

Favorable Selection in the Labor Market: A Theory of Worker Mobility in R&D Intensive Industries

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Abstract

This paper builds a theoretical model to address evidence on labor mobility patterns in technology-intensive firms engaged in R&D. Labor turnover in these firms is characteristically different from turnover in traditional industries both in size and composition. Specifically, the pool of workers switching employers comprises of relatively productive workers. Our model focuses on distinguishing features of R&D-intensive firms, in particular, the stochastic nature of returns to R&D investment and the transmission of knowledge spillovers through worker movement, to explain patterns of labor mobility in these firms. The analysis also serves as a tool to analyze the role of Non Disclosure Agreements in wage contracts.

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1 Introduction

Recent evidence in some industries, especially those involved in the research and development of new products and processes, indicates that highly productive workers switch employment often during the lifetime of their career.¹ In fact the success of many high technology firms in Silicon Valley has been attributed to worker mobility and the consequent transfer of ideas across firms. In such industries, there appears to be no stigma attached to a worker moving from one firm to another. To the contrary, workers who change jobs frequently are seen as enterprising and talented, while employees who stay in the same firm risk acquiring a reputation as “dead wood” or “lifers” -people who hang around because they are too lazy or not talented enough to receive jobs offers or cold calls from desperate headhunters.² In the words of an engineer, “A man who has not changed companies is anxious to explain why; a man who has (changed companies) perhaps several times, feels no need to justify his actions.” (Saxenian,1994).

The literature on asymmetric learning in labor markets is based on the idea that firms are likely to have greater information about the productivity of their own workers as compared to a new firm that attempts to hire the worker. When workers are always more productive being retained in their old firm, any turnover that occurs is either exogenous (Greenwald, 1986) or due to layoffs (Gibbons & Katz, 1991). Thus, this literature predicts that worker turnover will be composed of low ability workers only. However, as described above, there is strong evidence to suggest that the “marking effect” emphasized by Greenwald, where a worker’s perceived ability decreases with each move to a new firm, is absent in some labor markets.

This paper uses a model of asymmetric information with job levels, stochastic returns on investment

¹In an empirical study of the labor market for engineers in semiconductor firms, Angel (1989) finds that turnover in these firms cannot be explained solely by employment growth in the technology sector.

²See “Tech Employees Jumping Jobs Faster,” CNET News.com, June 14, 2000.

in research and development (R&D henceforth) and knowledge spillovers transmitted through worker mobility to reconcile evidence on the characteristics of worker movements in R&D intensive industries. The key results in the paper are driven by the stochastic nature of the R&D investment outcome and knowledge spillovers that workers carry from their old employment, when they are employed by a new firm. Several papers have focused on different channels by which technological spillovers might be transmitted and the effect that such spillovers have on incentives to innovate. Arrow (1962) was the first study to recognize worker mobility as a distinct source of spillovers. When spillovers are transmitted in this way, worker mobility becomes an important consideration in the strategic interaction between competing firms.

The main argument developed in the current analysis is the following. Workers that are assigned to technically challenging R&D projects carry spillovers in knowledge if they switch employers in the future. Since output in these projects are also likely to be more sensitive to the productivity of the worker, higher ability workers will be assigned to such projects. Stochastic returns on R&D implies that the current firm, which had successful R&D returns in the past, may not have a good R&D project to utilize in the current period. If this happens, the firm will have a pool of highly productive workers who have accumulated R&D experience, but do not have an opportunity to use their knowledge in the current firm. The productivity of such workers will be higher in another firm which has received a good draw of R&D in the current period. The resulting misallocation of worker productivities across firms will make some turnover of high ability workers efficient in our model. When such turnover of productive workers is realized as the equilibrium outcome, we will refer to it as a “favorable selection” of workers in the second-hand labor market. We also analyze the effects of spillovers on the job assignment and investment decisions of the firm.

The model generates a number of interesting results that explain observed empirical facts. First, even

with asymmetric information about worker productivities, the pool of workers changing jobs need not comprise low ability workers. To the contrary, as spillovers become significant, the average productivity of workers who turnover increases. In general, high spillovers lead to a favorable selection of high ability workers in the second-hand labor market, when variability in the returns from investment is high. Since high-technology industries frequently consist of numerous small firms, especially start-ups, with greater unpredictability in returns from innovation, the predictions of our model provide an explanation for the observed nature of labor turnover across these firms.

Second, recent evidence on turnover patterns in high-technology firms contradicts the standard prediction that there is a negative relationship between tenure and turnover rates. Recent empirical studies on technology workers find that tenure is not a significant predictor of turnover and separation rates for workers remain high even at more senior job levels.³ The results of the current analysis can provide an explanation for this finding. Since workers with greater tenure in the firm are more likely to have accumulated R&D knowledge within the firm, they are also more likely to move to a new employment if their current employer has a negative shock in R&D return.

Third, in a study of high-technology firms in Norway from 1986-1995, Moen (2005) finds that excess labor turnover is smaller in firms with higher R&D intensities.⁴ Our model can explain this negative correlation between turnover and R&D investment. The logic is that as investment increases, the benefit from retaining a worker with R&D experience in the current employment is higher. As a result, more workers are retained and turnover is lower.

³See Josefek and Kauffman (2003) and “The Competitive Semiconductor Manufacturing Human Resource Project: Second Interim Report,” Institute of Industrial Relations, University of California Berkeley (1996).

⁴Excess labor turnover refers to hires and quits in the firm over and above what is necessary to explain the change in the number of employees in the firm. Also, Moen measures R&D intensity in the firm as R&D man-years per employee. This measure is correlated with R&D spending in the firm.

The analysis also provides implications for the effect of knowledge spillovers on the efficiency of investment, job assignments and turnover. Given that workers can be more productive in a new firm, job assignment is inefficient even when the current employer can make counteroffers.⁵ The loss of surplus from worker turnover reduces investment incentives.

Finally, the model presented in this paper serves as a useful tool for analyzing the welfare implications of policies that restrict the flow of knowledge between competing firms (Covenant Not to Compete Clause, Non Disclosure Agreements). The central finding here is that contracts with Non Disclosure Agreements maximize industry output when knowledge spillovers are low. Restricting spillovers affects output in two ways. First, investment is enhanced since firms have a greater probability of retaining a worker and earning a positive surplus from her. However, the resulting misallocation of workers across firms lowers output. When spillovers are significant, the latter effect dominates and contracts that allow greater freedom for workers in the transmission of knowledge across firms maximize expected output.

The theoretical framework adopted in this paper draws from models of asymmetric learning with job assignment signaling. Waldman (1984) was the first to analyze the importance of job levels in signaling worker ability to new firms.⁶ If wages are determined by the outside wage offer that the worker receives, promoting a worker will signal to the market that she is of high ability, thereby driving up her wage. This will induce firms to promote fewer workers than is efficient for maximizing output.⁷ We build on Waldman's model of job assignments, but introduce two factors that distinguish our analysis. First,

⁵Golan(2005), in a recent paper has shown that when current employers can make counteroffers, if a worker is always more productive in the old firm, the promotion inefficiency disappears.

⁶See also Ricart i Costa (1988), Bernhardt (1995), Bernhardt & Scoones (1993) and Owan (2004). For empirical evidence on job assignment signaling see Devaro and Waldman (2005).

⁷His model was further extended by Zabojsnik and Bernhardt (2001) where they consider a tournament model of human capital investment and the worker with the highest level of human capital accumulation gets promoted.

firms invest in R&D, the outcome of which is stochastic each period. The second important distinction is that not all workers are more productive in the old firm, since they carry knowledge spillovers from R&D when they move to a new firm. The inefficiency in job assignments, as in Waldman, will be present in the current analysis as well. But, in our model, the inefficiency is driven by the potential loss in R&D knowledge via spillovers and worker mobility across firms.

