IFN Working Paper No. 792, 2009

Patent Scope and Technology Choice

Erika Färnstrand Damsgaard

Research Institute of Industrial Economics
P.O. Box 55665
SE-102 15 Stockholm, Sweden
info@ifn.se
www.ifn.se

Patent Scope and Technology Choice*

Erika Färnstrand Damsgaard†

October 31, 2011

Abstract

This paper analyzes effects of stronger patent rights on R&D and innovation. It presents a model where the scope of a patent affects an entrant firm's technology choice and thereby the amount of wasteful R&D duplication. The model predicts that negative effects of duplication can be sufficiently large to warrant stronger patent rights in the form of broad patent scope. This holds if the incumbent's innovation gain is large and the patented technology has a small advantage over alternative technologies.

JEL-codes: L51, K20

Keywords: innovation, patents, patent policy, licensing

*Financial support from Tom Hedelius' and Jan Wallander's Research Foundations is gratefully acknowledged. This paper was written within the Gustaf Douglas Research Program on Entrepreneurship. I want to thank Daron Acemoglu, Martin Bech Holte, Bengt Domeij, Ante Farm, John Hassler, Richard Jensen, Stephen Parente, Lars Persson, Marie Thursby, Fabrizio Zilibotti and seminar participants at ENTER Conference 2007, Foundation Urrutia Elejalde VII Winter Workshop 2007, IFN Stockholm Conference 2007, EPIP Conference 2007, REER 2007 and ZEW Conference 2008 for valuable comments. All remaining errors are my own.

†Research Institute of Industrial Economics, P.O. Box 55665, SE-10215 Stockholm, Sweden. Phone: +46 86654557. E-mail: erika.farnstrand.damsgaard@ifn.se

1 Introduction

It is well established that innovation is an important factor for economic growth. The incentives for innovation are determined by the system of intellectual property rights, which hereby plays a crucial role in the growth process. It is widely perceived that patent protection in the US has increased over the last two decades; see, for example, Jaffe (2000) and Gallini (2002). They point at two factors that suggest this to be the case. First, patent holders have been awarded greater power in infringement lawsuits by a broadening of the interpretation of patent claims. Second, patent protection has been extended to cover new areas, notably software, business methods and biotechnology, where a large number of patents with broad scope have been granted. According to Guellec and van Pottelsberghe (2007), a similar development has taken place in Europe. A broad patent scope implies a greater protection for the patent holder as more products will infringe on the patent and consequently require a license from the patent holder in order to be sold on the market. As is well established, such a strengthening of patent rights has an impact on incentives for innovation and research efforts. However, this paper argues that an increase in patent scope can affect not only investments in R&D, but also the allocation of R&D investment across technologies, and thereby the amount of wasteful duplication of R&D that takes place.

There are several research strategies that firms can pursue in order to find the next generation of a product in a given market. They can choose to build on the state-of-the-art technology in that market and invest in R&D to make improvements on it, or they can choose to direct their R&D to alternative technologies that are new to the market. If the state-of-the-art technology is covered by a patent that is broad in scope, new products building on the patented technology will be infringing on the patent. Consequently, entrant firms face two options: to conduct R&D on an alternative technology and avoid the risk of patent infringement, or conduct R&D using the patented technology and purchase a license from the patent holder. Purchasing a license can be very costly, or even impossible if the patent holder refuses to license to a competitor. In such a situation, the broad patent scope induces an entrant firm to direct its R&D to an alternative technology. Empirical studies show that patents in many instances do affect firms' choices of R&D projects. Lerner (1995) finds that firms with high litigation costs avoid research areas that are occupied by other firms, particularly when these firms have low litigation costs. Walsh, Arora and Cohen (2003) analyze the effect of patents on R&D in the pharmaceutical industry and find cases where firms direct R&D investment to research areas less covered by patents. A recent example comes from the auto industry; in November 2009, Shanghai Automotive Industry Corporation (SAIC) announced that it had developed a plug-in hybrid electromechanical coupling technology, which could help it "avoiding technical barriers from Toyota and GM's hybrid products".[1]

If entrant firms choose to do R&D on alternative technologies to avoid infringing on a patent, that has an effect on their investments. Due to higher costs or higher uncertainty, alternative technologies are likely to be ex ante less promising than the state-of-the-art technology. Hence, a broad patent scope could decrease entrant firms' incentives to invest in R&D for subsequent innovation. However, a broad patent scope implies that research efforts for subsequent innovation may be better allocated across different technologies. If many firms conduct R&D to develop the same technology, there is wasteful duplication of research investment. Firms may, for example, build parallel labs and carry out identical experiments or build identical prototypes, which is a waste of R&D resources from a welfare point of view. If they conduct R&D using different technologies, there is less wasteful duplication. Direct evidence of duplication of R&D is given by simultaneous innovation which is common in science, as discussed by Chatterjee and Evans (2004). An example in Murray (2008) is the invention of transgenic mice in 1980, which was reported by five independent research teams. Duplication of R&D which does not result in inventions is certainly more common.

I present a model which can analyze this trade-off between investments in R&D and wasteful duplication of R&D that patent scope creates. The model features an incumbent firm, which holds a patent, and an entrant. Both invest in R&D in order to find a new generation of a product. There are two possible strategies available to the entrant; to build on the patented state-of-the-art technology or to use an alternative technology. If the entrant invests in the state-of-of-the-art technology, there is wasteful duplication of R&D investment, whereas if the entrant chooses the alternative technology the allocation of total R&D investment is improved.

The model shows that if the incumbent firm's profit increase from innovation is large, and the patented technology has a small advantage relative to the alternative technology, a broad patent scope gives more innovation than a narrow patent scope. Hence, the negative effects of duplication are in some instances sufficiently large to warrant a broad patent scope. The intuition for the result is that if the patented technology has a small advantage, the entrant will not reduce his investment to any considerable extent if he is induced to conduct R&D on an

[1] Global Times, November 3, 2009.

alternative technology. In addition, if the incumbent's profit increase from innovation is high, his investment is large and the amount of wasteful duplication under a narrow scope is high. Consequently, a broad patent scope gives more innovation.

However, as the entrant's bargaining power in license agreements increases, a broad scope becomes less conducive to innovation. The explanation is that the entrant to a greater extent chooses licensing, in which case a broad patent scope does not reduce duplication because the entrant still does R&D on the state-of-the-art technology. I also find that if the model is extended to Stackelberg competition the advantage of a broad patent scope to a large extent disappears, as strategic overinvestment by the incumbent can eliminate any wasteful duplication. Consequently, the desirability of a broad patent scope relies heavily on low bargaining power for the entrant and simultaneous investment by firms.

There is a large theoretical literature on the economic effects of intellectual property rights. Several contributions concern the trade-off between patent scope and patent length, for example Klemperer (1990), Gilbert and Shapiro (1990) and Gallini (1992). These models focus on a single invention whereas, in practise, inventions are sequential. Green and Scotchmer (1995) construct a model with sequential innovation and find that a broad patent scope can be necessary to give the first innovator sufficient incentives to invest. Following Green and Scotchmer (1995), a number of papers have analyzed how patent scope affect the division of profits between the first and second innovator; Chang (1995), Matutes el al. (1996), Denicolo (2000), Erkal (2005) and Chou and Haller (2007) among others. O'Donoghue et al. (1998) also study patent scope in the context of sequential innovation, but focus on the trade-off between innovation and monopoly distortions. In similarity with O'Donoghue et al. (1998), Denicolo (2000), and Erkal (2005), this paper compares two distinct patent regimes; a broad and a narrow scope. It also features two firms, as in Green and Scotchmer (1995) and Chou and Haller (2007), but considers the incentives for subsequent innovation where the first firm competes with the second and inventions are intended for the same market, which implies business stealing. In the law and economics literature, Kitch (1977) argues that pioneering technologies should be granted patents with broad scope, as it will allow the innovator to coordinate further development of the technology and thereby, wasteful duplication of effort is reduced. His view is challenged by Merges and Nelson (1990) who argue that competition will give the patent holder higher incentives to develop his technology. Domeij (2000) discusses the effects of patent scope on duplication of investments in the context of the pharmaceutical industry. Common for these authors is that they do not formalize their arguments in a model. Formal models on duplication of effort in research and development include Tandon (1983), Jones and Williams (2000), Zeira (2003), Chatterjee and Evans (2004) and Cabral and Polak (2004).

The contribution of this paper is that it considers the impact of a particular feature of the patent system, namely patent scope, on duplication of R&D investment as well as on incentives to invest in R&D. The effect of patent scope on firms' choices of R&D projects has been shown empirically, and therefore is important to take into consideration when evaluating the impact of patent scope on innovation. Firms' choices of R&D projects and the technologies they build on in turn affects the amount of wasteful R&D duplication that takes place in the economy. Incorporating the effect of patent scope on technology choice and on wasteful duplication in the analysis delivers new insights. It shows that the benefits of a broad patent scope depend on market and technology characteristics, such as the availability of alternative technologies, the incumbent's ability to commit to R&D investment, as well as firms' bargaining powers in license agreements.

The paper is organized as follows. Section 2 describes the determination of patent scope in practise. Section 3 characterizes the model and Section 4 entails the investments and the probabilities of innovation resulting from the narrow and broad patent scope, respectively. Section 5 extends the model to allow for Stackelberg competition. Section 6 concludes.

