ELSEVIER
Journal of Economic Behavior & Organization
Vol. 45 (2001) 403–425
JOURNAL OF
Economic Behavior
& Organization
www.elsevier.com/locate/econbase

Innovation and reciprocal externalities: information transmission via job mobility☆

David P. Cooper*
Arthur Andersen LLP, 633 West Fifth Street, Los Angeles, CA 90071-2008, USA

Received 13 October 1999; accepted 1 August 2000

Abstract

The phenomenon of "job-hopping", frequent in environments such as Silicon Valley, challenges firms' ability to protect their proprietary information. This paper presents a two-period model of a competitive industry where workers may capitalize on information acquired on the job by migrating to rival firms. Equilibrium is characterized by levels of R&D investment and job mobility. Several intriguing results are specified. First, higher mobility generally corresponds to greater overall technological progress. Furthermore, the equilibrium rate of job mobility never exceeds the socially efficient rate. Finally, due to the existence of opposing external effects, an efficient outcome can be approximated despite apparent incentive problems. The paper suggests that contractual clauses intended to restrict mobility act as a double-edged sword. While helping firms protect research investments, they also prevent the exchange of workers when such exchanges are both individually and socially beneficial

JEL classification: J6; L2; O3

Keywords: Mobility; Turnover; R&D; Intellectual property

1. Introduction

Conventional Economic wisdom suggests that incentives to innovate depend strongly on firms' ability to appropriate the resulting benefits. Economists have long attempted to define conditions that enhance appropriability and to measure the associated impact on innovation. This paper deals explicitly with one factor that has received relatively little attention in the context of appropriability: inter-firm job mobility. Highly skilled workers such as scientists, engineers, or research managers, acquire valuable knowledge on the

☆ This paper is based on a chapter of my dissertation at UCLA.

* Tel.: +1-213-614-8734; fax: +1-213-614-6670.
E-mail address: david.p.cooper@us.arthurandersen.com (D.P. Cooper).

PII: S0167-2681(01)00154-8

job. Due to imperfect property rights over this knowledge, workers may exercise de facto property rights by migrating to a higher-paying rival. The central objective of this paper, therefore, is to examine firms' incentives to undertake research activity in a competitive environment where such job mobility is a consistent possibility. In doing so, the welfare implications of job mobility are explored. In particular, the idea that "good" incentives can exist when appropriability conditions seem poor is addressed.

Worker mobility facilitates knowledge dissemination. Traditional reasoning suggests that a more abundant flow of workers (and information) across firms implies lower appropriability, and thus lower incentives to innovate. In reality, however, we observe environments where intense innovative activity coexists with significant informational externalities, of which job mobility is a prominent example. Many of the high-tech industries located in Silicon Valley fit this description quite well. Can the market compensate firms for information lost to the competition through worker-migration? This question is addressed through a simple two-period model in which firms and workers are both essential complementary components of the innovation process. The level of R&D and the rate of job mobility are both determined endogenously by the model. The emphasis on job mobility is magnified by assuming it to be the only possible channel for information transmission between firms. Several interesting results emerge from the analysis. First, conditions resulting in higher levels of job mobility *do not* necessarily reduce firm-level R&D investment, and *always* increase the overall rate of technical progress. [1] As a result, contractual clauses and other means intended to reduce mobility, will generally be welfare *decreasing*. Furthermore, even when restrictions on worker movement are completely absent, the equilibrium mobility rate never exceeds the socially optimal rate.

1.1. Appropriability and job mobility

The relationship between appropriability and innovation has been studied intensively since Schumpeter's (1942) seminal work. [2] Despite Schumpeter's contention that market power is "the most powerful engine of technological progress" (p. 106), two other factors are generally considered better predictors of innovation-intensity. The first is the set of industry-specific variables (Scott, 1984; Mansfield, 1986; Levin et al., 1987). The second is the level of technological spillovers. Thus, identifying sources of spillovers has become important. Three main sources are typically discussed. First, spillovers can arise directly from the industry environment. Examples include "external economies" à la Marshall, and demand conditions (e.g. Bresnahan, 1986). Second, spillovers can result from "hostile" competitive behavior, due to industrial espionage, competitor intelligence, reverse engineering

[1] Here "technical progress" corresponds to the average firm's overall knowledge level. A firm's knowledge is obtained from its own R&D and/or from rivals' R&D through mobile workers. This notion is similar to "effective R&D" (Katz, 1986). Several papers (e.g. DeBondt et al., 1992) have shown a positive relationship between effective R&D and social welfare.

[2] According to Cohen and Levin (1989) the "Schumpetarian hypotheses" have inspired the second largest amount of empirical research in industrial organization (second only to the relationship between market concentration and profitability).

or other imitation-oriented activities.[3] Finally, spillovers may manifest as voluntary exchanges of information.[4]

Arrow (1962) recognized worker-mobility as a distinct source of potential spillovers. Rogers and Larsen (1984) describe job hopping in Silicon Valley as "a game of strategies and counter-strategies with the exchange of technical information one of its main purposes". What sets job mobility apart as a unique and interesting source of technological spillovers, is its dependence on the strategic interaction between workers and firms. Several important analytical differences from the standard notion of "knowledge spillovers" can be identified. First, information is transferred to only one additional firm at a time as opposed to the whole industry instantaneously.[5] Second, the spillover "rate" is determined *endogenously* by the rate of job mobility. Finally, a portion of the firm's knowledge is embodied in the worker, and thus cannot be retained when the worker leaves.

Historical examples of frequent job mobility within innovation-intensive settings do exist.[6] The canonical examples, however, are the high-tech industries of Silicon Valley. Currently the annual turnover rate among highly-skilled personnel in Silicon Valley is approximated at 20–25%, down from rates of 35–40% in the 1970s (Carnoy et al., 1997; Saxenian, 1994 and others). Angel (1989) found that only 40% of semiconductor engineers were likely to stay at the same job for more than 5 years. That number is likely much lower today. Carnoy et al. (1997) examine "flexible employment", including temporary employment, self-employment, and subcontracting, and find that these categories accounted for 30–40% of total employment and over 50% of net employment growth in Santa Clara county.

Intense movement of workers and information suggests a limited capacity of firms to appropriate the gains from their knowledge, leading to under-investment.[7] This conclusion, however, overlooks the fact that in most industries, a firm's profitability depends not only on its *absolute* performance level, but also on its *relative* performance compared to its rivals. This relative-performance component of a firm's profitability implies a negative externality associated with increased innovative activity, and creates a tendency for firms to over-invest in these activities. In essence, this is a mild version of a "patent-race" or "rat-race" scenario (see Ackerloff, 1976). In those models, *only* relative performance matters. Firms compete for a fixed prize (the patent), and increase their winning probability through investment in research.[8] A fundamental common result of these models is over-investment in research.[9]

Incorporating a rat-race component produces a competitive setting with powerful opposing external effects. Equilibrium firm-level investment must account for the net effect of these two externalities, and may approximate (coincide with) the efficient level, pro-

[3] Firms naturally also attempt to protect against the success of such activities. See Cooper and Kiousis (1997) for a more detailed discussion on this conflictual aspect of spillovers.

[4] Von Hippel (1988) calls these exchanges "informal know-how trading" and defines identifying criteria. Allen (1983) reconciles this behavior with profit maximization.

[5] Alternatively, the information exhibits "natural excludability" (see Zucker et al., 1998).

[6] Lamoreaux and Sokoloff (1999) find that highly-inventive individuals at the turn of the century (based on number of patents) often contracted with multiple assignees. Thus, they argue that these ". . . were employees who either moved restlessly from job to job or . . . behaved entrepreneurialy . . . "

[7] A standard public-goods argument (see Spence (1984) and many others).

[8] Reinganum (1989) presents a survey of patent-race models.

[9] Over-investment can also result from other factors such as speculation (see Hirshleifer, 1971).

vided they are of similar (identical) magnitudes. Although increased job mobility may reflect greater spillover externalities, it does not necessarily imply greater investment inefficiencies. In fact, when intense inter-firm rivalry is present, increased mobility rates may *reduce* investment inefficiencies by ameliorating the over-investment problem associated with negative (rat-race) external effects. This additional beneficial role of job mobility may have important implications for examining industries that exhibit high turnover rates.

