# When Do More Patents Reduce R&D?

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January 2006

## Abstract

This paper develops a simple duopoly model in which investments in R&D *and* patents are inputs in the production of firm rents. Patents are necessary to appropriate the returns to the firm's own R&D, but patents also create potential claims against the rents of rival firms.

Analysis of the model reveals a general necessary condition for the existence of a positive correlation between the firm's R&D intensity and the number of patents it obtains. When that condition is violated, changes in exogenous parameters that induce an increase in firms' patenting can also induce a decline in R&D intensity. Such a negative relationship is more likely when (1) there is sufficient overlap in firms' technologies so that each firm's inventions are likely to infringe the patents of another firm, (2) firms are sufficiently R&D intensive, and (3) patents are cheap relative to both the cost of R&D and the value of final output.

Keywords: Patents, Patent Thickets
JEL Codes: 034

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Thanks to Jim Bessen, Loretta Mester, Cecil Quillen, Leonard Nakamura, and Polk Wagner, Philip Webre, and Rosemarie Ziedonis for comments on earlier versions of the paper. The remaining errors are my own.

This paper presents a simple model that explores the relationship between the incentive to invent and the incentive to obtain patents. Unlike much of the previous literature, we do not treat these as a single decision. Instead we explore the factors required for investments in R&D and patents to be complementary in the manner typically assumed in most theoretical models and policy discussions.

We derive sufficient conditions for patents and R&D to be *substitute* inputs in the production of firm profits: (1) there must be sufficient overlap between the firms' patented inventions, (2) firms must be sufficiently R&D intensive, and (3) patents are cheap relative to both the cost of R&D and the value of final output. The first requirement may be due to the nature of a technology, but it can also result from the manner in which patents are drafted and examined. The latter two depend both on the pecuniary costs of R&D and patents and the standards required for patentable inventions. In such environments, firms increase their patenting in order to tax the rents earned on a rival's inventions and to mitigate similar behavior by their rivals. Firms respond by reducing their R&D investments.

Section 1 presents the model. Section 2 presents the main results. Section 3 investigates welfare implications. Section 4 places the results in the context of U.S. patent policy and empirical research on the economic benefits of the patent system. All proofs are found in Hunt (2006).

## 1. The Model

A measure of consumers have a unit demand for the final output (inventions), which can be interpreted as improvements in product quality. There is a competitive fringe of firms that are able to imitate and produce inventions at no cost, but they have no independent R&D capability. There are also two firms, sharing the same technology, that are capable of inventing and seeking property rights over their inventions. These two firms move simultaneously, deciding on the amount of R&D $(x_i)$ to perform and the number of patents $(n_i)$ to obtain. Both activities are subject to a constant marginal cost, *R* and *C*, respectively (final output is the numeraire). The required inputs are assumed to be purchased from competitive markets, so these prices also represent the social cost of performing R&D and obtaining patents.

An investment of $x_i$ in R&D leads to a measure of the final goods invented $f(x_i) = x_i^{\alpha}$, $\alpha < 1$. A firm that obtains a quantity of patents $n_i$ is able to appropriate a share of rents associated with its own innovations. Let $\theta(n_i) \in [0,1]$ denote this share and assume it follows an exponential distribution; that is, $\theta(n_i) = 1 - e^{-n_i}$. Ignoring the other firm for a moment, firm $i$ earns rents $\theta(n_i) f(x_i)$. The remainder, $\left[1-\theta(n_i)\right] f(x_i)$, is unprotected, so it is supplied by the competitive fringe of imitators. Thus patents are essential to protecting the firm's return on R&D investments.

In addition, some of the rival's inventions may infringe one or more of $i's$ patents. This will depend on the number of patents firm $i$ obtains, and the degree of overlap between the inventions produced by each firm. Let $\beta \in [0,1)$ denote this degree of overlap. Thus firm 1 may claim a share of the rents generated by firm 2 equivalent to $\beta\theta(n_1) f(x_2)$. This includes a share of what firm 2 would otherwise earn, $\theta(n_1) f(x_2)$, and a share, $\left[1-\theta(n_2)\right] f(x_2)$, that would otherwise be supplied by the competitive fringe. Firm 2 engages in the same activity, which extracts some rents from firm 1 and some output from the competitive fringe. The objective functions of the two firms are thus:

$$V^1 \equiv \theta(n_1)\left(1-\beta\theta(n_2)\right) f(x_1) + \beta\theta(n_1) f(x_2) - Rx_1 - Cn_1, \text{ and}$$

$$V^2 \equiv \theta(n_2)\left(1-\beta\theta(n_1)\right) f(x_2) + \beta\theta(n_2) f(x_1) - Rx_2 - Cn_2.$$

The parameter $\beta$ is a parsimonious way of modeling the degree to which a firm's property rights depend on their inventions. When $\beta = 0$, each firm derives rents only from its own R&D investments. When $1 > \beta > 0$, a firm is able to lay claim to the inventions of others, but not as easily as it can claim inventions of its own making. Note that while the exact mechanism of the transfers is not specified in the model, holding R&D constant, the transfers impose no losses in the total potential rents that can be earned.