2 Determination of patent scope

The scope of a patent is central to this analysis. Therefore, I will start with a brief introduction to the determination of patent scope in patent law and practice, as described in Merges and Nelson (1990). A patent application consists of a specification of the invention and a set of claims. The specification describes the problem the innovator faced, and how it was solved. The claims define what the inventor considers to be the scope of the invention, the "technological territory" where he can sue other parties for infringement. The general rule is that a patent's claims should extend beyond the precise disclosure of the invention in the specification. Otherwise, imitators could make minor changes to that example without infringing and the patent would be of little value. The inventor naturally wants to make the claims as broad as possible, and the patent examiner must decide what scope is appropriate, which claims should be admitted and which should not.

In infringement cases, the court examines whether there is “literal infringement”, namely the product literally falls within the boundaries of the patent claims. If not, the court also examines whether the product does the work in substantially the same way and accomplishes substantially the same result as the patented product, in which case it is also infringing. Consequently, patent scope is determined in two instances, by two separate authorities. Ex ante, if the patent holder has not sued any other party for infringement, the patent scope is defined by the claims as determined by the Patent Office. Ex post, in an infringement case, the patent scope is determined by the court, in its decision on whether the patent has been infringed.

3 The model

The economy has two firms, an incumbent and an entrant. Both firms make investments in R&D to find a new invention, which has the private value V when patented. The incumbent holds a patent connected to the current state-of-the-art technology and earns a profit from producing the corresponding product. The profit is expressed as a share of the value of the next invention, αV, where $\alpha \in [0, 1]$. The entrant earns no profits. Innovation is drastic; new inventions replace previous ones.

There are two possible research strategies for a firm to pursue. Strategy C is to build on the current state-of-the-art technology, technology C, and make an improved product. Strategy A is to use an alternative technology, technology A, for which there is no risk of patent infringement. In this context, an alternative technology should be more broadly interpreted as using another process, material, algorithm, chemical compound etc., depending on the industry and the nature of the product. I assume that each firm can pursue only one research strategy at a given point in time. A justification for this assumption is that using a technology requires a fixed cost or an investment in human capital. Irrespective of which technology is used, the private value of an invention is V.[2]

Each technology has an exogenous probability γ_k, $k \in \{C, A\}$, of leading to a new invention. The alternative technology has a weakly lower probability of leading to a new invention than the

[2] There is no strong reason to believe that using different technologies will generate inventions of exactly the same value. However, it makes it possible to distinguish the effects of patent regime on aggregate innovation from effects of a differing value of the invention.

state-of-the-art: $\gamma_A \leq \gamma_C$. The difference between γ_C and γ_A reflects the relative advantage of the state-of-the-art technology. I assume that either technology C or A leads to a new invention, but not both. This is a simplification of technology development, but it is made for tractability. I will discuss the implications of the assumption further below. In addition, I normalize the sum of γ_A and γ_C to 1, as this reduces the number of model parameters. Hence, $\gamma_A = 1 - \gamma_C$.

I postulate that the incumbent always invests in technology C, irrespective of the entrant's technology choice. The motivation is that the incumbent has already incurred the cost of investing in that technology and acquired the necessary human capital.

The possibility of duplication of R&D can be illustrated in terms of two urns, A and C, filled with marbles. Suppose that a firm's investment in R&D can be described as drawing a number of marbles from one of the urns, where each marble is equivalent to conducting one experiment. Each urn has its own set of marbles and the number of marbles is n_k, $k \in \{C, A\}$. Only one marble corresponds to a successful experiment, i.e. an invention, and this marble is denoted 1. With probability γ_C, marble number 1 is in urn C. Firm j purchases t_j, $j \in \{I, E\}$ marbles from urn k and the probability that it innovates, conditional on having chosen the right urn, is $\frac{t_j}{n_k}$. The draws of different firms are independent events. Suppose first that both firms choose urn C. The incumbent draws t_I marbles and replaces them, which gives him a conditional innovation probability equal to $\frac{t_I}{n_C}$. The entrant draws t_E marbles, which results in a conditional innovation probability of $\frac{t_E}{n_C}$. It is possible that both firms draw marble no 1. This is a duplication of R&D resources from the point of view of society.[3] A social planner is interested in the probability of any of the firms drawing marble no 1. For two events, A and B, the probability of at least one event occurring is: $P(A \cup B) = P(A) + P(B) - P(A \cap B)$. In our example, the probability of at least one invention is:

$$P(\textit{no } 1 \textit{ at least once}) = \gamma_C \left(\frac{t_I}{n_C} + \frac{t_E}{n_C} - \frac{t_I}{n_C}\frac{t_E}{n_C} \right).$$

The product $\frac{t_I}{n_C}\frac{t_E}{n_C}$ represents a waste of resources due to duplication.

Now, suppose that the incumbent draws marbles from urn C and the entrant draws marbles from urn A. They have probabilities $\frac{t_I}{n_C}$ and $\frac{t_E}{n_A}$, respectively, of drawing marble number 1, conditional on choosing the right urn. The probability that both firms draw the same marble is

[3] No firm draws the same marble twice; there is no duplication at the firm level.

zero. Hence, the probability of at least one invention is:

$$P(no\ 1\ at\ least\ once) = \gamma_C \frac{t_I}{n_C} + (1 - \gamma_C)\frac{t_E}{n_A}.$$

There is no waste of resources due to duplication.

Next, I turn to the characterization of equilibrium investments in R&D. In this paper, the R&D process is modeled as a one-shot game. This modeling choice is motivated by the fact that firms' R&D projects for development of new products are often close to irreversible, especially in the biotechnology and pharmaceutical industries. As a consequence, there is a positive probability that both firms innovate if they choose the same technology. In this case, each firm has probability $\frac{1}{2}$ of obtaining the patent.[4] In the baseline model, firms invest in R&D simultaneously. In Section 5, the model is extended to Stackelberg competition.

In the model, the equilibrium investments are defined as follows. The incumbent invests the amount of resources, p_I, which maximizes his expected payoff Π_I, where I denotes incumbent. The entrant chooses both which technology to invest in, denoted k, and the level of investment, p_E, which maximizes his expected payoff Π_E, where E denotes entrant. Each firm's investment is its probability of innovating, conditional on having chosen the technology that leads to a new invention. The timing of the game is as follows: First, the entrant chooses which technology to invest in. Second, given the entrant's technology choice, both firms simultaneously decide how much to invest.

An equilibrium is a triplet $\{k^*, p_I^*, p_E^*\}$, $k \in \{C, A\}$ and $p_I, p_E \in [0,1]$ such that $k^* = \arg\max_k \Pi_E(k, p_I^*(k), p_E^*(k))$, $p_E^*(k^*) = \arg\max_{p_E} \Pi_E(k^*, p_I^*(k^*), p_E)$ and

$p_I^*(k^*) = \arg\max_{p_I} \Pi_I(k^*, p_I, p_E^*(k^*))$. I divide the equilibria into two types, given the entrant's choice of technology: If the entrant chooses C, the equilibrium is denoted C and if the entrant chooses A, the equilibrium is denoted A. In order to interpret the firms' investments as conditional innovation probabilities, they must be bounded above by 1. I focus on the case where the optimal investment levels are interior solutions. In the baseline model, this is achieved by setting $V = 1$. The effects of varying V will be analyzed in Section 4.5.

[4] Suppose that the game lasts for a period of five years. If inventions arrive with a hazard rate that is constant over the period, conditional on both firms having innovated at the end of the period, the firms have the same probability of innovating at each point in time.

4 Patent scope

In this model, the scope of a patent can either be narrow or broad. If the scope of the patent on technology C is narrow, the entrant can choose technology C without any risk of infringement. If the patent scope is broad, the entrant is required to acquire a license from the incumbent if he chooses technology C and innovates. The entrant's invention is always infringing, hence, the scope covers all improvements of technology C.[5] Indeed, this can often be the case; an example is the patent on one-click buying, granted to Amazon.com. The patent covers all techniques of allowing customers to make online purchases with one single click. Another example, from the biotech industry, is the patent connected to the gene BRCA1, associated with breast cancer. The patent covers all diagnostic tests identifying mutations in BRCA1.

In the model, patent scope does not affect α, the incumbent's profit relative to the value of the invention, V.[6] Neither does it affect V directly. This model abstracts from the potential effects of patent scope on innovation through current profit and the value of an invention, and focuses on the effect through technology choice alone. Nevertheless, as a robustness check I also allow V to take a higher, exogenously given value under a broad relative to a narrow scope. The result is reported in Section 4.5.

4.1 Narrow patent scope

I start with a characterization of the investments and innovation probabilities under a narrow scope in equilibria C and A, respectively.

In equilibrium C, the entrant invests in technology C. Since the patent scope is narrow, there is no risk of patent infringement and the entrant can build on technology C without acquiring a license.

[5] This assumption is also made in O'Donoghue et al. (1998), Denicolo (2000), and Erkal (2005).

[6] A broad scope may increase the profits accruing to the patent holder if it discourages substitutes during the patented product's life. This would reduce the incumbent's investment in R&D under a broad scope relative to a narrow. The assumption that α is independent of scope gives an upper bound for the incumbent's investment under a broad scope, and an upper bound for the effects of patent scope.

