, the decision when to market the new technology, i.e. when to innovate, is equivalent to the decision at which quality level to market it. The first adopter of a new product will realize monopoly profits offering the innovative technology at a relatively low quality up to the point in time when a rival firm enters and offers the new technology incorporated in a product of higher quality. Subsequently,

both firms compete in an asymmetric duopoly. 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 from the entry of a rival and due to the setting with vertically differentiated products Zaby (2009), following van Dijk (1996), denotes the intensity of patent protection as the height of a patent. Assuming that patent protection is not perfect in the sense that it cannot cover all possible product qualities, the non-inventor may still enter the market with a non-infringing product in spite of a patent. As the non-innovator is forced to realize a given level of product quality to enter the market without infringing the patent, his date of market entry is possibly postponed by a patent. From the viewpoint of the innovator one can say, that the threat of market entry is mitigated by patenting.

From the date of market entry, the innovator profits from temporary monopoly power until a competitor is able to enter with a sufficiently improved - non-infringing - version of the basic innovation. At the same time he faces the drawback of the disclosure requirement linked to the patent which may enable the competitor to accomplish the follow-up innovation at an earlier point in time. Methodically the strategic decisions form a three stage game: On the first stage the inventor decides whether to patent or to rely on secrecy, on the second stage both firms choose their qualities and on the last stage of the game they compete in prices.

Due to the dynamic setting, patent protection may eventually come into operation even before the inventor decides to launch the new product on the market, thus leaving him more time to improve the basic invention in order to make a delayed market entry more profitable without facing the threat of a rival's entry. Our main result is that the inventor will patent his invention whenever his technological headstart is moderate and that he will rather rely on secrecy whenever his technological headstart is high. The latter is due to the fact that the positive protective effect of a patent is outweighed by its negative effect of the required disclosure.

Several empirical studies aim at analyzing the propensity to patent. Using the first wave of the German part of the CIS, König, Licht (1995) investigate the importance of patents compared to non-legal appropriation methods of research output. They find that the non-legal intellectual protection tools are more effective than patents. Moreover, König, Licht (1995) conclude that firms rather rely on a bundle of legal and non-legal appropriation mechanisms instead of solely patenting. In a direct comparison of the use of patents versus secrecy Hussinger (2006), using data from the year 2000 CIS on German manufacturing firms, finds that patents are effective to protect innovations, i.e. commercialized inventions, while secrecy is rather important for inventions which are in the pre-market phase. She implements the measure sales of

new products - which reflect the market success of innovations - as dependent variable and thereby obtains a new measure of the importance of intellectual property protection.

Arundel, Kabla (1998) use the data from the PACE survey of Europe's largest industrial firms to calculate the sales-weighted patent propensity rates for 19 industries. They find that only four industry sectors reveal patent propensities which exceed 50

This paper's empirical analysis is based on the Mannheim Innovation Panel of the year 2005 which includes characteristics of firms' innovation activities, like expenditures, R&D activities, IP protection mechanisms, but also firms' assessment of their competitive situation.

The analysis first looks at firms' propensity to patent which is linked to the technological lead and its reduction due to usability of unintended knowledge spillovers prevailing in the prospective industry. In order to reflect the reduction of technological lead due to the usability of unintended knowledge spillovers we include an interaction term into our probit estimation. From the theoretical model we expect that the impact of technological lead is negative whereas the interaction term should turn out to be positive.

The second empirical test analyzes the competitors' market entry decision. For its operationalization we use the firms' assessment of whether their market position is threatened by rivals' entry. This variable is measured on a four point Likert scale ranging from "fully applies" to "does not apply at all" and thus reflects the degree of entry threat. A high entry threat should in this setting reflect a soon market entry by competitors. To analyze the perceived entry threat we estimate an ordered probit and relate it to technological lead, the usability of unintended knowledge spillovers and patent breadth. According to our theoretical model, we conjecture that technological lead and patent breadth result in a lower threat of entry whereas we hypothesize the opposite effect for the interaction term of technological lead and the usability of spillovers.

The rest of the paper is organized as follows. In Section 2 we state the hypotheses which summarize the underlying theoretical model and present their empirical implementation. The following section 3 describes the data set and our proceeding in restricting the data sample and defining the variables. Section 4 presents our empirical results and Section 5 concludes.

2 Theoretical Model

2.1 The Model Setup

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, $\sigma_u^2 = x_h$, $u = i, j$, given the inventor's protection decision. On the third stage firms compete in prices, $\sigma_u^3 = p_u$, $u = i, j$. 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 will take a closer look at the dynamic nature of product quality. Following Dutta et al. (1995) and Hoppe and 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 period without involving any further research costs. Thus, the inventor's research time is given by

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

implying that the inventor has to invest $t_i(\bar{x}) = \bar{x}$ periods of time in order to reach a certain quality level \bar{x} . Thus, the adoption date $t_i(\bar{x})$ obviously defines the adopted quality level, \bar{x} . To capture the fact that the inventor has a technological headstart compared to his rival, we further assume that at the date of the invention ($t = 0$) he has a technological lead in height of γ which is assumed to be common knowledge. This means that the non-inventor will have to invest γ periods more than the inventor to reach a given quality level, so that his research time can be specified by $t_j(x) = x + \gamma$.

Regarding the asymmetric research capabilities of the firms, two important aspects should be taken into account which will allow a richer interpretation of our results: the existence of spillover effects on the one hand and the capability of firms to appropriate and thus profit from these spillovers on the other.¹ Note that in this setting spillovers may either be unintended leaks of information or may be the consequence of the choice to patent, as then full disclosure is required. We will measure the spillover of information

¹See Kamien and Zang (2000) for an extensive theoretical approach to this issue.

by an exogenously given spillover parameter λ . Note that this parameter may vary throughout different industries, thereby capturing industry specific differences concerning the usability of the knowledge spillovers. Whenever the invention is marketed, the usability of knowledge spillovers can be interpreted as the easiness of reverse engineering. Due to the existence of a spillover effect, the *initial* headstart of the inventor, say $\tilde{\gamma}$, has to be distinguished from his *effective* headstart, γ , where the latter accounts for a positive spillover effect. Whenever the inventor chooses secrecy, the extent of his technological lead at any point in time $t > 0$ will differ from his *initial* headstart if $\lambda > 0$. If the inventor decides to patent we have $\lambda = 1$, so that he has no effective headstart at all. The extent of the inventor's *effective* technological lead can thus be defined as $\gamma \equiv \tilde{\gamma}(1 - \lambda)$. Thus the non-inventor profits from the spillover of information as his research time is shortened by $\lambda\tilde{\gamma}$. For $\lambda > 0$ it can be specified by

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

Proceeding with the analysis we will start solving the three stage game, setting off with the last stage.

2.2 Price Competition

On the third stage of the game firms set their prices, $\sigma_u^3 = p_u$, $u = i, j$, given their strategic quality decisions on the previous stage. Potentially, two scenarios are possible: (i) the inventor offers the low quality while the non-inventor offers the high quality, or (ii) the non-inventor offers the low quality while the inventor offers the high quality. To keep the theoretical analysis short, we present the derivation of case (i) only stating the results of case (ii). See Zaby (2009) for an extensive analysis.

