Collusion and entry deterrence in a patent-thicket industry*

Guilherme P. de Freitas †
Instituto Nacional de Matemática Pura e Aplicada (IMPA)

July 2, 2006

Abstract

When patent standards are low and almost any relevant technology is not likely to be covered by a single patent, firms may create precautionary patent portfolios. This gives rise to the *patent thicket* problem: firms have to deal with innumerous uncertainties or negotiations in order to develop a new product or technology. We build a simple repeated game model that shows how the patent thicket may allow incumbent firms to keep away the competition through litigation threats. The model displays a subgame perfect equilibrium where incumbents are cooperative towards each other, but aggressive towards potential entrants.

Several technologies can be covered by a single patent. That is the reality of most technologies in the pharmaceutical and chemical industries. However, this is not the case of the software industry and possibly some other high-technology sectors. In these industries, a given technology is likely to be

*Revision 98. Latest version at http://archive.gpfreitas.com/papers/pthicketentry/.

†This is a work in progress: please, send all comments to guilherme@gpfreitas.com. The author is greatly indebted to Maurício Bugarin for the enlightening comments and suggestions. We thank Mirta Bugarin for some nice suggestions, including the title. The author is exclusively responsible for any errors. The financial support from CNPq/Brazil is gratefully acknowledged.

covered by multiple patents. These technologies are sometimes called *complex* technologies, a nomenclature that we will use henceforth.[1]

Complex technologies in presence of low patent standards[2] create incentive for firms to build strategic patent portfolios for precautionary reasons (Bessen 2003). This is best explained by Jerry Baker, Senior Vice President of Oracle Corporation:

> Our engineers and patent counsel have advised me that it may be virtually impossible to develop a complicated software product today without infringing numerous broad existing patents. Since the validity of many issued software patents is highly questionable and because Oracle is a company with sizeable resources with which to defend a lawsuit, many patent holders must be reticent to litigate an infringement action against us. Further, as a defensive strategy, Oracle has expended substantial money and effort to protect itself by selectively applying for patents which will present the best opportunities for cross-licensing between Oracle and other companies who may allege patent infringement. If such a claimant is also a software developer and marketer, we would hope to be able to use our pending patent applications to cross-license and leave our business unchanged. (USPTO 1994)

This gives rise to the *patent thicket* problem: firms have to deal with innumerous uncertainties or negotiations in order to develop a new product or technology.

The literature on patenting issues emphasizes, first, the role of patents in fostering innovation, and, second, patent race models.[3] Most of the patent race models address technologies that are covered by a single patent. Bessen

[1] In contrast, technologies that can be covered by a single patent are called *discrete* technologies.

[2] Low patent standards have become a real concern lately. See `http://www.freepatentsonline.com/crazy.html` for some very strange patents in the U.S. and `http://swpat.ffii.org/patents/samples/index.en.html` for vague, excessively broad or trivial software patents in Europe.

[3] Regarding the first topic, Arrow (1962), and Romer (1990) are classics of the traditional position that strong intellectual property rights are a good way to foster innovation. Boldrin and Levine (2005b) Bessen and Maskin (2004) give some good arguments for the opposing view. A more detailed and informal treatment of these ideas is given in chapter 5 of Boldrin and Levine (2005a). As for patent race models, Tirole (1988) is a good source for a first reading and further references.

(2003) presents a model of patent race with complex technologies, but he does not consider the "market entry" topic in his study.

Several issues related to patent thickets have already been addressed in the literature. Heller and Eisenberg (1998) suggest that high transaction costs may arise if innovators need to negotiate with many patent owners. Hold-up problems have also been stressed (Shapiro 2001). Patent pools and cross-licensing have been suggested by Shapiro (2001) and Lerner and Tirole (2004) as means to overcome this negotiation problems in some situations. Lerner and Tirole (2004) present a nice formal model for analyzing such problems.

Nonetheless, little progress has been made on the effects of the patent thicket on market *entry*. Gilbert and Newbery (1982) make an early contribution with a monopoly model in which the monopolist may prevent entrance by " patenting new technologies before potential competitors". They also show that "this activity can lead to patents that are neither used nor licensed to others". We could not find other relevant references, especially when it comes to oligopoly models.

