LABOR MOBILITY OF SCIENTISTS, TECHNOLOGICAL DIFFUSION, AND THE FIRM'S PATENTING DECISION*

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March 2004

ABSTRACT

We develop and test a model of the patenting and R&D decisions of an innovating firm whose scientist-employees sometime quit to join or start a rival. In our model, the innovating firm patents to protect itself from its employees. We show theoretically that the risk of a scientist's departure reduces the firm's R&D expenditures and raises its propensity to patent an innovation. We find evidence from firm-level panel data that is consistent with this latter result. Our results suggest that scientists' turnover is associated with cross-industry patenting variation and with recent economy-wide increases in patenting. Scientists' turnover may also partly account for why small firms have high patent-R&D ratios.

Keywords: Labor market for scientists and engineers, patents, research and development, job turnover, mobility of scientists, technological diffusion

JEL Classification Numbers: J63, O32, O34

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* We thank the editor, three anonymous referees, participants at the 2001 NBER Productivity Program Meeting and at the 2000 Southern Economic Association Meetings, seminar participants at the London Business School, Ohio State University, SUNY Albany, and SUNY Buffalo, and Chris Taber for helpful comments. All errors are exclusively the responsibility of the authors. The authors would like to thank Bronwyn Hall and Adam Jaffe for making the NBER-CWRU patent data available to us. Comments welcome at Jinyoung Kim, Department of Economics, SUNY Buffalo, 441 Fronczak Hall, Buffalo, NY 14260, jinkim@buffalo.edu; and Gerald Marschke, Department of Economics & Department of Public Administration and Policy, SUNY Albany, BA-110, Albany, NY 12222, marschke@albany.edu.

1. Introduction

Since the mid-1900s firms have acquired many of the innovations for new products and manufacturing processes through their own research and development efforts, rather than through licensing agreements with independent scientists. Internalizing the R&D enterprise has advantages over acquiring the innovations through arm's-length transactions because of the complementarities between the research conducted and the firm's production function—knowledge about the production function is costly to transmit to outsiders—and because of the difficulty of motivating contractors (see Lamoreaux and Sokoloff, 1999). But innovating in-house creates a challenge: firms risk their scientists, researchers, and other key personnel leaving after a discovery to exploit it on their own. One way that they can mitigate this risk is by patenting innovations as they are developed in the laboratory. In this paper we examine theoretically and empirically how the threat of a scientist leaving affects the firm's patenting and R&D decisions.

Through patenting, an innovating firm can attempt to prevent competitors from imitating new products and thus can preserve its market share. Secrecy offers the firm an alternative means of securing the returns to R&D while avoiding both the legal expenses of patent application and infringement prosecution, and the potentially much greater losses from disclosing sensitive information to competitors (Friedman, Landes and Posner, 1991; Cohen, Nelson, and Walsh, 2000). At the time patents are granted, the USPTO publishes the detailed technical information that firms have submitted in support of their patent application. Rival firms may be able to use this information to innovate around the patent. Nevertheless, in practice, firms often do not fully disclose the technical details of an innovation on patent applications. Nor does a secrecy strategy necessarily prevent an innovating firm's rivals gaining access to its secrets through reverse engineering, espionage, and especially former employees.

Technological know-how acquired through research experience is embedded in the scientist's human capital. This knowledge becomes available to a competitor when the employee switches jobs. Economists have long suspected that the inter-firm mobility of scientists transmits technological know-how across firms (Arrow, 1962; Stephan, 1996), but evidence is often anecdotal and econometric evidence is scarce. Levin, Klevoric, Nelson, and Winter (1987) present survey evidence that firms count the hiring of R&D employees from innovating firms as a means of learning about new technologies. Almeida and Kogut (1999) find that skilled engineers who hold major semiconductor patents experience high rates of inter-firm mobility. They find the scientific references that firms cite in their patent applications reflect the employment histories of their scientists, suggesting that ideas in the semiconductor industry are spread by the movement of key engineers among firms, especially within a geographical region. Articles in the business press suggest high tech firms actively encourage defections among competitors' technological personnel. Kerstetter (2000) and Hibbard (1998) provide several high profile examples of employee raids designed to gain access to competitors' technologies, supporting Kerstetter's claim that Silicon Valley firms live by the philosophy, "If you have trouble with the competition, simply raid its talent." Recently documented increases in scientists' and engineers' inter-firm mobility (Bureau of Labor Statistics, 2000[1]) suggest that employee misappropriation of technological know-how may be on the rise, especially among high-tech firms.

Trade secret laws and non-compete covenants in employment contracts, which provide that a leaving employee will not seek employment with the employer's competitor or found a competing start-up company, do not appear to limit the risk of this kind of misappropriation (see

Bongiorno and Marcellino, 1996; Jenero and Schreiber, 1999). Trade secret laws are difficult to enforce. Courts are reluctant to enforce non-compete covenants because of the restrictions they place on the worker's ability to secure employment (see Dworkin and Callahan, 1998; Gilson, 1999; Koh, 1998).[2] Thus, firms and employees cannot easily contract around the misappropriation problem.

The economics literature typically frames the patent as a device to exclude outsiders. In this paper, we emphasize a patent’s role in protecting an innovating firm from insiders. We hypothesize that a firm that risks losing innovations to departing scientists will move quickly to patent its scientists’ innovations. As the likelihood of a quit rises, so should the utility of patent protection. Increases in scientists’ mobility may therefore induce firms to substitute away from secrecy toward patenting, leading to an increase in firms’ propensities to patent per R&D dollar spent. As an increase in the potential external return to the acquired knowledge entices them to leave innovating firms, scientists become willing to take a salary cut, reducing the wage bill and thus the cost of R&D for innovating firms. This is the main story we investigate in this paper.

The paper is organized as follows. Section 2 lays out a formal model of a firm’s R&D and patenting decisions in an environment where scientist-employees turn over. Sections 3 and 4 respectively describe the data and explain our empirical strategy. Section 5 describes our results. Finally, Section 6 concludes the paper and includes a discussion of the importance of the mobility of scientific personnel in explaining observed cross-sectional and intertemporal variation in patenting and in explaining variation in patent-R&D ratios by firm size.

2. Model of firm's patenting and R&D decision

We formalize our ideas along the lines of Pakes and Nitzan (1983), who study how innovating firms contract with their scientific personnel when scientists may leave to set up rivals. We build on their model by allowing a firm to patent its innovations before the scientist leaves. We start with an entrepreneur who wishes to develop an idea into a marketable product. The entrepreneur seeks to hire a scientist to develop the idea. The scientist is the only additional input in the development process. When a scientist is hired, the project's development, production, and marketing take two periods. In the first period, the scientist develops the idea into a viable prototype. In the second period, the entrepreneur produces and markets the product, without the aid of the scientist. We assume that the product's life on the market ends at the end of the second period and that the revenue, ρ_i ($\in R^+$), is a random variable realized at the beginning of the second period with subscript i standing for 'internal.' By the end of the first period, the scientist possesses knowledge that enables him, if he desires, to market the innovation himself. At the beginning of the second period the entrepreneur and the scientist learn about the value of this knowledge to a rival. We assume that this 'external' value is a random variable, ρ_e ($\in R$), and the joint density for ρ_e and ρ_i is f, which is known to the entrepreneur and the scientist at the outset. ρ_e is the external value of the innovation *net* of moving costs, which include the set-up cost in the event the scientist establishes a start-up, or the search cost of finding a suitable rival firm otherwise, and any relocation expenses.

If the scientist finds the external value of the innovation sufficiently attractive, he sets up or joins a rival. The entrepreneur and the rival then proceed to market slightly different but highly substitutable products, both with a single period product cycle. The appearance on the market of the rival's product reduces the entrepreneur's revenue by $\lambda\rho_i$, where $\lambda \in [0,1]$. Alternatively, if the scientist chooses to stay, the entrepreneur markets the product alone. At the beginning of the second period, the entrepreneur decides whether to patent the product, taking into account the effect of patenting on the scientist's decision to leave. Should the scientist leave, we assume the patent reduces the entrepreneur's loss from the scientist's appropriation to $(1-\delta)\lambda\rho_i$, $\delta \in [0,1]$, and the revenues that the rival obtains from the substitutable good by $\gamma\rho_i$, $\gamma \in [0,1]$. δ and γ are parameters that describe how the patent regulates the entrepreneur's loss and the scientist's gain from his knowledge appropriation. We denote the patent's out-of-pocket costs and the costs from information disclosure as ν.[3] (See Appendix I for a summary of notations used in the model.)

We assume that the scientist like the entrepreneur is risk neutral and therefore maximizes his expected income. The scientist chooses at the beginning of the first period whether to accept the entrepreneur's offer or to work for another firm outside the R&D sector. To simplify the analysis we assume that outside the R&D sector he would acquire no appropriable proprietary knowledge but would receive his marginal product, $\overline{w}$, in either the first or the second period.[4] The entrepreneur's offer consists of a guaranteed first period wage, w_0, and a second period wage, w_1, when the scientist remains in the second period. The entrepreneur specifies the second period wage only after ρ_e and ρ_i are realized, taking the scientist's decision in the second period as given. If the scientist accepts the job offer in the first period, at the beginning of the second period he chooses among three options based on the realized ρ_e and ρ_i. He may remain with the entrepreneur, earning w_1 and performing work equal in value to $\overline{w}$. He may set up or join a rival, performing work equal in value to $\overline{w}$, and, in addition, marketing the entrepreneur's knowledge and receiving its full value, ρ_e (or $\rho_e-\gamma\rho_i$, if the entrepreneur has patented). Finally, he may move to the non-R&D sector and earn $\overline{w}$. Table 1 describes the entrepreneur's profit and scientist's second period wage for each combination of patenting and mobility decisions.