1.2. Human capital and job mobility

Firms can employ several means to minimize information lost through worker mobility. First, an optimal information structure reduces the possible gains to a defecting employee (see for example, Feinstein and Stein, 1988; Trebilcock, 1985). Firms also attempt to exercise formal intellectual property rights, however, this is often not feasible. Firms do possess property rights over patentable information conceived on the job, however, workers often bypass this obstacle by leaving the firm before their idea is revealed. [10] In reality, much of a firm's valuable information is not patentable at all. Only trade secrets are available as a formal intellectual-property tool for this information. Indeed, at least in theory, most information is suitable for trade-secret protection. [11] However, enforcement of this protection for information residing only in a worker's head is nearly impossible. This intangible nature of information, makes it "extremely difficult to distinguish between theft and independent discovery" (Cheung, 1982). A third way to prevent information outflow by inserting restrictions such as non-compete and non-disclosure clauses into employee contracts. The former clause is often invalidated in the US due to its anti-competitive nature. The latter clause has limited enforcement prospects. [12] Saxenian (1994) describes the difficulties faced by Silicon Valley firms as "early efforts to take legal action against departed employees proved inconclusive and protracted, and most firms came to accept high turnover as a cost of business in the region".

Workers transferring their productivity (in the form of gained knowledge and skills) to other firms is directly related to the story of human capital and general training as pioneered by Becker (1964). Becker argued that firms will often refuse to provide general training due to a lack of property rights. Several exceptions to this rule do exist, [13] however, they all share the treatment of human capital as a purely private good. This paper diverges by assuming that firms retain some information generated during "training" even after their employee leaves to a competitor. In other words, the emphasis here is on the *non-rivalrous* aspect of knowledge, implying that firm investment functions both as training *and* R&D. As a result, firms invest even when the likelihood of retaining their worker is low.

---

[10] See Merges (1998) for further discussion of this *exit option.*

[11] The American Law Institute (1939) states that "A trade secret may consist of any information . . . which gives an opportunity to obtain an advantage over competitors who do not know or use it."

[12] Cuvillier (1977) discusses legal and ethical issues surrounding these contractual arrangements.

[13] Informational asymmetry in the labor market is one such exception (e.g. Greenwald, 1986; Katz and Ziderman, 1990).

1.3. Other related papers

Nitzan and Pakes (1983) explicitly model the problem of hiring scientists who can profit from acquired knowledge by moving to a rival. Their model differs in that their "investment" choice is captured through a choice of scientist quality, rather than a research level. Furthermore, their strategic actors include only the firm and the worker, whereas I include the outside market as an additional entity. Nevertheless, several similarities arise. Most notably, both models produce an equilibrium where the sum of expected benefits is a necessary (although not sufficient) condition for a job switch to occur.

Chang and Wang (1995) examine the relationship between job mobility and investment in general human capital. They focus on general human capital investments made by *workers* rather than firms. They find that the overall level of human capital is inversely related to the level of market job turnover. This finding depends critically on their assumption of two worker types, one of which is "incompetent" and thus incapable of accumulating any human capital. Higher investment in human capital by competent workers increases their chance of being correctly identified by their employees, thus increasing their chance of being retained at their job, lowering the turnover rate. Rather than two types of workers, I assume a continuum of worker abilities drawn from a distribution with compact support. In this scenario, separating competent from incompetent workers becomes meaningless since all workers are at least marginally competent. In contrast to Chang and Wang, equilibrium investment in human capital (i.e. in R&D) may be either positively or negatively related to the job mobility rate.

Cole et al. (1998) analyze matching in a two-period assignment game where agents invest in increasing their productivity. The story fits one of workers and firms, where workers invest in human capital and firms invest in techniques to utilize that human capital. They find that even when pre-investment contracting is not feasible, an equilibrium with the efficient level of investment always exists. Thus, correct investment-incentives can exist even without well defined property rights. Similarly, I find that efficient investment in innovation can be reached with "reciprocal externalities".

The remainder of the paper is organized as follows. In the next section, I present the setup of the model. Following that, I solve for the equilibrium of the basic model and compare it with the equilibrium solutions of three important variations. The final section contains concluding remarks.

2. Model

The proposed approach is to analyze the behavior of a typical firm in a two-period, multifirm industry. Firms produce a single good of varying quality determined by the level of innovation. The environment is "competitive" in the sense that individual firms cannot affect industry-wide average research and wage levels. Firms face constant returns to increases in expected quality. Each firm requires one research manager (a *worker*) in both periods. In the first period, firms hire one worker each from a large population (i.e. more workers than firms), and invest in a research project. Production and marketing occur in the second period. Before the second period, a labor market takes place. Workers receive competing wage offers from their own firm and outside firms, and will choose to either stay or leave according to the higher offer. During the research stage, workers acquire valuable information. Also during the research stage (but after investment in research has occurred), both worker and firm discover their match quality. Based on this quality, the firm chooses the second-period wage offer.

With this setup in mind, the firm's second-period productivity (in monetary terms) is one of the following:

- If the firm retains its original (*inside*) worker, second-period productivity is defined as

$$x^{\mathrm{i}} = rq_1 \tag{1}$$

The variable r represents the firm's investment in R&D, chosen in the *first* period. The value of q_1 is the realization of a random variable Q_1, reflecting the match quality between worker and firm.[14] This random component is revealed to both the worker[15] and the firm (but not to competing firms) following the research decision. Q_1 is uniformly distributed on $[0, \Phi]$. Thus, $E(Q_1) = \Phi/2$.

- If the firm replaces its own worker with one previously employed at an outside firm, second-period productivity becomes

$$x^{\mathrm{o}} = (\alpha r + \beta \bar{r})k \tag{2}$$

where $\bar{r}$ represents the level of R&D investment at an average competing firm.[16] Two "informational" parameters are introduced in this stage: α and $\beta \in [0, 1]$. α measures the firm's marginal return on R&D in the event of exchanging workers. It represents both the firm's ability to retain value from its own research without its original worker *and* the firm's capacity to absorb information brought in by the outside worker it hires.[17] The second parameter, β, represents the percentage of the *rival* firm's research imported along with the worker. It is akin to a standard "spillover" parameter. The magnitudes of α and β are critical in determining the equilibrium rates of research and job mobility.

The value of k represents the match quality between a firm and an *outside* worker. It is given by

$$k = \rho q_1 + (1 - \rho)q_2 \tag{3}$$

where $\rho \in [0, 1]$, and q_1, q_2 are realizations of two iid random variables, Q_1 and Q_2. The notion is that second-period match quality depends on a convex combination of first period match quality and a second-period random component.[18] It follows directly from

[14] Most generally, match quality depends both on firm heterogeneity (pure matching) and worker heterogeneity (pure ability). This paper focuses mainly on the pure matching story. I examine the more generic case where workers' inherent abilities come into play in Section 3.4.

[15] Workers do not initially have complete information about their characteristics (see for example, Holmstrom, 1982).

[16] Outside firms appear homogeneous from any one firm's perspective. Therefore, the departure of one worker and arrival of a new one is treated as a worker exchange with an anonymous, "market" firm.

[17] Cohen and Levinthal (1989) introduce the notion of "absorptive capacity" as a measure of how effectively firms utilize R&D spillovers.

[18] Here q_1 represents the *outside* worker's match quality with the first-period employer.

this definition that k is itself the realization of a random variable K, with ex ante expectation

$$E(K) = \rho E(Q_1) + (1-\rho)E(Q_2) = \tfrac{1}{2}\Phi \tag{4}$$

In equilibrium, however, realizations of K will only occur for workers who switched jobs. Therefore, the relevant expectation of K is conditional on the expected match-quality with a *switching* worker. Given the simple distributional assumptions of the model, this expected match-quality is perfectly predicted by the ex ante *probability* of any given worker switching jobs. I define this probability as the *job mobility rate* and denote it by $m \in [0, 1]$. For any given mobility rate m, the expected match quality with an outside worker is calculated as

$$E(K|m) = \rho E(Q_1^{\mathrm{o}}|m) + (1-\rho)\tfrac{1}{2}\Phi \tag{5}$$

where Q_1^{o} is a random variable, the realization of which represents the match quality between an *outside* (i.e. job-switching) worker and that worker's first employer. The support of Q_1^{o} is determined by the mobility rate. In the extreme case where $m = 1$ (i.e. all workers change jobs), Q_1^{o} is uniformly distributed on $[0, \Phi]$, which is identical to Q_1. In the more typical case, where some workers stay and others leave, Q_1^{o} is uniformly distributed on $[0, q^*]$ with $q^* < \Phi$. The separation between switching and non-switching workers is determined via the wage offers made by firms. Workers with higher first-period match quality are less likely to change jobs because their employers will be willing to pay more in order to keep them. It follows that $\Phi/2 = E(Q_1) \geq E(Q_1^{\mathrm{o}}|m) = q^*/2$ and therefore $E(K) \geq E(K|m)$.[19] This inequality is strict unless $m = 1$.