The high-technology sectors, especially the software industry, are traditionally seen as highly competitive, with relatively easy entry. In fact, Hall and Ziedonis (2001) argue that, concerning the semiconductor industry, the strengthening of intellectual property rights in the US after the 80's has favored the entry of *specialized* small firms in *niche* product markets.

However, there appears to be a missing part in this story: what happens to the potential entrants that are not so specialized or are not entering niche product markets? Do they enter? Has the recent strengthening of intellectual property rights favored them? We haven't found a conclusive answer yet, but recent empirical research (see the next quotation) suggests that potentially competitive small firms trying to enter the market.

First, note that specialized entrants tackling niche product markets pose no real threat to the incumbents. They may even uncover new market opportunities for the incumbents. It is natural that incumbent firms do not use their power against these entrants. These entrants usually are "one-idea only" companies: in most cases, either they stay in their niche market or they sell their companies to the incumbents.[4]

[4] A recent example in the software industry is Skype™. They entered the VoIP niche, and then sold the company to eBay™. Check this at http://www.skype.com/company/news/2005/skype_ebay.html.

That said, there is ample evidence that incumbents are using the patent thicket to block competitors; they keep entrants away with litigation threats. [5] As put by Gallini (2002):

> Lanjouw and Schankerman (2001) show that, except for pharmaceutical patents, the probability of a particular patent being involved in a litigation suit is significantly lower when the patent holder has a large portfolio of patents. Small firms have a harder time engaging in defensive patenting: as a result, the costs of litigation fall more heavily on small firms: Lerner (1995) reports that in a survey of biotech firms, 55 percent of small firms and 33 percent of large firms report that litigation is a deterrent to innovation. Moreover, small firms are disadvantaged by costly preliminary injunctions: firms requesting injunctions tend to be twice as large as those that do not and are significantly larger than the defendant (Lanjouw and Lerner 2001).

The present work is a first attempt to model the following kind of phenomena: patents being used as a trading tool among dominant incumbent firms. In section 1 we build a simple model of an infinitely repeated game between two incumbents and a "pool" of potential entrants. In the model, patent infringements occur randomly every stage, and at each stage, the owner of the patent decides if he is going to sue or not the player that is breaking his patent. In section 2, we reach our main goal: we show that there exists a subgame perfect equilibrium in which the incumbents behave cooperatively towards each other and aggressively towards the potential entrants. The cooperation between the incumbents is achieved by classical trigger strategies.

As a first step in a broader research program, strong simplifying assumptions are widely used. Future extensions are mentioned in the last section.

[5] In fact, incumbents sometimes try to block entrance advertising that they won't necessarily sue the entrants, but the other incumbents may well not be so nice. Microsoft's "Get the Facts" campaign against the GNU/Linux Operating System contains such an argument. "Some companies may not be aware that they are liable for "unauthorized" use of the intellectual property rights contained in software. To help protect organizations from the risk of litigation, Microsoft provides uncapped monetary intellectual property indemnification on server and client software. In contrast, Linux and other open-source software vendors provide limited, if any, indemnification coverage." More details at http://www.microsoft.com/windowsserversystem/facts/topics/ipi.mspx.

1 The game and some basic definitions

There are two firms, A and B, which are dominant incumbents. There is also a "pool" of potential entrants — represented by a set E — that are trying to enter the market. These firms play an infinitely repeated game, where at each period one of them makes some "small innovation". Here "small innovation" means simply some small progress in the direction of a major innovation, like a new product or technology. The innovating firm cannot take advantage of the small innovation without leading to some patent infringement. Each firm must decide if it is going to sue the other firms when they break one of its patents, and when. Each firm can also choose not to use the small innovation at zero cost.