The expected payoff to the incumbent in equilibrium C is

$$\Pi_I(C, p_I, p_E) = \alpha V + \gamma_C p_I(1-p_E)V(1-\alpha) + \gamma_C p_E(1-p_I)(0-\alpha V) + \gamma_C p_E p_I\left(\frac{1}{2}V(1-\alpha) + \frac{1}{2}(0-\alpha V)\right) - \frac{p_I^2}{2}. \quad (1)$$

With probability $\gamma_C p_I(1-p_E)$, the incumbent innovates whereas the entrant does not. The gain is $V(1-\alpha)$, the value of the invention net of current profit, as the new product replaces the old one. I refer to $V(1-\alpha)$ as the incumbent's profit increase from innovation, i.e. the difference in profit after versus before he innovates. With probability $\gamma_C p_E(1-p_I)$ the entrant innovates but not the incumbent, and the latter loses his current profits. With probability $\gamma_C p_E p_I$ both firms innovate and the incumbent has probability $\frac{1}{2}$ of obtaining the patent. The variable cost of R&D is $\frac{p_I^2}{2}$. The first-order condition yields

$$p_I = \gamma_C V\left(1-\alpha-p_E\left(\frac{1}{2}-\alpha\right)\right).$$

The incumbent's investment is increasing in γ_C and V. It is increasing in p_E if $\alpha > \frac{1}{2}$. [7]

The expected payoff to the entrant in equilibrium C is

$$\Pi_E(C, p_I, p_E) = \gamma_C p_E(1-p_I)V + \gamma_C p_E p_I\frac{V}{2} - \frac{p_E^2}{2}. \quad (2)$$

With probability $\gamma_C p_E(1-p_I)$, the entrant innovates and gets V. With probability $\gamma_C p_E p_I$ both firms innovate and the entrant gets V with probability $\frac{1}{2}$. As described above, there is no need for the entrant to acquire a license to technology C and hence it pays no license fees. The variable cost of R&D is $\frac{p_E^2}{2}$. The first-order condition yields

$$p_E = \gamma_C V\left(1-\frac{p_I}{2}\right). \quad (3)$$

The entrant's investment is increasing in γ_C and V. It is decreasing in p_I; competition from the

[7] An increase in p_E reduces the probability that the incumbent wins; he innovates but the entrant does not. This decreases his incentives to invest. It also increases the incumbent's returns to investing in order not to lose current profit, which increases his incentive to invest. If $\alpha > \frac{1}{2}$, the expected payoff from winning is low. The latter effect dominates. If $\alpha < \frac{1}{2}$, the first effect dominates. The cutoff is at $\alpha = \frac{1}{2}$, given the assumption that if both firms innovate each has probability $\frac{1}{2}$ of obtaining the patent.

incumbent induces the entrant to invest less.

Solving for Nash equilibrium investment levels, given $V = 1$, yields the following investment by the incumbent and the entrant, respectively, where superscript C indicates equilibrium C,

$$p_I^C(\alpha, \gamma_C) = \frac{2\gamma_C \left(2(1-\alpha) + 2\alpha\gamma_C - \gamma_C\right)}{4 + 2\alpha\gamma_C^2 - \gamma_C^2} \tag{4}$$

$$p_E^C(\alpha, \gamma_C) = \frac{2\gamma_C \left(2 + \alpha\gamma_C - \gamma_C\right)}{4 + 2\alpha\gamma_C^2 - \gamma_C^2}. \tag{5}$$

The incumbent's investment $p_I^C(\alpha, \gamma_C)$ is increasing in γ_C and decreasing in α. The entrant's investment $p_E^C(\alpha, \gamma_C)$ is increasing in γ_C and α. An increase in γ_C implies a higher probability that technology C leads to a new invention, which increases both firms' investments. An increase in α decreases the incumbent's profit from innovating, $V(1-\alpha)$, which reduces his investment. The entrant responds to this reduction by increasing his investment.

Next, I turn to equilibrium A, where the entrant invests in technology A. The expected payoff to the incumbent is

$$\Pi_I\left(A, p_I, p_E\right) = \alpha V + \gamma_C p_I V(1-\alpha) + (1-\gamma_C) p_E (0 - \alpha V) - \frac{p_I^2}{2}.$$

Now, the incumbent's optimal investment is independent of the entrant's investment. Taking the first-order condition, given $V = 1$, yields

$$p_I^A(\alpha, \gamma_C) = \gamma_C \left(1-\alpha\right)$$

where superscript A indicates equilibrium A. The expected payoff to the entrant in equilibrium A is

$$\Pi_E\left(A, p_I, p_E\right) = (1-\gamma_C) p_E V - \frac{p_E^2}{2}.$$

With probability $(1-\gamma_C)p_E$, the entrant innovates and gets V, where $(1-\gamma_C)$ is the probability that technology A leads to a new invention. As can be seen from this expression, the entrant's optimal investment is independent of the incumbent's investment. Given $V = 1$, the first-order condition reads:

$$p_E^A(\gamma_C) = 1 - \gamma_C.$$

Now, I return to the assumption that both technologies cannot simultaneously lead to a new invention. Relaxing that assumption would have the following implications. There would be strategic interaction between the two firms in equilibrium A, which reduces the entrant's investment, and increases that of the incumbent, if α is sufficiently high. If both firms innovate, each obtain a patent and if they collude, each of them gets profit $\frac{V}{2}$. The firms still carry out different experiments, and there is no effect on duplication. Consequently, this assumption does not affect the main mechanisms of the model.

The next step is to determine which technology the entrant will invest in. The entrant chooses the technology which gives the highest expected payoff, given the equilibrium investments described above. The condition for when choosing C has a higher payoff to the entrant than choosing A is given below.

Proposition 1 *If $\alpha > \alpha_E$, the Nash equilibrium is C, where*

$$\alpha_E = \frac{4 - 8\gamma_C + \gamma_C^2 + \gamma_C^3}{2\gamma_C^3}.$$

Proof. See the Appendix. ■

The higher is α, the lower is the incumbent's investment, which increases the entrant's expected payoff from choosing C relative to A. The threshold α_E, where subscript E denotes entrant, is decreasing in γ_C, as a larger probability of success for technology C increases the entrant's relative expected payoff from choosing C. Given the two firms' optimal investments and the entrant's choice of technology, we can determine the aggregate innovation probability under a narrow scope. The aggregate innovation probability is defined as the probability of at least one firm innovating, and in analogy with the example in Section 3, can be expressed as follows:

$$i^N = \begin{cases} \gamma_C p_I^A(\alpha, \gamma_C) + (1 - \gamma_C) p_E^A(\gamma_C) & if\ \alpha \leq \alpha_E \\ \gamma_C \left(p_I^C(\alpha, \gamma_C) + p_E^C(\alpha, \gamma_C) - p_I^C(\alpha, \gamma_C) p_E^C(\alpha, \gamma_C) \right) & if\ \alpha > \alpha_E \end{cases} \tag{6}$$

where superscript N denotes narrow patent scope. Suppose first that $\alpha \leq \alpha_E$ so that the equilibrium is A. Since the two firms invest in different technologies, there is no wasteful duplication but the entrant invests in a technology with a disadvantage relative to the state-of-the-art technology; $\gamma_C > (1 - \gamma_C)$. Suppose now instead that $\alpha > \alpha_E$ so that the equilibrium is C. When both the entrant and the incumbent invest in the same technology, there is wasteful duplication of R&D investment and the last term gives the amount of wasteful duplication that occurs.

4.2 Broad patent scope

Now, I turn to a characterization of investments and technology choice under a broad patent scope. In this case, the entrant's invention will be infringing if it builds on technology C. The entrant therefore chooses between either conducting R&D on technology A or conducting R&D on technology C and acquiring a license from the incumbent.

If the entrant chooses to license, the license fee is specified as follows. The license agreement stipulates a fixed license fee, F, and I assume that the agreement is written ex post, after the entrant has innovated. The fee is determined by Nash bargaining. The share of the surplus from the license agreement that goes to each firm depends on its outside option and its bargaining power. The incumbent's outside option is to continue selling his patented product, with profit αV. The entrant's outside option is to conduct R&D on technology A. If the incumbent has all the bargaining power, he will demand a maximal fee such that the entrant receives his outside option, or slightly lower. In anticipation of this fee, the entrant never chooses technology C. Hence, if the incumbent has all bargaining power, no licensing will take place. This naturally gives a lower bound of the effects of licensing.

If, on the other hand, the entrant has all bargaining power, this results in the lowest possible license fee, $F = \alpha V$, and a maximal effect of license agreements on investments. This gives an upper bound on the effects of licensing. If the bargaining powers lie in between these two extremes, the effect of licensing on investments and innovation falls between the lower and the upper bound. First, I describe the equilibrium investments and innovation probabilities for the lower bound, when the incumbent has all bargaining power and the entrant never chooses licensing, and then I turn to the upper bound, when the entrant has all bargaining power and may choose to license the patent from the incumbent.