The parameter ρ represents the degree to which workers' abilities are correlated across firms. ρ equaling zero implies no such correlation, which is analogous to a pure "matching" game in which workers are ranked differently across firms. This is the basic case analyzed in the model. The more generic case of $\rho \in (0, 1)$ is examined in Section 3.4.

The timing of the game can be illustrated as follows:

1. Firms offer first-period wages, hire one worker each, and invest in research.
2. The first-period random component q_1 is revealed to the worker and the firm (but not to rival firms), thus determining the second stage productivity should the worker stay on at the firm.
3. Firms offer second-period inside and outside wages.
4. Workers accept the highest offer (stay if wage offer exceeds the outside offer, leave otherwise), thus determining the second-stage matches.
5. The second-period random component q_2 is revealed in the firms where mobility occurred.
6. Production takes place.

2.1. Workers and firms

Both workers and firms are assumed to be risk neutral. Workers maximize expected utility $E(w_1 + w_2)$, where w_1 and w_2 are wages received in the first and second periods,

[19] While K follows a uniform distribution, $K|m$ does not, since it is the *sum* of two uniformly distributed random variables. See Appendix A.1 for a derivation.

respectively. Workers have reservation utility u_r per period. Firms maximize their expected profits given by

$$E(\pi) = (1 + v)E(X) - vE(\bar{X}) - c(r) - w \tag{6}$$

where $E(X)$ is the firm's expected productivity (in dollar terms), and $E(\bar{X})$ is the analogous term for the average rival firm. The parameter v represents the extent to which the firm's profitability depends on its performance *relative* to the rest of the industry. One can think of v as measuring the degree of industry rivalry[20] or "rat-race" intensity. Notice that the expected revenue can be rewritten as $E(X) + v[E(X) - E(\bar{X})]$. This highlights the fact that although v may strongly impact firms' incentives, it will not affect this industry's first best outcome, because it fulfills a strictly redistributive purpose. In order to guarantee the existence of an equilibrium, v is restricted to the interval [0, 1].[21] $c(r)$ and w are the firm's research costs and wages, respectively, where $c(r)$ takes the specific form of $r^2/2$,[22] and $w = w_1 + w_2$.

The last step before solving the firm's problem is to specify its expected productivity, which can be expressed as

$$\begin{aligned} E(X|m) &= (1 - m)E(X^{\mathrm{i}}|m) + mE(X^{\mathrm{o}}|m) \\ &= (1 - m)(rE(Q_1^{\mathrm{i}}|m)) + m(\alpha r + \beta\bar{r})E(K|m) \end{aligned} \tag{7}$$

with

- $E(X^{\mathrm{i}}|m)$ defined as the firm's ex ante expected productivity when it keeps its original ("inside") worker.
- $E(X^{\mathrm{o}}|m)$ defined as the firm's ex ante expected productivity when it replaces its own employee with an "outside" worker from a rival firm.
- $m \in [0, 1]$ equals the ex ante probability that a worker separates from the original employer, i.e. the job mobility rate. m depends on the choice of r so it is determined endogenously.
- $E(K|m)$ equals the expected match quality with an outside worker, as defined in Eq. (5).
- $E(Q_1^{\mathrm{o}}|m)$ equals the ex ante expected realization of Q_1 associated with outside workers.
- $E(Q_1^{\mathrm{i}}|m)$ equals the ex ante expected realization of Q_1 associated with inside workers.

$E(Q_1^{\mathrm{o}}|m)$ and $E(Q_1^{\mathrm{i}}|m)$ represent the average expected worker quality within the populations of switching and non-switching workers, respectively. Both values depend uniquely

[20] For example, an industry where firms produce very differentiated products will have a less intense inter-firm rivalry than one where firms produce closely substitutable products.

[21] See Appendix A.2 for a proof. This restriction implies that "absolute" productivity dominates "relative" productivity in influencing firm profitability. This assumption seems quite realistic and agrees with other innovation models. For example, in a symmetric Cournot model of cost-reducing innovation with linear demand and constant marginal cost, firm i's profits (net of R&D costs) can be expressed as $b[(a - nc_i + (n-1)\bar{c})/((n+1)b)]^2$, where $\bar{c}$ is the average competing firm's marginal cost. The analog of v in that model is $(n-1)/n$ with n the number of firms.

[22] Since research enters linearly into the firm's productivity, diminishing returns to R&D are obtained through a convex cost function. This particularly simple quadratic form is found in many papers (e.g. D'Aspremont and Jacquemin, 1988).

on the mobility rate m, because m reflects the boundary between the two populations. Since firms discover the value of Q_1 associated with their own worker, it follows that workers who are kept at their jobs must have exhibited a first-period quality at least as great as those who ultimately change jobs. Thus, for all non-trivial cases (i.e. $\forall m < 1$), we will see $q_1^{\mathrm{i}}|m > q_1^{\mathrm{o}}|m$, and therefore $E(Q_1^{\mathrm{i}}|m) > E(Q_1^{\mathrm{o}}|m)$.

2.2. Solving the firm's problem

The maximization problem faced by the firm can now be expressed as

$$\max_r \left\{(1+v)\left[(1-m)rE(Q_1^{\mathrm{i}}|m) + m\left((\alpha r + \beta\bar{r})\rho E(Q_1^{\mathrm{o}}|m) + (1-\rho)\left(\tfrac{1}{2}\Phi\right)\right)\right] - vE(\bar{X}) - w - \tfrac{1}{2}r^2\right\} \quad (8)$$

which ultimately reduces to a decision problem in one variable (research). Before solving for the equilibrium level of research, however, we must negotiate two intermediate obstacles which depend directly on this choice of research. These two items are the equilibrium wages and the job mobility rate.

2.2.1. Wages

Workers earn wages in both periods. In the first period, since worker quality is unknown to firms, all workers will earn an identical wage w_1. In the second period the firm offers a wage schedule consisting of an *inside* wage offer to its own worker and an *outside* wage offer to potential new hires. Let w^{i} and w^{o} denote these wages, respectively. The quality of outside workers remains unknown, but firms form beliefs about the average quality of mobile workers. The second period finds an equal number of firms and trained workers. [23] Each firm is matched with one worker. A firm will either continue to be matched with its original worker or exchange this worker in favor of a random matching with an outside worker. The ultimate outcome depends on the second-period wage offers. Let $\hat{w}^{\mathrm{o}}$ denote the going outside market wage. [24] If $w^{\mathrm{i}} \geq \hat{w}^{\mathrm{o}}$, the firm keeps its original worker. If $w^{\mathrm{i}} < \hat{w}^{\mathrm{o}}$, the firm exchanges workers with the outside market.

In a symmetric equilibrium, all firms have already chosen the same level of research r^* in the first period. Therefore, $E(X^{\mathrm{o}}|m)$ can be directly obtained from Eq. (7):

$$E(X^{\mathrm{o}}|m) = r^*\left[(\alpha+\beta)\left(\rho E(Q_1^{\mathrm{o}}|m) + (1-\rho)\tfrac{1}{2}\Phi\right)\right] \quad (9)$$

It is reasonable to assume that both the worker and the firm have some degree of bargaining power with respect to the wage offer. Depending on the relative strengths of the two sides (and on any number of other features outside the scope of this paper) workers will thus be paid a share of their expected productivity. Let $\eta^{\mathrm{o}} \in [0, 1]$ denote the rule which determines this share. Thus, in equilibrium, the second-period outside wage is simply

$$w^{\mathrm{o}*} = \eta^{\mathrm{o}} E(X^{\mathrm{o}}) \quad (10)$$

[23] Additional *untrained* workers may exist but are not hired, because their productivity is too low.
[24] In equilibrium all firms will choose the same outside wage so $w^{\mathrm{o}*} = \hat{w}^{\mathrm{o}}$.