Table 1: Payoff to the scientist and profit to the entrepreneur in the second period

Scientist moves to rival	Entrepreneur patents	Scientist's payoff	Entrepreneur's profit
No	No (p=0)	$w_1(p=0)$	$\rho_i - w_1(p=0) + \overline{w}$
	Yes (p=1)	$w_1(p=1)$	$\rho_i - w_1(p=1) + \overline{w} - \nu$
Yes	No (p=0)	$\rho_e + \overline{w}$	$\rho_i - \lambda\rho_i$
	Yes (p=1)	$\rho_e - \gamma\rho_i + \overline{w}$	$\rho_i - (1-\delta)\lambda\rho_i - \nu$

Note: The scientist either stays with the entrepreneur or moves to a rival. As we explain below, he never moves to the non-R&D sector.

The entrepreneur's objective is to maximize expected profits from the project. The expected profit from hiring a scientist is,

$$(1)\ E(\pi) = -w_0 + \iint_{S,p=1}[\rho_i - w_1(p=1) + \overline{w}]f(\rho_e,\rho_i)d\rho_e d\rho_i + \iint_{M,p=1}[\rho_i - (1-\delta)\lambda\rho_i]f(\rho_e,\rho_i)d\rho_e d\rho_i$$

$$-\iint_{p=1} \nu f(\rho_e,\rho_i)d\rho_e d\rho_i + \iint_{S,p=0}[\rho_i - w_1(p=0) + \overline{w}]f(\rho_e,\rho_i)d\rho_e d\rho_i + \iint_{M,p=0}[\rho_i - \lambda\rho_i]f(\rho_e,\rho_i)d\rho_e d\rho_i$$

$$+\iint_{N} \rho_i f(\rho_e,\rho_i)d\rho_e d\rho_i\ ,$$

where the indicator p is 1 if the entrepreneur patents and zero otherwise, S is the set of ρ_e and ρ_i such that the scientist stays, and M is the set of ρ_e and ρ_i such that the scientist moves to a rival. We define N as the remaining set of ρ_e and ρ_i such that the scientist moves to the non-R&D sector. Moving to the non-R&D sector has no effect on the entrepreneur's expected profit. Note we are ignoring discounting for simplicity. Note also that the wage w_1 in the second period depends on the value of ρ_e and ρ_i and the entrepreneur's patenting decision. The entrepreneur hires the scientist if the expected profit is positive. The scientist accepts the contract in the first period if the expected earnings in two periods exceed $2\overline{w}$:

$$(2)\qquad 2\overline{w} \le w_0 + \iint_{S,p=1} w_1(p=1)f(\rho_e,\rho_i)d\rho_e d\rho_i + \iint_{M,p=1}(\rho_e - \gamma\rho_i + \overline{w})f(\rho_e,\rho_i)d\rho_e d\rho_i$$

$$+\iint_{S,p=0} w_1(p=0)f(\rho_e,\rho_i)d\rho_e d\rho_i + \iint_{M,p=0}(\rho_e+\overline{w})f(\rho_e,\rho_i)d\rho_e d\rho_i + \iint_{N}\overline{w}f(\rho_e,\rho_i)d\rho_e d\rho_i\ .$$

The entrepreneur's problem is to choose p, w_0, and w_1 to maximize (1) subject to the scientist's participation constraint, (2). The following derivation of the optimal patent and wage policy assumes a time-consistent equilibrium in which the entrepreneur and the scientist take the other party's decision in the second period as given.

In this framework, the scientist correctly anticipates that if he accepts the compensation package offer of w_0 and w_1, when the second period arrives, the entrepreneur will offer the wage that maximizes her second period net earnings. The entrepreneur sets w_0 so that the scientist's expected value of the contract equals his reservation earnings in two periods, $2\overline{w}$. Thus, to derive the firm's patent and wage policy, we first derive for each realized ρ_e and ρ_i the w_1 and p that maximize the entrepreneur's second period net revenue. We then substitute the optimal second period policy into (2) with equality to form the scientist's expected second period payoff and solve for w_0. In this derivation, we assume that the entrepreneur's gain from patenting exceeds the rival's loss, i.e. $\delta\lambda\rho_i > \gamma\rho_i$. This assumption is not crucial to the model and our main implications still hold under the alternative assumption.[5]

In our model, any exogenous change in the joint distribution of ρ_e and ρ_i can affect the entrepreneur's and the scientist's decisions. To simplify the analysis, assume that the random variable ρ_e is equal to $\overline{\rho}_e + \varepsilon_e$ and that ρ_i is equal to $\overline{\rho}_i + \varepsilon_i$, where ε_e and ε_i ($\varepsilon_e \in R$, $\varepsilon_i > -\overline{\rho}_i$) are mean zero random variables with joint density *g*, and $\overline{\rho}_e$ and $\overline{\rho}_i$ are the constant means of ρ_e and ρ_i, respectively.

For any draw of ρ_e and ρ_i at the beginning of the second period, one can easily show that from the scientist's perspective moving to the non-R&D sector cannot pay more than either staying or moving to a rival pays. Thus, the only issue to resolve is whether the scientist stays or moves to a rival firm. The entrepreneur's wage and patent policies and the scientist's mobility decision are depicted in Figure 1 on the ε_i-ε_e space. The derivation of the figure is detailed in Appendix II. Intuitively, Figure 1 indicates that a scientist is more likely to move the higher is the value of ε_e, given ε_i. Also, a scientist is more likely to stay, the higher is the value of ε_i, given ε_e. Regardless of the value of ε_i, when ε_e is low enough the entrepreneur has no incentive to patent since the threat of the scientist leaving is minimal. Regardless of the value of ε_e, when ε_i is low enough the entrepreneur will not patent because the potential loss without patent protection is small.

Substituting the optimal second period wage, patent, and mobility choices, into the participation constraint (2) yields w_0, the optimal wage in the first period. w_0 equates the scientist's expected payoff from accepting the entrepreneur's offer and his reservation earnings.[6] Substituting the optimal wage for w_0 in (1) gives us the following expression for the expected profit:

$$(1') \qquad E(\pi) = -\overline{w} + \iint_{S} \rho_i f(\rho_e,\rho_i)\,d\rho_e d\rho_i + \iint_{M} (\rho_i + \rho_e - \lambda\rho_i) f(\rho_e,\rho_i)\,d\rho_e d\rho_i$$

$$+ \iint_{M,p=1} (\delta\lambda\rho_i - \gamma\rho_i) f(\rho_e,\rho_i)\,d\rho_e d\rho_i - \iint_{p=1} v f(\rho_e,\rho_i)\,d\rho_e d\rho_i$$

This equation shows the cost and benefit of patenting. The last term on the right hand side of (1′) reflects the cost of patenting, which the entrepreneur bears both when the scientist stays and moves to a rival. The fourth term shows that patenting benefits the entrepreneur only when the scientist moves to a rival, and then, only to the extent that $\delta\lambda\rho_i - \gamma\rho_i > 0$. The benefit from patenting is less than $\delta\lambda\rho_i$ because any reduction in the scientist's expected gain from moving is anticipated by the scientist in the first period, and therefore must be added to the scientist's first period wage. The expected profit does not show a benefit for patenting when the scientist stays because the patent's benefit to the entrepreneur—the reduction in w_1 by $\gamma\rho_i$—represents an equivalent loss to the scientist, and thus must be added to the scientist's first period wage offer. Thus, patenting in the event that the scientist stays in the second period lowers her total profits, owing to the patenting cost ν.

The following proposition describes the effect of a change in the mobility of scientists in our model.

Proposition 1. An increase in the mean of ρ_e, $\overline{\rho}_e$, increases the probability of a scientist moving to a rival. An increase in $\overline{\rho}_e$ also raises the entrepreneur's propensity to patent an innovation.

Figure 2 shows the effect of an increase in $\overline{\rho}_e$ on the boundaries that divide ε_i-ε_e space into regions of patenting/no patenting and moving/staying. The dashed boundaries in Figure 2 result from an increase in $\overline{\rho}_e$. A scientist's likelihood of moving rises with the return to moving, and an increase in $\overline{\rho}_e$ means that the scientist will depart for lower draws of ε than before, shown as the expanding area of mobility in Figure 2 (Regions R1, R2, and R3). The increase in the return to moving raises the likelihood that the entrepreneur patents the innovation and Regions R2 and R4 in Figure 2 illustrate her response. Region R2 reflects an increase in patenting as she attempts to reduce the revenue loss from the departing scientist passing on his knowledge to rivals. The increased patenting represented by Region R4 arises even though the entrepreneur knows the scientist will stay. The entrepreneur patents more often to lower the scientist's second period reservation wage, which has risen with $\overline{\rho}_e$.

It is not improbable that a shock that raises $\overline{\rho}_e$ affects $\overline{\rho}_i$ simultaneously in the same direction. For example, a demand shock that increases the value of an innovation to the entrepreneur may also increase its value to the rival. Depending on the relative magnitude of a rise in $\overline{\rho}_e$ to that in $\overline{\rho}_i$, we can derive three cases. First, if the value $(\overline{\rho}_e - \lambda\overline{\rho}_i)$ rises as both parameters $\overline{\rho}_e$ and $\overline{\rho}_i$ are increased, we can show that the areas for mobility and for patenting in Figure 1 expand and hence the probabilities for both will be raised. Second, if $(\overline{\rho}_e - \lambda\overline{\rho}_i)$ falls but $[\overline{\rho}_e - \lambda(1-\delta)\overline{\rho}_i]$ rises, only the probability of patenting is raised unambiguously. Finally, suppose the shock raises the value of an innovation much more in the current firm than outside of the firm and so both $(\overline{\rho}_e - \lambda\overline{\rho}_i)$ and $[\overline{\rho}_e - \lambda(1-\delta)\overline{\rho}_i]$ fall. In this case, we can show that the probability that the scientist departs for a rival declines unambiguously while the change in the probability that the firm patents is ambiguous.

Proposition 2. If $\overline{\rho}_e$ and $\overline{\rho}_i$ rise simultaneously either by the same amount or by the same proportion, both the probability of a scientist moving to a rival and the entrepreneur's propensity to patent an innovation rise.

Equivalent increases in both parameters are a special case of the first case in the preceding paragraph since $\lambda < 1$. Figure 3 illustrates the case described in Proposition 2.