Spillovers, in our model, have a natural interpretation in terms of general human capital accumulation by workers. Pioneering work in exploring the implications of human capital investment was done by Becker (1964) who argues that firms might be reluctant to invest in general human capital since they cannot appropriate the benefits from these investments. On the other hand, benefits of firm specific human capital accrue entirely to the investing firm. Subsequently, several other papers have explored this question. Chang and Wang (1996) examine the relationship between job mobility and investment in general human capital in an asymmetric information setting. They propose a model where the outside market cannot observe the level of investment in human capital undertaken by the worker. This enables the original employer to appropriate some of the returns from human capital investment, thus providing an incentive to undertake general training investment. Acemoglu and Pischke (1998) derive a negative relationship between turnover of workers and human capital investment. They follow an approach similar to Greenwald where workers quit for exogenous reasons. The unique aspect of our paper is that turnover of workers occurs endogenously in response to stochastic R&D returns.

It is worthwhile to distinguish spillovers from the concept of trade secrets. Zabojnik (2002) develops a model of managerial turnover when managers have access to trade secrets of the firm which they can reveal to a rival firm through turnover. A crucial difference between the concept of trade secrets used in Zabojnik's model and spillovers as interpreted in the context of our model, is that spillovers directly influence the productivity of a worker in a new firm, and worker turnover helps in realizing this increased

productivity. Thus turnover can enhance industry output in an efficient way. By contrast, in Zabojnik's analysis, revealing trade secrets to other firms via turnover is a rent-seeking activity that does not enhance efficiency. Hence our model will have vastly different normative implications for policies that serve to restrict spillovers.

The only other paper to our knowledge that models R&D investment in the presence of spillovers via worker mobility is Cooper (2001). Cooper considers a model where competing firms invest in R&D and workers can switch employers in the event of a bad match with the current employer. When the worker does so, she is able to utilize a part of the R&D investment from her old employment in the new firm. Thus worker mobility helps to internalize spillovers and this mitigates the over-investment inefficiency caused by R&D spillovers. Our crucial point of departure, is the study of the interaction between job assignments and investments in an environment characterized by worker mobility. Thus while Cooper's model predicts that worker mobility will not depend on the level of R&D investment, we find that it does. This occurs, in our model, because firms always have the option of assigning a worker to a lower level job where there is no opportunity for the worker to acquire spillovers, and hence transfer of knowledge through worker turnover is avoided. The loss from misassigning a worker to prevent turnover is directly influenced by the level of investment in the firm. This generates a dependence of turnover on investment in the current specification and thus captures the empirical relationship between these two variables as established by Moen.

The structure of the paper is as follows. In Section 2, the model is outlined. Section 3 describes the equilibrium and efficient outcomes for job assignment, turnover and investment. Section 4 discusses the implications of restricting spillovers via Non Disclosure Agreements negotiated in wage contracts. In Section 5, we compare the predictions of our model to alternative theories of labor turnover. Finally, we conclude in Section 6. All proofs are in the appendix.

2 Model

There is free entry into production, where all firms are ex ante identical and the only input is labor. A worker's career lasts three periods. In each period the worker supplies one unit of labor inelastically. There are an infinite number of firms in the market. There are two job levels in the production hierarchy of firms— job level 1 and job level 2. Job level 2 involves working with technically challenging R&D projects that the firm receives. For ease of exposition we will refer to this job as the “R&D-intensive job”, and job level 1 as the “Non R&D-intensive job”.

In the first period, firms hire workers. We denote the ability of workers as θ . We assume that θ varies uniformly over the interval $[\theta^L, \theta^H]$, $\theta^L < \theta^H$. Firms and workers cannot observe θ . After the worker has been employed in the firm for more than one period, her ability becomes known to her current employer. Firms, however, cannot observe the ability of a new worker in any period. At the end of the first period firms invest $I \in [0, \bar{I}]$ in R&D. There is an increasing and convex cost function for R&D investment denoted by $c(I)$ with $c(0) = 0$ and $\lim_{I \rightarrow \bar{I}} c'(I) = \infty$.

In every period following the investment, there is an exogenous probability, $p \in (0, 1)$, that the firm will receive a successful R&D project to utilize its investment.⁸ The probability of a successful draw in any period is independent of the outcome in the previous period. If there is a successful draw, the return from the investment is rI , with $r > 1$. If the outcome of the draw is not successful in any period, the return from the investment is zero. The outcome of the return to investment is observable to all firms in every period.

Without loss of generality, we will refer to the current employer firm as i and a new employer as j .

⁸We implicitly assume that there are an infinite number of firms in the industry. This will ensure that there is always at least one firm that has a good return on its investment in any period. This is because the probability that all firms have zero returns on investment goes to zero. If n is the number of firms, $\lim_{n \rightarrow \infty} (1 - p)^n = 0$

The productivity of a worker in job level 1 is independent of her ability. For a worker who has been employed in firm i for τ periods, her output in job level 1 is

$$y_i^1 = x(1 + s_\tau),$$

where $x > 0$, $s_\tau = 0$ for $\tau = 0$ and $s_\tau = s$ for $\tau > 0$. That is, a worker who has been in a firm for more than one period accumulates firm specific human capital of s which increases the output she produces multiplicatively.

The output of worker k assigned to job level 2 in her current employment in period t , is

$$y_{itk}^2 = \theta_k(1 + s)(r_{it} + \alpha r_{it-1})I,$$

where r_{it} is the return from R&D investment in period t and $\alpha > 1$ denotes the continued internal utilization of the firm's previous period R&D return. In our model, a worker assigned to job level 2 does not produce anything if the firm does not realize a positive return on its investment.⁹

For worker k from firm i , output in a job level 2 position in a new firm j in period t is

$$y_{jtk}^2 = \theta_k(r_{jt} + \beta r_{it-1})I,$$

where $\beta > 1$ denotes knowledge spillovers carried to a new firm by a worker who has accumulated research experience from working at job level 2 in her old employment. We assume that $\beta < \alpha$, i.e. current employers with successful R&D can utilize their workers' research experience better than a new firm.¹⁰

⁹The results would remain unchanged if the output in job level 2 had a component that was independent of the R&D return, as long as the output of the highest ability level worker in job level 1 is sufficiently higher than her output in job level 2 when the firm has zero returns on R&D.

¹⁰See Moen (2005) for an empirical justification of this assumption.

We will make the following assumption to ensure that a worker about whom the firm has no information will be assigned to job level 1

$$\frac{\theta^H + \theta^L}{2} (\alpha + 1) (1 + s) r \bar{I} < x.^{11}$$

We also impose some structure on the cost function in order to ensure that firms choose a unique and positive level of investment in the first period equilibrium.¹²

The timing of events is as follows. In the first period, firms hire workers. Since a worker does not produce any output in job level 2 in the absence of an R&D investment, all workers are assigned to job level 1 in period 1. At the end of period 1, firms invest in R&D. In the beginning of period 2, the firms' R&D outcome is realized. Firms announce job assignments for each of their workers. The outside market makes wage offers to new workers. Each firm can make counteroffers to the workers that it wishes to retain. Workers accept the highest wage offer, and stay with the same firm if indifferent. The same sequence of events as in period 2, repeats in period 3. After period 3, the game ends.

In this set-up two aspects deserve attention. First, note that it is the presence of R&D spillovers in conjunction with the uncertainty in R&D outcome that induces turnover of workers in period 3. Workers who accumulate research experience are high ability workers employed in firms with past successes in R&D. These workers become more useful in other successful R&D firms if their old employer gets a bad draw of R&D return in any period. Hence we observe relatively higher ability workers moving to

¹¹The conditions on α are sufficient conditions for our equilibrium. A weaker condition would be to assume that β is high relative to the firm specific human capital s . The restrictions are imposed in terms of α since this determines the upper bound for β .