For the inside wage, w^{i}, lower and upper bounds can be defined. In order to retain its worker, the firm must offer a wage at least as great as the outside wage. Thus, the lower bound for the inside wage is $\underline{w}^{\mathrm{i}} = w^{\mathrm{o}*}$. What about the upper bound? A firm that prefers to keep its worker must satisfy the incentive compatibility constraint

$$rq_1 - w^{\mathrm{i}} \geq E(X^{\mathrm{o}}) - w^{\mathrm{o}*} \tag{11}$$

where the left-hand side denotes net profits (excluding research costs) from keeping the worker, and the right-hand side denotes the firm's net expected profits from exchanging workers with the outside market. The upper bound on the inside wage must make this constraint binding. Thus, we obtain $\bar{w}_i(q_1) = w^{\mathrm{o}*} + [rq_1 - E(X^{\mathrm{o}})]$. It is clearly seen that this upper bound depends on the realized match quality with the worker, q_1.

Any wage in the interval $[\underline{w}^{\mathrm{i}}, \bar{w}_i]$ is incentive compatible for both worker and firm, yielding a continuum of symmetric-equilibrium wages. Once again, with out loss of insight, worker and firm are assumed to split the surplus from their match in such a way that the worker is paid a proportion $\eta^{\mathrm{i}} \in [0, 1]$ of this surplus (with η^{i} independent of η^{o}). Therefore, the equilibrium inside wage offer as a function of worker quality is simply

$$w^{\mathrm{i}*}(q_1) = w^{\mathrm{o}*} + \eta^{\mathrm{i}}[rq_1 - E(X^{\mathrm{o}})] \tag{12}$$

Finally, firms will wish to terminate low-quality matches, and will do so by offering an inside wage $\tilde{w}^{\mathrm{i}} < w^{\mathrm{o}*}$ that the worker is guaranteed to reject, since it is below the outside opportunity. It follows that in equilibrium, no worker will earn below $w^{\mathrm{o}*}$ in the second period. Thus, for any pair $(\eta^{\mathrm{o}}, \eta^{\mathrm{i}})$, second-period equilibrium wages can be summarized by

$$w_2 = \begin{cases} w^{\mathrm{o}*} = \eta^{\mathrm{o}} E(X^{\mathrm{o}}) & \text{for } q_1 < q^* \\ w^{\mathrm{i}*}(q_1) = w^{\mathrm{o}*} + \eta^{\mathrm{i}}[rq_1 - E(X^{\mathrm{o}})] & \text{for } q_1 \geq q^* \end{cases} \tag{13}$$

where q^* is the critical value of q_1 separating workers retained workers from mobile workers. The next section is devoted to finding q^*.

Note that second-period wages are increasing in match quality. We can calculate expected second-period wages as $E(w_2) = mw^{\mathrm{o}*} + (1 - m)E[w^{\mathrm{i}*}(q_1)]$ which can be rewritten as

$$E(w_2) = \eta^{\mathrm{o}} E(X^{\mathrm{o}}) + (1 - m)\eta^{\mathrm{i}} \left[\tfrac{1}{2}(r\Phi - E(X^{\mathrm{o}}))\right] \tag{14}$$

Using Eq. (14), we obtain the following proposition.

Proposition 1. *Total expected wages earned over the two periods equal reservation wages, i.e.* $E(w_1 + w_2) = 2u_{\mathrm{r}}$.

The intuition for this is very simple. Since workers are ex ante on the long side of the labor market, they will be willing to (and thus forced to) pay a participation fee in the first period equal to their expected second-period gains. Formally, workers can calculate expected second-period wages: $E(w_2) = (1-m)E(w^{\mathrm{i}*}) + mw^{\mathrm{o}*}$. Thus, their expected second-period surplus can be defined as $E(S_2) = E(w_2) - u_{\mathrm{r}}$. Since these expected gains are common knowledge at the start of the game, firms can set first-period wages such that workers' participation constraint is binding, leading to $w_1 = u_r - E(S_2)$, $E(w_2) = u_r + E(S_2)$, and $E(w) = w_1 + E(w_2) = 2u_r$.

Not all workers earn the same wages. Some ultimately earn below and others above reservation wages. However, on an average, they all expect to earn $2u_r$ (an average of u_r per period), making them just willing to participate in the labor market. As a result of Proposition 1, total expected wage expenditures are constant, and thus do not play an active role in determining equilibrium levels of research and job mobility. The above result does not depend on a particular pair (η^o, η^i). It only requires this pair to be identical for all firms. In that sense, the equilibrium concept implemented here is fairly robust.

2.2.2. Employment threshold

Firms gain an informational advantage over their rivals regarding the characteristics of their own worker. They use that advantage when choosing wages. Firms wish to continue successful matches and terminate unsuccessful ones. In particular, they employ a simple decision rule, considering a match to be "successful" if it is better than some critical value. Define q^* as this threshold realization of q_1. Therefore, if $q_1 \geq q^*$ firms will offer a high enough inside wage $w^{i*} \geq w^{o*}$ to retain its worker. If $q_1 < q^*$ firms offer $\tilde{w}^i < w^{o*}$ ensuring their worker leaves.

Firms must be exactly indifferent between continuing and terminating a match with quality q^*. Once q^* is determined, the simple properties of the uniform distribution on $[0, \Phi]$ yield the following:

- $E(Q_1^i|m) = \frac{1}{2}(q^* + \Phi)$;
- $E(Q_1^o|m) = \frac{1}{2}q^*$;
- Mobility rate : $m = \dfrac{q^*}{\Phi}$;
- Staying rate : $1 - m = \dfrac{\Phi - q^*}{\Phi}$.

Proposition 2. *A symmetric-equilibrium employment threshold* $[q^* \in 0, \Phi]$ *exists and is unique.*

Proof. As stated above, the existence of such a threshold requires the firm to be exactly indifferent between keeping and exchanging its own worker. Thus, q^* must satisfy

$$\begin{aligned}&(1+v)rq^* - vE(\bar{X}) - w^{i*}(q^*) - \tfrac{1}{2}r^2\\ &\quad = (1+v)\left[(\alpha r + \beta\bar{r})\left(\tfrac{1}{2}\rho q^* + (1-\rho)\tfrac{1}{2}\Phi\right)\right] - vE(\bar{X}) - w^{o*} - \tfrac{1}{2}r^2 \quad \square \qquad (15)\end{aligned}$$

The left-hand side represents the firm's second-period profits from continuing a match of quality q^*, while the right-hand side represents expected second-period profits when exchanging that same worker for an outside one. Recall from Eq. (12) that $w^{i*}(q^*) = w^{o*}$. This means that Eq. (15) reduces to $rq^* = (\alpha r + \beta\bar{r})(\rho(\bar{q}^*/2) + (1-\rho)(\Phi/2))$ which yields the unique interior solution:

$$q^* = \frac{(1-\rho)(\alpha r + \beta\bar{r})\Phi}{2r - \rho(\alpha r + \beta\bar{r})} \qquad (16)$$

which simplifies in symmetric equilibrium (where $r = \bar{r}$) to

$$q^* = \frac{(1-\rho)(\alpha+\beta)\Phi}{2-\rho(\alpha+\beta)} \in [0, \Phi] \tag{17}$$

Note that both q^* and second-period wages are chosen simultaneously by each firm. All job-switching workers earn the same outside wage w^{o*}, while at the same time, workers who stay with their firms earn wages proportional to their match quality. As described above, the particular solution concept used here produces a wage schedule which is linear in match quality. However, in principle, any wage schedule $w^{i*}(q)$ contained in the interval $[w^{o*}, w^{o*} + rq - E(X^o|m)]$ could be supported in equilibrium.[25]

3. Equilibrium

This section solves explicitly for the symmetric non-cooperative equilibrium, and measures welfare implications through comparison to a benchmark efficient solution. The equilibrium is characterized by levels of research and job mobility. The equilibrium in both these dimensions is unique. The basic case analyzed is the *pure-matching* case where workers' abilities are uncorrelated across firms (i.e. $\rho = 0$). Next, this basic case is solved under two additional appropriability assumptions. First, results are compared to an extreme "zero-mobility" case where workers are restricted from changing jobs.