One might imagine that because ν includes the cost of information disclosure, ν rises with the value of the project to the firm, ρ_i. In the case where ν is proportional to ρ_i, one can easily confirm the finding in proposition 2: simultaneous and equivalent increases in $\overline{\rho}_e$ and $\overline{\rho}_i$ raise the probability of mobility and the entrepreneur's propensity to patent. This result also holds when $\nu = \bar{\nu} + \psi$, where ψ is a random variable and $\bar{\nu}$ is proportional to $\bar{\rho}_i$.[7]

The expected R&D expenditures for a research project, excluding the patenting cost, are as follows,

$$(3) \qquad \text{R\&D} = w_0 + \iint_{S,p=1} w_1(p=1)g(\varepsilon_e,\varepsilon_i)d\varepsilon_e d\varepsilon_i + \iint_{S,p=0} w_1(p=0)g(\varepsilon_e,\varepsilon_i)d\varepsilon_e d\varepsilon_i$$

$$= 2\bar{w} - \iint_{M,p=1}(\bar{\rho}_e + \varepsilon_e - \gamma\bar{\rho}_i - \gamma\varepsilon_i + \bar{w})g(\varepsilon_e,\varepsilon_i)d\varepsilon_e d\varepsilon_i - \iint_{M,p=0}(\bar{\rho}_e + \varepsilon_e + \bar{w})g(\varepsilon_e,\varepsilon_i)d\varepsilon_e d\varepsilon_i \,,$$

where the second equality comes from equation (2). The effect of an increase in $\bar{\rho}_e$ on the R&D expenditures is analyzed in Proposition 3.[8]

Proposition 3. An increase in $\bar{\rho}_e$ reduces the expected R&D expenditures of an innovation.

Proof. Differentiating R&D in (3) with respect to $\bar{\rho}_e$ yields

$$\partial(\text{R \& D})/\partial\bar{\rho}_e = -\int_{\nu/\delta\lambda-\bar{\rho}_i}^{\nu/\gamma-\bar{\rho}_i}\left[\frac{\partial}{\partial\bar{\rho}_e}\int_{\varepsilon_{e1}^*}^{\infty}(\bar{\rho}_e + \varepsilon_e - \gamma\bar{\rho}_i - \gamma\varepsilon_i + \bar{w})g(\varepsilon_e,\varepsilon_i)d\varepsilon_e\right]d\varepsilon_i$$

$$-\int_{\nu/\gamma-\bar{\rho}_i}^{\infty}\left[\frac{\partial}{\partial\bar{\rho}_e}\int_{\varepsilon_{e2}^*}^{\infty}(\bar{\rho}_e + \varepsilon_e - \gamma\bar{\rho}_i - \gamma\varepsilon_i + \bar{w})g(\varepsilon_e,\varepsilon_i)d\varepsilon_e\right]d\varepsilon_i$$

$$-\int_{-\infty}^{\nu/\delta\lambda-\bar{\rho}_i}\left[\frac{\partial}{\partial\bar{\rho}_e}\int_{\varepsilon_{e3}^*}^{\infty}(\bar{\rho}_e + \varepsilon_e + \bar{w})g(\varepsilon_e,\varepsilon_i)d\varepsilon_e\right]d\varepsilon_i$$

where $\varepsilon_{e3}^* = \lambda\varepsilon_i + \lambda\bar{\rho}_i - \bar{\rho}_e$, $\varepsilon_{e1}^* = \varepsilon_{e3}^* - \delta\lambda(\varepsilon_i + \bar{\rho}_i) + \nu$, and $\varepsilon_{e2}^* = \varepsilon_{e1}^* + \gamma(\varepsilon_i + \bar{\rho}_i) - \nu$. The bracket term in the first term on the right-hand side is $\int_{\varepsilon_{e1}^*}^{\infty} g(\varepsilon_e,\varepsilon_i)d\varepsilon_e$ $+[(\lambda - \delta\lambda + \gamma)(\varepsilon_i + \bar{\rho}_i) + \nu + \bar{w}]g(\varepsilon_{e1}^*,\varepsilon_i)$, which is positive. In the same way, we can show that other terms in the brackets are positive. ■

A rightward shift in the distribution of ρ_e, and therefore an increase in the mobility of a scientist, implies that the entrepreneur will be better able to exploit the gains to leaving, reducing the wage she has to pay the scientist. In other words, the scientist is willing to accept a lower wage when the prospects from leaving improve, which reduces the expected R&D expenditures.[9] For the effect of simultaneous increases in $\overline{\rho}_e$ and $\overline{\rho}_i$ on R&D expenditures, we have the following proposition.

Proposition 4. Simultaneously adding equivalent amounts to $\overline{\rho}_e$ and $\overline{\rho}_i$ reduces the expected R&D expenditures of an innovation if γ is small enough relative to $\delta\lambda$. (The proof can be provided upon request.)

The effect of an increase in $\overline{\rho}_e$ on the profitability of a research project is ambiguous, however. For a given value of ε_i where $\nu/(\delta\lambda)-\overline{\rho}_i \leq \varepsilon_i < \nu/\gamma-\overline{\rho}_i$, differentiating the profit with respect to $\overline{\rho}_e$ yields

$$\partial \mathrm{E}(\pi)/\partial\overline{\rho}_e = \int_{\varepsilon^*_{e1}}^{\infty} \mathrm{g}(\varepsilon_e,\varepsilon_i)d\varepsilon_e - \gamma(\varepsilon_i+\overline{\rho}_i)\mathrm{g}(\varepsilon^*_{e1},\varepsilon_i).$$

The first term on the right hand side of the equation is positive, reflecting the reduction in the scientist's wage following the improvement in his return from moving.[10] This effect is opposed by the increase in the entrepreneur's patenting expenses that follow from the increased mobility caused by the rise in $\overline{\rho}_e$. This effect is shown in the second term on the right hand side. $\gamma(\varepsilon_i+\overline{\rho}_i)$ is the profit reduction when the entrepreneur switches from a no-patenting to a patenting policy and the scientist goes from staying to moving. $\mathrm{g}(\varepsilon^*_{e3},\varepsilon_i)$ is the probability of the policy switch (see Region R2 in Figure 2). In the case where $\varepsilon_i \geq \nu/\gamma - \overline{\rho}_i$, these opposing effects remain and thus the effect of the $\overline{\rho}_e$ on profitability is again ambiguous. If $\varepsilon_i < \nu/(\delta\lambda) - \overline{\rho}_i$, we can show that an increase in $\overline{\rho}_e$ unambiguously raises the expected profit for the entrepreneur since the wage paid to a scientist is made lower without any additional increase in patenting cost.

If the entrepreneur's commitment to a labor contract can be enforced without cost in the second period (e.g., through reputation), the equilibrium wage and patent policy will be different from those in the equilibrium described in this section since the entrepreneur and the scientist can achieve a Pareto improvement by avoiding unnecessary patenting and its attendant costs when the scientist stays. One can show that in the commitment equilibrium, the firm patents less frequently, and that propositions 1 and 2 hold (the proof can be provided upon request).

3. Data description

We test our prediction on the relationship between labor mobility and the patent propensity against firm-level panel data. The dependent variable is the firm's patent count, and the explanatory variables are the firm's R&D expenditures and a measure of the labor mobility of research scientists, among others.

Our labor mobility data for scientists and engineers are taken from the Annual Demographic Files (March Supplements) of the Current Population Survey (CPS), conducted by the U.S. Census Bureau. Our labor mobility is measured by the turnover experience of all scientists and engineers,[11] based on whether a scientist changed employers during the previous year of the survey. The main advantages of using CPS March data are that the mobility can be defined consistently in every year since 1975, and that the CPS data represent a national population without the problem of attrition, in contrast to other panel data sources like the PSID. (See Stewart, 1998, for more details on the CPS data.) The March CPS generates on average records on 2,600 scientists and engineers annually between 1975 and 1997.

Our basic measure of job mobility is the share of scientists and engineers in **each industry and year** who changed their employers at least once within the previous year.[12] We call this measure the employer change rate (ECR). We compute separate measures by industry because we presume that the likelihood of a scientist leaving is mainly imposed on a firm by conditions in the firm's industry, and that industry-specific capital means scientists are significantly more likely to stay in the same industry when they change firms.[13] Regardless of how broadly we define the labor market in constructing our mobility measure, we may face a problem of reverse causality, that is, from patents to mobility. To minimize the problem, we account for possible endogeneity in our mobility measure (see section 5).

We compute a second measure of job mobility for scientists and engineers by **geographical region and year** (GEO). This second measure recognizes that for many scientists and engineers movement occurs within geographically defined markets, i.e., they may seek employment opportunities only within the region that they live. In this case, the job turnover facing a firm will be strongly related to labor mobility within its geographical area.[14]

Information on the number of patents, R&D expenditures, and other characteristics of each firm by year is taken from the data set recently created by researchers at the National Bureau of Economic Research and Case Western Reserve University. They created this data set by matching the patents in the U.S. Patent and Trademark Office (USPTO) to their assignees in the Standard and Poor's Compustat database. The patent data at the USPTO contain a wealth of information on each patent including the name of the assignee, a firm in about 70 percent of cases. The Compustat database contains extensive data (including R&D expenditures) on all publicly traded firms. To obtain the correct matching of patent to firm, NBER-Case Western Reserve University researchers undertook an extensive effort to link subsidiaries listed in the USPTO database to their parent companies in the manufacturing sector. They then matched the patents to the parent firms in the Compustat database for the period between 1964 and 1992.[15] While the matching would not be perfectly representative because about 30 percent of patent grantees are non-firm organizations and individuals, nevertheless, the patents captured in this process would comprise most of the patents originating from firms because most large patenting organizations are both in the manufacturing sector and publicly traded.

The USPTO-Compustat data set contains about 4,800 firms in an unbalanced panel, extending from 1957 to 1995. The average number of firms in the data each year is about 1,700, ranging from a low of 691 in 1961 to a high of 2,054 in 1992. The USPTO granted 3,585 patents to the firms in the data set who applied for patent grants in 1961. The number of patents granted reached 16,553 in 1992. The data indicate a decline in the number of patents granted after 1992 because of the time lag between application and grant. Patent applications in the last two years of the data set were still under review at the USPTO in 1995. For this reason, we use only firm data prior to 1993. For reasons we explain below, we use only the years following 1975.