Assume for simplicity that costs of production are zero. Subsequent to the unique quality decision of the firms on the second stage of the game, price competition will take place in every period up to infinity. Consequently, we first need to derive the profits a firm realizes in one period so that in a second step we will be able to derive the discounted overall profits the firms realize. Let us proceed with the per period profits.

The demand that firms face is modeled using the idea of the natural-oligopoly model of Shaked and 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 $b > 2a > 0$. 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.

As we assume that quality rises costlessly over time, the early adopter, firm i , will necessarily offer the relatively lower quality x_l^i . All consumers with a quality preference $\theta \geq p_l^i/x_l^i$ will buy one unit of the product with quality x_l^i from the temporary monopolist in every period until his rival firm enters with a higher quality x_h^j at a later point in time. Straightforward computation yields the monopoly profit that the early adopter realizes in every period until his rival enters the market

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

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

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

and the corresponding profits per period

$$\pi_h = A_h(x_h^j - x_l^i) \tag{5}$$

$$\pi_l = A_l(x_h^j - x_l^i) \tag{6}$$

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

Using the per period profits derived above we can determine the overall profits firms can realize. We denote the point in time when the early adopter enters the market with a low quality by t_i and the point in time when the late adopter enters with a higher quality by t_j , respectively. Further we assume that all future profits are discounted with the interest rate $r > 0$.

The early adopter's overall profit consists of two parts: the monopoly profits he realizes from his adoption in t_i until the second firm enters in t_j and the

²To 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, $ax_l^i - p_l^i \geq 0$. Inserting p_l^i as stated in equation (4), rearranging terms yields

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

as market coverage condition.

subsequent duopoly profits. Thus the lifetime profits of firm i amount to

$$L_i(x_l^i) = \int_{t_i(x_l^i)}^{t_j(x_h^{j*})} e^{-rt} \pi_m dt + \int_{t_j(x_h^{j*})}^{\infty} e^{-rt} \pi_l dt. \quad (7)$$

The late adopter earns duopoly profits π_h per period starting with his entry into the market in t_j with a high quality x_h^j . Thus the lifetime profits of firm j amount to

$$F_j(x_h^j, x_l^i) = \int_{t_j(x_h^j)}^{\infty} e^{-rt} \pi_h dt. \quad (8)$$

2.3 Quality Choices

Moving one stage backwards both firms will make their strategic quality decisions given the inventor's protection decision on the first stage where he either (a) chooses to protect his invention by a patent or (b) chooses to keep his invention secret. The late adopter j has to decide when to adopt the new technology after the innovator i has already adopted the low quality x_l^i . Inserting π_h as defined in equation (5) into the discounted overall profit function of firm j , equation (8), optimization with respect to the quality level x_h^j yields the optimum differentiation strategy given the early adopter's quality decision, x_l^i ,

$$x_h^{j*} = x_l^i + \frac{1}{r}. \quad (9)$$

Obviously we have a constant optimum level of differentiation, $x_h^{j*} - x_l^i = 1/r$. We can now derive the adoption dates by inserting this differentiation level into the respective research time functions (1) and (2). We get $t_i(x_l^i) = x_l^i$ and $t_j(x_h^{j*}) = x_l^i + 1/r + \gamma$. Inserting the later into equation (8) we have the lifetime profits of the non-inventor as late adopter subject to x_l^i ,

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

The innovator as early adopter anticipates the optimum differentiation strategy of his rival, x_h^{j*} . Inserting π_m and π_l defined by equations (3) and (6), taking into account the optimum level of differentiation, $x_h^{j*} - x_l^i = 1/r$, as well as the adoption dates derived above, solving the integrals yields the overall profit of the inventor as early adopter subject to x_l^i

$$L_i(x_l^i) = \frac{(1 - e^{-1-r\gamma}) \pi_m + e^{-1-r\gamma} \pi_l}{r e^{rx_l^i}}. \quad (10)$$

Optimization of $L_i(x_l^i)$ with respect to x_l^i then yields the profit maximizing adoption quality for firm i

$$x_i^* = \frac{1 - e^{-1-r\gamma}(1 + A_l/A_m)}{r(1 - e^{-1-r\gamma})}. \quad (11)$$

This changes in scenario (ii) where the non-inventor is the first adopter. As early adopter the non-inventor j could enter the market in $t_j(x_l^i) = x_l^i + \gamma$ and the inventor as second adopter would follow with $x_h^{j*} = x_l^i + 1/r$ in $t_i(x_h^{j*}) = x_l^i + 1/r$.³ Inserting these adoption dates into equation (7) and solving the integrals yields the overall profits of the non-inventor as early adopter

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

and the inventor as late adopter would realize

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

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 $L_j(x_l^i) > 0 \forall t > \gamma$ and $L_j(x_l^i) = 0 \forall t \leq \gamma$.

So far we derived the lifetime profit functions for the possible scenarios solely depending on the adoption quality of the first adopter, $L_i(x_l^i)$, $L_j(x_l^i)$, $F_i(x_l^i)$ and $F_j(x_l^i)$. Note that the asymmetric adoption capabilities of the firms 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^i can be replaced by time, $x_l^i = t$.

³To assure that $t_j(x_l^i) < t_i(x_h^{j*})$ we assume that $\gamma < 1/r$ holds throughout the rest of the paper.

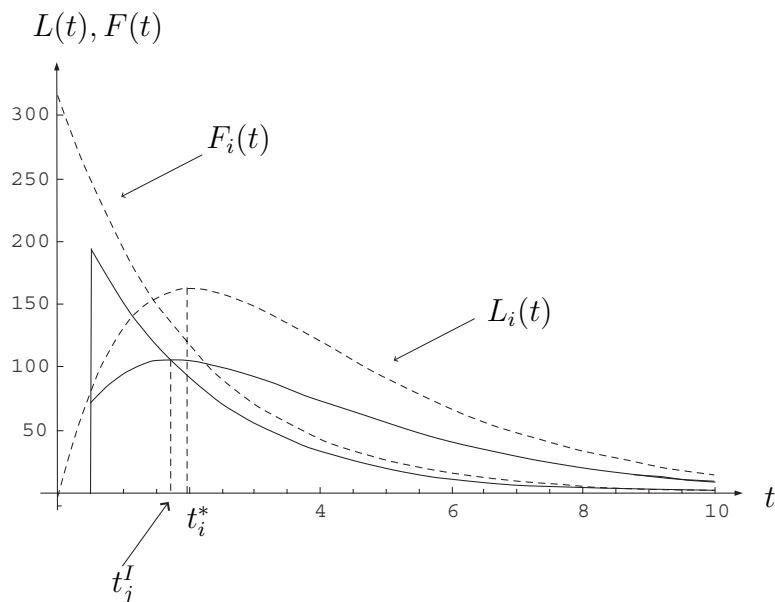


Figure 1: Preemption, with $\gamma = 0.5$ $a = 6$, $b = 25$, $r = 0.5$

Figure 1 depicts these profit functions where the dashed lines represent the possible lifetime profits of the inventor and the solid lines represent those of the non-inventor.