Second, a duopoly case is examined in order to introduce an additional strategic dimension. Finally, the pure matching assumption is relaxed to allow workers' abilities to be somewhat correlated across firms, i.e. ρ varies in (0, 1).

3.1. The basic matching game

This section presents the basic format that assumes workers' abilities to be uncorrelated across firms. Thus, a worker's ability at two separate firms is simply two independent draws q_1 and q_2, from the uniform distribution on $[0, \Phi]$ (i.e. $\rho = 0$ and $k = q_2$). It follows that the expected quality of the match with a new employer will *always* be the average quality $\Phi/2$, regardless of this worker's ability at a previous firm. This describes a scenario in which all workers have the same potential abilities but specialize in different tasks, so they are ranked differently across firms. I will relax this assumption in Section 3.4, allowing workers to have inherently different abilities.

Substituting $\rho = 0$ into Eq. (16), we obtain the employment threshold

$$q^* = \frac{(\alpha + (\beta\bar{r}/r))\Phi}{2} \tag{18}$$

From the previous section, we are now able to completely specify the expected-profit function, which the firm maximizes with respect to the level of R&D.

$$\max_r \left\{(1+v)\left[\left(1-\frac{q^*}{\Phi}\right)\left(r\frac{q^*+\Phi}{2}\right)+\frac{q^*}{\Phi}(\alpha r+\beta\bar{r})\right]-v\bar{x}-w-\frac{r^2}{2}\right\} \tag{19}$$

[25] The only reasonable requirement being a positive slope.

Substituting the value of q^* into the maximization problem, the first order condition yields levels of research and job mobility that characterize the symmetric equilibrium:

$$r^* = \bar{r}^* = \tfrac{1}{8}(\Phi(1+v)(4+\alpha^2-\beta^2)), \qquad m^* = \tfrac{1}{2}(\alpha+\beta) \tag{20}$$

An important result that emerges from this analysis is the absence of a one-to-one relationship between R&D and job mobility. The mobility rate depends on the *total* amount of information the firm can hope and expect to obtain when exchanging workers with the market. This total "innovative productivity" is positively influenced both by retaining more information from original matches (i.e. a larger α) and by more information being transferred through job mobility (a larger β). But these two parameters have opposing effects on the equilibrium level of R&D. The level of investment is positively related to α but inversely related to β because a higher β implies a greater benefit to free-riding on others' research efforts. Thus, an equal increase in α and β will have a zero (or close to zero) effect on the level of R&D while at the same time unambiguously increasing the level of job mobility.

A second central result pertains to the welfare implications of increased job mobility. The total surplus generated per firm in this equilibrium [26] can be found by substituting $q^* = (\alpha+\beta)\Phi/2$ back into the firm's profit function, yielding

$$G = \tfrac{1}{8}(r^*\Phi(4+(\alpha+\beta)^2)) - \tfrac{1}{2}r^{*2} \tag{21}$$

where r^* is given in Eq. (20). First partial derivatives reveal that these gains are always increasing in both α and β, and therefore also in m. [27] Thus, we arrive at the fairly appealing conclusion that circumstances which lead to higher equilibrium rates of job mobility also result in greater social gains. This result is a feature of the technology. When job mobility is a better transporter of information, it occurs more frequently, and expected benefits increase as well. This implies that any potential decrease in individual-firm R&D caused by additional mobility is dominated by increased innovation generated by better dissemination of information.

3.1.1. Efficiency

How do these outcomes compare to a measure of a social optimum? In the current setting, since all firms are ex ante identical, and all face diminishing returns in research, it is clearly optimal for each firm to invest the same amount in R&D. Therefore, finding the optimal solution for a representative firm will also yield the solution to the social maximization problem. In order to obtain the socially-optimal mobility rate, we need to solve for the employment threshold, by solving the equation $rq^* = (\alpha r+\beta\bar{r})(\Phi/2)$ immediately yielding $q^* = (\alpha+\beta)(\Phi/2)$. Substituting into the social maximization function, [28] gives us the following:

$$r_s^* = \tfrac{1}{8}(\Phi(4+(\alpha+\beta)^2)), \qquad m_s^* = \tfrac{1}{2}(\alpha+\beta) \tag{22}$$

[26] In this analysis, the total surplus is in a sense equivalent to some measure of the rate of "technical progress", since both depend only on the amount of per firm innovative activity.

[27] Since m depends only on α and β and on both positively, it follows that $(\partial G/\partial\alpha), (\partial G/\partial\beta) > 0 \Rightarrow (\partial G/\partial M) > 0$.

[28] The social objective function differs essentially from the decentralized problem only in that all research levels are chosen simultaneously.

A comparison of the outcomes in Eqs. (22) and (23) reveals two thought provoking results. First, we observe that the non-cooperative job mobility is "efficient", in that it is *identical* to the socially-optimal rate. This has appealing implications for questioning the standard justifications for restricting the freedom of workers to change jobs. In particular, the standard "appropriability" argument appears to be invalidated. [29] Second, since the job mobility rate is efficient, any possible inefficiencies in this industry can only arise due to disparities in R&D levels. [30] What can we expect regarding the magnitude of this disparity? As shown earlier, the non-cooperative R&D level is inversely related to the spillover parameter β. In contrast, the socially optimal research level depends positively on β. This is because the social optimum maximizes the sum of gains to all firms, and thus internalizes the above spillover externality. One may therefore expect increased job mobility due to higher spillovers (higher β) to widen the gap between the actual and the optimal rates of research. This conjecture, however, ignores the opposing, negative ("race") externality as measured by the parameter v. Comparing Eqs. (20) and (22) shows that the magnitude of the spillover parameter does not provide sufficient information to determine the magnitude of the industry-wide inefficiencies. Specifically, we have

$$r^* = r_s^* \Leftrightarrow v = \frac{2\beta(\alpha+\beta)}{4+\alpha^2-\beta^2} = v^* \tag{23}$$

When $v = v^*$, we can say that externalities are "reciprocated", with the forces leading to under-investment in R&D offsetting those leading to over-investment, allowing the industry to achieve the first best outcome.

The following proposition summarizes the basic matching equilibrium.

Proposition 3. *(i) The equilibrium rate of job mobility is always efficient. (ii) Greater equilibrium job mobility rates correspond to greater social gains. (iii) The equilibrium level of R&D approaches (equals) the efficient level when opposing externalities are of similar (identical) magnitude, i.e. when $v \sim v^*$.*

Thus, in the basic matching case, the existence of reciprocated externalities is both a necessary and sufficient condition for achieving efficient rates of research investment and job mobility.

3.2. Restricted mobility

As shown in the previous section, the rate at which workers changed jobs in equilibrium was identical to the socially-optimal rate. In other words, the lack of formal restrictions on workers' freedom did not lead, as one might expect, to an overflow of opportunistic job mobility. In order to verify, however, that restrictions on job mobility are detrimental, one must also measure the effect on the level of research. It could be argued that when workers

[29] Section 3.2 further illustrates this point by explicitly prohibiting mobility.

[30] This can be seen directly by expressing the maximized social gains (per firm) as $G^* = \arg\max_r\{[(r\Phi(4+(\alpha+\beta)^2))/8] - r^2/2\}$.

must stay at their jobs, firms can better appropriate the returns from their investment and will thus invest more in research. This section examines the overall effect of restricting job mobility.

Mobility restrictions could be due to many factors, ranging from high search or moving costs of, to contractual limitations. This section assumes that job mobility is completely *prohibited*, so the mobility rate equals zero by construction. Thus, firms are "stuck" with whatever match they receive in the first period. The firm's maximization problem is considerably simplified to

$$\max_r \left\{(1+v)\tfrac{1}{2}r\Phi - v\bar{x} - w - \tfrac{1}{2}r^2\right\} \tag{24}$$

which yields the equilibrium per firm research and surplus levels

$$r_z^* = (1+v)\tfrac{1}{2}\Phi, \qquad G_z = \tfrac{1}{8}\Phi^2(1-v^2) \tag{25}$$

with the subscript 'z' denoting the zero mobility case.

A quick comparison of Eq. (25) with Eqs. (20) and (21) reveals the following proposition.