Define $\mathcal{P} = \{A, B\} \cup E$ as the set of players. At each period $t \in \{1, 2, 3, \ldots\}$, an ordered pair $(i_t, p_t) \in \mathcal{P} \times \mathcal{P}$ is chosen at random according to a probability π. Player i_t is called the *innovator* at stage t and player p_t is called *patent owner* at stage t; the pair (i_t, p_t) defines the *state* at the stage t. The interpretation of π is the following: π_{xy} is the probability that player x innovates, thus potentially infringing one of player y's patents. We assume that $\pi_{AB} = \pi_{BA}$, which is greater than $\pi_{EA} = \pi_{EB}$ which is in turn greater than $\pi_{AE} = \pi_{BE}$. The inequalities are a natural way to model the fact that the incumbents' patent portfolios should be much larger than the entrant's.[6] We treat the incumbents symmetrically for simplicity reasons. Also, we rule out the uninteresting case of a firm "infringing" a patent owned by itself setting $\pi_{xx} = 0$ for all $x \in \mathcal{P}$. We also set $\pi_{xy} = 0$ for all $x, y \in E$, ruling out the possibility that an entrant breaks another entrant's patent. This simplifying assumption will help us focus on the real problem that is the interaction between entrants and incumbents. A remark: the probability π does not depend on the stage t, that is, $\text{Prob}(i_t = x, p_t = y) = \pi_{xy}$ for all t.

The *stage game* goes as follows (see figure 1): the innovator must decide if he is going to take advantage of the small innovation or not; that is, he must choose an element from $\{U, NU\}$ where U stands for "use the small innovation" and NU stands for "not use the small innovation". In case he does not use the small innovation, he receives a *stage payoff* of zero, and so do the other players. If the innovator decides to use the innovation, then the patent owner must decide if he is going to sue the innovator or not; he must

[6] Here we assume that the incumbents are highly innovative. This need not be the case. We will discuss this topic in the last section.

choose an element from $\{S, NS\}$, where S and NS stand for "sue" and "not sue", respectively. If he does not sue, then he gets a stage payoff of zero and the innovator gets a stage payoff of $I > 0$, the benefit of the innovation. If the patent owner sues the innovator, then he gets a stage payoff of $L > 0$, which is the gain from the lawsuit, and the innovator gets a stage payoff of $-L$, the cost of the lawsuit. The players who are neither the innovator nor the patent owner receive a stage payoff of zero. This stage game is repeated infinetely many times.[7]

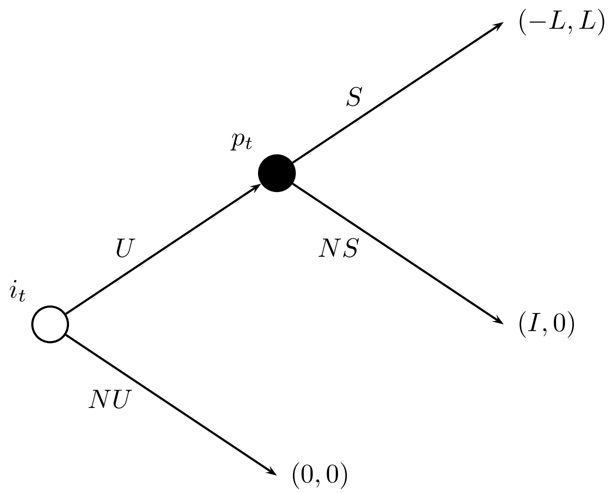

Figure 1: The extensive form of the stage game played between the innovator i_t and the patent owner p_t.

The repeated game

At each stage t, a pair of players $(i_t = x, p_t = y)$ is selected according to π to play the stage game described in the previous section. Thus, $a_x^{i_t}(y) \in \{U, NU\}$ is the *move* of the innovator x. If $a_x^{i_t}(y) = U$, then $a_y^{p_t}(x) \in \{S, NS\}$ is the move of the patent owner y; if $a_x^{i_t}(y) = NU$, then the patent owner y

[7]The rest of section 1 describes the game in terms of the traditional repeated games framework and introduces our main solution concept: the subgame perfect equilibrium. Those already familiar with these concepts should be able to skip to section 2 without any real problems.

does not move. If a player is not the innovator nor the patent owner, then he does not move.

Every player observes what happens at each stage, which is completely described by four elements:

1. the stage t;
2. the state $(i_t = x, p_t = y) \in \mathcal{P} \times \mathcal{P}$;
3. the move $a_x^{i_t}(y)$ of the innovator;
4. the move $a_y^{p_t}(x)$ of the patent owner, in case the innovator has used the innovation. If the innovator has chosen not to use the innovation, then the patent owner does not move.