Whenever $L_u > F_u$, firms prefer to be the first adopter and whenever $F_u > L_u$ firms prefer to wait until a rival has entered and then enter as second adopter.⁴ As we will see, the actual quality choices of the inventor and his rival crucially depend on the inventor's protection decision on the first stage of the game. If he chooses to patent his invention, a given range of quality levels will be protected by the patent 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 headstart but misses the benefits of patent protection. Proceeding with the second stage of the game, we need to distinguish the subgames *secrecy* and *patent*.

⁴Note 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.

2.3.1 Quality choices if the invention is kept secret

Whenever the inventor decides to keep his invention secret on the first stage of the game, $\sigma_i^1 = S$, the strategy space concerning the non-inventor's quality choice is not constrained. In Figure 1 obviously 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 other will follow the adoption strategy *adopt first* ($\sigma_u^2 = x_i^j$) in the area where $L_u > F_u$, no one is able to actually reach his profit maximizing quality level. The argumentation behind this is straightforward, see Zaby (2009). Both have the incentive to preempt each other until one reaches the adoption date at which early and late adoption yield the same profits, which is the case at 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 this 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 shows that if both firms follow the strategy *adopt first*, the inventor will always win the preemption race.⁵

Consequently the equilibrium choice of the inventor 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 $L_j(t_j^I - \epsilon) < F_j(t_j^I)$.⁶ 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.⁷

The following Proposition summarizes our results so far.

Proposition 1 *If the inventor chooses to keep his invention secret, $\sigma_i^1 = S$, the subgame secrecy has an preemption equilibrium where the inventor adopts first with the lower quality $\sigma_i^{2*} = x_j^I$ and the non-inventor is the late adopter with the higher quality $\sigma_j^{2*} = x_j^I + 1/r$.*

Note that without a technological lead ($\gamma = 0$) both firms are symmetric and try to simultaneously adopt at $t^I = t_j^I = t_i^I$. Then firm i (j) is successful

⁵See Zaby (2009), Lemma 1.

⁶We assume that $c \in [0.2384, 0.5[$ to assure the existence of this subgame equilibrium. See Zaby (2009), Footnote 10 for details.

⁷Obviously 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 . For a high value of γ , $\gamma > \hat{\gamma} \equiv \frac{1}{r} \ln \left[e - \frac{4(2b-a)^2}{b^2} \right]$, the order of both points is reversed for firm j , so his strategy changes from *adopt first* to *wait*. In this case an additional subgame perfect Nash equilibrium prevails, see Zaby (2009). As this is not substantial for our empirical analysis we exclude it here by assuming $\gamma \leq \hat{\gamma}$ throughout the paper.

with probability $p(1-p)$.⁸

2.3.2 Quality choices if the innovation is patented

If the inventor patents his basic invention on the first stage of the game, $\sigma_i^1 = P$, the non-inventor is deterred from adopting the new technology up to a certain quality level which 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.⁹

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^{i*} . This is due to the fact that a patent mitigates the threat of entry. As a given range of product space is protected from entry by a rival, the inventor can postpone his entry long enough to realize a higher product quality, $x_i^P > x_i^{i,S}$. Note that this positive effect is opposed by the negative effect of the required disclosure which may compensate the positive effect completely, see the following Section.

We will distinguish three patent types according to their protectional degree: weak *protective* patents, strong *protective* patents and *delaying* patents. Patents of height $\phi \in]x_i^{i,S}, x_i^{i*}[$ are defined as *weak protective* patents having the positive effect of protecting the quality range up to ϕ . Patents of height $\phi \in [x_i^{i*}, x_h^{j*}[$ are defined as *strong protective* patents as they allow the inventor to reach his profit maximizing quality x_i^{i*} . Both patent types mildly soften the threat of entry as they still admit the non-inventor to follow his best differentiation strategy. The strongest protectional degree is reached with *delaying* patents. They are defined as patents 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 so the mitigating effect on the threat of entry is very high.¹⁰

⁸This corresponds to the preemption equilibrium analyzed by Dutta et al. (1995).

⁹Patent height can be understood as a specification of the term “patent breadth“ which is usually associated with horizontally differentiated products, see Denicolò (1996) for an extensive discussion of the concepts of patent breadth.

¹⁰In 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 $\phi < b$

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.*

- (i) *With a weak protective patent the inventor adopts the quality $\sigma_i^{2*} = \phi$ and the non-inventor can follow his profit maximizing strategy. The threat of entry is mildly softened.*
- (ii) *With a strong protective patent the inventor adopts the quality $\sigma_i^{2*} = x_i^{i*}$ and the non-inventor can follow his profit maximizing strategy. The threat of entry is mildly softened.*
- (iii) *With a delaying patent the inventor adopts the quality $\sigma_i^{2*} = x_i^{i*}$ and the non-inventor is forced to wait until he reaches the quality $\sigma_j^2 = \phi + \epsilon$. The threat of entry is strongly mitigated.*

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.

2.4 The Patenting Decision

On the first stage of the game the inventor decides whether to patent, $\sigma_i^1 = P$, or to keep his invention secret, $\sigma_i^1 = S$. Naturally he will choose to patent whenever this yields higher profits than he could realize by keeping the invention secret. As a patent has the drawback of the disclosure requirement linked to it, he has to consider the tradeoff between a positive and a negative patent 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,

$$\Delta^+ = L_i(x_i^{i,P})|_{\gamma>0} - L_i(x_i^{i,S})|_{\gamma>0}. \quad (12)$$

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 the spillover parameter λ is set to unity, so that the effective headstart of the inventor, γ , becomes zero.

throughout the rest of the paper.

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 patent effect can be measured by the difference between the profit of the inventor with and without a technological lead,

$$\Delta^- = L_i(x_l^{i,P})|_{\gamma>0} - L_i(x_l^{i,P})|_{\gamma=0}. \quad (13)$$

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 (12) and (13) this patent effect can be derived as

$$\Delta_P = L_i(x_l^{i,P})|_{\gamma=0} - L_i(x_l^{i,S})|_{\gamma>0}. \quad (14)$$

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.