How should we interpret $\beta$? For some industries it is a question of technology. Firms may draw from similar technical fields and arrive at similar solutions even when they apply them to different problems. This is particularly true for industries that advance through cumulative innovation and where firms may rely on a common set of building blocks derived from previous innovations. In addition, some products incorporate several, if not dozens, of potentially patentable innovations. Two examples of such an environment are semiconductors and computer software.

The size of $\beta$ might also depend on the breadth of claims contained in patents.[1] If broad claims are regularly granted, it is more likely that firms will infringe each other's patents. Under this interpretation it is possible that patent breadth, and therefore $\beta$, can be influenced by policymakers or the courts.

A third, and more controversial, interpretation is that $\beta$ is a measure of a firm's effectiveness in obtaining property rights over things it has not really invented. While this is explicitly prohibited by U.S. patent law, it might nevertheless arise from mistakes in the

[1] The trade-off between patent breadth and length is studied in Gilbert and Shapiro (1990) and Klemperer (1990).

examination of patent applications. This is a topic that has received considerable attention in recent years (Federal Trade Commission (FTC) 2003, Jaffe and Lerner 2004, Merrill, Levin and Myers 2004).

## 2. Equilibrium and Comparative Static Results

The first order conditions for firm 1 are

[1] $$\theta_1\left(1-\beta\theta_2\right) f_1' - R = 0 \text{, and}$$

[2] $$\left(1-\theta_1\right)\left\{\left(1-\beta\theta_2\right) f_1 + \beta f_2\right\} - C = 0,$$

where the subscripts refer to the variable for the appropriate firm. Note that in [1] the increase in revenue associated with additional R&D reflects the effect of firm 1's patenting and that of its rival, which the firm takes as given. In [2], the increase in revenue resulting from additional patenting includes the additional revenue firm 1 can extract from its rival.

The first order conditions imply the following relationship between R&D and patenting:

[3] $$\frac{R}{C} = \frac{f_1'}{f_1}\left(\frac{\theta_1}{1-\theta_1}\right)\left[\frac{(1-\beta\theta_2) f_1}{(1-\beta\theta_2) f_1 + \beta f_2}\right].$$

Let $P \equiv R/C$ denote the relative cost of the inputs and $\tau_1 \equiv \left(1-\beta\theta_2\right) f_1 \big/ \left[\left(1-\beta\theta_2\right) f_1 + \beta f_2\right]$. Thus when R&D is significantly more expensive than patenting, the firm will obtain more patents for every increment of R&D it performs. The wedge $\tau_1$ is decreasing in the rival's R&D investments and patenting, and in $\beta$, but is increasing in the firm's own R&D.

Substituting $\theta(n) = 1 - e^{-n}$ in [3] and rearranging terms, we find that

[4] $$\theta_i = \frac{Px_i}{\alpha\tau_i + Px_i}.$$

Thus, holding constant the rival's behavior, firm $i$'s patent portfolio is strictly increasing in the amount of R&D it performs.

**Proposition 1**: If the costs of obtaining patents (*C*) and doing R&D (*R*) are sufficiently small, there exists a unique symmetric interior equilibrium, $(x^*, n^*)$, in pure strategies.

A sufficient condition for satisfying the second order condition and the participation constraint is that $C \le \tilde{C}$ where

[5] $$\tilde{C} = \frac{\alpha(1-\alpha)}{-Ln(1-\alpha)}(1-\beta\alpha+\beta)\left\{\frac{\alpha^2}{R}[1-\beta\alpha]\right\}^{\frac{\alpha}{1-\alpha}}.$$

Figure 1 plots this constraint (the continuous line) in the space of the input prices for a particular set of parameter values $(\beta = 0.6,\ \alpha = 0.5)$. Next, we turn to the comparative static properties of the equilibrium:

**Proposition 2:** The equilibrium number of patents, $n^*$, is decreasing in both the cost of obtaining patents (*C*) and the cost of doing R&D (*R*). The equilibrium level of R&D, $x^*$, is always decreasing in *R* and is decreasing (increasing) in *C* when $1-2\beta\theta(x^*) > 0$ $\left(1-2\beta\theta(x^*) < 0\right)$.

Thus the model generates the typical input price responses for patents, but not always for R&D. Ordinarily we expect that, where patents are essential to appropriating returns to innovation, reducing the cost of obtaining these property rights encourages more R&D. Proposition 2 shows this intuition holds only when the rival firm cannot extract a majority of the potential rents associated with firm $i$'s innovations. This is ensured if $\beta < 1/2$, but not otherwise.