¹²A sufficient condition to guarantee that the total expected surplus from a worker at the end of period 1 is concave in I , is to assume that costs are convex enough. In particular, we assume that $c''(I) I^3 \geq \frac{x}{r^2} \frac{(1+s)(\alpha+2)}{\theta^H - \theta^L}$ for every $I \in [0, \bar{I}]$.

new firms, and the average ability of workers who change employment increases as spillovers become larger. The R&D investment decision of the firm will then depend on the extent of turnover that occurs. Second, the inefficiency in promotions arises because assigning the worker to a higher level job increases her productivity in all firms. If firms have successful R&D returns in any period, not promoting a worker entails a cost in terms of lost utilization of returns from R&D investment. At the same time assigning a worker to the higher level job increases the probability that the firm will lose the worker to a new firm in the third period if it does not realize successful returns on its investment. The greater the former effect the lower will be the inefficiency in promotion decisions.

3 Analysis

In this section we will solve for the outcome of this model by backward induction. The solution concept used is Perfect Bayesian Equilibrium.

3.1 Job Assignments and Turnover

In order to derive the job assignment and turnover outcomes for period 2 and 3 we will take as given the symmetric equilibrium investment of firms in period 1, I^* . Later we derive the equilibrium investment explicitly. We represent the R&D outcome history of firm i in period 3 by the tuple (r_{i2}, r_{i3}) , where each takes the value of r or zero depending on whether the R&D draw was successful or not in periods 2 and 3 respectively. Thus, a firm with history (r, r) had successful outcomes in both periods. History $(r, 0)$ means the firm had a positive return in period 2 but not in period 3. The four possible histories that a firm can have in period 3 are (r, r) , $(r, 0)$, $(0, r)$ and $(0, 0)$. Also, we will refer to workers who have worked in a job level 2 position in a firm that had successful R&D as workers with “R&D experience”.

Turnover of workers can occur only if worker productivity is higher in another firm. In firms with

history (r, r) , and $(0, r)$, the worker is always more productive in the old employment due to better internal utilization of research experience and the firm specific human capital accumulated by the worker. Hence turnover will never occur in these two cases. In the case where a firm has history $(0, 0)$, turnover will not occur simply because the firm does not have an incentive to assign any worker to job level 2 in either period and a worker with no R&D experience is always more productive with her original employer. Hence, the only case where turnover can occur is when a firm realized a high draw in period 2, but did not receive successful returns in period 3, i.e. in firms with history $(r, 0)$.¹³ In such firms, workers may be more productive in another firm if the spillovers they carry are high enough. Since we are interested in considering all possible ranges of β where promoted workers are more productive in a new firm, we will assume that the firm specific human capital is low enough to allow these situations to arise. Thus, we will restrict $s < \frac{1}{\alpha}$.

In the following proposition, we describe the conditions under which turnover of workers can occur.

Proposition 1 *Suppose that workers with $\theta \geq \hat{\theta}_2$, $\hat{\theta}_2 \in (\theta^L, \theta^H)$, were assigned to job level 2 in period 2 in firms with $r_{i2} = r$. Then, there exists $\hat{\beta} \in [0, \alpha]$, such that given the possible histories of R&D realizations, turnover occurs in period 3, if only if a firm has R&D outcome history $(r, 0)$ and $\beta \geq \hat{\beta}$ where*

$$\hat{\beta} = \alpha(1 + s) - 1.$$

There are two factors that determine how productive a worker with R&D experience is in the current firm with R&D outcome history $(r, 0)$ – the firm specific human capital, s , and internal utilization of

¹³Shih (2004), in a survey of work organization in Silicon Valley, notes that engineers are expected to manage their own careers and keep up to date with technology whether by staying in the same firm or moving to another firm if there are better opportunities outside. This provides some evidence that worker turnover is more likely to occur in firms that, currently, do not have challenging projects for their workers.

R&D experience, α . The productivity of the worker at a new firm depends on the magnitude of the spillover parameter. The greater the spillovers, β , compared to α and s , the greater the expected productivity of the worker in a new firm relative to her productivity in the current employment.

Since we are interested in characterizing the turnover of workers in the model, for the rest of the analysis in this paper we will restrict attention to the case where turnover occurs in period 3. Thus, we will focus attention on firms that have R&D outcome history $(r, 0)$ with $\hat{\beta} \leq \beta \leq \alpha$. We further assume that $\frac{1}{\alpha+1} \leq p \leq 1$. This restriction ensures that the probability of a successful investment return in the future is high enough so that a positive measure of workers is promoted in firms that received a good draw on its investment in period 2.

Proposition 2 describes the equilibrium outcome for periods 2 and 3 in a firm with R&D outcome history $(r, 0)$.

Proposition 2 *For a firm with R&D history $(r, 0)$, the equilibrium outcome for job assignment and turnover in periods 2 and 3 has the following properties:*

(a) *In period 3, there exists $\hat{\theta}_3 \in [\frac{x}{rI^*}, \theta^H]$ such that a worker with ability θ moves to a new firm if and only if $\frac{x}{rI^*} \leq \theta \leq \hat{\theta}_3$ where*

$$\hat{\theta}_3 = \frac{x}{rI^*} \frac{\beta + 1}{2\alpha(1 + s) - \beta - 1}$$

In the new firm they earn a wage given by $w_3^2(r, 0) = \hat{\theta}_3 \alpha (1 + s) r I^$.*

(b) *All workers with $\theta < \frac{x}{rI^*}$ are retained in job level 1 at a wage of x and workers with $\theta > \hat{\theta}_3$ are retained in job level 2 at a wage of $w_3^2(r, 0)$.*

(c) *In period 2, all workers are retained in the same firm and a worker with ability θ is promoted to job level 2 if and only if $\theta \geq \frac{x}{rI^*}$. A promoted worker is paid a wage given by*

$$w_2^2(r) = x + px(\alpha(1 + s) + s - \beta).$$

A worker retained in job level 1 receives a wage of $x(1 + s)$.

Proposition 2 yields a number of insights about the characteristics of labor turnover in these firms. First, note that in the period 3 outcome in firms with history $(r, 0)$, it is not the lowest ability workers who are moving to new firms. Since a firm will promote its better workers in period 2, such workers will gain R&D experience. Potentially, they can be more useful in another firm in period 3. Hence it is these workers who turnover ($\frac{x}{rT^*} \leq \theta \leq \hat{\theta}_3$).¹⁴ Contrary to the predictions by Greenwald, the lowest ability workers are the ones who are the least likely to change firms. This is because in our model, turnover is efficient only if the worker has accumulated spillovers from working in an R&D-intensive job. Since lower ability workers are less likely to be assigned such jobs in period 2 they are also less likely to turnover in period 3. Also, as spillovers increase it becomes increasingly costly for the old firm to retain workers with R&D experience, since the wage they command in the outside market increases. This leads to greater turnover.

Second, there is no turnover in any firm in period 2. Turnover occurs only in period 3 after a measure of workers have acquired knowledge spillovers from being employed in R&D-intensive jobs in period 2. Thus, our results provide an explanation for empirical evidence on the absence of a negative relationship between tenure and turnover. Since promotions occur in the later part of the worker's career and knowledge spillovers that determine her productivity in a new firm are tied to promotions, turnover does not decrease with tenure. We examine this finding in greater detail in Section 5 where we compare our analysis to other models of turnover.

Third, an intuitive result that emerges from Proposition 2 is that as investment increases, the proportion of workers who turnover decreases since the benefit from retaining workers with R&D experience

¹⁴This result is similar to Perri (1995) where he shows that the winner's curse phenomena that arises when a firm can make counteroffers disappears when job assignments signal ability and there is some exogenous turnover.

is greater when investment is higher. The probability that a worker moves to a new firm is $\hat{\theta}_3 - \frac{x}{rI^*}$.

After substituting for $\hat{\theta}_3$, the expression that denotes this probability is

$$\Pr\left(\frac{x}{rI^*} \leq \theta \leq \hat{\theta}_3\right) = 2\frac{x}{rI^*}(\beta + 1)\frac{\beta + 1 - \alpha(1 + s)}{2\alpha(1 + s) - \beta - 1}.$$

The above expression is decreasing in I^* . As I^* increases, the benefit from retaining a worker with R&D experience in the current employment is higher. As a result, more workers are retained and turnover is lower. Thus, the model captures the negative dependence of R&D investment and turnover found by Moen (2005).