Proposition 4. *(i) Complete restriction of worker-mobility may either increase or reduce the level of R&D. (ii) Regardless of the effect on research, the net effect of this restriction on total gains from trade is negative*.

To verify (ii), note that $G \geq G_z \Leftrightarrow (4+\alpha^2-\beta^2)(4+\alpha^2)(1-v)+4\alpha\beta+\beta^2(3+v) \geq 16(1-v)$, which holds for all parameter values $\alpha, \beta, v \in [0, 1]$. The intuition for this result is that although prohibited mobility assures firms of protecting their investments, it also penalizes them. The "penalty" manifests in their inability to gain access to workers whose movement would improve the (expected) welfare of all sides involved: the worker, the worker's home firm, and the worker's destination firm. Another way of saying this is that workers play a crucial *pollinating* role in the optimal creation and dissemination of information. Thus, although firms may find it optimal to *individually* restrict the mobility of their own workers, legal mechanisms which universally *prohibit* such restrictions may be desirable in a large variety of settings.

3.3. A duopoly game

The majority of this paper assumes a competitive setting with many firms, bypassing several strategic issues related to technological innovation. In particular, a large number of firms implies that no individual firm can influence industry-wide research and/or wage levels. This section presents a short excursion into a duopoly model where strategic considerations play a more dominant role.

An example we can imagine is of two suppliers, firm i and firm j, who produce and sell a particular computer part to many computer assemblers. As before, each firm attempts to improve its' product quality through investment in innovation. The algorithm for calculating equilibrium wages is the same as in the basic case. However, each firm must now account explicitly for its rival's research level in calculating the threshold match-quality level, q^*.

Firm i would thus solve the following equation for q_i^*:

$$(1+v)r_i q_i^* - v r_j \left(\tfrac{1}{2}\Phi\right) = (1+v)(\alpha r_i + \beta r_j)\tfrac{1}{2}\Phi - v(\alpha r_j + \beta r_i)\tfrac{1}{2}\Phi \tag{26}$$

which yields

$$q_i^* = \frac{\Phi[(1+v)(\alpha r_i + \beta r_j) + v((1-\alpha)r_j - \beta r_i)]}{2(1+v)r_j} \tag{27}$$

and in symmetric equilibrium, where $r_i = r_j = r^*$,

$$q_i^* = q_j^* = \frac{\Phi(v+\alpha+\beta)}{2(1+v)} \tag{28}$$

As before, the probability that a firm will want to exchange workers equals q^*/Φ, where q^* is now given by Eq. (28). As before, this probability is not a monotonic function of firm R&D levels. Recall that in the basic case, this probability was equal to $(\alpha+\beta)/2$ (see Eq. (20)). Note that $((v+\alpha+\beta)/2(1+v)) < (\alpha+\beta)/2 \Leftrightarrow \alpha+\beta > 1$. That is, we observe that duopolists' desire to terminate their current match depends on the magnitude of the feedback effect generated through the impact on their rival's productivity. When this effect is large enough (i.e. $\alpha+\beta > 1$), firms will be more eager to retain their own worker than in the competitive case. However, in contrast to the competitive framework, in a duopoly, the *probability* that firms wish to exchange workers *does not* equal the actual probability of job mobility. This is because duopolists have only one potential "trade partner", so *both* firms must desire an exchange in order for such an exchange to take place. Thus, duopoly mobility rate equals $(q_i^*/\Phi)(q_j^*/\Phi) = (q^*/\Phi)^2 = [(v+\alpha+\beta)/2(1+v)]^2$, considerably lower than desired by individual firms (and workers), and virtually always lower than the competitive equilibrium mobility rate $(\alpha+\beta)/2$.

This brief exercise reveals a labor market "friction" associated with small numbers of firms. Increasing the number of firms increases each firm's probability of successfully completing a desired worker exchange. In the limit, approaching a continuum of firms, the representative firm's probability of completing such an exchange approaches one, reverting to the basic case analyzed in Section 3.1. Consequently, even without explicit output-market inefficiencies,[31] there is an additional loss of surplus associated with small numbers of firms.

3.4. An ability game

The analysis has thus far assumed that variations in productivity levels depend entirely on variations in random matching outcomes. This assumption is now relaxed, allowing a more general approach that accounts for possible differences in workers' *inherent* abilities. Accounting for such differences, a high observed productivity could occur either as a result of a high match quality, or a high inherent worker ability. The degree to which inherent abilities are present will impact the results of this model.

[31] Although this is a duopoly, we are continuing to assume a competitive output market in the sense that firms face flat demands.

Formally, recall that match quality is given by $K = \rho Q_1 + (1-\rho)Q_2$, where Q_1 is the match quality at the first firm, ρ is the correlation of abilities across firms, and Q_2 is the match quality at the second firm. Q_1 and Q_2 are two iid random variables uniformly distributed on $[0, \Phi]$. As ρ increases from 0 to 1, workers' inherent abilities play an increasingly significant role. In the extreme case where $\rho = 1$, *only* abilities matter. In that case each worker has exactly the same ability at any firm, eliminating firm heterogeneity from the picture. As found in Section 2.2.2, the employment threshold for the generic ability game where ρ varies in [0, 1] is

$$q^* = \frac{(1-\rho)(\alpha r + \beta \bar{r})\Phi}{2r - \rho(\alpha r + \beta \bar{r})} \tag{29}$$

Since the job mobility rate, m, depends uniquely on the threshold q^*, the percentage of workers changing jobs in symmetric equilibrium (where $r = \bar{r}$) equals

$$m_{\mathrm{a}}^* = \frac{(1-\rho)(\alpha+\beta)}{2-\rho(\alpha+\beta)} \tag{30}$$

To solve for the equilibrium level of R&D, substitute q^* into the firm's maximization problem

$$\max_r \left\{(1+v)\left[\left(1-\frac{q^*}{\Phi}\right)\left(r\frac{q^*+\Phi}{2}\right)+\frac{q^*}{\Phi}(\alpha r+\beta\bar{r}) \times\left(\left(\rho\frac{q^*}{2}+(1-\rho)\frac{\Phi}{2}\right)\right)\right]-\frac{r^2}{2}\right\} \tag{31}$$

yielding [32]

$$r_{\mathrm{a}}^* = \frac{\Phi(1+v)\alpha^2(1-\rho^2)-2\alpha\rho(2-\beta\rho)+\alpha^2\rho^2+(2-\beta)(2-\beta(2\rho-1))}{2[2-\rho(\alpha+\beta)]^2} \tag{32}$$

We observe that the mobility rate m_{a}^* is strictly decreasing with respect to ρ. As ρ increases, firms only want to retain relatively high ability workers, producing an adverse selection problem in the outside labor market. This reduces firms' employment threshold even further, implying less workers on the outside market and resulting in a lower mobility rate.

3.4.1. Efficiency

The welfare maximizing employment threshold is obtained by solving

$$rq^* = (\alpha r + \beta\bar{r})\left(\rho q^* + (1-\rho)\tfrac{1}{2}\Phi\right) \tag{33}$$

to arrive at

$$q_{\mathrm{sa}}^* = \begin{cases} \dfrac{(1-\rho)(\alpha+\beta)\Phi}{2-2\rho(\alpha+\beta)} & \text{if } \rho \le \min\left\{\dfrac{1}{\alpha+\beta}, \dfrac{2-\alpha-\beta}{\alpha+\beta}\right\} \\ \Phi & \text{otherwise} \end{cases} \tag{34}$$

[32] In calculating the expected productivity of an outside worker, given by $(\rho(q_{\mathrm{a}}^*/2)+(1-\rho)Q/2)$ above, the firm takes $q_{\mathrm{a}}^* = [(1-\rho)(\alpha R+\beta R)Q]/[2R-\rho(\alpha R+\beta R)] = [(1-\rho)(\alpha+\beta)Q]/[2-\rho(\alpha+\beta)]$ as a given constant, since it depends exclusively on the R&D choices of other firms.