Suppose first that the incumbent has all bargaining power in licensing negotiations, and demands an license fee so high that the entrant chooses not to license, but instead to do R&D on technology A. The firms are in equilibrium A, and given their optimal investments, the aggregate innovation probability is equal to

$$i^B = \gamma_C p_I^A(\alpha, \gamma_C) + (1 - \gamma_C) p_E^A(\gamma_C) \tag{7}$$

where superscript B denotes broad patent scope. The expression can be compared to the innovation probability under a narrow patent scope under the condition $if\ \alpha \leq \alpha_E$, as given by (6). If the entrant chooses technology A, there is no difference between the patent regimes. Under both a broad and narrow scope firms choose different technologies and there is no wasteful duplication, but the entrant chooses a technology that is less promising than the state-of-the-art.

Next, I turn to the case when the entrant has all bargaining power in licensing negotiations, which gives the minimum license fee, $F = \alpha V$. Now, the entrant either chooses technology C and pays the license fee $F = \alpha V$ or chooses technology A. I start with describing the optimal payoffs in the former case.

The expected payoff to the incumbent when the entrant chooses technology C and acquires a license is

$$\Pi_{I,L}(C, p_I, p_E) = \alpha V + \gamma_C p_I (1 - p_E) V (1 - \alpha) + \gamma_C p_E (1 - p_I)(0) \\ + \gamma_C p_E p_I \left(\frac{1}{2} V (1 - \alpha) + \frac{1}{2}(0) \right) - \frac{p_I^2}{2}, \tag{8}$$

where subscript L denotes licensing. The difference between (8) and (1) is that if the entrant innovates and the incumbent does not, the incumbent gets a license fee equal to αV and he loses current profit αV. The net gain is zero. In case both innovate and the entrant gets the patent, the net gain is again zero.

The expected payoff to the entrant when he chooses technology C and obtains a license is

$$\Pi_{E,L}(C, p_I, p_E) = \gamma_C p_E (1 - p_I) V (1 - \alpha) + \gamma_C p_E p_I \frac{V(1-\alpha)}{2} - \frac{p_E^2}{2}. \tag{9}$$

The difference between (9) and (2) is that the entrant's net gain is $V(1 - \alpha)$. Solving for the Nash equilibrium, given $V = 1$, yields:

$$p_{I,L}(\alpha, \gamma_C) = p_{E,L}(\alpha, \gamma_C) = \frac{2\gamma_C(1-\alpha)}{2 + \gamma_C(1-\alpha)}.$$

The optimal investments for the two firms are identical. The explanation is that the entrant indirectly takes into account the incumbent's profit loss through the license fee. In addition, the incumbent's expected payoff from not innovating if the entrant innovates is zero, as the license revenue compensates for the loss of current profit. One can compare the investments above to the equilibrium investments in equilibrium C under a narrow scope. Then, I find that for all

$\alpha > 0$,

$$p_{I,L}(\alpha, \gamma_C) < p_I^C(\alpha, \gamma_C), \tag{10}$$

$$p_{E,L}(\alpha, \gamma_C) < p_E^C(\alpha, \gamma_C). \tag{11}$$

The entrant invests less in R&D on technology C if he must acquire a license than if not, because the net profit is lower. The incumbent invests less in R&D on technology C if he can license his patented technology than if not, because he has less to lose from not innovating.

Under a broad patent scope, the entrant chooses between conducting R&D on technology C, which has a higher probability of success but where the profit net of the license fee is $V(1-\alpha)$, and conducting R&D on technology A, which has a lower probability of success but yields a profit V since there is no need to acquire a license. The following condition determines when the entrant chooses C over A:

Proposition 2 *Let the license fee be αV. The entrant chooses technology C even under a broad patent scope if $\alpha \leq \alpha_L$, where*

$$\alpha_L = \frac{3\gamma_C - 2 + \gamma_C^2}{\gamma_C + \gamma_C^2}.$$

Proof. See the Appendix. ■

The entrant chooses technology C for a sufficiently low α, that is when the license fee is sufficiently low. If the license fee is high, a broad patent scope induces the entrant to conduct research on alternative technologies to avoid patent infringement. As described in the introduction, a real world example of such a case is the development of a new plug-in hybrid electromechanical coupling technology by Shanghai Automotive Industry Corporation (SAIC). The threshold α_L, where L denotes licensing, is increasing in γ_C. A higher advantage for technology C relative to A increases the payoff to the entrant from choosing C.

When the entrant has all bargaining power, the probability of innovation can be expressed as follows:

$$i^B = \begin{cases} \gamma_C\left(p_{I,L}(\alpha, \gamma_C) + p_{E,L}(\alpha, \gamma_C) - p_{I,L}(\alpha, \gamma_C)\, p_{E,L}(\alpha, \gamma_C)\right) & if\ \alpha \leq \alpha_L \\ \gamma_C p_I^A(\alpha, \gamma_C) + (1-\gamma_C) p_E^A(\gamma_C) & if\ \alpha > \alpha_L \end{cases} \tag{12}$$

Suppose that $\alpha \leq \alpha_L$. The entrant chooses to do R&D on technology C and acquire a license.

In this case, there is wasteful duplication of R&D as captured by the last term. If instead, $\alpha > \alpha_L$, the entrant chooses technology A and there is no wasteful duplication. In similarity to when the entrant has no bargaining power, in this case there is no difference between the patent regimes.

4.3 Does a broad scope give a higher probability of innovation?

To assess the effects of an increase in patent scope on innovation, it is instructive to return to the trade-off between investment in R&D and the allocation of investment. A narrow patent scope allows both firms to do research on the most promising technology, but gives rise to wasteful duplication of R&D. A broad patent scope forces the entrant to acquire a costly license or do research on an alternative technology which has a relative disadvantage, but can reduce the amount of wasteful duplication. To answer the question: Does a broader scope give a higher probability of innovation?, it remains to determine which effect dominates and under what conditions. I solve for the innovation probabilities for a narrow and broad patent scope respectively, for all values of $\gamma_C \in [0.5, 1]$ and $\alpha \in [0, 1]$ and the result is shown in Figure 1 below.

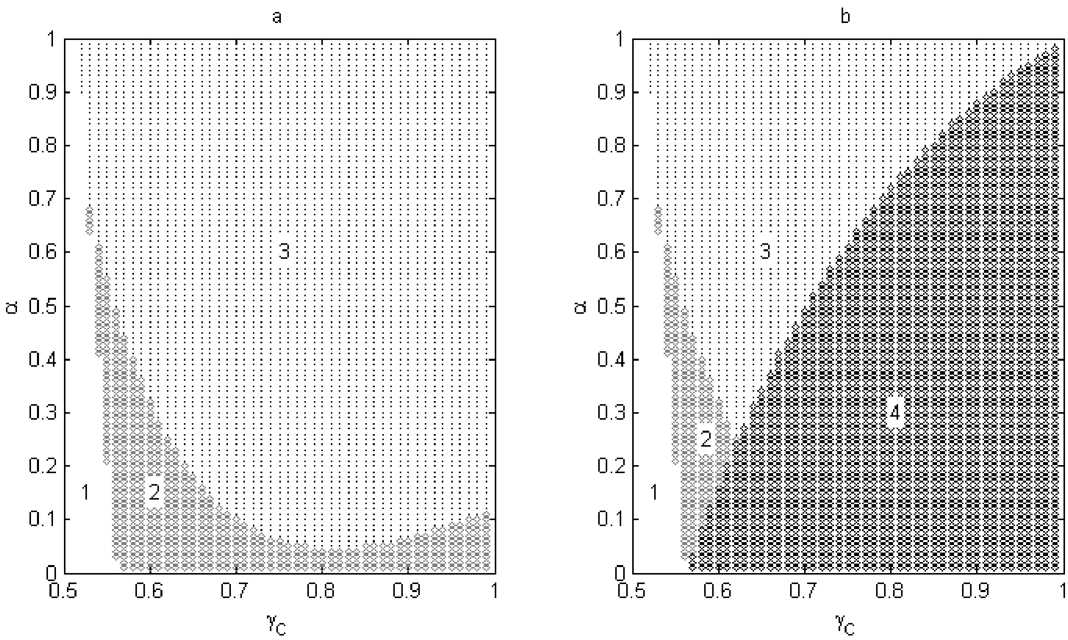

Figure 1: Innovation probabilities. Area 1: Patent scope is inconsequential. Area 2: $i^N < i^B$. Area 3: $i^N > i^B$. Area 4: the entrant chooses licensing and $i^N > i^B$.

In the figure, Panel **a** shows the innovation probabilities when the incumbent has all bargaining power, and consequently no licensing takes place. This case gives the lower bound of the effects of licensing. Panel **b** shows the innovation probabilities when the entrant has all bargaining power and may choose licensing depending the expected payoffs from choosing A relative to C. This case gives the upper bound of the effect of licensing. In both panels, the area labeled 1 is the area in which the entrant chooses equilibrium A even under a narrow scope and patent scope has no effect on the innovation probabilities. Both areas 2 and 3 are areas in which the entrant chooses technology A under a broad scope and technology C under a narrow scope. Hence, patent scope affects the entrant's technology choice and a broad scope can reduce wasteful duplication of R&D. However, in area 2, a broad patent scope gives more innovation than a narrow scope, while in area 3, a narrow patent scope gives more innovation. As seen in the figure, a broad scope gives more innovation for low values of γ_C and α, that is if technology C has a small advantage relative to the alternative and the incumbent's profit increase from innovation is high. If technology C has a small advantage, the entrant will not reduce his investment to any considerable extent if he is induced to conduct R&D on technology A. If the incumbent's profit increase from innovation is high, his investment is large and the amount of wasteful duplication under a narrow scope is high. Consequently, a broad patent scope gives more innovation. However, it is clear from comparing areas 2 and 3 that a narrow scope gives more innovation for a lion's share of the parameter space.