In the first period, all firms are identical with respect to the information they have concerning worker abilities. Due to competition for workers in the external labor market, firms make zero profits and all workers are paid their total expected surplus from all three periods, given the investment that the firm will undertake at the end of the period. Since all workers are assigned to job level 1 by assumption the expected output from a worker in period 1 is $x(\theta^H - \theta^L)$. Suppose the expected surplus from a worker in period 2 and period 3 is given by $\pi(I^*)$, the first period wage is thus

$$w_1 = x(\theta^H - \theta^L) + \pi(I^*).$$

3.2 Investment in R&D

In this subsection we derive the equilibrium R&D investment in period 1. Given the structure we have imposed on costs, the R&D investment chosen by firms will be high enough to make it worthwhile to promote a positive measure of workers if the firm has a successful R&D draw in any period. If $\pi^{r_2 r_3}$ denotes the expected surplus across periods 2 and 3 from a worker of unknown ability if the firm realized a R&D outcome vector of (r_2, r_3) , then the total expected profit from investing I in R&D in period 1 is

$$\pi(I) = (1 - p)^2 \pi^{00}(I) + p(1 - p) [\pi^{0r}(I) + \pi^{r0}(I)] + p^2 \pi^{rr}(I) - c(I).$$

In the following proposition we compare the equilibrium level of investment and promotion with the efficient level.¹⁵ We will assume that the profit function is such that a positive measure of workers are promoted in period 2 at the equilibrium level of investment chosen by the firms in period 1.¹⁶

Proposition 3 *The equilibrium levels of investment and job assignment are inefficient and the inefficiency increases as spillovers become larger.*

Similar to what was found by Waldman (1984), period 2 promotions are inefficient in firms that had successful R&D that period. But now the inefficiency arises because promoting a worker raises the wage that she can command in the next period due to the spillovers from R&D experience that she can potentially utilize in a new firm. Hence, the firm's incentive to promote is lower than the output-maximizing incentive.

Note that spillovers have a salutary effect on the efficient investment level in the industry since it increases the productivity of promoted workers in period 3. On the other hand, large spillovers lower the investment level chosen by the firms. Hence, as β increases, the difference between the efficient investment level and the equilibrium level widens. Now as investment levels fall due to higher spillovers, fewer workers are promoted. On the other hand, efficiency requires that more workers should be assigned to job level 2, both due to a direct effect on output of an increase in β and also the consequent increase in the efficient investment level in period 1. This means that the efficient and equilibrium promotion cut-offs also diverge as β increases.

The effect of spillovers on the promotion cut-off provides an interesting result concerning the relationship between spillovers and the average ability of the turnover pool in period 3. This is formalized in the following proposition.

¹⁵In the current analysis, efficiency refers to maximization of expected output.

¹⁶See Proof of Proposition 3 in the Appendix for a detailed description of the conditions.

Proposition 4 *The average ability of a worker from a firm with R&D outcome history $(r, 0)$, who changes employers in period 3, increases as spillovers increase.*

Equilibrium investment decreases as spillovers increase. This is intuitive since spillovers only affect the wages that have to be paid out in period 3. The greater is β , the lower is the value of a marginal increase in investment expenditure. As spillovers increase the cut-off ability level of the worker who changes employment increases, i.e. $\hat{\theta}_3$ increases. At the same time the adverse effect on equilibrium investment means a lower benefit from promoting a worker in period 2. Hence the ability level of the marginal promoted worker in period 2 also increases. Thus, as spillovers increase, we are likely to find better and better workers changing employers.

3.3 Turnover Efficiency: The Case of Favorable Selection

Asymmetric information about worker abilities in the presence of spillovers also leads to a third kind of inefficiency, namely inefficient turnover resulting from a misallocation of workers across firms. Specifically, consider the outcome in firms with R&D history $(r, 0)$ in period 3. All workers with research experience from such firms are more productive in a firm that has successful R&D returns in period 3. Hence efficient turnover will mean that all workers with research experience in firms with $r_{i3} = 0$, should turnover. In the following analysis, we look at conditions that lead to efficient turnover in period 3, abstracting away from the investment and promotion inefficiencies that occurred in the previous two periods.¹⁷

The nature of the relationship between spillovers, turnover and investment highlighted in Propositions 3 and 4 suggests that for spillovers high enough, firms that realize R&D outcome $(r, 0)$ in period

¹⁷Allocation of workers across firms is inefficient in period 2 as well. For example, high ability workers in firms with $r_{i2} = 0$, should be assigned to job level 2 positions in firms that have $r_{i2} = r$.

3 may not find it worthwhile to retain any promoted worker. In this case, all workers with $\theta \geq \frac{x}{rI^*}$ will turnover leading to a favorable selection of workers in the second-hand labor market. In other words, given the set of workers who are promoted, the allocation of workers across firms in period 3 becomes efficient.¹⁸

Under our assumptions, the highest level of spillovers that the worker can carry to a new firm is α . This will be the case when R&D knowledge is perfectly substitutable across different industries. Let \hat{I} represent the lowest level of investment such that a firm with history $(r, 0)$ finds it worthwhile to retain a positive measure of workers with R&D experience when $\beta = \alpha$. Then such a firm will not find it worthwhile to retain any worker with R&D experience in period 3 if the equilibrium investment level falls below \hat{I} . The equilibrium investment level chosen by firms in period 1 in turn depends on the probability of a successful draw, p . Thus the composition of turnover will depend on both the level of spillovers and the probability of a positive return on R&D investment.

The following proposition describes the conditions under which we will see a favorable selection of workers in the turnover pool.

Proposition 5 *There exist ψ_1 and ψ_2 , with $\psi_1 < \psi_2$, and $\hat{p} \in \left[\frac{1}{\alpha+1}, 1\right]$, such that if*

$$(i) \ c'(\hat{I}) > \psi_2, \text{ or}$$

$$(ii) \ \psi_1 < c'(\hat{I}) < \psi_2 \text{ and } \frac{1}{\alpha+1} < p \leq \hat{p},$$

then in period 3, for spillovers high enough, all workers with ability $\theta \geq \frac{x}{rI^}$ from firms with R&D outcome $(r, 0)$ turnover in period 3.*

The above proposition suggests that we should observe turnover of highly productive workers in industries where knowledge spillovers and variance in returns to investment are high. For spillovers

¹⁸Investment and job assignment inefficiency are aggravated since the loss from turnover reduces incentives for investing in and utilizing R&D.

high enough, the wage that needs to be paid to retain workers with R&D experience in firms that have outcome $(r, 0)$ is greater than their productivity in the firm. Thus, all high ability workers with R&D experience turnover. The intuition for why variability in returns to investment is important for the existence of favorable selection is as follows. Consider a situation where p is too high, so that equilibrium investments in period 1 are very high. When this is the case the firm with R&D history $(r, 0)$ in period 3 will have an incentive to use its informational advantage about worker abilities to retain some of its high ability workers with R&D experience. On the other hand if p is too low and hence investments are very low, the firm with a successful return in period 2 will not find it worthwhile to assign any worker to the R&D-intensive job. In this case no worker will have R&D experience so that turnover will not occur in period 3. Thus, a favorable selection of high ability workers is observed when p is high enough so that it is profitable to promote workers to the R&D job in period 2, but p is not high enough to make it worthwhile to retain any worker with R&D experience in period 3 if a zero return on R&D is realized. Intermediate values of p correspond to higher variance in R&D returns.

4 Restricting Spillovers through Non Disclosure Agreements

The current model generates some useful predictions about clauses in wage contracts that serve to restrict the flow of knowledge across competing firms. Many firms in R&D intensive industries include Non Disclosure Agreements in their wage contracts for new hires. This prevents the worker from using any information acquired in the current firm if, in the future, she is hired by a competing firm. Our model allows us to describe the conditions under which such restrictions will be efficient. In the current set-up, any restrictions on the flow of knowledge or information through worker movement, such as Non-Disclosure Agreements, will translate into reductions in β incorporated in the wage contract in

period 1.