Table 2 reports summary statistics of mobility measures and other variables used in our analysis. Panel 1 of Table 2 shows the statistics of the sample before we exclude firms with no R&D expenditures. Panel 2 shows the characteristics of the subsample used in the estimation of the determinants of patenting. Because the subsample contains only those firm-years for which positive levels of R&D expenditures are reported, it is much smaller. Note that the firms that most often report positive levels of R&D are both large (by the sales measure) and employ high levels of plants and equipment relative to labor.

4. Empirical strategy

As our starting point, we consider the effect of the mobility of scientists on the firm's patenting decision following the Poisson-based econometric specification of Hausman, Hall, and Griliches (1984), and Hall and Ziedonis (2001). We favor a Poisson-based specification because the number of patents granted to a firm in a particular year is a count variable, often taking the value of zero or one. We assume that the expected number of patents granted to a firm, conditional on its characteristics, is

$$E(P_{ft} \mid X_{ft}, M_{ft}) = \lambda_{ft} = \exp(\alpha_f + X_{ft}\beta + R_{ft}\beta^R + M_{ft}\zeta)$$

where P_{ft} is the number of patents granted to firm f that were applied for in year t, X_{ft} is a 1xK vector of firm f's characteristics in year t, R_{ft} is the logarithm of firm f's year t R&D expenditures deflated by the GNP deflator, and M_{ft} measures the level of job mobility among scientists and engineers working for firm f in period t. Properly measured, the variation in M_{ft} reflects variation in exogenous determinants of mobility, such as changes in the external net value of innovation ρ_e in our model. We include R&D expenditures because we wish to test the theoretical result that mobility raises the firm's propensity to patent holding the R&D constant. Following Hall and Ziedonis, X_{ft} includes the logarithms of sales (LnSALES), as a measure of the size of the firm, to account for scale economies in producing patents, and the capital-labor ratio (LnK/L), measured as the deflated plant and equipment over the number of employees.[16] We include the capital labor ratio because given R&D expenditures a highly capitalized firm may have stronger incentives to patent than less capitalized firms. A patent infringement suit that leads to court injunction and production stoppage will be more destructive for a firm that has made a large capital investment in a state-of-the-art physical plant. Such vulnerability may encourage the firm to develop a diverse portfolio of patents that it can use as a bargaining chip to ward off infringement suits (Cohen et al., 2000; Parr and Sullivan, 1996). We assume that the firm specific constant term, α_f, is random and that $\exp(\alpha_f)$ is distributed gamma. We obtain estimates of β, β^R, and ζ, using maximum likelihood estimation techniques for the Poisson-gamma mixture.

5. Empirical results

Table 3 shows our estimation results of the determinants of the firm's patenting decision, employing the random-effects Poisson model as described in section 4. The dependent variable is the firm's patent applications in year *t* that were eventually granted. In all panels in the table, the explanatory variables include the logarithm of our mobility measure (LnECR or LnGEO)[17], of sales (LnSALES), of the capital-labor ratio (LnK/L), and of R&D expenditures (LnR&D), all measured in year *t*.[18] Note that in relating our mobility measure with the contemporaneous patenting count, we are assuming that the threat of a scientists' departure affects the firm's patenting decision in the same period. We also include as a regressor the logarithm of the mean age of scientists and engineers in each industry by year (LnAGE) because of the link between age and turnover (see, for example, Hall, 1982). Inter-firm mobility is much higher among the young, who also have fewer skills and are less productive. By adding age, we partly control for the changing distribution of skills in the labor force that may accompany changes in the mobility, and thus we more precisely isolate the effect of mobility on patents. Note that in the Poisson specification the estimated coefficients for the log-transformed regressors have an elasticity interpretation.

In Panel 1, we find that both R&D expenditures and sales are strongly positively related to patenting. This finding is repeated in the other regressions in Table 3. We find in this table that the estimated effect of LnK/L on patenting is not generally consistent with the theoretical prediction and the effect's estimated sign varies across specifications. The estimated effect of LnAGE suggests that more experienced researchers are more productive in generating patents. Holding constant the mean age of scientists in the relevant year and industry and the firm's R&D expenditures, the estimated effect of mobility on patenting is positive and significant. This is consistent with our story: the increased likelihood of a scientist departing the firm increases the employer's incentive to patent an innovation.

The key variables in our estimation may be time trended, in which case the estimated effect of LnECR on patenting could be spurious. To test the sensitivity of our result to a time trend effect, we introduce the time trend, T, as an additional right-hand side variable. The results reported in Panel 2 show that the effect of LnECR is still positive and significant with T included. Panel 3 adds to the base specification the square of the log of R&D expenditures to test whether elasticity of patenting with respect to R&D changes with the size of the R&D operation. The coefficient corresponding to $(\text{LnR\&D})^2$ is positive but insignificant.

Panels 4 and 5 respectively show the results from re-estimating the Panels 1 and 2 specifications using the geographical measure for mobility (GEO).[19] The age variable (AGE) used in this table is defined for the firm's region and year. We find the effect of mobility on patenting is significantly positive and the magnitude of the effect is greater than that found using ECR.[20] The estimates of the coefficients corresponding to LnSALES and LnR&D in Panels 4 and 5 are similar to their counterparts in Panels 1 and 2.

Note that our theoretical analysis implies a relationship between ρ_e and patenting, not between mobility and patenting. We use mobility as a proxy for ρ_e because ρ_e cannot directly be observed. We argue that because mobility is a monotonic function of ρ_e, say $M(\rho_e)$, a positive relationship found between mobility and patenting implies a positive relationship between ρ_e and patenting. We recognize that this approach is loose but it yields a simple way to estimate an approximate size and direction of the effect of ρ_e on patenting. If we take our model seriously, however, the appropriate regressor is not M, but the inverse function of M whose functional form is unknown. Olley and Pakes (2000) suggest that in situations like this the function can be approximated non-parametrically, say by a polynomial expansion.

Panel 6 shows the results of a Poisson regression, with a sixth order polynomial expansion of ECR used in place of LnECR.[21] Only the estimates of the coefficients corresponding to the first three terms are reported; the z scores for the coefficient estimates corresponding to the higher order terms were quite small. In this specification, the test of our model is whether any coefficient estimates corresponding to the polynomial terms are significant. We take the fact that the coefficient estimates for the first, second, and third order terms are significant as evidence that ρ_e affects patenting.

In addition to the random effects specifications, we estimated fixed-effects Poisson models (results not shown), which show qualitatively and quantitatively similar impacts of labor mobility on patenting. We also tested the sensitivity of our estimates to the distributional assumption for the random effect. The estimated effect of mobility was as pronounced whether we assumed its distribution normal or gamma.

Table 4 reports the results of additional sensitivity analyses of mobility's effect on patenting propensity. To control for the potential endogeneity of R&D expenditures and our measures of mobility, we use generalized method of moments (GMM) to estimate the patent-mobility relationship with the mobility measures and R&D treated as endogenous variables.[22] Recall that the model says that while changes in mobility may lead firms to patent more often, by patenting more often a firm may induce some of its scientists to move. Our model thus predicts that higher patenting leads to more mobility. This direction of causality should be more important the more narrowly we define the firm's labor market. In the limiting case, where we define the firm's labor market as the pool of worker's working at the firm, the endogeneity of the mobility estimate is obvious. Our model also says that firms jointly determine whether to patent and how much to spend on R&D.

We begin with the assumption that the random variable P_{ft} is related to the explanatory variables according to

$$\begin{aligned} P_{ft} &= \exp(\alpha_f + X_{ft}\beta + R_{ft}\beta^R + M_{ft}\zeta) + u_{ft} \\ &= \mu_{ft} q_f + u_{ft} \end{aligned}$$

where $\mu_{ft}=\exp(X_{ft}\beta+R_{ft}\beta^R+ M_{ft}\zeta)$, α_f is now the firm-specific fixed effect, $q_f=\exp(\alpha_f)$, and u_{ft} is the error term. R_{ft} and M_{ft} are assumed endogenous, that is, $E(R_{ft}\, u_{ft}) \neq 0$ and $E(M_{ft}\, u_{ft}) \neq 0$. We use Wooldridge's quasi-differencing transformation to remove the fixed effects (see Wooldridge, 1991, 1997 and Windmeijer, 2000), which leads to the following moment conditions:

$$(4) \qquad E\left(Z_{ft-s}\left(\frac{P_{ft}}{\mu_{ft}} - \frac{P_{ft-1}}{\mu_{ft-1}} \right)\right) = 0,$$

where $s \geq 2$ for $Z_{ft}= R_{ft}, M_{ft}$ and $s \geq 0$ when Z_{ft} includes X_{ft} and additional instruments (described below).

In our empirical work, the instruments and lags we use produce more moment conditions than the number of parameters we wish to estimate. Our estimates of the parameters minimize a quadratic function formed by the weighted sample moment conditions corresponding to (4) and the data. The GMM model adds generality by allowing the regressor M_{ft} and R_{ft} to be correlated with the contemporaneous and past realizations of the residual. In this way, we allow patenting to "cause" mobility and R&D expenditure decisions.[23]

The specifications in Panels 1 and 2 of Table 4 are identical to the specifications in Panels 1 and 4 of Table 3, respectively. We use lagged mobility and the logarithms of the fractions of scientists who are white (LnWHITE) and who are male (LnMALE) as instruments for mobility in all panels of the table. We use the latter two variables as instruments because of the well-known finding in the empirical literature that non-whites and women have higher rates of turnover (see Mincer and Jovanovic, 1981).[24] We instrument R&D expenditures with lagged R&D.[25]

Like the Poisson estimation, the GMM estimation generates statistically significant and positive estimates of the effect of labor mobility on patenting propensity. Interestingly, the coefficient estimates on both measures of mobility estimated by the GMM are quantitatively smaller than those from the Poisson estimation. This finding is consistent with our theoretical story that reverses the causality: by patenting more often the firm induces some of its scientists to move. By controlling for this direction of causality, the GMM estimation shows a smaller effect of the mobility measure on patenting propensity.