In panel **b** of Figure 1, the area labelled 4 is where $\alpha < \alpha_L$; the entrant chooses to do R&D on technology C and acquire a license if the patent scope is broad. Hence, the entrant invests in technology C even under a broad patent scope. In this case there is wasteful duplication of R&D under both narrow and broad scope. However, under a narrow scope, no license is required and the innovation probability is given by $i^N = \gamma_C \left(p_I^C(\alpha, \gamma_C) + p_E^C(\alpha, \gamma_C) - p_I^C(\alpha, \gamma_C)\, p_E^C(\alpha, \gamma_C)\right)$. Under a broad scope, it is given by $i^B = \gamma_C \left(p_{I,L}(\alpha, \gamma_C) + p_{E,L}(\alpha, \gamma_C) - p_{I,L}(\alpha, \gamma_C)\, p_{E,L}(\alpha, \gamma_C)\right)$. The difference in innovation probabilities lies in the investment levels: both incumbent and entrant invest less under a broad scope, as shown by (10) and (11). Therefore, if the entrant chooses to acquire a license, a narrow scope always gives more innovation than a broad scope; $i^N > i^B$.

As described above, panel Panel **b** shows the case where the entrant has all bargaining power. As the entrant's bargaining power decreases, the license fee increases, which shifts area 4 to the right until it disappears and we reach the lower bound on the effects of licensing, as depicted in

Panel **a**. Comparing Panels **a** and **b**, it can be concluded that the area of the parameter space in which a broad scope gives more innovation is decreasing in the entrant's bargaining power. If the entrant has higher bargaining power in license negotiations, he will be more likely to choose technology C and obtain a license and in that case a broad patent scope does not reduce wasteful duplication. Consequently, a broad patent scope is less conducive to innovation as the entrant's bargaining power increases.

4.4 Social surplus

The previous section shows under what conditions a broad and a narrow patent scope, respectively, give the highest probability of innovation. However, maximizing innovation is desirable only insofar as it is also socially optimal. In addition to the duplication effect, a social planner must take two other effects of R&D into account. The first effect is the social value of an invention, which is typically considered to be larger than the private value. The second effect is the business stealing effect; as entrant firms innovate, the incumbent's profit is lost. Therefore, I analyze the effects of patent scope on social surplus, taking these effects into account.

I assume that the private value of an invention is proportional to the social value. In addition, the social value of the new invention is S and of the current one is αS. I define the social surplus under a narrow and broad scope as s^N and s^B, respectively;

$$s^N = i^N S(1-\alpha) - \frac{\left(p_I^C(\alpha,\gamma_C)\right)^2 + \left(p_E^C(\alpha,\gamma_C)\right)^2}{2}$$
$$s^B = i^B S(1-\alpha) - \frac{\left(p_I^A(\alpha,\gamma_C)\right)^2 + \left(p_E^A(\gamma_C)\right)^2}{2}$$

The numerical solution shows that for most of the parameter space, the patent scope which generates the highest innovation probability is also the scope that is socially optimal. However, when α is close to 1, a broad scope, which implies less innovation, gives the highest surplus. This holds irrespective of the amount of licensing that occurs. The reason is that the invention generates such a small increase in social value that it is optimal to restrict the investments in R&D. The tentative conclusion is that the socially optimal patent scope is that which maximizes innovation, except when the increase in social value from the invention is small.[8] The result

[8] The numerical solution for $S = 5V$ shows that restricting investments is optimal for $\alpha > 0.9$. This cutoff level depends on S/V and if it is sufficiently large, restricting investments will never be optimal.

can be compared to Chang (1995), which shows that a broad scope is optimal if the invention generates a very small increase in social value, which also holds true in this model. However, Chang (1995) also shows a broad scope is optimal if it generates a very large increase in social value, which corresponds to the case when the incumbent's profit increase is high. As argued in this paper, that result can hold with qualifications: namely, that there are viable alternatives to the state-of-the-art technology available to entrant firms.

4.5 Robustness checks

In the baseline model, I have set the value of the invention, V, to $V = 1$ to ensure that equilibrium investments are interior solutions. Now, I allow for corner solutions where p_I and p_E equal 1, and analyze the effects of an increase in V. I find that an increase in V increases the area of parameter space for which a broad scope gives more innovation than a narrow scope. The reason is that an increase in V increases the investment by both firms, while under a narrow scope, there is also an increase in the amount of duplication.[9]

As a robustness check, I also allow V to take a higher, exogenously given value under a broad relative to a narrow patent scope. This captures, albeit crudely, the notion that in a broad patent scope regime, firms can expect future patent to be broad in scope. Let $V^B = \theta V^N$, $\theta = 1.5$; firms expect that a broad patent scope increases the value of the invention by 50 percent. The result is an increase in the area of parameter space for which a broad scope gives more innovation than a narrow scope, as compared to Figure 1. However, it is still the case that a broad patent scope gives more innovation for at most half the total area of parameter space spanned by α and γ_C.

In this model, patent scope is modeled as binary; either it is narrow or broad. This modeling choice has clear advantages; it captures the effect of patent scope on technology choice and duplication in a transparent way, and allows for analytical solutions. However, as an additional robustness check, I also construct a version of the model where patent scope is a continuous variable. Now, it is necessary to resort fully to numerical solutions. I solve the model for the patent scope that maximizes the probability of innovation in case of no licensing, and find that

Additional details are available upon request.

[9]An increase in V also increases the area of parameter space for which patent scope is inconsequential; it increases the incumbent's investment, which decreases the entrant's payoff in equilibrium of type C but not A.

the main results remain; the optimal patent scope is broadest when α is low, and γ_C is low.[10]

5 Extension of the model: Stackelberg competition

Until now, it has been assumed that the two firms simultaneously decide how much to invest. Suppose instead, as is common in many industries, that the incumbent can commit to an investment in R&D. For example, he builds a new research lab or employs researchers. The entrant observes the incumbent's investment and then decides which technology to invest in and how much to invest. In order to keep the model tractable, I abstract from licensing. Hence, it is assumed that under a broad patent scope, the entrant always invests in technology A.

Introducing Stackelberg competition in this framework affects the interaction between the two firms as follows. As shown in the main model, in equilibrium C, the two firms' investments depend upon each other, whereas in equilibrium A, they are independent. Hence, in equilibrium C, the incumbent can affect the entrant's investment level. In addition, the incumbent can affect the entrant's technology choice. If the incumbent's investment is sufficiently large, the entrant gets a higher expected payoff from avoiding competition from the incumbent and consequently he chooses technology A over technology C. By strategic overinvestment, the incumbent can keep the entrant out of its patented technology. This occurs even if the patent scope is narrow, so that there is no risk of patent infringement. Therefore, introducing Stackelberg competition can have important implications in this model, as will be seen below. I start by describing the equilibrium investment levels under a narrow patent scope.

5.1 Narrow patent scope

Under a narrow patent scope, the entrant can choose technology C without any risk of infringement. Let the investment by the incumbent and the entrant in equilibrium C be $p_{I,S}$ and $p_{E,S}$, respectively, where subscript S denotes Stackelberg competition. Now, the incumbent chooses $p_{I,S}$ first. The entrant observes $p_{I,S}$, and then chooses $p_{E,S}$. Hence, the incumbent's chosen investment level directly affects the entrant's investment, and the incumbent takes this into account. To find the optimal investment by the incumbent, I insert (3) into (1). Setting $V = 1$

[10] Additional details are available upon request.

and taking the first-order condition yields

$$p_{I,S}(\alpha,\gamma_C)=\frac{\gamma_C\left(2-2\alpha-\gamma_C+3\alpha\gamma_C\right)}{2\alpha\gamma_C^2-\gamma_C^2+2}. \tag{13}$$

The optimal investment by the entrant is then given by (13) and (3);

$$p_{E,S}(\alpha,\gamma_C)=\frac{\gamma_C\left(2\alpha\gamma_C-2\gamma_C-\gamma_C^2+\alpha\gamma_C^2+4\right)}{2\left(2\alpha\gamma_C^2-\gamma_C^2+2\right)}.$$

Comparing the incumbent's investment under Stackelberg competition to that of the main model, it is possible to show the following.

Proposition 3 *For $\alpha\in[0,1]$ and $\gamma_C\in\left[\frac{1}{2},1\right]$, $p_{I,S}(\alpha,\gamma_C)>p_I^C(\alpha,\gamma_C)$.*

Proof. See the Appendix. ■

If the incumbent is a Stackelberg leader, he optimally invests more than if the two firms move simultaneously.