Restrictions on the extent of spillovers that can be transmitted through worker turnover in period 3 has two counteracting effects on expected output in period 1. On the one hand, lower spillovers improve investment incentives by reducing the loss in R&D knowledge through worker turnover thus allowing the firm to appropriate more of its investment returns in the future. On the other hand, lower spillovers worsen the misallocation of R&D workers across firms and hence adversely affect output in later periods. The relative strength of the two opposing effects will depend on the level of actual spillovers that can be transmitted via R&D workers across firms. When this is high the potential misallocation of workers is an important concern so that efficient contracts will not restrict the transmission of spillovers. In the remaining part of the paper we formalize the conditions under which we might expect to observe restrictive wage contracts for new workers. We also describe the case when spillovers are not easily contractible. Even if actual spillovers are low enough so that spillovers should be restricted in wage contracts, the extent to which this is possible will depend on the contractibility of knowledge spillovers. When knowledge spillovers are mostly in the form of general experience from working with R&D they may be hard to restrict through Non Disclosure Agreements.

In order to analyze the implications of Non Disclosure Agreements, we will first derive the effect of spillovers on the total expected wages that the worker receives over the lifetime of her career. This will then determine the optimal decision with respect to restricting spillovers in the first period wage contract.

In the first period, since all firms are identical with respect to information about worker abilities, competition will ensure that any agreement negotiated in the wage contract is efficient. Hence, the wage contract that dominates the labor market will be the one that maximizes total expected wages. We will assume that workers do not know their ability before they begin employment. The outcome in terms

of restrictions in wage agreements will, therefore, depend on whether total expected wages, which we will denote by $W(\beta)$, increases or decreases with β . Restricting spillovers affects total expected wages in the first period in two ways. First, as spillovers are restricted, investment and hence promotions are enhanced. This increases the first and second period wages for the worker. We will call this the “investment effect”. Second, the promotion wage in the period 3 is increasing in β , so that restrictions on β will lower the expected period 3 wage. We will call this the “turnover effect”. The net impact of restricting β will depend on which of these two effects dominates.¹⁹

Restrictions on the transmission of spillovers through worker mobility are feasible only to the extent that the knowledge acquired by the worker can be contracted upon. If, for instance, a large part of the knowledge spillovers acquired by a worker during her career cannot be contracted upon in the initial contract, so that there is favorable selection in the labor market even after all contractible spillovers have been restricted, then workers will prefer contracts that allow for spillovers to be as high as possible. Hence, it is important to distinguish between information acquired by a worker which is contractible and general experience gained from working with R&D processes, which is not contractible. The latter kind of spillover cannot be restricted by means of Non Disclosure Agreements. We will assume that the total spillovers carried by a worker is the sum of the two kinds of spillovers, i.e.

$$\beta = \beta^C + \beta^{NC},$$

where β^C represents the contractible part of information acquired by a worker from holding an R&D intensive job in the current firm, while β^{NC} is the portion of spillovers that cannot be contracted, for

¹⁹Motta and Ronde (2002) analyze the optimality of non compete clauses in a framework where workers choose effort to produce an innovation. They obtain a similar result. If the firm’s investment is crucial to innovation, these clauses enhance investment incentives, whereas if the worker’s effort is more important, output is affected by restrictions on worker mobility, since they reduce the incentive for effort.

example tacit knowledge learned from working with technology, spin-offs etc. β^{NC} then represents the lowest level of spillovers that can be ensured by the firm through Non Disclosure Agreements.

In the following analysis we will restrict the parameter space to the region where favorable selection can occur. Following Proposition 5, for spillovers high enough we will observe a favorable selection of workers in the labor market as all promoted workers turnover from firms with R&D outcome $(r, 0)$ in period 3. We will assume that as β increases, the investment effect becomes weaker while the turnover effect becomes more and more dominant. A sufficient condition that guarantees this is that the total expected wage function is convex, in particular,

$$\left. \frac{\partial^2 W(\beta)}{\partial \beta^2} \right|_{IT} > 0.^{20}$$

Proposition 6 *There exists $\beta' \in [0, \alpha]$ such that the following describes the optimal outcome for restrictions on β in the first period wage contract,*

(a) *If $\beta^{NC} \geq \beta'$, then no restrictions are imposed on spillovers.*

(b) *If $\beta^{NC} < \beta'$ and $W(\alpha) \geq W(0)$, there exists a $\beta'' \in [\beta', \alpha]$, such that no restrictions are imposed if $\beta \geq \beta'$.*

(c) *If $W(\alpha) < W(0)$, there exists $\beta''' \in [0, \beta']$, such that if $\beta^{NC} \leq \beta'''$, all contractible spillovers are restricted.*

Given our assumption about the convexity of the total expected wage function, workers receive high wages in one of two cases: 1) when spillovers are low and the investment effect is large, or 2) when spillovers are high and the turnover effect is large. The above proposition says that workers will prefer contracts with no restrictions on knowledge spillovers when these spillovers are significant and not easily contractible. If actual spillovers are large, workers prefer to take a wage cut in the early part of their

²⁰This will be true under our assumption that the investment cost function, $c(I)$ is sufficiently convex.

career, in order to experience high wage growth from possible turnover in the future. In addition, if non-contractible spillovers are high so that actual spillovers cannot be restricted to the extent where the investment effect is large enough, the gain from restricting β , in terms of higher initial wages, will be relatively low.

In general, Proposition 6 suggests that if a large part of the spillovers accumulated by the worker represents tacit knowledge, then we should observe fewer restrictions on the flow of knowledge and information across firms through worker movement. This seems to describe the environment that characterized worker mobility in Silicon Valley in the 1970s. As Saxenian notes, even though departing employees were asked to sign Non Disclosure Agreements that prevented them from revealing company secrets, much of the useful knowledge arose from the experience of developing new technology which could not be contracted.

There is a second way in which firms can restrict the effect of knowledge spillovers. Employers in such industries have also been known to include Non Compete Clauses in wage contracts. Such clauses prohibit a worker from accepting employment in a competing firm for a given period of time after the termination of her contract. Hence, they directly eliminate turnover of workers rather than deterring turnover by reducing the worker's outside option. California's state law instituted in 1870 makes it impossible to enforce such contracts. In our model Non Compete Clauses in wage agreements is equivalent to reducing β all the way to zero. The preceding analysis suggests that including Non Compete Clauses will enhance output if actual spillovers are low.

5 Discussion

In this section we discuss alternative models with endogenously driven labor turnover. Most of these models focus on explanations involving heterogenous firm-worker matches or worker preferences for employment. As the quality of the firm-worker match is revealed over time, separations occur when the quality of the match is lower than the average expected quality in the labor market. However, once the true match quality is revealed to be high, the possibility of turnover no longer exists for the worker. In contrast, our model suggests that the true firm-worker match quality itself might change over time depending on the stochastic realization of R&D investment. Thus a worker may produce high output in the firm when it has a good return on R&D. But the match quality between the same firm and worker may deteriorate in the future in the event of a negative R&D shock to the firm's investment. A key finding in our model that derives from the variability in firm-worker match quality over time is the absence of a negative relationship between tenure and turnover. This result distinguishes our analysis from previous models of labor turnover.

Several explanations have been advanced to explain the traditional finding that turnover decreases with tenure and labor market experience. Burdett (1978) uses a job search model to explain why the probability of quits decreases with job tenure. In his model, the worker receives a wage offer in every period, drawn from a non-degenerate distribution and the worker quits if and only if the new wage offer is higher than the current wage. As the worker's tenure in the job increases the probability of receiving a new wage offer higher than the existing one falls thus generating a negative relationship between quit rates and job tenure. In Jovanovic (1979), worker-firm matches are experience goods: the quality of a given match is unknown *ex ante* and information is gradually revealed as production takes place. At each point in time a worker is paid the expected value of her marginal product at the current employer.