If $\beta \geq 1/2,$ and firms are sufficiently active in their R&D and patenting, reductions in the cost of patenting will reduce R&D. This occurs when $C \leq \hat{C}$ where

$$\hat{C} = \left( \beta - \frac{1}{4\beta} \right) \left( \frac{\alpha}{4\beta R} \right)^{\frac{\alpha}{1-\alpha}}.$$

Figures 1 plots this constraint (the dashed line) in the space of input prices. Since $\hat{C} < \tilde{C}$, the set of input prices that ensures existence of an interior equilibrium can be divided into a region where R&D is decreasing in the cost of patenting and another where R&D is increasing in the cost of patents (for other examples, see Hunt 2006).

## 3. Welfare Analysis

What would a social planner do? It is easy to show that the amount of innovation in the private equilibrium is always less than the first best outcome.[2] In the first best solution, patents are unnecessary. In a second best world, and where R&D subsidies cannot be funded from an external source, the social planner may "tax" patenting to stimulate private R&D investments.[3]

To be concrete, suppose the planner levies a tax, $\varepsilon$, such that the private cost of obtaining a patent is now $c = C + \varepsilon,$ where *C* continues to denote the social cost of resources devoted to patent prosecution. The planner chooses $\varepsilon$ to maximize $f(x^*) - Rx^* - Cn^*,$ where $\left(x^*, n^*\right)$ denote the equilibrium levels of activity in the private equilibrium with firms responding to the input prices *R* and *c*.

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[2] This is true even if we assume $\beta$ is also a measure of the degree of overlap in the firms' R&D programs.

[3] Another second best solution would be to merge the two firms. But once the model is generalized to include racing, a single firm may do less R&D than two firms (Lee and Wilde 1980) and this would be compounded in a dynamic model where the monopolist is concerned about replacing its own profits.

It is easy to show the social planner will never permit the private cost of patents to be so low that the counter-intuitive outcome defined in Proposition 2 would occur. This follows from the first order condition of the planner's problem:

$$[6] \qquad \frac{\partial x^*}{\partial C}\left[ f'(x^*) - R \right] - \frac{dn^*}{dc} C = 0.$$

So long as $dn^* / dc < 0,$ the first order condition can be satisfied only if the planner chooses $\varepsilon$ , so that $dx^* / dc < 0$. At an optimum, the planner is trading off marginal reductions in the number of inventions that are worth $f'(x^*) - R > 0$ against marginal reductions in resources devoted to patenting, which cost *C*.

Thus far we have treated the overlap parameter $\beta$ as an exogenous aspect of the technological environment. Suppose the social planner has some control over the magnitude of $\beta$ , perhaps through legal doctrines that determine the breadth of patent claims. Hunt (2006) shows that, if the output elasticity is not too small $(\alpha \geq 1/2),$ $dx^* / d\beta < 0$. In that case, the social planner would prefer less overlap and therefore more narrow patents. However, firms would respond to such a change by increasing their patent activity $(dn^* / d\beta < 0)$.

## 4. Discussion

This paper develops a simple model that illustrates the relationship between firms' R&D and patenting decisions. It is typically the case that these two activities are complementary—firms that do a lot of R&D also tend to patent more. And ordinarily, reducing the cost of R&D, or of patenting, will stimulate additional investments in R&D.

But as the model illustrates, this intuition does not always hold. Each firm cares about the patent strategies of its rival, which affects the rents it earns on its own discoveries, as well as the rents earned when the rival infringes its own patents. A necessary condition is a significant overlap between the rights granted to each firm ($\beta$ must be at least ½). Then, if firms are sufficiently active in their R&D and patenting, incremental reductions in the cost of obtaining patents result in less, rather than more R&D. This does not imply the elimination of R&D investments, but rather less innovation than would otherwise occur.

Thus there may be instances where raising patent costs can actually induce more R&D. This might be achieved via a patent tax or by increasing the requirements that must be satisfied in order to obtain a patent. For example, policymakers could increase the *inventive step* (the standard of nonobviousness in U.S. law) required to obtain a patent so that the most trivial advances over the prior art do not qualify for patent protection (Hunt 1999).

The model suggests that the counter-intuitive outcome is more likely to occur in high-tech industries that do a lot of R&D and patenting, and which tend to advance via cumulative innovation.[4] Previous empirical work has identified a number of industries with such characteristics, including electronics, computers, and semiconductors, and they account for most of the rapid growth in U.S. patenting in recent years (see Hall 2003 and references therein). They are also the industries where researchers identify what is sometimes called "strategic patent" behavior, including the assembly of large portfolios for wholesale cross-licensing and possibly deceptive patent prosecution (Grindley and Teece 1997, Graham and Mowery 2004).