The incumbent's ability to influence the entrant's technology choice can be described as follows. The level of investment by the incumbent which induces the entrant to choose technology A is denoted $\bar{p}_I$.[11] It can be expressed as

$$\bar{p}_I(\gamma_C)=\frac{2\left(2\gamma_C-1\right)}{\gamma_C}. \tag{14}$$

The incumbent has to invest less than $\bar{p}_I(\gamma_C)$ for equilibrium C to arise. Likewise, the incumbent must invest at least $\bar{p}_I(\gamma_C)$ for equilibrium A to arise. $\bar{p}_I(\gamma_C)$ is increasing in γ_C; the higher is the relative advantage of technology C, the larger is the investment required to keep the entrant out of it. Note that if $\gamma_C>\frac{2}{3}$, not even the maximal investment by the incumbent, $\bar{p}_I(\gamma_C)=1$, can prevent the entrant from choosing technology C.

In order to establish which equilibria will arise under Stackelberg competition, I define a threshold $\alpha_S\in(0,1)$, where S denotes Stackelberg competition, such that the incumbent's payoffs in the two types of equilibria are equal:

$$\Pi_I(A,\bar{p}_I(\gamma_C),p_E^A(\gamma_C))=\Pi_I(C,p_{I,S}(\alpha_S,\gamma_C),p_{E,S}(\alpha_S,\gamma_C)).$$

[11] I assume that if indifferent, the entrant chooses A.

Given the threshold α_S, it is possible to show the following:

Proposition 4 *If $\alpha > \alpha_S$, the Nash equilibrium is C.*

Proof. See the Appendix. ■

If $\alpha \leq \alpha_S$, the incumbent will choose the investment level $\bar{p}_I(\gamma_C)$ and thereby, he induces the entrant to choose to conduct R&D on technology A. I denote this strategic overinvestment by the incumbent. As α increases, the incumbent's incentives for innovation decrease and he prefers to invest less. However, it is only in equilibrium C that he can reduce his investment, as he must invest at least $\bar{p}_I(\gamma_C)$ in equilibrium A. For α above the threshold α_S, the incumbent obtains a higher expected payoff in equilibrium C and chooses not to strategically overinvest. Hence, the equilibrium is C.

Given the optimal investment by both firms, we can characterize the resulting innovation probability. Let $i^{N,S}$ be the innovation probability under a narrow scope, where superscript S denotes Stackelberg competition. It is given by

$$i^{N,S} = \begin{cases} \gamma_C \bar{p}_I(\gamma_C) + (1-\gamma_C) p_E^A(\gamma_C) & if\ \alpha \leq \alpha_S \\ \gamma_C \left(p_{I,S}(\alpha_S, \gamma_C) + p_{E,S}(\alpha, \gamma_C) - p_{I,S}(\alpha, \gamma_C) p_{E,S}(\alpha, \gamma_C) \right) & if\ \alpha > \alpha_S \end{cases} \tag{15}$$

Now, if $\alpha \leq \alpha_S$, the equilibrium is A, and there is no wasteful duplication of R&D. If, instead, $\alpha > \alpha_S$, the equilibrium is C and there is wasteful duplication of R&D.

5.2 Broad patent scope

If the patent scope is broad, the entrant chooses technology A, since there is no possibility for licensing. In equilibrium A, two firms' investments are independent and the incumbent's commitment to an R&D investment has no effect. Just as in the case of simultaneous moves, the entrant optimally invests $p_E^A(\gamma_C)$ under Stackelberg competition. Hence, the probability of innovation is

$$i^{B,S} = \gamma_C p_I^A(\alpha, \gamma_C) + (1-\gamma_C) p_E^A(\gamma_C) \tag{16}$$

where superscript S denotes Stackelberg competition. If we compare this expression to the innovation probability under a narrow scope, as given by (15), it is clear that if $\alpha \leq \alpha_S$ such that the entrant chooses A under a narrow scope, the only difference between the patent regimes is that under a narrow scope, the incumbent strategically overinvests whereas under a broad scope there is no need to do so; $\bar{p}_I(\gamma_C) > p_I^A(\alpha, \gamma_C)$.[12] Hence, total R&D investment is higher and it follows that $i^{N,S} > i^{B,S}$. If instead, $\alpha > \alpha_S$, the trade-offs between a broad and a narrow scope are as in the main model; a narrow scope gives wasteful duplication whereas a under a broad scope the entrant invests in a less promising technology. Again, the net effect will depend on parameter values.

5.3 Effects of patent scope on the probability of innovation

Which patent scope gives the highest innovation probability depends on the parameters α and γ_C in the model with Stackelberg competition as well as in the main model. I solve for the innovation probabilities for a narrow and broad patent scope respectively, for all values of $\gamma_C \in [0.5, 1]$ and $\alpha \in [0, 1]$ and the result is shown in Figure 2 below.

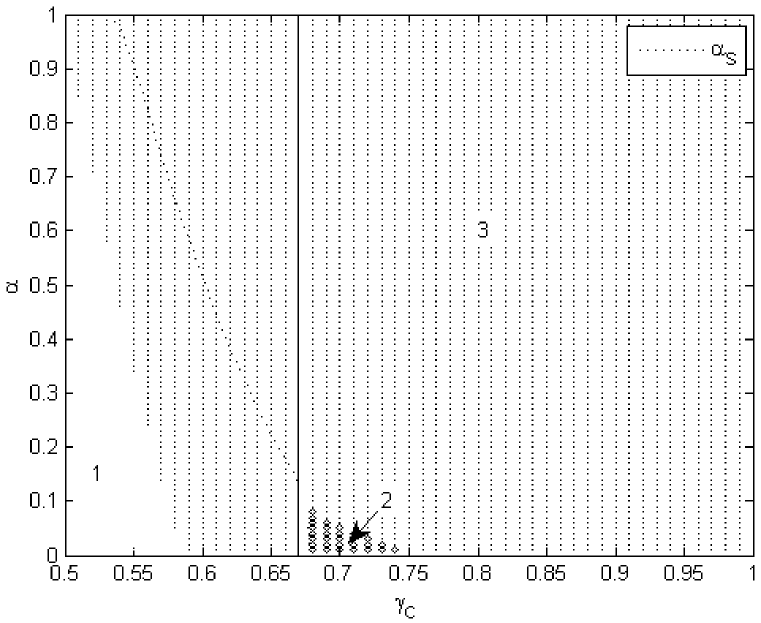

Figure 2: Innovation probabilities, Stackelberg competition. Area 1: Patent scope is inconsequential. Area 2: $i^{N,S} < i^{B,S}$. Area 3: $i^{N,S} > i^{B,S}$.

In the figure, the area labeled 1 is the area in which the entrant chooses equilibrium A even under a narrow scope and patent scope has no effect on the innovation probabilities. Area 2 is where a broad scope gives more innovation than a narrow scope and 3 is where a narrow scope

[12] If $\bar{p}_I(\gamma_C) \leq p_I^A(\alpha, \gamma_C)$, patent scope has no effect on innovation probabilities.

gives more innovation. The figure shows that a broad scope gives more innovation for only a small subset of parameter space; area 2. This holds for values of α close to zero and values of γ_C close to 0.7. Why does a broad patent scope give more innovation in this area of parameter space? The vertical line gives the threshold $\gamma_C = \frac{2}{3}$, above which the incumbent can no longer induce the entrant to choose A. In area 2, $\gamma_C > \frac{2}{3}$ which implies that under a narrow patent scope, the entrant chooses technology C. In this case, the negative effects of wasteful duplication under a narrow scope are sufficiently large that a broad scope gives more innovation.

To the left of area 2, the equilibrium under a narrow scope is A, as the incumbent chooses to overinvest sufficiently to keep the entrant out of technology C. As described above, there is no wasteful duplication under a narrow patent scope and the only difference between the patent regimes is that under a narrow scope, the incumbent strategically overinvests which implies that total R&D investment is higher. Hence, a narrow scope gives more innovation.

To the right of area 2, the entrant chooses C under a narrow scope. Here, a higher value of γ_C increases total investments under a narrow scope sufficiently to give more innovation than under a broad scope.

With Stackelberg competition, we see that the incumbent's ability to commit affects both optimal investment levels and the amount of wasteful duplication that occurs. If the incumbent induces the entrant to choose technology A, there is no wasteful duplication under a narrow scope, which in turn removes the imperative for a broad patent scope. If we compare Figures 1 and 2, it is clear that if commitment is possible, the potential benefit of a broad patent scope is almost eradicated.

6 Concluding comments

The model developed in this paper is motivated by the perceived increase in patent protection in the US and Europe, manifested by an increase in patent scope. The main finding is that under some conditions, the negative effects of R&D duplication are sufficiently large to warrant a broad patent scope: If the incumbent's profit increase from innovation is large, and if the patented technology has a small advantage relative to the alternative technology, a broad patent scope gives more innovation than a narrow scope. The former implies a high degree of wasteful duplication if firms choose the same technology and the latter that the entrant's investment in the alternative technology is high if he is induced to choose it. However, the higher is the entrant's bargaining power in license negotiations, the less conducive is a broad scope to innovation. As the license fee decreases, the entrant more often chooses licensing, which implies wasteful duplication of R&D. I also find that if the model is extended to Stackelberg competition the advantage of a broad scope to a large extent disappears, as strategic overinvestment by the incumbent can eliminate wasteful duplication under a narrow patent scope.