The worker stays at the current employer if productivity is revealed to be sufficiently high but leaves otherwise. With greater tenure with the current employer, little learning takes place so that there is a smaller probability that the expected marginal product will decline sufficiently to cause the worker to move to a new firm. Other explanations for the observed relationship focus on the accumulation of firm-specific human capital by the worker. As the worker's tenure with the firm increases, the firm-specific component of human capital becomes stronger thus tying the worker more and more to the same firm.²¹ Topel and Ward (1992) empirically test for the effect of job tenure and labor market experience on the probability that the worker will change jobs. They find that while the initial period in a worker's career is marked by frequent job changes, both wages and employment relationships stabilize as the career matures.

However, some recent studies of labor markets in high-technology industries suggest that the standard empirical findings on the tenure-turnover relationship do not hold in these markets. Josefek and Kauffman (2003), using data on Information Professionals, find that tenure in the firm is not a significant predictor of the probability of turnover. A case study of human resource practices in a semiconductor manufacturing firm conducted by the Institute of Industrial Relations at University of California, Berkeley, finds that separation rates do not monotonically decline as tenure increases. In fact, separation rates remain high for most cohorts even up to the seventh or eighth year of tenure.

Previous models of labor turnover were based on the premise that a stable employment relationship between the firm and worker is always first-best efficient. Thus, as informational asymmetries about worker ability, wage offers or match-quality are eliminated over time, the labor market equilibrium moves closer to stable employment in one firm. Our model allows the optimal firm-worker match to vary across time, so that even in the absence asymmetric or incomplete information, turnover might

²¹See Parsons (1972) and Mincer and Jovanovic (1981).

be efficient at different points in time. This then severs the link between tenure and turnover made possible by information revelation over time. We thus find that our model provides a more suitable characterization of the labor market in R&D-intensive environments.

6 Conclusion

Contrary to predictions of the adverse selection literature on labor turnover, evidence of labor mobility patterns in high-technology industries indicates that firms which undertake R&D investments are likely to lose their most talented workers to outside competition. In this paper we develop a model combining elements of asymmetric information, job levels and stochastic R&D realization to address this issue. Workers assigned to R&D intensive jobs carry knowledge spillovers when they move to a new firm. Since a worker's output in an R&D intensive job is likely to be sensitive to his ability the firm will want to assign higher ability workers to such jobs. The stochastic nature of R&D returns implies that the current firm that had good returns from its investment in the past may not have a successful R&D project to utilize in the current period. When this happens the firm will have a pool of highly productive workers that have acquired R&D experience but do not have an opportunity to utilize it in the current employment. Their marginal return will be higher in a firm that has successful returns on its investment in the current period. The resulting misallocation makes some turnover efficient.

Our model can also explain some empirical evidence on labor market experience and turnover that are different in high technology firms. Specifically, our analysis provides an explanation for the observed absence of a negative correlation between probability of turnover and tenure in technology firms.

We also analyze the relationship between spillovers and investment in this framework. Previous work that studied labor mobility as a possible source of technological spillovers between firms predicted

that preventing workers from carrying knowledge spillovers across firms will have unfavorable welfare consequences. In this paper, we study the effect of such spillovers when there are multiple job levels in a firm. When this is the case, the presence of spillovers affects job assignment decisions. We find that when this aspect is incorporated into the analysis, the relationship between spillovers and investment might be more subtle than previously identified. While restricting spillovers increases the inefficient allocation of workers across firms, it enhances investment and also leads to a more efficient allocation of workers within the firm. In general, if spillovers are significant for worker productivity, then restricting workers from transmitting them across firms will lower output.

Finally, we believe that our work can be fruitfully extended to build a theory of firm evolution and worker mobility in R&D intensive industries. While traditional studies of the firm-size and turnover have found a negative relationship between the two, evidence from high-technology firms appears to be less straightforward.²² Josefek and Kauffman (2003) do not find that the likelihood of separation declines with firm-size. At the same time, other studies of the evolution of Silicon Valley firms suggest that turnover is positively correlated with organizational age.²³ A possible explanation for this phenomenon is that as firms become larger, organizational imperatives force the firm to become more rigid and bureaucratic. Such firms are more interested in preserving their competitive advantage in existing areas of specialization rather than developing new avenues for research. Thus worker turnover does not decrease with firm size. Aspects of firm-heterogeneity and organizational characteristics distinguishing small and large firms will thus need to be incorporated into the current framework in order to develop a richer theory of labor turnover in high-technology industries.

²²See Anderson and Meyer (1994).

²³See Baron, Hannan and Burton (2001).

7 Appendix

Proof of Proposition 1. Turnover cannot occur when all workers are more valuable to the old employer. First consider the case where $r_{i2} = r$. For $\hat{\theta}_2 \geq \frac{x}{(\beta+1)rI^*}$, the period 3 wages of workers that were assigned to job level 2 in period 2 are determined by the worker's expected productivity in job level 2 outside. Then all promoted workers will be more valuable in job level 2 in the old firm if $r_{i3} = r$. Hence, we cannot get turnover in cases where a firm has $r_{i3} = r$. In firms with R&D history $r_{i2} = 0$ no turnover occurs since all workers are assigned to job level 1 in period 2, and no new firm will be willing to assign a completely unknown worker to job level 2 given our assumption that $\frac{\theta^H + \theta^L}{2} (\alpha + 1) (1 + s) r\bar{I} < x$. Hence turnover can occur only if a firm has outcome history $(r, 0)$ and workers who accumulated research experience from holding job level 2 positions in that firm are more productive in a new firm that has a good R&D draw in period 3. This will happen when

$$\alpha\theta(1+s)rI^* \leq \theta(1+\beta)rI^*$$

$$\beta \geq \alpha(1+s) - 1 = \hat{\beta}$$

Since $s < \frac{1}{\alpha}$, $\hat{\beta} < \alpha$. When $\beta \geq \hat{\beta}$, given that a positive measure of workers was promoted in period 2, current employers with history $(r, 0)$ will not find it profitable to retain the lowest ability worker who was promoted since she will have to be paid a wage that is higher than her productivity. Hence, there will be a set of relatively lower ability workers among the promoted workers who will turnover. ■

Proof of Proposition 2. (a) As usual in such models, we first derive the equilibrium in period 3 and then work backwards. Suppose workers with $\theta \geq \hat{\theta}_2$ were assigned to job level 2 in period 2. These workers are more productive in a new firm in the current period since $\beta \geq \hat{\beta}$. But since the original firm has an informational advantage about the ability levels of its own workers, it will try to retain the best of its promoted workers. Thus suppose the market believes that a promoted worker who comes

to the firm for employment has expected ability θ^e then it will be willing to pay a new worker from a firm with R&D outcome history $(r, 0)$ a wage of $Max\{\theta^e(1+\beta)rI^*, x\}$. As long as $\hat{\theta}_2 \geq \frac{x}{(\beta+1)rI^*}$, the outside wage for a promoted worker will be $\theta^e(1+\beta)rI^*$. In the next part of the proposition we will show that this true. At this outside wage firm i will retain a worker of ability θ if and only if

$$\alpha\theta(1+s)rI^* \geq \theta^e(1+\beta)rI^*$$

The cut-off level of ability above which a worker is retained is then

$$\hat{\theta}_3 = \theta^e \frac{(1+\beta)}{\alpha(1+s)}$$

Then, since a worker is retained if and only if $\theta \geq \hat{\theta}_3$, the conditional expected ability of the worker is $\theta^e = \frac{\hat{\theta}_2 + \hat{\theta}_3}{2}$. Solving for $\hat{\theta}_3$ we get

$$\hat{\theta}_3 = \hat{\theta}_2 \frac{\beta+1}{2\alpha(1+s) - \beta - 1} > \hat{\theta}_2$$

Thus, workers with $\theta \in [\hat{\theta}_2, \hat{\theta}_3]$ move to a new firm. The wage for workers with $\theta \geq \hat{\theta}_2$ is

$$\frac{\alpha(1+s)}{2\alpha(1+s) - \beta - 1} (1+\beta)\hat{\theta}_2 rI^*$$

The period 2 promotion cut-off, $\hat{\theta}_2$ is derived in the next part of the proof as $\frac{x}{rI^*} \geq \frac{x}{(\beta+1)rI^*}$. By substituting the value of $\hat{\theta}_2$ we get the wage as given in the proposition.