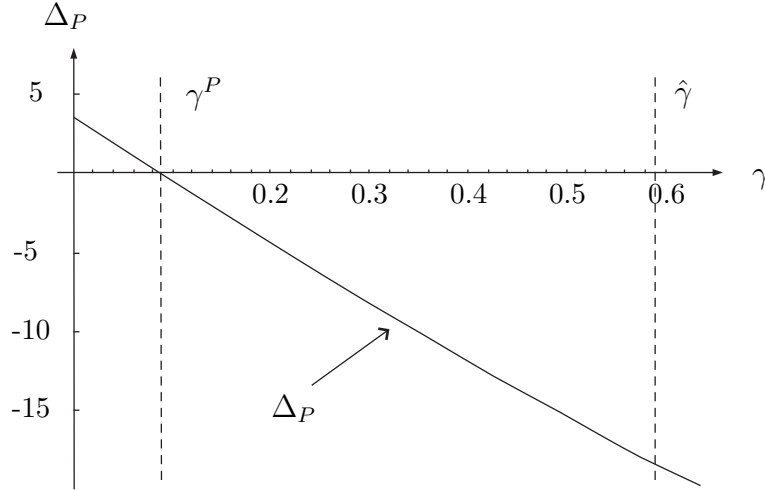


Figure 2: Δ_P for $a = 6$, $b = 25$, $r = 0.5$ and $\phi = x_l^{i*}$

Figure 2 depicts the patent effect for strong protective patents, $\phi \geq x_l^{i*}$. As we assumed $\gamma < \hat{\gamma}$ (see Footnote 7) a preemption equilibrium would result if the inventor chose secrecy. From Proposition 1 we know that then he would realize the quality $x_l^{i,S} = x_h^{j,I}$. By patenting the inventor could increase his profits since he would be able to choose $x_l^{i,P} = x_l^{i*} > x_h^{j,I}$ due to the *protective effect* of the patent.

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 $\gamma = \gamma^P$ 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 unique and stable subgame perfect Nash equilibria of the considered three stage game.

Proposition 3 *The patenting decision of the inventor crucially depends on the extent of his technological headstart. He will choose to*

- (i) *patent if a preemption equilibrium would prevail with secrecy and his technological lead is small, $\sigma_i^1 = P$ iff $\gamma \leq \gamma^P < \hat{\gamma}$*
- (ii) *keep his invention secret if a preemption equilibrium would prevail with secrecy and his technological lead is high, $\sigma_i^1 = S$ iff $\gamma^P < \gamma < \hat{\gamma}$*

The above Proposition states that the disclosure requirement plays a decisive role for the patenting decision of an inventor. If his discovery incorporates a substantial amount of proprietary knowledge the drawback of a patent as appropriation mechanism is immense. Naturally the value of the spillover parameter may influence this result as the following Corollary states.

Corollary 1 *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 and $\partial\Delta_P/\partial\gamma < 0$.*

Recalling the interpretation of λ as the easiness of reverse engineering, this leads to the interesting conclusion that the propensity to patent increases as reverse engineering becomes easier. Thus a firm operating in an industry sector where reverse engineering is a substantial threat will rather choose to patent than rely on secrecy as even a large initial technological headstart will diminish due to the high value of the parameter λ . Consequently, following our results stated in Proposition 3, the protective effect of the patent then outweighs the disclosure effect which is weakened due to the high value of λ , leading the inventor to the decision to patent his invention.

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 2 *The inventor's propensity to patent increases if the height of a weak protective patent, $\phi =]x_l^{i,S}, x_l^{i*}[$, or a delaying patent, $\phi > x_h^{j*}$, increases. It remains unchanged if the height of a strong protective patent, $\phi = [x_l^{i*}, x_h^{j*}]$, 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 2. 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 Hypotheses and their empirical implementation

In this section, we derive hypotheses based on the model in Section 2 in order to verify the theoretical results. Contrary to the theoretical procedure which uses backward induction we will use a chronological approach for the empirical analysis, i.e. we will first empirically investigate the driving factors behind the patenting decision and will then, in a second step, examine the theoretical results concerning rival's timing of market entry, i.e. the threat of entry the innovator faces. Some crucial assumptions were made to solve the theoretical model: The world in which the model and its results are valid is one of vertically differentiated products, i.e. the firms compete in quality.

Recall the results on the first stage of the three-stage game: The patenting decision entails two opposing effects: a protective effect and a disclosure effect. Obviously, a firm decides to patent if profits generated by the protective effect exceed the reduction of profits by the disclosure effect, otherwise the results of the R&D activities are appropriated by secrecy. Both effects are driven by the three parameters extent of the technological lead, γ , usability of technological spillover, λ , and intensity of patent protection, ϕ . The spillover are expected to be higher in industries where reverse engineering is easy. While, for example, in *pharmaceuticals* the patenting rate is rather high, in an industry sector such as *precision instruments* the patenting rate is

found to be rather low. Relating this observation to the fact that a patent forces the disclosure of technological knowledge and therefore facilitates the research efforts of rival firms, some industry specific differences concerning the usability of the disclosed information have to exist, which account for the difference in patenting rates. In the theoretical model, we captured this aspect by linking the technological headstart of a successful inventor to an industry specific parameter that reflects the easiness of reverse engineering (see Arundel et al. (1995)). Summarizing the theoretical results concerning the patenting decision, we derive the following hypotheses:

Hypothesis 1 *Whenever the disclosure requirement has an impact, the protective effect of mitigating the threat of entry may be overcompensated by the disclosure effect so that the higher the technological lead of the inventor, the lower is his propensity to patent.*

Hypothesis 2 *In industries in which spillover are easy to use, e.g. because they are characterized by easy-to-achieve reverse engineering, the technological lead will diminish and hence the propensity to patent will increase.*

In the next step, we present how we implement our theoretical results into an estimation Equation. From above we know that the effective technological lead consists of the initial headstart of the inventor which is eventually decreased by an industry-specific spillover effect:

$$\gamma = \tilde{\gamma}(1 - \lambda) = \tilde{\gamma} - \lambda\tilde{\gamma}.$$

As stated in Hypotheses 1 and 2, the decision to patent is mainly driven by the initial headstart. We translate the theoretical result into the following empirical Equation:

$$P = \beta_1 + \beta_2 TL + \beta_3 RE + \beta_4 TL * RE + Controls, \quad (15)$$

where P denotes the patenting decision, TL the technological lead and RE the easiness of reverse engineering. In line with the theoretical findings we conjecture a negative influence of the technological lead (TL) and a positive effect of the interaction term of TL and RE . As in the theoretical model reverse engineering has no direct effect on the propensity to patent, we expect to find no significant effect empirically.

Given the patenting decision on the second stage of the game firms decide on when to enter the market. As we find that the inventor always takes the lead, the adoption choice of the non-inventor crucially depends on the extent of the inventor's technological headstart. Hence, we come to our next hypotheses.

Hypothesis 3 *The rival's market entry is delayed if the effective technological headstart of the leading innovator is large. Reverse engineering has a detrimental effect on the technological lead and hence increases the threat of rival's entry.*

Furthermore, if an inventor chooses to patent, the mandatory disclosure of the invention enables its rival to enter the market at an earlier point in time as the inventor loses his lead. As the disclosure effect is opposed by the protective effect of a patent, the patentee's competitor might be forced to postpone his market entry in order to develop a non-infringing product. This mitigates the threat of entry that the patentee faces and naturally this effect should be stronger, the higher the level of patent protection is. Thus we propose the following Hypothesis.