Such a description is called a *stage description.* A *history* at stage t is a full description of what happened in the game just before the moves at stage t. Thus, a history at stage t is a list H_t of stage descriptions up to stage $t-1$ plus the state at stage t. At each one of the stages t, every player observes the corresponding history of the game H_t. We call H_1 a *beginning* of the game. A *play* is an infinite sequence H_∞ of stage descriptions.

A *strategy* for player x is a function s_x that assigns a move to each possible history H_t at each stage $t \in \{1, 2, 3, \ldots\}$. The *strategy set* of player x is the collection of all such functions. A *strategy profile* for this game is a rule specifying a strategy for each one of the players.

There is also a *payoff function* G that assigns a point $G(H_\infty) \in \mathbb{R}^{\#\mathcal{P}}$ to each possible play H_∞. We call the coordinate functions G^x player x's payoff function and $G^x(H_\infty)$ his payoff. The payoff $G^x(H_\infty)$ for player x is some average of the stage payoffs he receives during the play H_∞.

We assume players are *rational* in the sense that they want to maximize their expected payoffs. Here the expectation is taken with respect to some belief over the other players' strategies and the correspondent probability induced by π (which is known by all the players) on the space of plays. Note that this expected payoff will be simply some average of the expected stage payoffs induced by the strategy profile.

The description of the game, from the beginning of the section until the previous paragraph is *common knowledge*[8] to all the players.

[8]In the sense of Aumann (1976).

Solution concepts

A strategy defines what players will do in every possible state (i_t, p_t) of a stage t. With this information we can calculate the players' *expected stage payoff* according to the probability π. Thus, given the player's strategies, it is possible to calculate their *expected payoffs* for the game as a whole.

A *Nash equilibrium* (NE) is a strategy profile s^{NE} such that $E_\pi[G^x(s^{NE})] \geqslant E_\pi[G^x(s'_x, s_{-x})]$ holds for every other possible s'_x in player x's strategy set and for every $x \in \mathcal{P}$. Here, s_{-x} denotes the strategies of all players but x and E_π is the expectation with respect to the probability induced by π on the space of payoffs.[9]

A *subgame* is an auxiliary game defined by the shift of the beginning of the game to one of the possible histories H_t. Formally, given a specific history H_{t_0}, we define the subgame at H_{t_0} as the game that starts at $H'_1 = H_{t_0}$ with possible histories H'_t of the type H_{t_0+t-1}. However, not every history H_{t_0+t-1} of the original game will be a history H'_t of the subgame, because some of them can't be reached once the player has reached H_{t_0}. In fact, only the histories H_{t_0+t-1} that coincide with H_{t_0} in the first $t_0 - 1$ periods and the state at t_0 are possible histories H'_t of the subgame.[10] A *subgame perfect equilibrium* (SPE) is a strategy profile that induces a Nash equilibrium at every subgame of the original game.

2 Collusion and entry deterrence as a subgame perfect equilibrium

In this section we will show that in a very standard model there is a subgame perfect equilibrium in which the incumbents behave cooperatively one towards the other (that means not suing) and aggressively towards the entrant (they sue the entrants whenever they can).

It should be emphasized that in the presence of the patent thicket, firms usually adopt patent portfolio strategies instead of individual patent strategies:

[9] Given a strategy profile, the probability π induces a probability on the space of plays, which in turn induces a probability on the space of payoffs.

[10] We can also define a subgame in terms of the *game tree*. A subgame is then an auxiliary game defined by the shift of the initial node to one of the other nodes.

> ... note that these are expressly patent portfolio strategies — firms interact over entire portfolios rather than over individual patents. Instead of licensing carefully chosen individual patents — as in most of the economics literature on licensing — firms in semiconductors, electronics and computers negotiate based on the relative heights of their stacks of all related patents, and they license entire portfolios for a technology field, including patents for which they have not yet filed applications. (Bessen 2003)

There is a good reason for firms not adopting individual patent strategies: when a great number of patents is involved, negotiating over individual patents would be cumbersome and costly.

We do not attempt to accurately model this patent portfolio strategies. Nonetheless, we will restrict attention to strategies that do not conflict with this observation. The players of our model will not be concerned about specific patents; instead, they will pay attention to the overall behavior of the other players when it comes to patent infringement and litigation.