[4] A similar intuition obtains from dynamic models of innovation. Hunt (2004) shows that a low inventive step, making patents easy to obtain, can reduce the rate of innovation in industries where R&D is the most productive.

Bessen and Hunt (2003) present empirical results consistent with the phenomenon modeled here in the context of patenting computer software. Obtaining such patents was difficult, but not impossible, during the 1970s and early 1980s. Over time, however, courts have become more receptive to such patents and their numbers have grown rapidly, primarily among firms in the industries described above. Bessen and Hunt (2003) find that, all else equal, firms that concentrated on obtaining software patents experienced a statistically and economically significant decline in their R&D intensity relative to other firms.

Of course, this is a highly stylized model that omits a number of important considerations from the analysis. For example, it is possible that the deleterious effects of excessive patenting can be mitigated through licensing arrangements or patent pools, assuming these can be negotiated without excessive transactions costs.[5] But it is not immediately obvious, in the context of "cheap" patents, that licensing arrangements improve innovation incentives. For example, Bessen (2003) shows that, when patent standards are low, firms are able to assemble large patent portfolios, which they use to make aggressive licensing demands. This encourages more patenting, but less R&D. Under higher standards, such a strategy is not cost effective.

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[5] FTC (2003), Chapter 3, provides a detailed discussion of reasons why these transactions costs may be large for some industries. For an empirical analysis of the effects of fragmented property rights in the semiconductor industry, see Ziedonis (2003).

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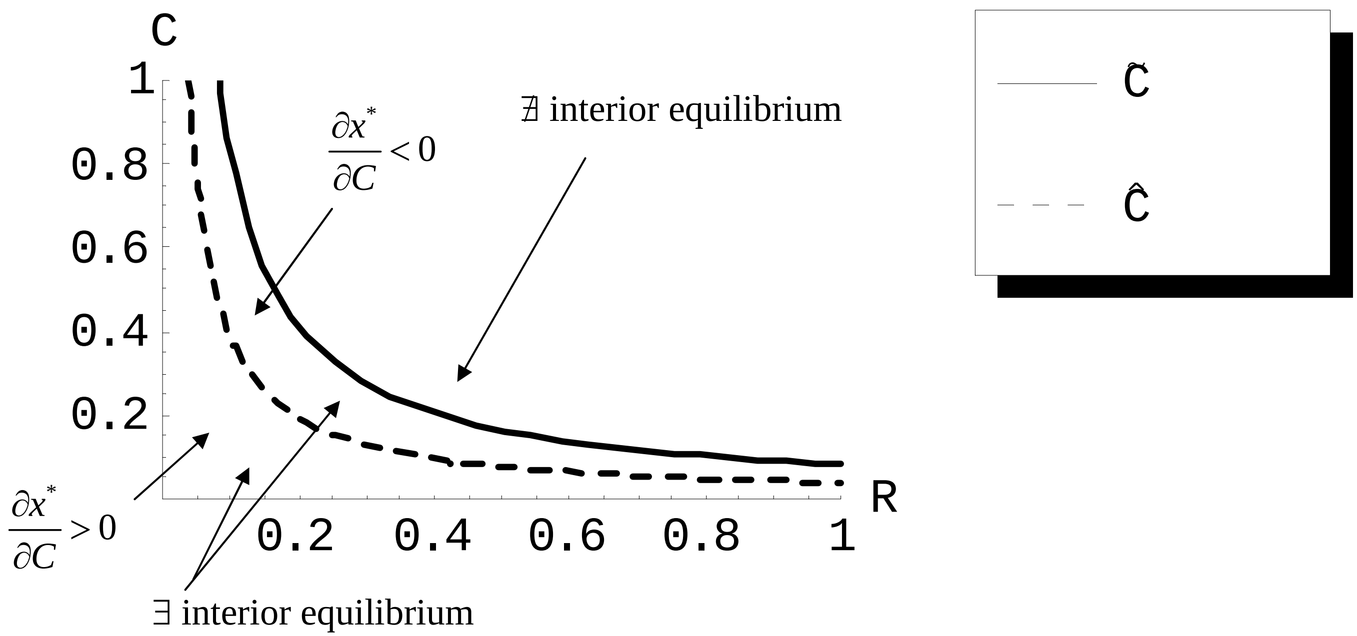
Figure 1



C
1
0.8
0.6
0.4
0.2
R
0.2
0.4
0.6
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1
∄ interior equilibrium
$\frac{\partial x^*}{\partial C} < 0$
$\frac{\partial x^*}{\partial C} > 0$
∃ interior equilibrium
$\tilde{C}$
$\hat{C}$