Hypothesis 4 *The threat of entry decreases with the intensity of patent protection, i.e. patent scope.*

From Proposition 2 we know that the threat of entry is weakened with either a weak or strongly protective patent and that the threat of entry is strongly mitigated with a delaying patent. In combination with Hypothesis 3 this translates into the following empirical model:

$$TOE = \beta_1 + \beta_2 TL + \beta_3 RE + \beta_4 TL * RE + \beta_5 DP + \beta_6 SP + \beta_7 WP + Controls,$$

where TOE is the threat of entry, DP reflects delaying patents, SP strongly and WP weakly protective patents. For a definition of TL and RE see the previous equation. The technological lead, TL , should now have a negative effect on the threat of entry, i.e. the time until entry increases with the extent of the technological headstart. The interaction term with reverse engineering should again reveal the opposite effect while the sole effect of RE should not be significant. As the theoretical model predicts, a delaying patent should have a negative effect on the perceived intensity of the threat of entry, while strong and weak patents should have a negative or an insignificant effect.

4 Data set

The basis for the empirical analysis is the Mannheim Innovation Panel (MIP) of the year 2005. The MIP is an annual survey which is conducted by the Centre for European Economic Research (ZEW) Mannheim. The aim of the survey is to provide a tool to investigate the innovation behavior of German manufacturing and service firms. Regularly – currently every two years – the

MIP is the German contribution of Community Innovation Survey (CIS). Our empirical investigations are based on XX firms.

In the year 2005, the survey contained additional questions concerning the firm's perception of the competitive situation. Questions concerning the characteristics and the importance of specific competitive factors like price or quality are asked as well as the perceived competitive situation with respect to the number of competitors and their relative size.

4.1 Sample definition

In order to test our hypotheses, we need to restrict our sample to innovative firms, i.e. we exclude firms which did not launch a new product or process within the period 2002 to 2004. Furthermore, the theoretical model is designed for vertically differentiated products, i.e. the competitive situation is characterized by quality competition. In the 2005 survey, one question is aimed at the characterization of the competitive situation on the main product market. The firms are asked to rank the following choices according to their importance: quality, price, technological advance, advertisement, product variety, flexibility towards customers. We keep those observations for which firms have indicated that quality is the most, second or third most important feature of competition.

The first part of the empirical analyzes deals with the propensity of patenting vs. secrecy and whether it depends on technical leadership (Hypotheses 1 and 2). In the theoretical model, patenting and secrecy are excluding categories: A firm can either patent or keep the R&D results secret.¹¹

For the investigation of the threat of entry (Hypotheses 3 and 4), we need to include patent scope in the data set. For this we used patent information from the European Patent Office (EPO) for the observation period 2002 to 2004 including the IPC codes stated in every patent application. The complete classification codes assign a patent into specific clusters which vary in their aggregational level, see the following table.¹²

¹¹For the empirical implementation, this assumption needs to be treated carefully. In the data set, we find several examples of firms which use both patenting and secrecy. Hence, we observe that firms may have more than one innovation and that these may be treated differently. Assuming that firms which indicate patents as highly important use patenting as their main IP protection strategy, all other protection strategies are ignored. Furthermore, all firms which use other formal mechanisms like trademarks are dropped even if they indicate that they use secrecy. A reason for this procedure is that formal protection dominates strategic mechanisms and we do not account for other formal protection methods besides patenting (Blind et al. (2006)).

¹²Actually also any additional information complementing the invention information which may be useful for search purposes can be classified by IPC codes through the patent

Table 1: International Patent Classification (IPC)
Code of the European Patent Office

| Section | Class | Subclass | Group | |
|---------|-------|----------|------------|----------|
| | | | Main Group | Subgroup |
| A | 01 | B | 33/0 | 33/08 |

As a patent may be codified by more than one IPC Code, the variation of codes is a good indicator for different levels of patent scope. The IPC Guide gives a quite clear statement on the relation between the IPC code and the scope of the respective patent.

The titles of sections, subsections and classes are only broadly indicative of their content and do not define with precision the subject matter falling under the general indication of the title. In general, the section or subsection titles very loosely indicate the broad nature of the scope of the subject matter to be found within the section or subsection, and the class title gives an overall indication of the subject matter covered by its subclasses. By contrast, it is the intention in the Classification that the titles of subclasses [...] define as precisely as possible the scope of the subject matter covered thereby. The titles of main groups and subgroups [...] precisely define the subject matter covered thereby [...]

(§68, IPC Guide)

In line with the above quote, since “*the class title gives an overall indication of the subject matter covered by its subclasses*”, we define the alternative patent scopes *weakly protective*, *strongly protective* and *delaying* patents starting with variations at the class level, as variations at the sectional level (including subsections), only “*very loosely indicate the scope*” of the respective patent. Thus we implement the alternative patent scopes from our theoretical model as follows: Whenever a classification symbol differs on the level of classes or subclasses, we characterize the respective patent as *delaying*. We define a patent as *strongly protective*, if the IPC codes vary in groups and as *weakly*

authorities (§123, IPC Guide). To distinguish the Classification symbols referring to the invention information and those referring to additional information, the invention information symbols are displayed in bold font style while the additional information symbols are displayed in non-bold font style (§160, IPC Guide). As the average patent is assigned two IPC codes we propose that this distinction is not crucial for our empirical analysis.

protective, if the IPC codes differ in subgroups. Additionally all patents with a single IPC code are classified as *weakly protective* patents.

In a next step we merge this information to the MIP data set we defined above.¹³ By this we condense the EPO data to the firm level. Hence, we now observe firms holding various numbers of *delaying*, *strongly* and/or *weakly protective* patents. We identified only few firms that stated to hold a patent in the MIP survey but had no equivalent entry in the EPO data set. Due to the missing information we dropped these observations.

4.2 Variable definition and descriptive statistics

In this section we describe how we define the core variables of the estimations. First, we take a look at our dependent variables: *Patenting* is measured as a dummy variable indicating whether an inventor uses patenting to protect his intellectual property. In our data set about 60% of the firms applied for a patent in the relevant period (see Table 2).

To reflect the extent of the *threat of entry* (TOE) we refer to a firm's perception on whether its market position is threatened by the entry of new rivals, which is ranked on a 4-digit Likert scale.¹⁴ This ordered variable is our indicator whether technological lead and the opposing effect of reverse engineering induce early market entry by rivals. If the time until the rival's entry is short, the variable *threat of entry* should be ranked higher than if the time until market entry is longer and the effective technological lead is larger. Hence, we assume that firms rank the *threat of entry* higher when they fear rival's entry.

¹³The merge was conducted by Thorsten Doherr, ZEW, Mannheim, using a computer assisted matching algorithm on the basis of firm names.

¹⁴Respondents could choose between *fully applies*, *rather applies*, *hardly applies* and *does not apply*.