Workers who were assigned to job level 1 in period 2, i.e. those with $\theta < \hat{\theta}_2$ will receive an outside wage according to their productivity in job level 1 in a new firm, which is x .

(b) In period 2 a worker employed in a firm with $r_{i2} = r$ is always more productive in firm i than in a new firm. Hence all workers are retained in the same firm and there will be no turnover.

(c) Given that $p \geq \frac{1}{\alpha+1}$, then for every $\beta < \alpha$, $\beta < \frac{p\alpha(1+s) - (1-p)s}{p}$. When this is the case, the wage for a promoted worker in the outside market is determined by her expected productivity in a job level

2 position in a new firm. So if the market believes that workers with $\theta \geq \hat{\theta}_2$ are promoted in firms with $r_{i2} = r$, the wage for a promoted worker will be

$$\hat{\theta}_2 r I^* + p \hat{\theta}_2 r I^* (s + \alpha(1 + s) - \beta)$$

which is the total expected output in a new firm of a promoted worker with the lowest ability, i.e. $\hat{\theta}_2$. A worker who is not promoted will have to be paid a wage of $x(1 + s)$, which is the total expected output from the lowest ability worker in job level 1 across periods 2 and 3. Comparing the net profit from promoting a worker with the net payoff from keeping her in job level 1, we obtain the cut-off, $\hat{\theta}_2 = \frac{x}{rI^*}$. Substituting for $\hat{\theta}_2$ in the wage expression above, we get $x + px(s + \alpha(1 + s) - \beta)$ as the job level 2 wage. ■

Proof of Proposition 3. First we derive the equilibrium investment in period 1. The expected surplus from a worker in the following two periods for each possible R&D outcome vector is given below.

$$\begin{aligned} \pi^{00}(I) &= sx \\ \pi^{0r}(I) &= \frac{\int_{\theta^L}^{\hat{\theta}_2} sx d\theta + \int_{\hat{\theta}_2}^{\theta^H} [\theta(1 + s)rI - x] d\theta}{\theta^H - \theta^L} \\ \pi^{r0}(I) &= \frac{\int_{\theta^L}^{\hat{\theta}_2} sx d\theta + \int_{\hat{\theta}_2}^{\theta^H} [\theta(1 + s)rI - w_2^2(r)] d\theta + \int_{\hat{\theta}_3}^{\theta^H} [\alpha\theta(1 + s)rI - w_3^2(r, 0)] d\theta}{\theta^H - \theta^L} \\ \pi^{rr}(I) &= \frac{\int_{\theta^L}^{\hat{\theta}_2} sx d\theta + \int_{\hat{\theta}_2}^{\theta^H} [\theta(1 + s)rI - w_2^2(r) + \theta(1 + s)(1 + \alpha)rI - x(\beta + 1)] d\theta}{\theta^H - \theta^L} \end{aligned}$$

Then, the total expected profit from investing I in R&D in period 1 is

$$\pi(I) = (1 - p)^2 \pi^{00}(I) + p(1 - p) [\pi^{0r}(I) + \pi^{r0}(I)] + p^2 \pi^{rr}(I) - c(I).$$

Under our assumption on the convexity of the cost function, the above profit function will be concave. We also need to ensure that the equilibrium investment level I^* is positive. If $I < \frac{x}{\theta^H r}$, even the highest ability worker is more productive in job level 1 so that it is not worthwhile to promote any worker in any period. In this case the surplus in every contingency following the investment is $sx - c(I)$ which is strictly decreasing in I . Hence, if $I^* < \frac{x}{\theta^H r}$, then $I^* = 0$. In order to ensure that $I^* > 0$ we will assume that there exists an investment level, $\tilde{I} > \frac{x}{r\theta^H}$ such that $\pi(\tilde{I}) = sx$. Given that $\pi(I)$ is concave, under this restriction, in order for the profit function to intersect sx at a point beyond $\frac{x}{r\theta^H}$, it must have a maxima beyond $\frac{x}{r\theta^H}$. Then the equilibrium level of investment I^* solves $\pi'(I^*) = 0$.

Next we derive the optimal investment, which is obtained by maximizing the output from efficient assignment and turnover following the investment. The output from investing I , for each R&D outcome vector is given below.

$$Y^{00}(I) = \frac{\int_{\theta^L}^{\hat{\theta}_2^o(0)} 2x(1+s) d\theta + \int_{\hat{\theta}_2^o(0)}^{\theta^H} \theta r I [1 + p(\alpha + 1)(1+s) + (1-p)(1+\beta)] d\theta}{\theta^H - \theta^L}$$

$$Y^{0r}(I) = Y^{00}(I)$$

$$Y^{r0}(I) = \frac{\int_{\theta^L}^{\hat{\theta}_2^o(r)} 2x(1+s) d\theta + \int_{\hat{\theta}_2^o(r)}^{\theta^H} \theta r I [2 + s + \beta] d\theta}{\theta^H - \theta^L}$$

$$Y^{rr}(I) = \frac{\int_{\theta^L}^{\hat{\theta}_2^o(r)} 2x(1+s) d\theta + \int_{\hat{\theta}_2^o(r)}^{\theta^H} \theta r I (2 + \alpha)(1+s) d\theta}{\theta^H - \theta^L}$$

where,

$$\hat{\theta}_2^o(0) = \frac{2(1+s)}{1+p(1+s)(1+\alpha) + (1-p)(1+\beta)} \frac{x}{rI}$$

$$\hat{\theta}_2^o(r) = \frac{2(1+s)}{(1+s)(1+p(1+\alpha)) + (1-p)(1+\beta)} \frac{x}{rI}$$

These are the efficient period 2 promotion cutoffs for each realization of r_{i2} obtained by comparing the

total output from assigning a worker to job level 1 in the same firm to the total output from assigning her to job level 2 in the same firm if $r_{i2} = r$ or job level 2 in a new firm with a successful period 2 outcome if $r_{i2} = 0$. If $r_{i2} = 0$, then workers with $\theta \geq \hat{\theta}_2^o(0)$ should move to a firm with successful R&D in period 2, while the remaining workers should stay in the same firm. If the firm has a successful draw in period 3, all workers should be retained, and workers should be assigned to job level 2 if and only if $\theta \geq \hat{\theta}_2^o(r)$. The total expected output from investing I is

$$Y(I) = (1-p)^2 Y^{00}(I) + p(1-p) [Y^{0r}(I) + Y^{r0}(I)] + p^2 Y^{rr}(I) - c(I)$$

Given our restriction on the convexity of the cost function, $Y(\cdot)$ is concave in I . Let I^o denote the optimal investment. Then I^o solves $Y'(I^o) = 0$. We'll assume that the I^o lies in the range where $\hat{\theta}_2^o(r) < \hat{\theta}_2^o(0) < \theta^H$ so that there is always a positive measure of workers that should be optimally assigned to job level 2 in period 2. Some extensive algebra shows that $Y'(I^*) > 0$. This implies that $I^o > I^*$.²⁴ Also it can be seen that $\frac{\partial Y'(I)}{\partial \beta} > 0$ so that $\frac{\partial I^o}{\partial \beta} > 0$ while $\frac{\partial \pi'(I)}{\partial \beta} < 0$ so that $\frac{\partial I^*}{\partial \beta} < 0$. This means that as spillovers increase, the equilibrium level of investment diverges more and more from the optimal level, i.e. as β increases $I^o - I^*$ increases.