This paper shows that the effects of an increase in patent scope depend on technology and market characteristics, such as the availability of alternative technologies, the incumbent's gains from innovation and ability to commit to R&D investment, as well as the firms' bargaining powers in license agreements. An increase in patent scope may increase innovation in a given market. However, it requires that conditions on the form of competition, the technological alternatives and license agreements etc., are met. According to this model, a uniform increase in patent scope across industries, such as awarding patent holders larger powers in infringement lawsuits which is argued has taken place in the US and Europe, cannot be optimal. It has substantial policy implications: in 2008, the US courts alone handled 2 605 patent infringement cases.[13]

This result raises a new question: is the optimal policy implementable? To set the optimal scope ex ante, the Patent Office must make predictions of, for example, the technology's advantage relative to alternatives and the patent holder's incentive for further improvement of the invention he seeks to patent. This might seem an inherently difficult task for the patent examiner. However, the patent scope is also determined ex post, if the patent holder sues another party for infringement. At this point in time, the necessary characteristics are observed rather than predicted. To implement the optimal policy, courts should find a product infringing only if the patent holder has large incentives for innovation and there are viable alternatives to the patented technology. If entrant firms anticipate such a decision by the court, they can make the socially desirable technology choice.

A direction for future research is to increase the realism of the model by extending it to a dynamic framework, where the effects of expectations and the dynamics of technology development can be analyzed.

[13] The National Law Journal, January 19, 2009.

Appendix

Proof of Proposition 1

I assume that if indifferent, the entrant chooses A. The entrant chooses C if $\Pi_E\left(C, p_I^C(\alpha,\gamma_C), p_E^C(\alpha,\gamma_C)\right) > \Pi_E\left(A, p_I^A(\alpha,\gamma_C), p_E^A(\gamma_C)\right) \Leftrightarrow \frac{2\gamma_C^2(2+\alpha\gamma_C-\gamma_C)^2}{\left(4+2\alpha\gamma_C^2-\gamma_C^2\right)^2} > \frac{1}{2}(1-\gamma_C)^2$, which can be simplified to $\alpha > \frac{4-8\gamma_C+\gamma_C^2+\gamma_C^3}{2\gamma_C^3}$.

Proof of Proposition 2

Let $V=1$. I assume that if indifferent, the entrant chooses A. The entrant chooses C if $\Pi_{E,L}\left(C, p_{I,L}(\alpha,\gamma_C), p_{E,L}(\alpha,\gamma_C)\right) > \Pi_E\left(A, p_I^A(\alpha,\gamma_C), p_E^A(\gamma_C)\right) \Leftrightarrow \frac{2\gamma_C^2(1-\alpha)^2}{(2+\gamma_C(1-\alpha))^2} > \frac{1}{2}(1-\gamma_C)^2$, which can be simplified to $\alpha < \frac{3\gamma_C-2+\gamma_C^2}{\gamma_C+\gamma_C^2}$.

Proof of Proposition 3

$p_{I,S}(\alpha,\gamma_C) > p_I^C(\alpha,\gamma_C) \Leftrightarrow \frac{\gamma_C(2-2\alpha-\gamma_C+3\alpha\gamma_C)}{2\alpha\gamma_C^2-\gamma_C^2+2} > \frac{2\gamma_C(2(1-\alpha)+2\alpha\gamma_C-\gamma_C)}{4+2\alpha\gamma_C^2-\gamma_C^2}$. It can be simplified to $0 > \gamma_C\left(6\alpha\gamma_C-2\gamma_C-4\alpha+\gamma_C^2-3\alpha\gamma_C^2-4\alpha^2\gamma_C+2\alpha^2\gamma_C^2\right)$. Let $J(\alpha,\gamma_C) = 6\alpha\gamma_C-2\gamma_C-4\alpha+\gamma_C^2-3\alpha\gamma_C^2-4\alpha^2\gamma_C+2\alpha^2\gamma_C^2$.The problem is $\max_{\gamma_C,\alpha} J(\alpha,\gamma_C)$ s.t. $0 \leqslant \alpha \leqslant 1$ and $\frac{1}{2} \leqslant \gamma_C \leqslant 1$ which yields a global maximum at $J(0,0.5) = -0.75$. Hence, $p_{I,S}(\alpha,\gamma_C) > p_I^C(\alpha,\gamma_C)$.

Proof of Proposition 4

Let $p_{I,S}^C(\alpha,\gamma_C) = \min(p_{I,S}(\alpha,\gamma_C), \bar{p}_I(\gamma_C))$. I define $\hat{\alpha}_1 = \frac{3\gamma_C^3-8\gamma_C+4}{\gamma_C^2(5\gamma_C-2)}$. If $\alpha > \hat{\alpha}_1$, $p_{I,S}^C(\alpha,\gamma_C) = p_{I,S}(\alpha,\gamma_C)$.If $\alpha \leq \hat{\alpha}_1$, $p_{I,S}^C(\alpha,\gamma_C) = \bar{p}_I(\gamma_C)$. Let $p_{I,S}^A(\alpha,\gamma_C) = \max(p_I^A(\alpha,\gamma_C), \bar{p}_I(\gamma_C))$. I define $\hat{\alpha}_2 = \frac{\gamma_C^2-4\gamma_C+2}{\gamma_C^2}$. If $\alpha > \hat{\alpha}_2$, $p_{I,S}^A(\alpha,\gamma_C) = \bar{p}_I(\gamma_C)$. If $\alpha \leq \hat{\alpha}_2$, $p_{I,S}^A(\alpha,\gamma_C) = p_I^A(\alpha,\gamma_C)$. Case 1: $\alpha \leq \hat{\alpha}_1$ and $\alpha \leq \hat{\alpha}_2$. Case 2: $\alpha > \hat{\alpha}_1$ and $\alpha \leq \hat{\alpha}_2$. Case 3: $\alpha \leq \hat{\alpha}_1$ and $\alpha > \hat{\alpha}_2$. Case 4: $\alpha > \hat{\alpha}_1$ and $\alpha > \hat{\alpha}_2$. I assume that if indifferent, the incumbent chooses A.

Case 3: Compare $\Pi_I(C, \bar{p}_I(\gamma_C), p_E)$, where $p_E = \gamma_C\left(1-\frac{\bar{p}_I(\gamma_C)}{2}\right)$, and $\Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right)$. $\Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right) = \frac{-10\gamma_C^2+8\gamma_C+4\gamma_C^3+2\alpha\gamma_C^2-2\alpha\gamma_C^3-\alpha\gamma_C^4-2}{\gamma_C^2}$, and $\Pi_I(C, \bar{p}_I(\gamma_C), p_E) = \frac{-9\gamma_C^2+8\gamma_C+\gamma_C^3+2\gamma_C^4+\alpha\gamma_C^2+\alpha\gamma_C^3-3\alpha\gamma_C^4-2}{\gamma_C^2}$. $\Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right) > \Pi_I(C, \bar{p}_I(\gamma_C), p_E)$ can be simplified to $\gamma_C^2(2\gamma_C-1)(1-\gamma_C)(1-\alpha) > 0$. For $\gamma_C \geq \frac{1}{2}$ and $\alpha \leq 1$: $\gamma_C^2(2\gamma_C-1)(1-\gamma_C)(1-\alpha) \geq 0$. The equilibrium is A. **Case 1**: Compare $\Pi_I(C, \bar{p}_I(\gamma_C), p_E)$, where $p_E = \gamma_C\left(1-\frac{\bar{p}_I(\gamma_C)}{2}\right)$, and $\Pi_I\left(A, p_I^A(\alpha,\gamma_C), p_E^A(\gamma_C)\right)$. From Case 3, it is clear that $\Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right) \geq \Pi_I(C, \bar{p}_I(\gamma_C), p_E)$. In addition, $\Pi_I\left(A, p_I^A(\alpha,\gamma_C), p_E^A(\gamma_C)\right) \geq \Pi_I(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C))$ as $p_I^A(\alpha,\gamma_C) = \arg\max_{p_I} \Pi_I(A, p_I, p_E)$. Hence, $\Pi_I\left(A, p_I^A(\alpha,\gamma_C), p_E^A(\gamma_C)\right) \geq \Pi_I(C, \bar{p}_I(\gamma_C), p_E)$. The equilibrium is A.