Table 2: Descriptive Statistics for Patenting Decision Estimation with Vertically Differentiated Products

| | Mean | Std. Dev. | Min | Max |
|-------------------------------|-------|-----------|-------|-------|
| <i>patent</i> | 0.595 | 0.491 | 0 | 1 |
| <i>technological lead</i> | 0.589 | 0.492 | 0 | 1 |
| <i>reverse engineering</i> | 0.684 | 0.465 | 0 | 1 |
| <i>tech. lead * rev. eng.</i> | 0.382 | 0.486 | 0 | 1 |
| <i>complexity</i> | 0.378 | 0.485 | 0 | 1 |
| <i>log(employees)</i> | 4.563 | 1.696 | 0.693 | 9.077 |
| <i>human capital</i> | 0.267 | 0.266 | 0.000 | 1.000 |
| <i>R&D intensity</i> | 0.066 | 0.130 | 0.000 | 1.100 |
| <i>strong competition</i> | 0.132 | 0.339 | 0 | 1 |
| <i>medium competition</i> | 0.209 | 0.407 | 0 | 1 |
| <i>EU</i> | 0.673 | 0.469 | 0 | 1 |
| <i>non_EU</i> | 0.491 | 0.500 | 0 | 1 |
| <i>subsidy</i> | 0.419 | 0.494 | 0 | 1 |
| <i>customer power</i> | 0.303 | 0.460 | 0 | 1 |
| <i>obsolete</i> | 0.089 | 0.285 | 0 | 1 |
| <i>tech. change</i> | 0.465 | 0.499 | 0 | 1 |
| <i>cooperation</i> | 0.453 | 0.498 | 0 | 1 |
| <i>diversification</i> | 0.658 | 0.241 | 0.003 | 1.000 |
| <i>east</i> | 0.292 | 0.455 | 0 | 1 |
| <i>No. of observation</i> | | 740 | | |

Next we define the explanatory variables. The central variables of the theoretical model are technical leadership and the easiness of reverse engineering. Both constructs are not straightforward to implement empirically. In MIP 2005, *technical leadership* is defined by the variable temporal headstart over competitors. Hence, we create a dummy variable indicating whether the importance of technological leadership is high. About 60% of all firms state that technological leadership is a substantial characteristic of the competitive environment in their main product market.

The other theoretical concept that has to be transformed into empirical terms is the easiness of reverse engineering. Reverse engineering can also be thought

of as the usability of spillover. As stated in Arundel et al. (1995), reverse engineering is a characteristic of the industry and not of the firm. We construct a dummy variable which has unit value if the market is characterized by easy-to-substitute products. Hence, we assume that if the firm's most important product is easy to substitute, reverse engineering is a mechanism that is at work in the industry where it operates. In our data set almost 70% of the innovating firms operate in a market where reverse engineering prevails.

From the theoretical model we know that the technical leadership of a firm may be reduced by the possibility of reverse engineering. To implement this fact in our empirical analysis we create an interaction term (*tech. lead * rev. eng.*). From Table 2 we know that 38% of all innovating firms state that their competitive environment is characterized by a high relevance of technical leadership and at the same time reverse engineering plays an important role.

For the definition of *weak*, *strong* and *delaying* patents see the above section. According to the descriptive statistics in Table 3 16% of the firms applied for at least one delaying patent, while only 10% applied for a strong, and 18% for a weak patent. Note that it is possible that a firm holds various patents belonging to different categories.

Furthermore, we control for several factors that may influence our dependent variables. Firm size is represented by the number of *employees* in the year 2002, *human capital* by the share of employees holding a university degree. Market structure is reflected by two dummy variables indicating whether the number of main competitors is between 6 and 15 (*medium competition*) or exceeds 15 (*strong competition*). Finally we describe the competitive situation with respect to the geographical dimension of the product market. We control for two world regions, the *EU* and *non-EU*. Germany is considered separately as it serves as reference category in the regression. Thus it is not contained in the variable *EU*.

Customer power refers to the fact that the share of sales by the three most important customers exceeds 50% of total sales.

In order to capture whether the market is characterized by certain market entry barriers, we control for *capital intensity* defined as tangible assets per employee and for *R&D intensity* defined as expenditures for in-house R&D activities per sales. If firms cooperate with others, e.g. competitors, customers, universities, in conducting R&D this may influence their IP protection strategy. Therefore we include a dummy variable reflecting whether research cooperations take place. We also control for *public* R&D subsidies by either regional, national or European authorities.

Table 3: Descriptive Statistics for Threat of Entry Estimation

| | Mean | Std. Dev. | Min | Max |
|-------------------------------|-------|-----------|-------|-------|
| <i>threat of entry</i> | 1.517 | 0.806 | 0 | 3 |
| <i>technological lead</i> | 0.413 | 0.493 | 0 | 1 |
| <i>reverse engineering</i> | 0.698 | 0.459 | 0 | 1 |
| <i>tech. lead * rev. eng.</i> | 0.273 | 0.446 | 0 | 1 |
| <i>delaying</i> | 0.160 | 0.367 | 0 | 1 |
| <i>strong</i> | 0.096 | 0.295 | 0 | 1 |
| <i>weak</i> | 0.183 | 0.387 | 0 | 1 |
| <i>complexity</i> | 0.275 | 0.447 | 0 | 1 |
| <i>secrecy</i> | 0.525 | 0.500 | 0 | 1 |
| <i>log(employees)</i> | 4.147 | 1.732 | 0.000 | 9.077 |
| <i>R&D intensity</i> | 0.060 | 0.281 | 0.000 | 6.427 |
| <i>capital intensity</i> | 0.124 | 0.363 | 0.000 | 4.554 |
| <i>strong competition</i> | 0.191 | 0.393 | 0 | 1 |
| <i>medium competition</i> | 0.223 | 0.417 | 0 | 1 |
| <i>new to market</i> | 0.434 | 0.496 | 0 | 1 |
| <i>subsidy</i> | 0.294 | 0.456 | 0 | 1 |
| <i>obsolete</i> | 0.098 | 0.297 | 0 | 1 |
| <i>tech. change</i> | 0.484 | 0.500 | 0 | 1 |
| <i>diversification</i> | 0.677 | 0.243 | 0.005 | 1.000 |
| <i>east</i> | 0.316 | 0.465 | 0 | 1 |
| <i>No. of observations</i> | 748 | | | |

To capture relevant product characteristics, we include an indicator whether a product becomes *obsolete* quickly. As the fact that a rapid change of production or service generating technologies may play an important role concerning the decision to patent and the perceived threat of market entry the respective indicator *tech. change* is included as control variable. Furthermore we control for the individual *complexity* of product design.¹⁵ Additionally a

¹⁵Note that we need to distinguish individual complexity and industry-specific complexity which can be described by the substitutability of products in the respective competitive environment of a firm.

firm's degree of *diversification* might be an impact factor in our estimations so that we use a measure reflecting the share of sales originating from a firm's top-selling product or service.

The intensity of the *threat of entry* may be strongly influenced by the fact that a product is *new* to the market. Therefore we include a dummy variable reflecting whether the responding firm has introduced such a product in the relevant time period.

In order to capture regional and sectoral differences we include an indicator whether the firm is located in eastern Germany (*east*) and define 11 *industry dummies*.

The estimation of the threat of entry further incorporates a control variable for the use of *secrecy* as an IP appropriation mechanism. As secrecy may provide similar protection compared to a patent without the drawback of mandatory disclosure choosing this protection strategy may have a relevant impact on the dependent variable .

5 Empirical results

To test our hypotheses regarding firm's patenting behavior, we estimate a probit model and calculate the marginal effects evaluated at the sample means. The standard errors are obtained by using the delta method. The calculation of the marginal effect of the interaction term is based on Ai and Norton (2003). The results are displayed in Table 4.