The mobility of scientific personnel within an R&D-doing firm's geographical area shows a pronounced, statistically significant, positive effect on the firm's patents. This finding has an implication for the literature on spillovers. Jaffe, Trajtenberg, and Henderson (1993) report that in their patent applications, firms often cite the work of external scientists, but that these scientists tend to work locally. Their findings suggest that geographical proximity is necessary for a technological spillover to take place. Our finding that geographical mobility has a strong effect on patenting propensity suggests that the movement of researchers among firms (and between academia and firms) may be an important mechanism for the transmission of these spillovers.

Panel 3 includes calendar year dummies as additional regressors instead of a time trend as in Panel 2 of Table 3. Note that in this specification the estimated coefficient associated with LnECR captures only cross-industry variation in LnECR. The coefficient estimate associated with LnECR is positive and significant. When we include as regressors industry dummies in Panel 4 so that we have only within-industry variation in LnECR, the coefficient estimate associated with LnECR is significant and slightly greater than the coefficient estimate associated with calendar year dummies. This result indicates that variation in patenting propensity is not only driven by cross-industry variation but also by time series variation in our ECR mobility measure.

In Panels 5 and 6, we repeat the same specifications in Panels 3 and 4 with LnGEO in place of LnECR. Unlike ECR, variations in patenting can be mostly accounted for by within-region, time-series variation of our geographical mobility measure GEO, but not by its cross-region variation. One explanation for this is that the number of regions is significantly fewer than the number of industries in our data.

Past researchers (e.g., Kortum and Lerner, Hall and Ziedonis) have isolated for study industries in the so-called high technology sector. Panels 7-10 show the results from splitting the sample into a high-tech and non high-tech subsamples. Following Chandler (Business History Review, Summer 1994), we define high-tech industries to include computers and computing equipment, electrical machinery, electronic instruments and communication equipment, transportation equipment, optical and medical instruments, and pharmaceuticals. Panels 7 and 8 include LnECR while Panels 9 and 10 include LnGEO. The estimates of the elasticity of patenting with respect to our mobility measures are in general statistically significant for both regressions. However, the estimate is about five times larger for the high-tech industry sample in case of LnECR and about two times larger in case of LnGEO.

6. Concluding remarks

In the first half of the paper, we developed a model for understanding the effect of the threat of a scientist's technology transfer to a rival on his employer's R&D and patenting decisions. In our model, while working in the employer's laboratory, scientists develop technical knowledge that in later periods they can exploit at a rival firm. Because this technological knowledge has value with other employers, it is general human capital for which the scientist is willing to pay. Like Pakes and Nitzan, we show that when the return to leaving rises, the wages a firm pays for the scientist's services drop, and so do the R&D expenditures. We also show that when patenting reduces the firm's loss when the scientist leaves or his wage when he stays by more than the patenting cost, the firm patents.

Our regression results show that a firm's patenting propensity and mobility rates for scientists and engineers are positively correlated, consistent with our hypothesis that firms use patenting to minimize the harm caused by departing scientists. Our finding that mobility of scientists and engineers within geographical regions has a pronounced effect on patenting is consistent with evidence elsewhere of localized technological spillover effects. Our findings are robust to various sensitivity analyses we conduct, including models that take into account the potential endogeneity of our labor mobility measures.

Our results are not only statistically significant, but economically significant as well. The average number of patents per real R&D dollar in our data varies by industry and region. The mean patent-R&D ratio—where R&D is measured in millions of 1982-84 dollars—ranges from 0.62 to 3.13 across the 15 industries we study, and from 1.29 to 4.54 across the 9 geographical regions. Our empirical estimates suggest that a reduction in the industry-specific measure of mobility (ECR) by one half would lower a typical firm's patent-R&D ratio by 2 percent; a reduction in the geographic-specific measure of mobility (GEO) by one half would lower this ratio by 9 percent.[26] Moreover, our estimation results can explain some of the increase in the economy-wide patent-R&D ratio since the mid-1980s (see Kortum and Lerner, 1998). Our mobility measure increases from 0.125 in 1984 to 0.156 in 1997, a 25 percent increase.[27] This change accounts for 0.7 to 3 points (or 4 to 17 percent) of the 18 percent increase in the patent-R&D ratio over the period 1984-97.[28]

Our results may help explain the substantial variation that we observe in patent-R&D ratios across firms of different size. Griliches (1990) attributes the higher patent-R&D ratios in small firms to selection bias and the differential role of formal R&D for small and large firms. Our data show researchers working in firms whose employment levels range from 0 to 499, from 500 to 999, and above 1000 have employer change rates of 0.20, 0.16, and 0.11, respectively.[29] This is consistent with the finding in the labor literature that the job turnover rate is significantly higher among workers in small firms (see Oi, 1983). Our data show that the patent-R&D ratio of the smallest group divided by the ratio of the largest group is 0.433/0.371 = 1.17. Of this 17 percent difference between the patent-R&D ratios of small versus large firms, our estimates can explain 2 to 8 points, or 12 to 47 percent.

While the empirical results generally support the implications of our theoretical model, we have left a number of issues unaddressed. First, our paper ignores the effect of a departing scientist on the receiving firm's or rival's patenting decision. Suppose the incoming scientist brought to his new employer an idea that could be used to develop a "spillover" good. As the scientist is brought on board, or shortly afterwards, the new employer might patent some part of the technology underlying the spillover good. However, at the same time, the firm's R&D expenditure would rise, as the firm must compensate the scientist. Depending on the size of the compensation and what fraction of it appears in the firm's R&D budget, the firm's patent-R&D ratio may rise or fall upon hiring the scientist.

Second, we have not addressed a number of issues behind the increase in mobility. For instance, we have not dealt with the effect of labor mobility on the organization of R&D activities in firms. Nor have we investigated more fundamental forces behind the labor mobility change of scientists such as changes in R&D spillovers and other labor market factors. We leave these issues to future work.

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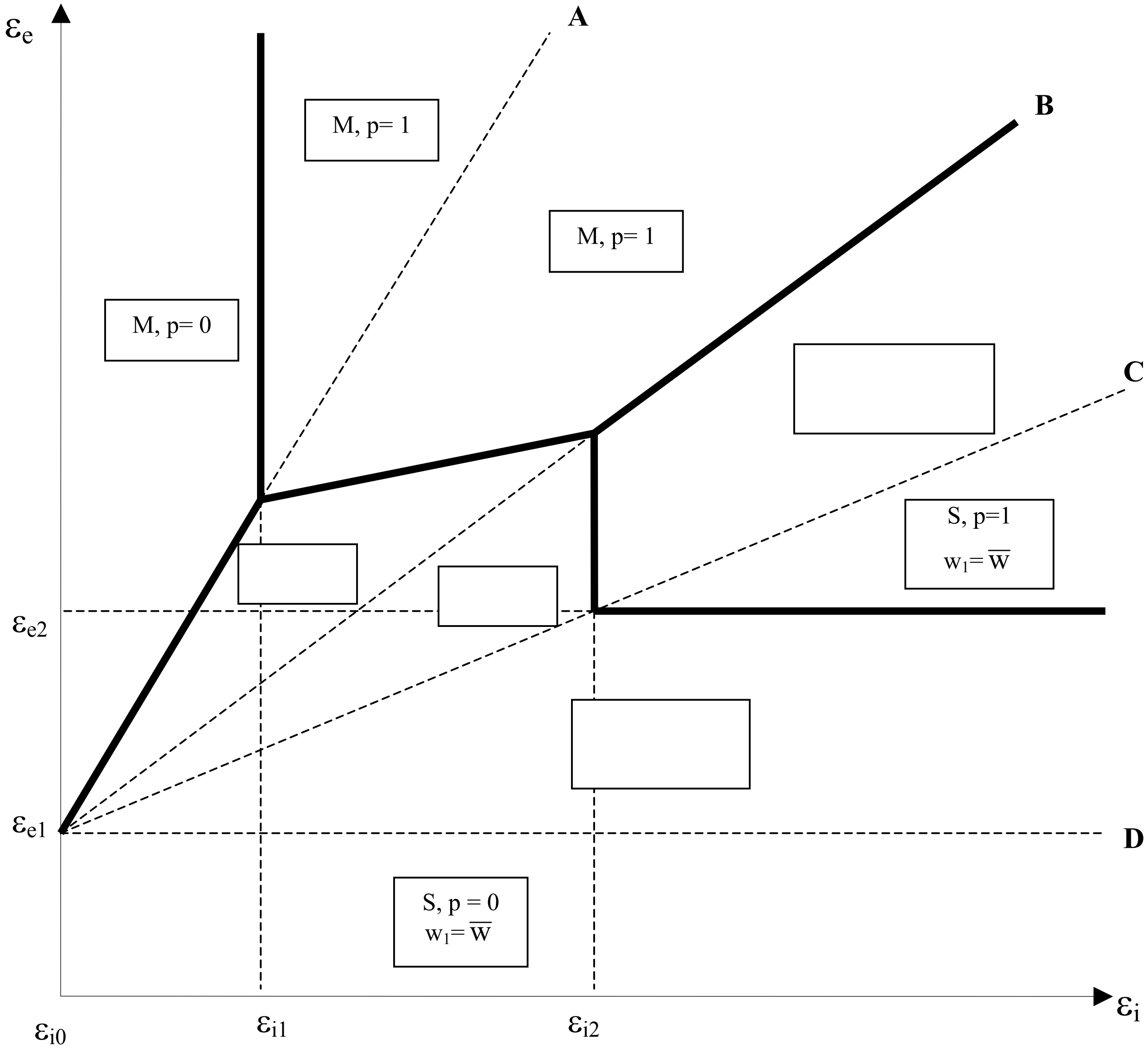
Figure 1
Patent Decision and Mobility