In particular, we will assume that as the potential entrants are, for practical matters, indistinguishable, hence incumbents will treat them evenly. Thus, we will treat any firm of the entrant pool as a generic potential entrant, player C.

Assume firm A behaves according to the trigger strategy s_A defined by[11]

$$\begin{aligned} a_A^{p_t}(B) &= \begin{cases} S & \text{if } B \text{ sued } A \text{ on any stage before } t; \\ NS & \text{otherwise} \end{cases} \\ a_A^{i_t}(B) &= \begin{cases} U & \text{if B has not sued A before } t; \\ NU & \text{otherwise} \end{cases} \\ a_A^{p_t}(C) &= S \text{ for every } t; \\ a_A^{i_t}(C) &= NU \text{ for every } t; \end{aligned} \tag{1}$$

[11] A reminder: $a_x^{i_t}(y)$ is the move of player x when he is the innovator at stage t and player y is the patent owner. Conversely, $a_y^{p_t}(x)$ is the move of player y at stage t when he is the patent owner and the innovator x used the innovation, thus infringing on of y's patents.

Firm B behaves according to s_B defined in a symmetric way:

$$
\begin{aligned}
&a_B^{p_t}(A) = \begin{cases} S & \text{if } A \text{ sued } B \text{ on any stage before } t; \\ NS & \text{otherwise} \end{cases} \\
&a_B^{i_t}(A) = \begin{cases} U & \text{if A has not sued B before } t; \\ NU & \text{otherwise} \end{cases} \\
&a_B^{p_t}(C) = S \text{ for every } t. \\
&a_B^{i_t}(C) = NU \text{ for every } t;
\end{aligned}
\tag{2}
$$

First let's take a look at a potential entrant C. It is clear that, given the incumbents' strategies above, he can do no better than being totally defensive and non-cooperative, defining s_C according to:

$$
\begin{aligned}
&a_C^{p_t}(i_t) = S, \quad \text{and} \\
&a_C^{i_t}(p_t) = NU \quad \text{for every } t \text{ and } i_t, p_t \in \{A, B\}.
\end{aligned}
\tag{3}
$$

Doing so, his *expected stage payoff* is zero at every stage. In fact, it is a certain payoff; it is as if he had quit the game. Nothing happens if he changes his behavior when he is the patent owner, because the incumbents will not infringe one of the entrant's patents. If he changes his behavior when he is the innovator, his stage payoff will decrease strictly. As his payoff function G^C is some average of the stage payoffs, a unilateral change of strategy cannot improve his payoff.

It is straightforward to check that if the entrant behavior is as in (3), then incumbents can do no better than following (1) and (2). In words, entrants will not enter the market fearing the incumbents litigation threats; incumbents will not use entrants' innovations in order to avoid lawsuits.

Let's now take a look at the incumbents while keeping the strategy of the entrant fixed as in (3). It is easy to observe that once A decides to sue B for the rest of the game, B should avoid lawsuits by choosing NU whenever he is the innovator. A symmetrical argument applies for the case when B decides to sue A for the rest of the game. That is the strategy specified in (1) and (2). Therefore, after a stage at which any of the incumbents has behaved non-cooperatively towards the other, they will gain stage payoffs of zero for the rest of the game.

However, the strategies of the incumbents lead them to cooperative behavior, because it requires them not to sue at the beginning of the game. This would allow the incumbents to enjoy fearlessly the benefits of innovation. In fact, if they follow the strategies defined by (1) and (2), they won't ever sue each other. The question is: is it rational for them to do so? In other words, wouldn't any of them profit from changing unilaterally his strategy? Won't they be tempted to sue at some stage?

If the incumbents follow the strategies (1) and (2), then they will receive an expected stage payoff of $I\pi_{AB}$ every stage (remember how we have fixed C's behavior). Now suppose that at some stage t the state is $(i_t = B, p_t = A)$ and B uses the innovation. If A sues B, A receives a stage payoff (not an expected one) of L at stage t, and a constant expected stage payoff of zero for the rest of the game. The case for the state $(i_t = B, p_t = A)$ is symmetrical. In other words, if one of the incumbents sue the other at some stage, then he gains a stage payoff of L (which is greater than zero, what he would get if he did not sue), but forfeits an expected stream of constant value $I\pi_{AB}$ for the rest of the game.