The right-hand side of Eq. (34) represents the parameter restrictions that must be satisfied to guarantee a mobility rate strictly less than one. As shown, when ρ is large enough, it is optimal for *all* workers to change jobs. Substituting q^*_{sa} into the welfare maximization function:

$$\max_r \left\{ \left(1-\frac{q^*_{\mathrm{sC}}}{\Phi}\right)\left(r\frac{q^*_{\mathrm{sC}}+\Phi}{2}\right)+\frac{q^*_{\mathrm{sC}}}{\Phi}r(\alpha+\beta)\left(\left(\rho\frac{q^*_{\mathrm{sC}}}{2}+(1-\rho)\frac{\Phi}{2}\right)\right)-\frac{r^2}{2}\right\}$$

produces the efficient outcome for the ability game:

$$(m^*_{\mathrm{sa}}, R^*_{\mathrm{sa}}) = \begin{cases} \left(\dfrac{(1-\rho)(\alpha+\beta)}{2-2\rho(\alpha+\beta)},\right. & \\ \quad \left.\Phi\left(\dfrac{1}{2}+\dfrac{[(1-\rho)(\alpha+\beta)]^2}{8(1-\rho(\alpha+\beta))}\right)\right) & \text{if } \rho \le \min\left\{\dfrac{1}{\alpha+\beta}, \dfrac{2-\alpha-\beta}{\alpha+\beta}\right\} \\ \left(1, \tfrac{1}{2}\Phi(\alpha+\beta)\right) & \text{otherwise} \end{cases} \tag{35}$$

Partial derivatives show that the mobility rate m^*_{sa} is increasing in ρ-the reverse from the non-cooperative-equilibrium. This is because it is socially desirable for a worker to move whenever it creates an increase in *net* expected surplus for the original firm *plus* the new hiring firm. It ignores the effect of this movement on any individual firm's surplus. Thus, a stronger inherent-ability component (i.e. a bigger ρ), implies increased divergence between social and firm-level incentives.

The ability game is summarized as follows.

Proposition 5. *With* $0 < \rho < 1$, *the equilibrium mobility rate is always below the socially optimal rate, leading to an inefficiency*.

Proof. By simple inspection

$$m^*_{\mathrm{a}} = \frac{(1-\rho)(\alpha+\beta)}{2-\rho(\alpha+\beta)} < \frac{(1-\rho)(\alpha+\beta)}{2-2\rho(\alpha+\beta)} = m^*_{\mathrm{sa}}, \quad \forall \rho \in (0,1] \qquad \square$$

The inefficiency in the ability game is due to a discrepancy between optimal and actual job mobility rates. This discrepancy is a result of adverse selection in the labor market. In equilibrium firms retain more of their own workers then is socially desirable. This inefficiency cannot be eliminated through "reciprocal externalities" and will thus persist regardless of the rat-race intensity.

4. Conclusions

This paper examines job mobility as a vehicle for intra-industry knowledge dissemination. It emphasizes firms' inability to exercise property rights over R&D knowledge, enabling workers to profit from this knowledge through job mobility. The analysis differs from a typical training and human capital story by considering the duplicative nature of knowledge — two firms may utilize the same knowledge simultaneously. Specifically, a firm benefits from information generated by a worker's research even after that worker leaves. This duplicative element is a critical determinant of both R&D investment and job mobility, which together describe the equilibrium. Market performance viś a viś the efficient benchmark is measured along these two dimensions.

Poorly defined property rights typically imply incorrect incentives for investment. Standard reasoning suggests that unrestricted mobility adversely affects appropriability of research investments, thus hindering technical progress. Several results of this paper clash with this line of reasoning. First, equilibrium mobility is not strictly negatively correlated with R&D investment. Second, contrary to standard intuition, the non-cooperative outcome does not produce a flood of opportunistic mobility. In fact the equilibrium mobility rate never exceeds the socially optimal rate, and exactly equals it under certain conditions. Third, and perhaps most intriguing, changes in informational factors associated with increased mobility rates also generally correspond to greater social gains.

No *causal* relationship between job switching and technological progress is posited. Rather, these results are meant to provide economic rationale behind the coexistence of high rates of job mobility along with intense innovative activity. To complete the analysis, I present a variation of the model where worker mobility is *prohibited*, and show that this restriction unambiguously reduces total social welfare. The intuition for this result relies on recognizing the fact that restrictions on worker mobility act as a double edged sword. While protecting firms against defecting workers, these restrictions also deny firms access to better matches with *outside* workers, in essence constituting a self-imposed penalty. This result calls for a more thorough investigation of when (and if so which) restrictions on worker mobility should be tolerated.

This paper also emphasizes effects associated with mobility-related externalities. Economic theory makes clear-cut predictions regarding the effect of externalities on incentives to invest in information. Positive externalities such as mobility-related knowledge spillovers lead to under-investment. This paper proposes that negative, rat-race type externalities exist in most "typical" innovative markets to counter these spillovers. The race aspect arises because one determinant of profitability is measured purely by the firm's performance relative to its rivals. These opposing external effects have been referred to as the "appropriability" and "business-stealing" effects (e.g. Tirole, 1988) or more classically as the "public good" and the "commons" effects (e.g. Hirshleifer and Riley, 1992), respectively. The equilibrium investment level is the net outcome of these two effects. Very little existing research deals explicitly with environments containing both forces. The existence of opposing, "reciprocal" externalities produces two intriguing, although perhaps not astonishing results. First, it enables environments with powerful external effects to mimic ones without any external effects. Thus, an efficient outcome can be approximated if the opposing externalities are of similar magnitude. Second, specifically in the context of job mobility, positive externalities may actually reduce inefficiencies by mitigating an otherwise more severe over-investment problem.

Finally, variations on assumptions regarding worker abilities are explored. Differences in worker-productivity can result from either different *inherent* worker abilities or different random matching outcomes (or a combination of both). When differences in inherent abilities are absent (i.e. a pure random-matching game), the equilibrium mobility rate is socially optimal. The introduction of differences in inherent abilities leads to a divergence between private and social interests, translating into greater inefficiencies. In particular, as differences in inherent abilities play an increasing role, the equilibrium mobility rate declines (as firms attempt to hang on to better workers), while the optimal mobility rate increases.

Acknowledgements

I am grateful to my advisor, Joe Ostroy, for many helpful discussions and comments. In addition, I thank Hongbin Cai, Juan Jose Ganuza, Fabio Kanczuk, Federico Weinschelbaum, and seminar participants at UCLA and the National Institute of Standards and Technology. All remaining errors are mine.

Appendix A

A.1. Derivation of the distribution of the random variable $K|m$

For a given mobility rate m, the random variable $K|m$ is simply the sum of two uniformly distributed random variables:

$$K|m = \rho Q_1^{\mathrm{o}}|m + (1-\rho)Q_2$$

The first random variable, $\rho Q_1^{\mathrm{o}}|m$, is uniformly distributed on $[0, \rho q^*]$, where q^* is the critical match quality separating workers who switch jobs from those who stay. Thus, a worker who switches jobs will never have a match quality greater than q^* with his/her original employer. The second random variable, $(1-\rho)Q_2$, is distributed uniformly on $[0, (1-\rho)\Phi]$. Denote these two random variables as Y_1 and Y_2, with probability density functions of

$$f_1(Y_1) = \frac{1}{\rho q^*}$$

and

$$f_2(Y_2) = \frac{1}{(1-\rho)\Phi}$$

respectively. Thus, Y_1 can be rewritten as $K|m - Y_2$. Since Y_1 and Y_2 are independent, the density function $g(K|m)$ of their sum, is calculated by solving the following equation:

$$g(K|m) = \int f_1(K|m - Y_2) f_2(Y_2)\,\mathrm{d}Y_2 = \int \frac{1}{\rho q^*}\frac{1}{(1-\rho)\Phi}\,\mathrm{d}Y_2$$

The solution has two possible cases. In case 1, $\rho q^* < (1-\rho)\Phi$. In this case, the range of $K|m$ is divided into three regions. In the first region, $K|m \in [0, \rho q^*]$. In this region, the possible range of Y_2 is $[0, K|m]$. The second region has $K|m \in [\rho q^*, (1-\rho)\Phi]$. In this region, the possible range for Y_2 is $[K|m - \rho q^*, K|m]$. The final region of $K|m$ is