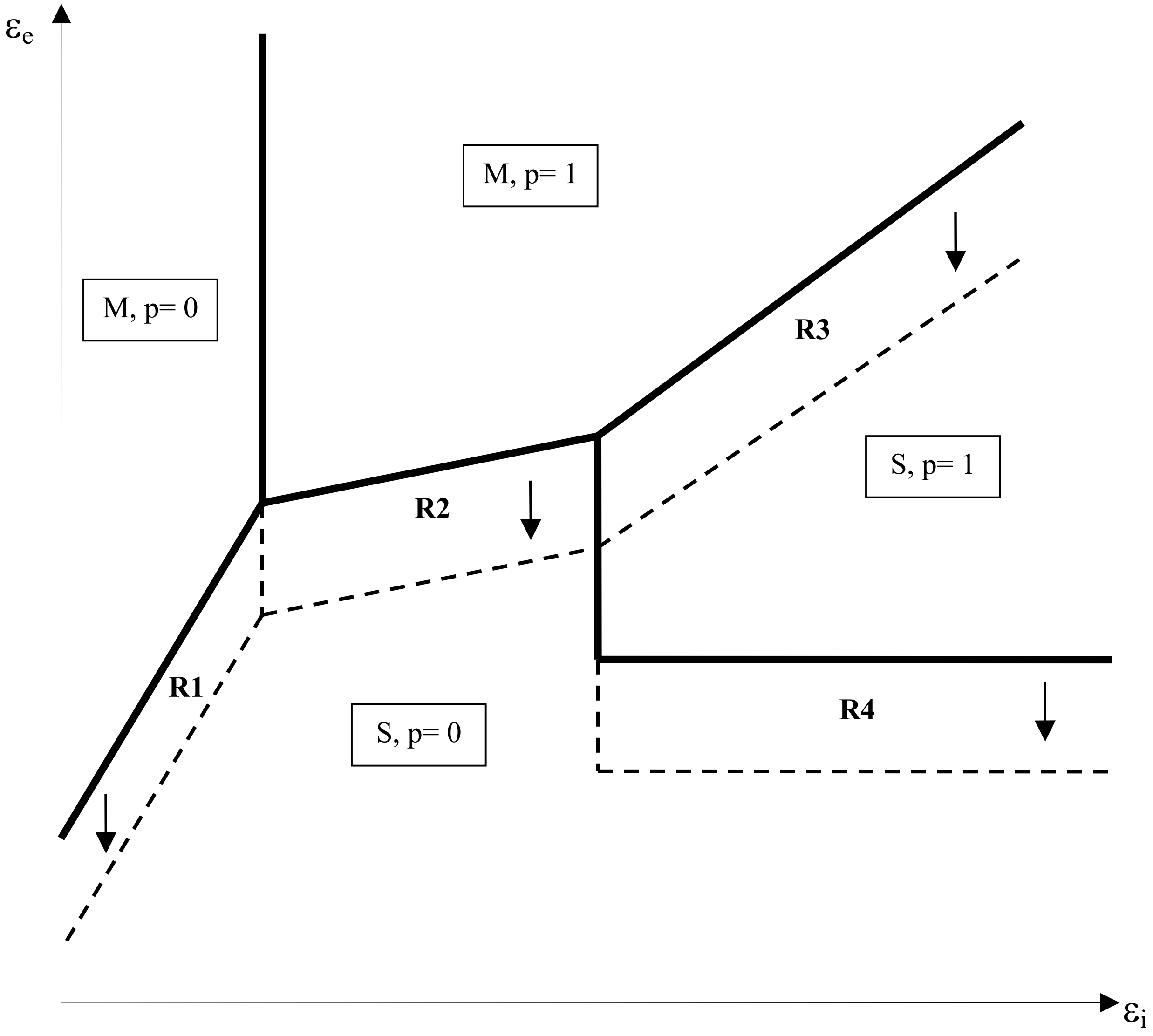


M: move to a rival, S: stay, p = 1 if patented, 0 otherwise

$\varepsilon_{e1} = -\ \overline{\rho}_e$
$\varepsilon_{e2} = \nu - \overline{\rho}_e$

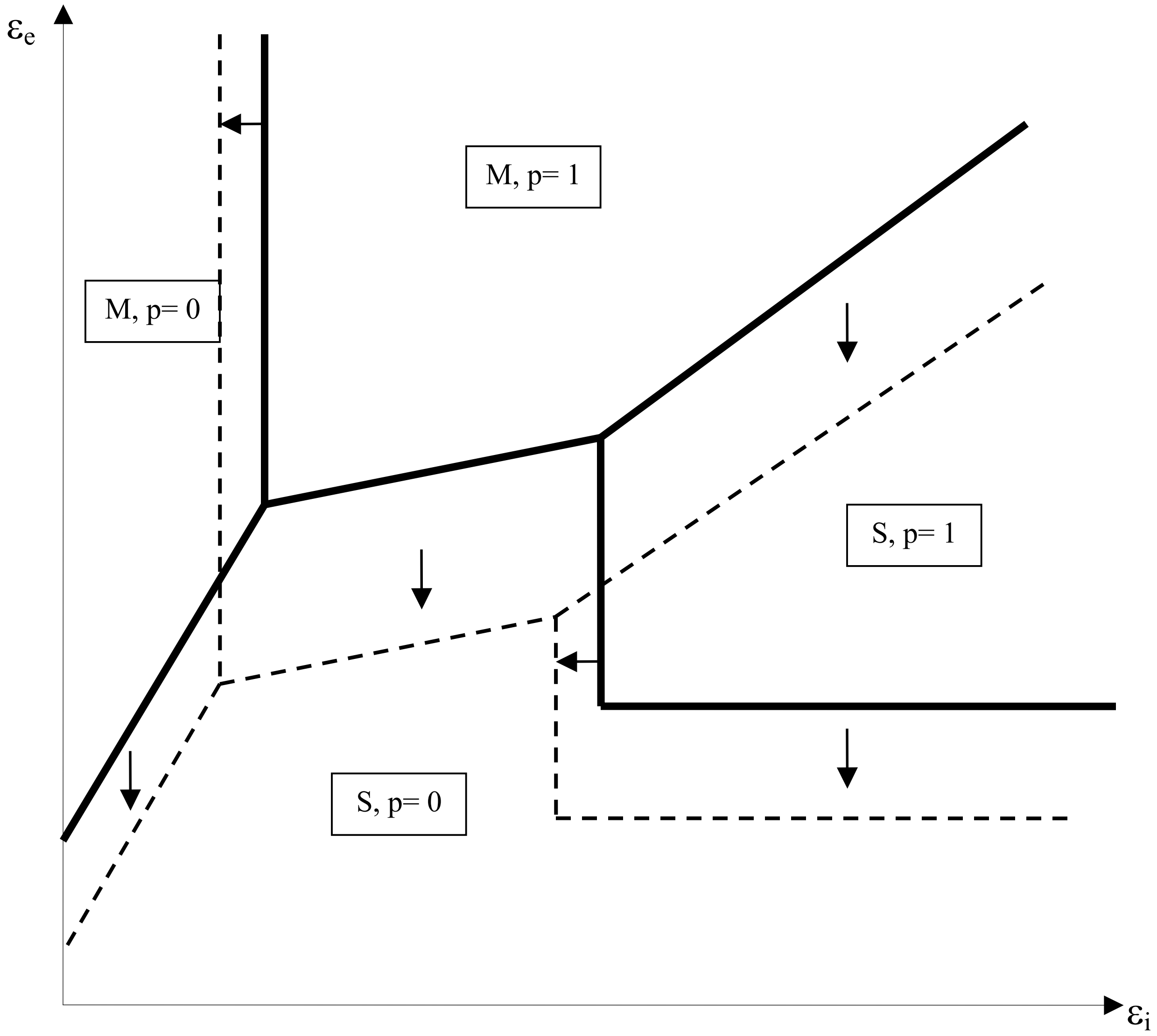
$\varepsilon_{i0} = -\ \overline{\rho}_i$
$\varepsilon_{i1} = \nu/(\delta\lambda) - \overline{\rho}_i$
$\varepsilon_{i2} = \nu/\gamma - \overline{\rho}_i$

Figure 2
Effect of $\overline{\rho}_e$ on Mobility and Patenting



M: move to a rival, S: stay, p = 1 if patented, 0 otherwise

Figure 3
Effect of simultaneous and equivalent increases in $\bar{\rho}_e$ and $\bar{\rho}_i$ on Mobility and Patenting



M: move to a rival, S: stay, p = 1 if patented, 0 otherwise

Table 2 Sample Statistics

Variables	(1) Full Sample (31503 obs)				(2) R&D Sample (21030 obs)			
	Mean	Std. Dev.	10th percentile	90th percentile	Mean	Std. Dev.	10th percentile	90th percentile
Patents	7.89	40.41	0	10	11.50	48.98	0	20
R&D (million $ 1982-84)	19.08	122.91	0	22.26	28.58	149.53	0.17	41.04
ECR	0.12	0.04	0.07	0.18	0.12	0.04	0.06	0.17
GEO	0.13	0.02	0.10	0.16	0.13	0.02	0.10	0.16
SALES (million $ 1982-84)	863.1	4099.7	6.44	1560.6	1034.6	4705.7	5.72	1984.9
K/L	2006.7	47546.6	0.83	795.0	2645.2	58034.2	0.69	937.9
AGE_ECR	38.32	1.81	35.89	40.47	38.28	1.81	35.88	40.47
AGE_GEO	37.75	0.77	36.97	38.61	37.75	0.78	36.81	38.56
MALE	0.83	0.10	0.69	0.95	0.84	0.10	0.70	0.95
WHITE	0.92	0.04	0.87	0.97	0.92	0.04	0.86	0.97

Notes: (1) R&D sample contains only firms that report positive R&D expenditures
(2) ECR = share of scientists and engineers who changed their employers at least once within the one-year period, by **industry** and year
(3) GEO = share of scientists and engineers who changed their employers at least once within the one-year period, by **location** and year
(4) K/L = Plants and equipments (mil. 1982-84$)/employment (1000s)
(5) AGE_ECR (AGE_GEO) = average age of scientists and engineers by industry and year (by location and year)
(6) MALE (WHITE) = fractions of scientists and engineers who are male (white)