Unlike the case for the entrant, we cannot draw any further conclusions about the incumbents' behavior without some extra information on their payoff functions, the probability π and the stage payoffs, I and L. As we shall see, all other things being equal, higher I and $\pi_{AB} = \pi_{BA}$ favor cooperation among the incumbents. So does a lower L and a payoff function that puts more weight on the future.

The discounted case

Remember that the expected payoff of the players is simply some average of the expected stage payoffs. Assume that, given a sequence $(v_1, v_2, \ldots)$ of expected stage payoffs, the expected payoff of the incumbents is given by $(1-\delta)\sum_{t=1}^{\infty}\delta^{t-1}v_t$ where $\delta \in (0,1)$.

The parameter δ represents how much the incumbents value future payoffs: a higher δ means more weight on the future, while a lower δ means more weight on the present. For simplicity, we assume that the value of δ is common knowledge between the incumbents.

We can now calculate the expected payoff[12] of the patent owner if he decides to sue. It is simply $(1-\delta)L$. In fact, the patent owner gains this payoff certainly. If the patent owner decides not to sue, then his expected

[12]Note that this expectation is calculated after the player knows he is the patent owner, that is, after all the players observe the state.

payoff is

$$0 + (1-\delta)\sum_{t=2}^{\infty}\delta^{t-1} I\pi_{AB} = \delta I\pi_{AB}. \tag{4}$$

Thus, an incumbent will sue when

$$(1-\delta)L > \delta I\pi_{AB}. \tag{5}$$

As none of these parameters depend on the specific stage at which the decision is taken, A will sue B at the first opportunity, and vice-versa.

Summing up, the incumbents will act non-cooperatively throughout the game if $(1-\delta)L > \delta I\pi_{AB}$ holds. Whereas if $(1-\delta)L < \delta I\pi_{AB}$, then they will cooperate. If instead of a inequality we have an equality, then they will be indifferent between suing and not suing.

If indeed there is an incentive for cooperation, then A is acting optimally given B's strategy and vice-versa. In fact, when the cooperation condition holds, if the players are following the strategies defined by (1), (2) and (3), then we have shown above that each player is acting optimally given the other players' behavior. In other words, they are playing a Nash equilibrium. [13]

The analysis we made was naturally placed at the beginning of the game. However, it could perfectly have been made after any possible history H_t. It is straightforward to check that the strategy profile (s_A, s_B, s_C) defined by (1), (2) and (3) is also a subgame perfect equilibrium.

3 Concluding remarks

As a first attempt to study the effects of patent thickets on market entry, the model presented here, although still very simple, has two main contributions.

First, even though in a simplified way, we could successfully model the behavior of incumbent firms that act cooperatively towards each other and aggressively towards entrants. Second, this model provides an ample agenda for future research, as we discuss next.

We assumed that firms could stay at the potential entrant pool at no cost. In fact, firms trying to enter a certain market must make an effort that

[13] Note that if there is incentive for non-cooperative behavior, then our strategies are *not* a Nash equilibrium. The problem lies in the first stage at which one of the incumbents would sue the other.

usually translates itself into high initial spendings in research and development (R&D) or marketing. Hall and Ziedonis (2001) point out that in their study of the semiconductor market, "entrants (half of whom are design firms, which specialize in R&D) show some increasing R&D intensities at first and then a decline".[14] If we include this costs, there should be even less incentive for market entry in the model.

We could also change the probability π so as to make the entrants more innovative: this would probably strengthen the incentive for the incumbents to deter entry.

We also bypassed market-share issues. However, it is important that we incorporate them into the model. This should provide the incumbents with even greater incentive to block the entrants. It would bring the model closer to real world situations and, possibly, provide new insights and ideas.