$[(1-\rho)\Phi, \rho q^*+(1-\rho)\Phi]$. In this region, the possible range for Y_2 is $[K|m-\rho q^*, (1-\rho)\Phi]$. As a consequence, the density function of $K|m$ is rewritten as

$$g(K|m) = \begin{cases} \int_0^{K|m} \dfrac{1}{\rho q^*} \dfrac{1}{(1-\rho)\Phi}\, \mathrm{d}Y_2 & \text{for } K|m \in [0, \rho q^*] \\ \int_{K|m-\rho q^*}^{K|m} \dfrac{1}{\rho q^*} \dfrac{1}{(1-\rho)\Phi}\, \mathrm{d}Y_2 & \text{for } K|m \in [\rho q^*, (1-\rho)\Phi] \\ \int_{K|m-\rho q^*}^{(1-\rho)\Phi} \dfrac{1}{\rho q^*} \dfrac{1}{(1-\rho)\Phi}\, \mathrm{d}Y_2 & \text{for } K|m \in [(1-\rho)\Phi, \rho q^* + (1-\rho)\Phi] \end{cases}$$

which translates into

$$g(K|m) = \begin{cases} \dfrac{K|m}{\rho q^*(1-\rho)\Phi} & \text{for } K|m \in [0, \rho q^*] \\ \dfrac{1}{(1-\rho)\Phi} & \text{for } K|m \in [\rho q^*, (1-\rho)\Phi] \\ \dfrac{\rho q^* + (1-\rho)\Phi - K|m}{\rho q^*(1-\rho)\Phi} & \text{for } K|m \in [(1-\rho)\Phi, \rho q^* + (1-\rho)\Phi] \end{cases}$$

The second case, where $\rho q^* > (1-\rho)\Phi$, can be analyzed similarly.

A.2. Existence of a symmetric equilibrium requires an upperbound on v: a proof

For the simpler case of restricted mobility (Section 3.2), recall that the firm maximizes $(1+v)r(\Phi/2) - v\bar{r}(\Phi/2) - (r^2/2)$ with respect to r, while treating the industry wide research level, $\bar{r}$ as a constant. This yields the optimal choice $r_{\mathrm{z}}^* = (1+v)(\Phi/2)$, provided that $v \leq 1$, because the symmetric equilibrium payoff is $r_{\mathrm{z}}^*(\Phi/2) - (r_{\mathrm{z}}^{*2}/2) = [(1-v^2)/2](\Phi/2)^2$ which is negative for all $v > 1$. Thus, for large values of v, it would pay each firm individually to deviate and choose $r = 0$ thereby receiving a payoff of zero. But given all other firms choose $r = 0$, the optimal strategy for any individual firm would be to revert to the original choice of $r_{\mathrm{z}}^* = (1+v)(\Phi/2)$. Thus, for $v > 1$, a symmetric Nash equilibrium does not exist. The argument in the basic case (Section 3.1) is identical. It produces an upper bound of

$$\bar{v} = \frac{4+\alpha^2+4\alpha\beta+3\beta^2}{4+\alpha^2-\beta^2} > 1$$

References

Ackerloff, G., 1976. The economics of caste and of the rat-race and other woeful tales. Quarterly Journal of Economics 90, 599–617.

Allen, R.C., 1983. Collective invention. Journal of Economic Behavior and Organization 4, 1–24.

American Law Institute, 1939. Restatement of Torts, Section 757.

Angel, D., 1989. The labor market for engineers in the US semiconductor industry. Economic Geography 65 (2), 99–112.

Arrow, K.J., 1962. Economic welfare and the allocation of resources for invention. In: The Rate and Direction of Inventive Activity. Princeton University Press, New York.

Becker, G., 1964. Human Capital National Bureau of Economic Research, New York.

Bresnahan, T., 1986. Measuring spillovers from technical advance: mainframe computers in financial services. American Economic Review 76, 742–755.

Carnoy, M., Castells, M., Benner, C., 1997. Labour markets and employment practices in the age of flexibility: a case study of Silicon Valley. International Labour Review 136 (1), 27–48.

Chang, C., Wang, Y., 1995. A framework for understanding differences in labor turnover and human capital investment. Journal of Economic Behavior and Organization 28, 91–105.

Cheung, S., 1982. Property rights in trade secrets. Economic Inquiry 20 (1), 40–53.

Cohen, W., Levin, R.C., 1989. Innovation and market structure. In: Schmalansee, R., Willig, R. (Eds.), Handbook of Industrial Organization, Vol. I. North-Holland, Amsterdam, pp. 1060–1107.

Cohen, W., Levinthal, D., 1989. Innovation and learning: the two faces of R&D. Economic Journal 99, 569–596.

Cole, H.L., Mailath, G.J., Postlewaite, A., 1998. Efficient non-contractible investments. University of Pennsylvania CARESS Working Paper #98-13.

Cooper, D.P., Kiousis, P.K., 1997. Strategic knowledge protection: endogenous spillovers in duopoly. Mimeo, UCLA.

Cuvillier, R., 1977. Non-competition and non-disclosure obligations: bond or bondage for the employee. International Labor Review 115 (2), 193–209.

D'Aspremont, C., Jacquemin, A., 1988. Cooperative and noncooperative R&D in a duopoly with spillovers. American Economic Review 78, 1133–1137.

DeBondt, R., Slaets, P., Cassiman, B., 1992. The degree of spillovers and the number of rivals for maximum effective R&D. International Journal of Industrial Organization 10, 35–54.

Feinstein, J., Stein, J., 1988. Employee opportunism and redundancy in firms. Journal of Economic Behavior and Organization 10, 401–414.

Greenwald, B., 1986. Adverse selection in the labor market. Review of Economic Studies LIII, 325–347.

Hirshleifer, J., 1971. The private and social value of information and the reward to inventive activity. American Economic Review 61, 561–574.

Hirshleifer, J., Riley, J., 1992. The Analytics of Uncertainty and Information. Cambridge University Press, Cambridge.

Holmstrom, B., 1982, Managerial incentive problems — a dynamic perspective. In: Essays in Economics and Management in Honor of Lars Wahlbeck. Swedish School of Economics, Helsinki.

Katz, M., 1986. An analysis of cooperative R&D. Journal of Economics 17, 527–543.

Katz, E., Ziderman, A., 1990. Investment in general training: the role of information and labor mobility. The Economic Journal 100, 1147–1158.

Lamoreaux, N., Sokoloff, K., 1999. Inventors, firms and the market for technology: US manufacturing in the late 19th and early 20th centuries. In: Raff, D., Lamoreaux, N., Temin, P. (Eds.), Learning by Doing in Firms, Markets, and Nations. University of Chicago Press, Chicago.

Levin, R.C., Klevorick, A.K., Nelson, R.R., Winter, S.G., 1987. Appropriating the returns from industrial R&D. Brookings Papers on Economic Activity 783–820.

Mansfield, E., 1986. Patents and innovation: an empirical study. Management Science 32, 173–198.

Merges, R.P., 1998. Property rights theory and employee inventions. Unpublished Manuscript.

Nitzan, S., Pakes, A., 1983. Optimum contracts for research personnel, research employment, and the establishment of rival enterprises. Journal of Labor Economics 1 (4), 345–365.

Reinganum, J., 1989. The timing of innovation: research development and diffusion. In: Schmalansee, R., Willig, R. (Eds.), Handbook of Industrial Organization, Vol. I. North-Holland, Amsterdam, pp. 849-908.

Rogers, E., Larsen, J., 1984. Silicon Valley Fever: Growth of High Technology Culture. Basic Books, New York.

Saxenian, A., 1994. Regional Advantage: Culture and Competition in Silicon Valley and Route 128. Harvard University Press, Cambridge, MA.

Schumpeter, J.A., 1942. Capitalism, Socialism, and Democracy. Harper, New York.

Scott, J.T., 1984. Firm vs. industry variability in R&D intensity. In: Griliches, Z. (Ed.), R&D, Patents, and Productivity. University of Chicago Press for the NBER, Chicago.

Spence, M., 1984. Cost reduction, competition, and industrial performance. Econometrica 52, 101–121.

Trebilcock, M., 1985. Post-employment contractual restraints. Mimeo, Faculty of Law, University of Toronto, Toronto.

Tirole, J., 1988. The Theory of Industrial Organization. MIT Press, Cambridge.

Von Hippel, E., 1988. The Sources of Innovation. Oxford University Press, Oxford.

Zucker, L., Darby, M., Brewer, M., 1998. Intellectual capital and the birth of US biotechnology enterprises. American Economic Review 88 (1), 290–306.