Case 2: $\Pi_I\left(C, p_{I,S}(\alpha,\gamma_C), p_{E,S}(\alpha,\gamma_C)\right) = \frac{\left(8\alpha+4\gamma_C^2-4\gamma_C^3+\gamma_C^4-20\alpha\gamma_C^2+16\alpha\gamma_C^3-2\alpha\gamma_C^4+12\alpha^2\gamma_C^2-12\alpha^2\gamma_C^3+\alpha^2\gamma_C^4\right)}{4\left(2\alpha\gamma_C^2-\gamma_C^2+2\right)}$

and $\Pi_I\left(A, p_I^A(\alpha,\gamma_C), p_E^A(\gamma_C)\right) =$

$\frac{1}{2}\gamma_C\left(4\alpha+\gamma_C-4\alpha\gamma_C+\alpha^2\gamma_C\right)$. $\Pi_I\left(A, p_I^A(\alpha,\gamma_C), p_E^A(\gamma_C)\right) > \Pi_I\left(C, p_{I,S}(\alpha,\gamma_C), p_{E,S}(\alpha,\gamma_C)\right)$ can be simplified to

$0 > \frac{\left(-16\alpha\gamma_C+8\alpha-4\gamma_C^3+3\gamma_C^4-4\alpha\gamma_C^2+24\alpha\gamma_C^3-14\alpha\gamma_C^4+8\alpha^2\gamma_C^2-28\alpha^2\gamma_C^3+19\alpha^2\gamma_C^4-4\alpha^3\gamma_C^4\right)}{4\left(2\alpha\gamma_C^2-\gamma_C^2+2\right)}$ The denominator is positive. Let the numerator be denoted $K(\alpha,\gamma_C)$.The problem is $\max_{\gamma_C,\alpha} K(\alpha,\gamma_C)$ s.t. $\alpha \in [0.000, 0.280]$ and $\gamma_C \in [0.550, 0.590]$ which yields a global maximum at $K(0.280, 0.550) = -0.24$. Hence, $\Pi_I\left(A, p_I^A(\alpha,\gamma_C), p_E^A(\gamma_C)\right) > \Pi_I\left(C, p_{I,S}(\alpha,\gamma_C), p_{E,S}(\alpha,\gamma_C)\right)$. The equilibrium is A. **Case 4**: $\Pi_I\left(C, p_{I,S}(\alpha,\gamma_C), p_{E,S}(\alpha,\gamma_C)\right) > \Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right) \Leftrightarrow$

$\frac{8\alpha+4\gamma_C^2-4\gamma_C^3+\gamma_C^4-20\alpha\gamma_C^2+16\alpha\gamma_C^3-2\alpha\gamma_C^4+12\alpha^2\gamma_C^2-12\alpha^2\gamma_C^3+\alpha^2\gamma_C^4}{4\left(2\alpha\gamma_C^2-\gamma_C^2+2\right)} > \frac{-10\gamma_C^2+8\gamma_C+4\gamma_C^3+2\alpha\gamma_C^2-2\alpha\gamma_C^3-\alpha\gamma_C^4-2}{\gamma_C^2}$ Let $\alpha_S = \frac{-4\gamma_C^2+24\gamma_C^3-38\gamma_C^4+12\gamma_C^5+3\gamma_C^6}{-4\gamma_C^4+4\gamma_C^5+9\gamma_C^6} + \frac{2\sqrt{20\gamma_C^4-128\gamma_C^5+320\gamma_C^6-408\gamma_C^7+301\gamma_C^8-144\gamma_C^9+49\gamma_C^{10}-10\gamma_C^{11}}}{-4\gamma_C^4+4\gamma_C^5+9\gamma_C^6}$ This gives $\alpha > \alpha_S : \Pi_I\left(C, p_{I,S}(\alpha,\gamma_C), p_{E,S}(\alpha,\gamma_C)\right) > \Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right)$, $\alpha \le \alpha_S$:

$\Pi_I\left(C, p_{I,S}(\alpha,\gamma_C), p_{E,S}(\alpha,\gamma_C)\right) \le \Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right)$. Show that $\hat{\alpha}_1 < \alpha_S$ for $\gamma_C \in [0.5332, 0.6667]$.

$\hat{\alpha}_1 < \alpha_S \Leftrightarrow \frac{3\gamma_C^3-8\gamma_C+4}{\gamma_C^2(5\gamma_C-2)} < \frac{-4\gamma_C^2+24\gamma_C^3-38\gamma_C^4+12\gamma_C^5+3\gamma_C^6}{-4\gamma_C^4+4\gamma_C^5+9\gamma_C^6} +$

$\frac{2\sqrt{20\gamma_C^4-128\gamma_C^5+320\gamma_C^6-408\gamma_C^7+301\gamma_C^8-144\gamma_C^9+49\gamma_C^{10}-10\gamma_C^{11}}}{-4\gamma_C^4+4\gamma_C^5+9\gamma_C^6}$. This can be simplified to:

$0 < 8\gamma_C^4\left(1-\gamma_C\right)\left(2\gamma_C-1\right)\left(4\gamma_C+9\gamma_C^2-4\right)\left(4\gamma_C-\gamma_C^2+\gamma_C^3-2\right)\left(2\gamma_C^2-6\gamma_C+\gamma_C^3+4\right)$ which holds for $\gamma_C \in [0.5332, 0.6667]$. Show that $\hat{\alpha}_2 < \alpha_S$ for $\gamma_C \in [0.5332, 0.6667]$. $\hat{\alpha}_2 < \alpha_S \Leftrightarrow \frac{\gamma_C^2-4\gamma_C+2}{\gamma_C^2} <$

$\frac{-4\gamma_C^2+24\gamma_C^3-38\gamma_C^4+12\gamma_C^5+3\gamma_C^6}{-4\gamma_C^4+4\gamma_C^5+9\gamma_C^6} + \frac{\left(2\sqrt{20\gamma_C^4-128\gamma_C^5+320\gamma_C^6-408\gamma_C^7+301\gamma_C^8-144\gamma_C^9+49\gamma_C^{10}-10\gamma_C^{11}}\right)}{-4\gamma_C^4+4\gamma_C^5+9\gamma_C^6}$. This can be simplified to

$0 < \gamma_C^8\left(4\gamma_C+9\gamma_C^2-4\right)\left(28\gamma_C-79\gamma_C^2+108\gamma_C^3-67\gamma_C^4+14\gamma_C^5-\gamma_C^6-4\right)$ which holds for $\gamma_C \in [0.5332, 0.6667]$. Hence, for $\alpha > \alpha_S$, the equilibrium is C.

References

[1] Cabral, L., and Polak, B. (2004), Does Microsoft Stifle Innovation? Dominant Firms, Imitation and R&D Incentives, CEPR Discussion Paper no. 4577.

[2] Chang, H. (1995), Patent Scope, Antitrust Policy, and Cumulative Innovation, *RAND Journal of Economics* 26, 34-57.

[3] Chatterjee, K., and Evans, R. (2004), Rivals' search for buried treasure: competition and duplication in R&D, *RAND Journal of Economics* 35, 160-183.

[4] Chou, T., and Haller, H. (2007), The Division of Profit in Sequential Innovation for Probabilistic Patents, *Review of Law and Economics* 3, 581-609.

[5] Denicolo, V. (2000), Two-Stage Patent Races and Patent Policy, *RAND Journal of Economics* 31, 488-501.

[6] Domeij, B. (2000), *Pharmaceutical Patents in Europe*, Norstedts, Stockholm.

[7] Erkal, N. (2005), The decision to patent, cumulative innovation, and optimal policy, *International Journal of Industrial Organization* 23, 535-562.

[8] Gallini, N. (1992), Patent Policy and Costly Imitation, *RAND Journal of Economics* 23, 52-63.

[9] Gallini, N. (2002), The Economics of Patents: Lessons from Recent U.S. Patent Reform, *Journal of Economic Perspectives* 16, 131-154.

[10] Gilbert, R., and Shapiro, C. (1990), Optimal patent length and breadth. *RAND Journal of Economics* 21, 106-112.

[11] Green, J., and Scotchmer, S. (1995), On the Division of Profit in Sequential Innovation. *RAND Journal of Economics* 26, 20-33.

[12] Guellec, D., and van Pottelsberghe de la Potterie, B. (2007), *The economics of the European patent system: IP Policy for Innovation and Competition.* Oxford University Press, Oxford.

[13] Jaffe, A. (2000), The U.S. patent system in transition: policy innovation and the innovation process, *Research Policy* 29, 531-557.

[14] Jones, C., and Williams, J. (2000), Too Much of a Good Thing? The Economics of Investment in R&D, J*ournal of Economic Growth* 5*,* 65-85.

[15] Kitch, E. (1977), The Nature and Function of the Patent System, *Journal of Law and Economics* 20*,* 265-290.

[16] Klemperer, P. (1990), How broad should the scope of patent protection be? *RAND Journal of Economics* 21, 113-130.

[17] Lerner, J. (1995), Patenting in the Shadow of Competitors, *Journal of Law and Economics* 38*,* 463-495.

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

[19] Merges, R., and Nelson, R. (1990), On the Complex Economics of Patent Scope, *Columbia Law Review* 90*,* 839-916.

[20] Murray, F. (2008), The Oncomouse that Roared: Resistance & Accomodation to Patenting in Academic Science, forthcoming in *American Journal of Sociology.*

[21] O'Donoghue, T., Scotchmer, S., and Thisse, J. (1998), Patent Breadth, Patent Life, and the Pace of Technological Progress, *Journal of Economics and Managment Strategy* 7, 1-32.

[22] Tandon, P. (1983), Rivalry and the Excessive Allocation of Resources to Research, *Bell Journal of Economics* 14*,* 152-165.

[23] Walsh, J., Arora, A., and Cohen, W. (2003), Effects of Research Tool Patents and Licensing on Biomedical Innovation, in: W. Cohen and S. Merrill (Eds.) *Patents in the Knowledge-Based Economy*, Committee on Intellectual Property Rights in the Knowledge-Based Economy, National Research Council.

[24] Zeira, J. (2003), Innovations, Patent Races and Endogenous Growth. CEPR Discussion Paper no. 3974.