There is another extension that should be included in future versions of the model: strategic patenting. If we introduce R&D decisions, incumbents could try to increase their market share either through real innovation or through defensive and offensive patenting strategies.[15] This would allow us to examine rent-seeking behavior and would bring the model closer to patent race models. In fact, this would be more a "patent portfolio" race model.[16]

We should also allow for variable benefits from innovation, with some degree of randomness. This would greatly enrich the model, because entrants with high-value innovations could have much more bargaining power against the incumbents. An entrant with a high-value innovation could try to persuade the incumbents to be more "friendly". Moreover, if we additionally introduce different types of entrants, a "strong" entrant with a high-value innovation could, for example, force his way into the market while a "weak" entrant would simply sell the high-value innovation to the incumbents. Probably the "strong" and "weak" categories would be related to financial power.

Finally, we could also analyze how "environmental variables" such as

[14] In their study, the incumbents had declining R&D expenditures and the entrants' R&D spending was accompanied by a very high patenting rate. This fact suggests that entrants might be feeling the need to first build significant patent portfolios and only after that create new products and enter the market. This might be a noteworthy welfare problem that requires further scrutiny.

[15] A defensive patenting strategy would be to selectively apply for patents that would provide the best defense against possible lawsuits; an offensive strategy would be to apply for very broad and vague patents that would allow the patentee to threaten to sue his competitors.

[16] The term "patent portfolio race" is taken from Hall and Ziedonis (2001)

lead time advantage and level of intellectual property protection influence the behavior of firms. This last step should be more adequate for empirical research.

References

Arrow, K. J. (1962). Economic welfare and the allocation of resources for invention. In The Rate and Direction of Inventive Activity: Economic and Social Factors. Princeton: NBER Report,Princeton University Press.

Aumann, R. J. (1976). Agreeing to disagree. *The Annals of Statistics 4*(6), 1236–9.

Bessen, J. (2003, Mar). Patent thickets: strategic patenting of complex technologies. mimeo, Boston University School of Law. Available at SSRN: http://ssrn.com/abstract=327760.

Bessen, J. and E. Maskin (2004, Dec). Sequential innovation, patents, and imitation. Available for download at http://www.sss.ias.edu/publications/papers/econpaper25.pdf.

Boldrin, M. and D. K. Levine (2005a, Nov). Against intellectual monopoly. Available at http://www.dklevine.com/general/intellectual/against.htm.

Boldrin, M. and D. K. Levine (2005b, Jan). The economics of ideas and intellectual property. *Proceedings of the National Academy of Science (PNAS). 102*(4), 1252–1256. Available at http://www.pnas.org/cgi/content/abstract/102/4/1252.

Gallini, N. T. (2002). The economics of patents: lessons from recent U.S. patent reform. *Journal of Economic Perspectives 16*(2), 131–54.

Gilbert, R. J. and D. M. G. Newbery (1982). Preemptive patenting and the persistence of monopoly. *American Economic Review 72*(3), 514–26.

Hall, B. H. and R. H. Ziedonis (2001). The patent paradox revisited: an empirical study of patenting in the U.S. semiconductor industry, 19791995. *RAND Journal of Economics 32*(1), 101–128.

Heller, M. A. and R. S. Eisenberg (1998, May). Can patents deter innovation? The anticommons in biomedical research. *Science 280*(5364), 698–701.

Lanjouw, J. O. and J. Lerner (2001, October). Tilting the table? The use of preliminary injunctions. *Journal of Law and Economics 44*(2), 573–603.

Lanjouw, J. O. and M. Schankerman (2001, Dec). Enforcing intellectual property rights. NBER Working Paper No. W8656. Available at http://www.nber.org/papers/w8656.

Lerner, J. (1995). Patenting in the shadow of competitors. *Journal of Law and Economics 38*(2), 463–95.

Lerner, J. and J. Tirole (2004). Efficient patent pools. *American Economic Review 94*(3), 691–711.

Romer, P. (1990). Endogenous technical change. *Journal of Political Economy 98*, S71–S102.

Shapiro, C. (2001). *Innovation Policy and the Economy*, Volume 1, Chapter Navigating the patent thicket: cross licenses, patent pools, and standard-setting. MIT Press.

Tirole, J. (1988). *Theory of industrial organization*. MIT Press.

USPTO (1994, Jan). Public hearing on use of the patent system to protect software-related inventions. Transcription of proceedings. Available at http://www.uspto.gov/web/offices/com/hearings/. San Jose, California.