Table 3 Patenting Regressions

Dependent Variable: Patents

Random Effects Poisson Model

	(1)		(2)		(3)		(4)		(5)		(6)	
	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z
LnECR	0.0287	5.23	0.0255	4.63	0.0257	4.66						
LnGEO							0.1303	7.03	0.0596	3.11		
LnSALES	0.4128	43.43	0.3971	41.04	0.3962	40.93	0.3469	28.71	0.3649	30.08	0.3917	40.38
LnK/L	-0.0077	-7.16	-0.0034	-2.98	-0.0036	-3.05	0.0334	16.18	0.0381	18.22	-0.0037	-3.16
LnR&D	0.3090	38.53	0.3474	38.15	0.3320	25.43	0.4041	38.15	0.3396	29.53	0.3492	38.29
$(LnR\&D)^2$					0.0022	1.64						
LnAGE	0.9580	17.72	1.0217	8.74	1.0236	18.77	3.2061	17.19	2.2144	11.15	1.0026	18.15
T			-0.0053	-8.92	-0.0057	-8.93			0.0124	14.40	-0.0040	-6.67
ECR											90.0545	6.34
ECR^2											-2377.06	-6.80
ECR^3											30405.25	7.14
Constant	-4.9248	-24.12	-5.1075	24.91	-5.1023	-24.87	-12.8184	-19.25	-9.5180	-13.54	-6.4013	-20.97
Observations	21030 (2740 firms)		21030 (2740 firms)		21030 (2740 firms)		14385 (1894 firms)		14385 (1894 firms)		21030 (2740 firms)	
Log Like.	-44599		-44423		-44422		-29286		-29182		-44300	
Wald χ^2	11837.5		12217.0		12234.6		9295.3		9607.2		12474.8	
p value	0.00		0.00		0.00		0.00		0.00		0.00	

Note: The z columns report the ratios of the coefficient to its standard error. The p value reported is of the test that the population coefficients are jointly zero. The random effects follow a gamma distribution. The last row reports a Wald chi-square statistic for testing the specification in the column. Column 6 reports the results from of an estimation that contains a sixth order polynomial expansion of ECR. The coefficient estimates for fourth order terms and higher are omitted from the table due to space considerations.

Table 4 Patent Regressions: Sensitivity Analyses

Dependent Variable: Patents

	(1) GMM		(2) GMM		(3) Poisson w/ year dummies		(4) Poisson w/ industry dummies		(5) Poisson w/ year dummies		(6) Poisson w/ industry dummies	
	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z
LnECR	0.0081	6.34			0.0256	4.36	0.0292	5.31				
LnGEO			0.0471	4.17					0.0157	0.47	0.1264	6.82
LnSALES	0.2810	26.95	0.1746	19.07	0.3420	34.37	0.4324	43.98	0.3198	25.92	0.3662	29.23
LnK/L	0.0025	1.29	0.0407	10.34	0.0334	21.34	-0.0076	-7.13	0.0382	18.29	0.0337	16.32
LnR&D	0.1066	16.82	0.1629	18.39	0.3630	39.47	0.3001	36.86	0.3713	31.92	0.3975	36.91
LnAGE	0.2239	4.21	1.0844	9.71	0.2886	4.90	0.9534	17.62	0.6484	2.45	3.1653	16.96
Observations	19368 (1982 firms)		7747 (904 firms)		21030 (2740 firms)		21030 (2740 firms)		14385 (1894 firms)		14385 (1894 firms)	
Sargan χ^2	495.25		311.02									
d.f.	480		315									
Log Like.					-43394		-44374		-29008		-29223	
Wald χ^2					14562.9		12492.5		10101.1		9522.1	
p value	0.306		0.553		0.00		0.00		0.00		0.00	

Note: The z columns report the ratios of the coefficient to its standard error. The p values given in columns 1 and 2 are for the test of the null hypothesis that the moment conditions hold for all instruments. The p values in columns 3-6 are of the test that the population coefficients are jointly zero. Columns 1 and 2 are the results of the Generalized Method of Moments while the rest of the table is based on random-effects Poisson estimation. The random effects are assumed to follow a gamma distribution. Estimated coefficients for calendar year dummies and industry dummies in columns 3-6 are not reported to save space.

Table 4 Patent Regressions: Sensitivity Analyses (continued)

Dependent Variable: Patents

	(7) Poisson High tech firms		(8) Poisson Non high tech firms		(9) Poisson High tech firms		(10) Poisson Non high tech firms	
	Coef.	z	Coef.	z	Coef.	z	Coef.	z
LnECR	0.0154	9.11	0.0032	1.46				
LnGEO					0.1637	6.33	0.0878	3.29
LnSALES	0.4195	29.65	0.3953	29.76	0.4078	22.96	0.2872	16.46
LnK/L	0.0071	4.43	-0.0166	-11.34	0.0283	8.42	0.0356	13.48
LnR&D	0.2985	25.41	0.3108	27.78	0.3563	23.86	0.4390	28.00
LnAGE	1.9293	25.34	0.2368	3.08	5.1963	21.26	0.2688	0.92
Constant	-8.4566	-30.05	-2.3169	-7.93	-20.0725	-23.09	-2.0734	-1.99
Observations	11012 (1490 firms)		10545 (1255 firms)		8072 (1125 firms)		6313 (771 firms)	
Log Like.	-22369		-22951		-15636		-13545	
Wald χ^2	8679.4		4024.5		6320.7		3119.6	
p value	0.00		0.00		0.00		0.00	

Note: The z columns report the ratios of the coefficient to its standard error. The p values are of the test that the population coefficients are jointly zero. The results in all columns are based on random-effects Poisson estimation. The random effects follow a gamma distribution. High tech industries include Computers & computing equipment (industry 8), Electrical machinery (9), Electronic instruments & communication equipment (10), Transportation equipment (11), Optical & medical instruments (13) and Pharmaceuticals (14). This grouping follows Chandler (Business History Review, Summer 1994).

Appendix I: Notations Used in the Theoretical Model

ρ_i	Internal revenue generated by innovation for entrepreneur in the second period (marketing phase); a random variable that is realized at the beginning of the second period
ρ_e	External value of innovation in second period to entrepreneur's rival, net of scientist-worker's moving cost (includes a random variable that is realized at the beginning of the second period)
f	Joint density of ρ_e and ρ_i
λ	A rival using the innovation in the second period, markets product that reduces the entrepreneur's revenue received by $\lambda\rho_i$, where $\lambda \in [0,1]$
δ	A patent reduces the entrepreneur's loss from the rival's appropriation to $(1-\delta)\lambda\rho_i$, $\delta \in [0,1]$
γ	A patent reduces the rival's gain from its appropriation by $\gamma\rho_i$, $\gamma \in [0,1]$.
ν	The cost to the entrepreneur of patenting; it includes out-of-pocket costs and the costs from information disclosure
$\overline{w}$	The marginal product of the scientist who has no experience at the firm
w_0	The entrepreneur's first period (developmental phase) wage offer to the scientist
w_1	The entrepreneur's second period (marketing phase) wage offer to the scientist
p	An indicator variable, equal to one if the entrepreneur patents in the second period and zero, otherwise
S	The set of ρ_e and ρ_i such that the scientist remains with the entrepreneur in the 2nd period
M	The set of ρ_e and ρ_i such that the scientist moves to a rival in the second period
N	The set of ρ_e and ρ_i such that the scientist moves to the non-R&D sector in the 2nd period
$\overline{\rho}_e$	The expected value of ρ_e
ε_e	A noise term; $\rho_e = \overline{\rho}_e + \varepsilon_e$
$\overline{\rho}_i$	The expected value of ρ_i
ε_i	A noise term; $\rho_i = \overline{\rho}_i + \varepsilon_i$
g	Joint density of ε_e and ε_i

Appendix II: Decisions on Mobility and Patenting

We first suppose $\rho_e > \lambda\rho_i$, or $\varepsilon_e > \lambda\eta + \lambda\overline{\rho}_i - \overline{\rho}_e$. The scientist's gain from establishing or joining a rival exceeds the firm's loss ($= \lambda\rho_i - \delta\lambda\rho_i + \overline{w}$), whether the firm patents or not. Thus, the scientist leaves the entrepreneur for the rival and earns $\rho_e - \gamma\rho_i + \overline{w}$ if the entrepreneur patents, and $\rho_e + \overline{w}$ otherwise. She patents only if the gain to patenting exceeds its cost, i.e. $\nu \le \delta\lambda\rho_i$. This first case corresponds to the area above line A in Figure 1.

Suppose, instead, $\lambda\rho_i - (\delta\lambda\rho_i - \gamma\rho_i) < \rho_e \le \lambda\rho_i$. In the absence of patenting, the establishment of a rival would cost the entrepreneur more than it would benefit the scientist. In this case, the entrepreneur offers the scientist $w_1 = \rho_e + \overline{w}$, the smallest wage that the scientist would accept to stay. In this range of ρ_e, patenting causes the benefit to the scientist from leaving to exceed its cost to the entrepreneur. Thus, when the entrepreneur patents the innovation, the scientist leaves to form a rival. The entrepreneur patents if her second period earnings after patenting are greater than they would be otherwise. That is, the entrepreneur patents if $\nu \le \rho_e - (1-\delta)\lambda\rho_i$. This threshold between patenting and non-patenting is illustrated in Figure 1 as the solid line in the range $\varepsilon_{i1} < \varepsilon_i \leq \varepsilon_{i2}$ connecting the two lines A and B.

Consider now the entrepreneur's optimal strategy when $\gamma\rho_i < \rho_e \leq \lambda\rho_i - (\delta\lambda\rho_i - \gamma\rho_i)$. In this case, ρ_e is low enough that whether the firm patents or not, the loss to the entrepreneur if the scientist sets up a rival exceeds the scientist's gain. Thus, the entrepreneur always offers the scientist the minimum w_1 to induce him to stay, which is $\rho_e + \overline{w}$ if she does not patent, and $\rho_e - \gamma\rho_i + \overline{w}$ otherwise. By reducing the return to the scientist in his best alternative employment, patenting reduces the wage offer necessary to retain him. Thus, the entrepreneur patents only if $\nu \leq \gamma\rho_i$. This third case corresponds to the area between lines B and C in Figure 1.