Recall from the theoretical model that the technological lead is defined by $\gamma = \tilde{\gamma} - \lambda\tilde{\gamma}$ so that the effect of λ , the easiness of reverse engineering, is only included in the interaction term $\lambda\tilde{\gamma}$. For a correct empirical implementation of our theoretical model our estimation equation nevertheless needs to contain the sole effect of λ which is implemented by the variable *RE*. Actually we find an insignificant effect of *RE*, so that our theoretical model is confirmed. Our theoretical model predicts that the patenting behavior is negatively influenced by the technological lead of the innovator. This is the basic statement of Hypothesis 1. Our empirical results correctly display a negative sign of the respective marginal effect, but it turns out to be insignificant. At first view this is a puzzling result. The insignificance of the effect states that whether there is a technological lead or not does not influence firms' patenting propensity if the industry is characterized by the absence of easiness of reverse engineering. Suppose a firm's technological lead is small, then our theoretical model predicts that the propensity to patent is high. In practice, patent law requires a sufficiently high inventive step incorporated in the invention in order to fulfil the patentability requirements Consequently a

small technological lead is not eligible for patent protection – a fact which is disregarded by the theoretical model. Hence our empirical finding that the technological lead has an insignificant effect can be properly substantiated. Additionally our theoretical model states that in an industry, in which the easiness of reverse engineering is high, the technological lead is reduced so that patenting becomes more attractive to an innovator. This effect is implemented empirically by the interaction term of technological lead and reverse engineering which we expect to have a positive effect (see Hypothesis 2). This is confirmed by the empirical findings.

As pointed out in the literature review at the beginning of this chapter patenting behavior of firms is positively influenced by the size of the firm as well as by its R&D intensity. Our results are in line with those results. Interestingly the control variables reflecting the strength of competition with respect to competitors, customers and regional dimensions are mainly insignificant for the patenting decision. An exception is the positive effect for *non_EU*. An intuition for this surprising result is that firms which are inter alia active in non-EU markets tend to rate protection in their home-market as more important than firms operating solely in the German home-market. A possible explanation is that those firms fear the entry of foreign firms with substitute products. Further we find that R&D cooperation has a positive significant effect on the propensity to patent whereas being located in Eastern Germany has a negative impact.

Table 4: Results of the Patenting Decision Estimation with Vertically Differentiated Products

| | Marginal Effect | Standard Error |
|--|-----------------|----------------|
| <i>technological lead</i> | -0.012 | 0.040 |
| <i>reverse engineering</i> | 0.006 | 0.043 |
| <i>tech. lead * rev. eng.</i> | 0.143* | 0.085 |
| <i>complexity</i> | -0.060 | 0.041 |
| <i>log(employees)</i> | 0.081*** | 0.015 |
| <i>human capital</i> | 0.128 | 0.109 |
| <i>R&D intensity</i> | 0.781*** | 0.219 |
| <i>strong competition</i> | -0.042 | 0.061 |
| <i>medium competition</i> | -0.021 | 0.049 |
| <i>EU</i> | 0.030 | 0.050 |
| <i>non_EU</i> | 0.112** | 0.045 |
| <i>subsidy</i> | 0.102** | 0.050 |
| <i>customer power</i> | -0.070 | 0.046 |
| <i>obsolete</i> | 0.000 | 0.072 |
| <i>tech. change</i> | -0.042 | 0.041 |
| <i>cooperation</i> | 0.099** | 0.047 |
| <i>diversification</i> | -0.138 | 0.088 |
| <i>east</i> | -0.110** | 0.049 |
| <i>industry dummies</i> | <i>included</i> | |
| <i>Log likelihood</i> | -382.08 | |
| <i>McFadden's adjusted R²</i> | 0.235 | |
| $\chi^2(all)$ | 235.05*** | |
| $\chi^2(ind)$ | 42.33*** | |
| <i>Number of observations</i> | 740 | |

*** (**, *) indicate significance of 1 % (5 %, 10 %) respectively.

This table depicts marginal effects of a probit estimation regarding the determinants of the patenting decision. Marginal effects are calculated at the sample means and those of the interaction terms are obtained according to Ai and Norton (2003). Standard errors are calculated with the delta method.

$\chi^2(all)$ displays a test on the joint significance of all variables.

$\chi^2(ind)$ displays a test on the joint significance of the industry dummies.

Generally empirical evidence based on firm-level surveys finds that the propensity to patent varies by industry sectors. Our industry dummies are jointly significant hinting at structural differences between industry sectors. However, due to the fact that we explicitly include the main factors driving these differences in our estimation, e.g. reverse engineering, complexity, technical change, we are not able to confirm significant differences between sectors.¹⁶ After the discussion of the results concerning the first stage of our theoretical game we now turn to the findings regarding the second stage where the market entry decision of competitors is analyzed. This decision is empirically implemented by using firms' statement with respect to the perceived importance of the threat of market entry by potential rivals. As threat of entry is measured on a four-point Likert scale we estimate an ordered probit model. Marginal effects are calculated at the sample means and standard errors using the delta method. For the calculation of the interaction effect we rely on Mallick (2009). The results are depicted in Table 5.

The Hypothesis 3 stating that the interaction term, $TL * RE$, has a positive impact on the intensity of threat of entry is not confirmed by the estimation results. However, we find a positive effect of reverse engineering which has to be interpreted as the effect of reverse engineering in the absence of technological lead. A possible reasoning behind this finding is that the detrimental effect of reverse engineering on technological lead is not sufficiently high to induce a significant impact on the threat of entry, i.e. a significant effect of the interaction term $TL * RE$.

Regarding Hypothesis 4 the predictions of the theoretical model are validated by the empirical findings. To test the hypothesis we implement three alternative measures for the intensity of patent protection. The strongest level of protection, i.e. a delaying patent, has a significant negative effect on the threat of entry while lower intensities of patent protection, i.e. weak and strong patents, reveal no significant effect.

Firm's capital intensity, which can be interpreted as a barrier to market entry for competitors, is found to have a negative significant effect on the threat of entry. However, our control variables reflecting the number of competitors operating in a market show positive significant effects. This opposes our conjecture that more intensive competition decreases the perceived intensity of the threat of entry. Our interpretation of this result is that the number of competitors implicitly reflects the market size. More competitors in the market may be an indicator for the fact that the market has the potential of absorbing even more firms. Furthermore it could also be an indicator for a market with low entry barriers. Following this argument the fact that many

¹⁶This result originates from tests on the equality of coefficients of industry dummies.

competitors operate in a market can either signal low market entry costs or can signal that the market bears no room for further entry. As we find a positive significant effect of a market with a large number of competitors, it must be that market entry barriers are low so that firms perceive a high threat of further market entry.

In line with economic intuition the empirical results state that if services or products become obsolete quickly or production technologies change rapidly this has a positive significant effect on the intensity of the threat of entry. Further our estimation results show that the lower the level of diversification in a firm is, the higher this firm rates the intensity of the market entry threat.