ρ_e may also fall between 0 and $\gamma\rho_i$. If the entrepreneur chooses not to patent, the gain to the scientist in forming a rival would exceed the loss to the entrepreneur. Thus, if she does not patent she would offer a wage equal to $\rho_e + \overline{w}$ to retain the scientist. If she were to patent and if the scientist were to leave, he would choose not to exploit his knowledge since marketing a similar product would earn him $\rho_e - \gamma\rho_i < 0$. By patenting, she reduces the wage necessary to retain the scientist by ρ_e, and thus patents only if $\nu \leq \rho_e$. If she patents, she offers the scientist $\overline{w}$ to stay and earns nothing from the scientist's services. This fourth case corresponds to the area between lines C and D in Figure 1.

Finally, suppose $\rho_e < 0$. In this case, the entrepreneur does not patent, and offers $\overline{w}$ to the scientist, who stays in the second period and produces $\overline{w}$ (the area below line D in Figure 1).

Appendix III: Industry Classification and Geographical Region Code

Industry 1: Food & tobacco
Industry 2: Paper & paper products
Industry 3 Chemical products
Industry 4 Plastics & rubber products
Industry 5: Primary metal products
Industry 6: Fabricated metal products
Industry 7: Machinery & engines
Industry 8: Computers & computing equipment
Industry 9: Electrical machinery
Industry 10: Electronic instruments & communication equipment
Industry 11: Transportation equipment
Industry 12: Motor vehicles
Industry 13: Optical & medical instruments
Industry 14: Pharmaceuticals
Industry 15: Misc. manufacturing

Region 1: New England
Region 2: Middle Atlantic
Region 3: Northeast Central
Region 4: Northwest Central
Region 5: South Atlantic
Region 6: Southeast Central
Region 7: Southwest Central
Region 8: Mountain
Region 9: Pacific

Endnote

[1] The Bureau of Labor Statistics (see the BLS document, *Labor Force Statistics from the Current Population Survey*, online at http://stats.bls.gov/cps_over.htm) reports that the median years of tenure with the current employer for engineers fell from 6.3 in 1983 to 4.8 in 2000, a drop of 24 percent.

[2] Gilson has argued that the rise of Silicon Valley is due in large part to the California courts' refusal to enforce non-compete clauses in employment contracts. Gilson suggests the courts' refusal to enforce these clauses coupled with the natural mobility of scientists and managers resulted in the diffusion of technological innovation. (See also Saxenian, 1994).

[3] The entrepreneur risks a competitor discovering the entrepreneur's idea independently or through reverse engineering, without the aid of entrepreneur's former worker. One can show that allowing competitors to imitate and the entrepreneur to combat it through patenting does not qualitatively change our theoretical results below.

[4] In the second period he earns w^* if he stays at the same non-R&D firm, or $\overline{w}$ if he moves. We assume that $w^* \geq \overline{w}$ since the scientist accumulates firm specific human capital. For simplicity we let $w^* = \overline{w}$ in the following exposition, which does not change our main findings.

[5] When the entrepreneur designs a patent application to establish a monopoly in a certain technological area, she will be more likely to tailor the patent to enlarge its immediate benefit $\delta\lambda\rho_i$, while, as we show below, minimizing $\gamma\rho_i$. Thus, the tendency is for larger $\delta\lambda\rho_i$ relative to $\gamma\rho_i$.

[6] We are assuming there is no minimum wage, i.e. w_0 can be negative.

[7] The proofs can be provided upon request.

[8] Note that we have excluded the scientist's earnings at a rival from the calculation of a project's R&D. This is appropriate in the event the scientist only leaves to set up a new firm, where he is unlikely to report his activities as R&D. If, on the other hand, the scientist moves to an established firm, $\overline{w}$ will almost surely be counted as R&D, if not ρ_e, too. In this case, (3) should include on the right hand side $\iint_{M,P=0} \left(\overline{\rho}_e + \varepsilon_e + \overline{w}\right) g\left(\varepsilon_e, \varepsilon_i\right) d\varepsilon_e d\varepsilon_i + \iint_{M,P=1} \left(\overline{\rho}_e + \varepsilon_e - \gamma\rho_i + \overline{w}\right) g\left(\varepsilon_e, \varepsilon_i\right) d\varepsilon_e d\varepsilon_i$.

[9] The assumption that the wages paid to the defecting scientist are not counted in the R&D expenditures is crucial to the comparative statics we do with R&D. Alternatively, if we assume that both ρ_e (or $\rho_e - \gamma\rho_i$ if the innovation is patented) and $\overline{w}$ paid by the receiving firm are counted in its R&D expenditures, then we can show that mobility has no effect on R&D because an increase in $\overline{\rho}_e$ reduces the wage paid by the entrepreneur by the same amount it increases the expenditures at the rival.

[10] Pakes and Nitzan also find that improvements in the scientist's outside opportunities cause the wage paid to fall commensurately. Technical knowledge acquired by the scientist is a form of general human capital, so this result is not surprising (see Becker, 1964). Moen (2000) provides empirical support for this result. Using Norwegian matched employer-employee data, he finds that technical workers in R&D intensive firms accept lower wages early in their career in exchange for higher wages later.

[11] We include the following occupation categories for scientists and engineers (the three-digit 1980 standard occupational classifications are in parentheses): Engineers (044-059), Mathematical and computer scientists (064-068), Natural scientists (069-083), Clinical laboratory technologists and technicians (203), Engineering and related technologists and technicians (213-216), Science technicians (223-225), and Computer programmers (229).

[12] See the industry classification in Appendix III.

[13] According to the CPS data, the average of ECR over the period 1975 to 1992 is 0.11. This is lower than the average job turnover rate for all workers during 1975-95, at 0.28 (Stewart, 1998). Turnover

rates may be lower for scientists and engineers because they are more highly educated, more often male, and older than the average worker. In general workers with these traits have lower job turnover rates.

[14] Ideally, we would like measures of mobility for each industry in each geographical area. Because the size of the sample is too small to estimate separate industry measures by region, we construct mobility estimates for scientists and engineers aggregating across industries in 9 regions (see Appendix II), and then match these measures to firms by their region of incorporation.

[15] Details of the matching process and the resulting data file can be found in Hall and Ziedonis, Hall, Jaffe, and Trajtenberg (1999), and Hall (1990).

[16] Hall and Ziedonis, inspired by Merges and Nelson (1990), also include a dummy variable capturing whether the firm owned and operated its own manufacturer or specialized in product design alone. The authors reason that manufacturing firms may be more likely to patent because they may require access to a larger set of process and product technologies than design firms, making them vulnerable to a patent infringement lawsuit. We have not included this variable in our analysis since collecting information on firm type is prohibitively costly for our much larger sample, and the random or fixed effects we use in our estimation models will pick this up.

[17] A Box-Cox test shows that the logarithmic form of the mobility variable produces a better fit than the linear form. Moreover, when run with the linear form of the mobility variable, our model generally produces results that are qualitatively and quantitatively similar to the results produced with the log form.

[18] Our use of contemporaneous R&D, as opposed to lagged R&D, follows the extensive literature estimating patent production functions (e.g., Hall, Grilliches, and Hausman, 1986). Evidence suggests that R&D activities and innovations occur somewhat simultaneously. Moreover, if a firm attempts to patent an innovation, it files the application while the innovation is being developed or very shortly afterwards (Hall et al.).

[19] The sample used in Panel 4 is smaller than in Panel 1 because some firms in the Compustat data do not report a location.

[20] The reader should note the following caveat for the GEO measure: The geographical measure of mobility is based on the state of the firm's incorporation. For many large firms, only a portion (or perhaps none) of their R&D operations are located in the state of their incorporation.

[21] We added polynomial terms until the change in log-likelihood ceased to be statistically significant. We report the results from a sixth order polynomial expansion of ECR because we found no statistical difference in the log-likelihood when we went from a sixth order to a seventh order expansion.

[22] We thank Frank Windmeijer for providing his Gauss program, EXPEND, used to estimate these models (see Windmeijer, 2002).

[23] The propensity to patent and mobility may be related through other shared factors. For example, the advent of a new technology may lead both to more patenting and increase the re-shuffling of workers among firms. Suppose there are two industries employing biochemists. In industry A, biochemists develop drugs to fight disease and in industry B they are employed for another purpose. Suppose in industry A, a new technology is developed that lowers the costs of drug discovery, raising the marginal product of biochemists working there. We would then expect that firms in industry B would lure biochemists from industry A, raising mobility, until the marginal products are equal across industries. Simultaneously, the new drugs enabled by the technological shock would generate new patents. By using the GMM, we can isolate the effect of mobility on patenting from those of other factors which simultaneously influence mobility and patenting.

[24] A Basmann's test applied to the linear regression specification indicates these variables can be excluded from the estimated regressions and used as instruments. The mean age of scientists is used as

a regressor instead of an instrument since the Basmann's test rejects the hypothesis that it is excludable from the reduced-form model.

[25] We use as instruments the second through fourth lags of the mobility and R&D measures, and the contemporaneous through fourth lags of the remaining variables.

[26] These calculations are based on the estimated coefficients associated with LnECR and LnGEO in panels 1 and 4 of Table 3, assuming that R&D expenditures are not affected by changes in these mobility measures. The predicted reductions of the patent-R&D ratio are derived as exp(.0287*ln2) = 1.02 and exp(0.1303*ln2) = 1.09. The other calculations described below are derived similarly.

[27] Among engineers, the median tenure with the current employer experienced a similar decline over that period. See endnote 1.

[28] *Science and Engineering Indicators* (National Science Foundation, 1998) reports that average annual domestic patents granted per billion research dollars in the U.S. (expressed in 1982-84 dollars) rose from 401 in 1984 to 475 in 1997.

[29] These calculations are based on post-1986 data only because 1987 is the first year in which the CPS contains the size of workers' employers by number of employees.