Table 5: Ordered Probit for Threat of Entry Estimation

| threat | strong | medium | weak | no |
|-------------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| | Marg. Eff. (Std. Err.) | Marg. Eff. (Std. Err.) | Marg. Eff. (Std. Err.) | Marg. Eff. (Std. Err.) |
| <i>technological lead</i> | 0.020 (0.016) | 0.028 (0.022) | -0.029 (0.024) | -0.019 (0.015) |
| <i>reverse engineering</i> | 0.039** (0.015) | 0.061*** (0.021) | -0.056** (0.022) | -0.043** (0.017) |
| <i>tech. lead * rev. eng.</i> | 0.009 (0.026) | 0.000 (0.041) | -0.014 (0.037) | 0.006 (0.031) |
| <i>delaying</i> | -0.040** (0.018) | -0.067* (0.036) | 0.057** (0.025) | 0.050 (0.031) |
| <i>strong</i> | -0.019 (0.023) | -0.029 (0.039) | 0.027 (0.033) | 0.021 (0.030) |
| <i>weak</i> | 0.011 (0.024) | 0.016 (0.031) | -0.017 (0.035) | -0.010 (0.020) |
| <i>complexity</i> | 0.021 (0.017) | 0.028 (0.022) | -0.030 (0.025) | -0.018 (0.015) |
| <i>secrecy</i> | -0.022 (0.016) | -0.031 (0.023) | 0.032 (0.024) | 0.021 (0.016) |
| <i>log(employees)</i> | 0.005 (0.004) | 0.007 (0.007) | -0.007 (0.006) | -0.005 (0.005) |
| <i>R&D intensity</i> | 0.026 (0.025) | 0.036 (0.035) | -0.037 (0.036) | -0.025 (0.024) |
| <i>capital intensity</i> | -0.047** (0.022) | -0.066** (0.031) | 0.068** (0.033) | 0.045** (0.022) |
| <i>strong competition</i> | 0.060** | 0.069*** | -0.086*** | -0.044*** |

Table continued on the next page

| threat | strong | medium | weak | no |
|--|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| | Marg. Eff. (Std. Err.) | Marg. Eff. (Std. Err.) | Marg. Eff. (Std. Err.) | Marg. Eff. (Std. Err.) |
| | (0.025) | (0.022) | (0.033) | (0.015) |
| <i>medium competition</i> | 0.046** (0.022) | 0.057*** (0.021) | -0.067** (0.030) | -0.037*** (0.014) |
| <i>new to market</i> | -0.019 (0.015) | -0.027 (0.021) | 0.028 (0.021) | 0.019 (0.015) |
| <i>subsidy</i> | 0.012 (0.017) | 0.016 (0.022) | -0.017 (0.024) | -0.011 (0.015) |
| <i>obsolete</i> | 0.051* (0.031) | 0.058** (0.029) | -0.072* (0.042) | -0.036** (0.018) |
| <i>tech. change</i> | 0.034** (0.015) | 0.047** (0.020) | -0.049** (0.022) | -0.032** (0.015) |
| <i>diversification</i> | 0.063** (0.028) | 0.089** (0.042) | -0.092** (0.041) | -0.060** (0.031) |
| <i>east</i> | -0.029 (0.015) | -0.029 (0.022) | 0.029 (0.022) | 0.020 (0.016) |
| <i>industry dummies</i> | <i>included</i> | <i>included</i> | <i>included</i> | <i>included</i> |
| <i>Log likelihood</i> | | -417.94 | | |
| <i>McFadden's adjusted R²</i> | | 0.037 | | |
| $\chi^2(all)$ | | 65.21*** | | |
| $\chi^2(ind)$ | | 8.72 | | |
| <i>Number of observations</i> | | 748 | | |

*** (**, *) indicate significance of 1 % (5 %, 10 %) respectively.

This table depicts marginal effects for an ordered probit of the estimation of threat of entry. Marginal effects are calculated at the sample means and those of the interaction terms are obtained according to Mallick (2009). Standard errors are calculated with the delta method.

$\chi^2(all)$ displays a test on the joint significance of all variables.

$\chi^2(ind)$ displays a test on the joint significance of the industry dummies.

6 Conclusion

This paper intended to empirically verify the theoretical results and predictions obtained in Section 2. Several hypotheses summarizing the theoretical results concerning the propensity to patent with vertically as well as horizontally differentiated products thereby formed the basis of our empirical examination.

From the analysis of the propensity to patent in a market with vertically differentiated products we deduced four hypothesis. Two refer to the first stage of the theoretical model, i.e. the patenting decision of the inventor, while the others concern the second stage of the model, the market entry decisions of the firms.

The first, Hypothesis 1, proposes that the higher the technological lead of the inventor, the lower is his propensity to patent. This could not be confirmed by our empirical estimation. A possible explanation for this is that the theoretical approach ignores the fact that minor technological advances are not applicable for patent protection.

Hypothesis 2 states that if reverse engineering is easy to achieve, the technological lead is reduced so that patenting becomes more attractive, i.e. the propensity to patent increases. To test this hypothesis we implemented an interaction term of technological lead and reverse engineering. As the effect of the interaction term is found to be positive and significant, this hypothesis is confirmed.

Regarding the second stage of the theoretical model, Hypothesis 3 suggests that reverse engineering reduces the technological lead so strongly that the threat of entry increases. This finding is not confirmed empirically. Since we find that the single effect of reverse engineering is positive, the effect of reverse engineering on the technological lead is obviously not strong enough to induce a positive effect of the interaction term. Nevertheless we can confirm empirically that the threat of market entry decreases with the intensity of patent protection, which is a result of the theoretical model formulated in Hypothesis 4. For a delaying patent, i.e. very strong patent protection, we find a significant negative effect on the threat of entry. Our empirical results concerning the propensity to patent in a market with vertically differentiated products are summarized in the following table.

The probably most puzzling and equivocative result of our theoretical analysis is the finding that the propensity to patent decreases the higher the technological lead of an innovator is. The commonly perceived intuition suggests the opposite, namely that an innovation is patented, the greater the technological advance it embodies. Our empirical estimation offers the solution to this puzzle: we find that in our model setting the commonly suggested interdependence of technological lead and the propensity to patent only holds if the respective market is characterized by easy-to-achieve reverse engineering. Thus our theoretical findings do not contradict common intuition but constrain its validity to markets where reverse engineering is easy. Consequently, in a market where reverse engineering is difficult, our findings propose that the propensity to patent decreases when the technological lead rises.

Table 6: Hypotheses tested for the Case with Vertically Differentiated Products

| Hypothesis | description | estimation result |
|------------|---|-------------------|
| 1 | the higher the technological lead, the lower the ptp | not confirmed |
| 2 | if rev. eng. is easy, the ptp increases with the technological lead | confirmed |
| 3 | rev. eng. reduces the technological lead and thereby increases the TOE | not confirmed |
| 4 | the TOE decreases with the intensity of patent protection | confirmed |

ptp = propensity to patent
 rev. eng. = reverse engineering
 TOE = threat of entry

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