Next we show that job assignment is inefficient. First note that for any given level of investment the a positive measure of workers ought to be assigned to job level 2 in period 2 when $r_{i2} = 0$. However, in equilibrium all workers are retained in job level 1 in the same firm. In the case where $r_{i2} = r$, $\hat{\theta}_2^o(r) < \frac{x}{rI} = \hat{\theta}_2$, hence fewer workers are assigned to job level 2 than is efficient for maximizing output. At the same time note that $\frac{\partial}{\partial I} (\hat{\theta}_2^o(r) - \frac{x}{rI}) < 0$. Thus given that $I^o > I^*$ it will be true that $\hat{\theta}_2^o(r, I^o) < \frac{x}{rI^*}$. In order to see how β affects this difference, note that since $\frac{\partial I^*}{\partial \beta} < 0$, $\frac{\partial}{\partial \beta} (\frac{x}{rI^*}) > 0$. On the other hand $\frac{\partial \hat{\theta}_2^o(r)}{\partial \beta} < 0$ both because of the direct effect of spillovers on $\hat{\theta}_2^o$ at any given level

²⁴A more detailed proof of Proposition 2 is available from the author upon request.

of investment as well the positive effect of spillovers on optimal investment. Thus as β increases the difference between the equilibrium and optimal promotion cutoffs for firms with $r_{i2} = r$ increases. For firms with $r_{i2} = 0$, $\frac{\partial \hat{\theta}_2^o(0)}{\partial \beta} < 0$, so again the promotion inefficiency increases with β . ■

Proof of Proposition 4. The average ability of a worker who changes firms in period 3 from an $(r, 0)$ firm is $\frac{\hat{\theta}_2 + \hat{\theta}_3}{2} = \frac{\alpha(1+s)\hat{\theta}_2}{2\alpha(1+s)-\beta-1}$. Since $\frac{\partial \hat{\theta}_2}{\partial \beta} > 0$, it follows that $\frac{\partial}{\partial \beta} \left(\frac{\hat{\theta}_2 + \hat{\theta}_3}{2} \right) > 0$. ■

Proof of Proposition 5. $\hat{\theta}_3$ is increasing in β and at $\beta = \alpha$, there is complete turnover of all promoted workers if $\hat{\theta}_3 \geq \theta^H$, which implies that at I^* ,

$$x(1 + \alpha) - \theta^H r I^* (\alpha(1 + 2s) - 1) \geq 0$$

i.e. if and only $I^* \leq \hat{I}$, where

$$\hat{I} = \frac{x}{\theta^H r} \frac{\alpha + 1}{\alpha(1 + 2s) - 1}.$$

Since we have assumed that a positive measure of so that $I^* > \frac{x}{\theta^H r}$, we need to check if $\pi'(\hat{I}) \leq \pi'(I^*) = 0$. We can show that $\pi'(\hat{I})$ is increasing in p . At $p = \frac{1}{\alpha+1}$,

$$\pi'(\hat{I})_{p=\frac{1}{\alpha+1}} = \frac{2\theta^{H^2} r (1+s)^2 \alpha (1-\alpha s)}{(\theta^H - \theta^L)} \frac{2+3\alpha}{(1+\alpha)^4} - c'(\hat{I})$$

At $p = 1$

$$\pi'(\hat{I})_{p=1} = \frac{2\theta^{H^2} r (1+s)^2 \alpha (1-\alpha s)}{(\theta^H - \theta^L)} \frac{(2+\alpha)}{(1+\alpha)^2} - c'(\hat{I})$$

Let us define ψ_1 and ψ_2 as

$$\begin{aligned} \psi_1 &= \frac{2\theta^{H^2} r (1+s)^2 \alpha (1-\alpha s)}{(\theta^H - \theta^L)} \frac{2+3\alpha}{(1+\alpha)^4} \\ \psi_2 &= \frac{2\theta^{H^2} r (1+s)^2 \alpha (1-\alpha s)}{(\theta^H - \theta^L)} \frac{(2+\alpha)}{(1+\alpha)^2} \end{aligned}$$

where $\psi_1 < \psi_2$. Then if $c'(\hat{I}) > \psi_2$, $I^* \leq \hat{I}$, and $\hat{\theta}_3 \geq \theta^H$. If $\psi_1 \leq c'(\hat{I}) \leq \psi_2$, define \hat{p} as the p that solves

$$\pi'(\hat{I}; \hat{p}) = 0$$

Then given that $\frac{\partial \pi'(\hat{I})}{\partial p} > 0$, $\pi'(\hat{I}) \leq 0$ if and only if $p \leq \hat{p}$. Thus for $p \leq \hat{p}$, we again have that $I^* \leq \hat{I}$, so that $\hat{\theta}_3 \geq \theta^H$ and all promoted workers turnover when $(r, 0)$ occurs. ■

Proof of Proposition 6. First let us consider the case where turnover is inefficient in period 3, that is where a positive measure of R&D workers is retained in firms with R&D outcome $(r, 0)$. After some simplification, the expression for $\frac{\partial W(\beta)}{\partial \beta}$ is given below. The subscript IT , denotes inefficient turnover.

$$\begin{aligned} \frac{\partial W(\beta)}{\partial \beta} \Big|_{IT} &= \frac{\partial I^*}{\partial \beta} \frac{x^2(1+s)}{rI^{*2}(\theta^H - \theta^L)} \left(2 - p + \frac{p(1-p)\alpha(\beta+1)}{2\alpha(1+s) - \beta - 1} + p^2(\alpha+1) \right) \\ &+ \frac{4p(1-p)}{\theta^H - \theta^L} \frac{x^2}{rI^*} \frac{(\beta+1 - \alpha(1+s))\alpha^2(1+s)^2}{(2\alpha(1+s) - \beta - 1)^3} \end{aligned}$$

The first expression in the above sum represents the investment effect of spillovers. From Proposition 3 we know that $\frac{\partial I^*}{\partial \beta} \leq 0$. Hence, this effect enhances wages as β is restricted. The second term is the turnover effect which is positive.

The expression for $\frac{\partial W(\beta)}{\partial \beta}$ when we have favorable selection is given as

$$\frac{\partial W(\beta)}{\partial \beta} \Big|_{FS} = \frac{1}{2} \frac{p(1-p)}{\theta^H - \theta^L} \left(\theta^{H^2} - \frac{x^2}{r^2 I^{*2}} \right) > 0.$$

In order to determine the level of restrictions that will be imposed in the first period wage contract, we have to compare the wage at the restricted and unrestricted level of spillovers. Given the assumption that $\frac{\partial^2 W(\beta)}{\partial \beta^2} > 0$, $W(\beta)$ is convex in the region where turnover is inefficient. The wage function for the region of favorable selection is linear and increasing in β .

$$\frac{\partial W(\beta)}{\partial \beta} \Big|_{\beta=0} < 0$$

Thus the wage function over the entire range of $\beta \in [0, \alpha]$, initially decreases and gradually starts to increase as the turnover effect begins to dominate with higher and higher β . When β becomes high and favorable selection sets in, $W(\beta)$ increases linearly with β . Let β' be the level of spillovers that correspond to the minimum of $W(\beta)$ over $\beta \in [0, \alpha]$. If $\beta^{NC} > \beta'$, then, since $W(\beta)$ is increasing in this

range, $W(\beta^{NC}) < W(\beta^{NC} + \beta^C)$. Hence workers prefer contracts that impose the least restriction on β . If $\beta^{NC} \leq \beta'$, and $W(\alpha) \geq W(0)$, then given the convexity of $W(\beta)$, we can find $\beta'' \in [\beta', \alpha]$ where $W(\beta'') = W(\beta^{NC})$, so that for every $\beta \geq \beta''$, $W(\beta) > W(\beta^{NC})$. So if actual spillovers are higher than β'' , no restrictions will be imposed. If $W(\alpha) < W(0)$, then let β''' be the β that solves $W(\beta''') = W(\alpha)$. The wage function is decreasing in the range $[0, \beta''']$. Then for every $\beta \in [\beta''', \alpha]$, $W(\beta) < W(\beta''')$. If $\beta^{NC} \leq \beta'''$, $W(\beta^{NC}) > W(\beta''') > W(\beta)$ for every $\beta \geq \beta'''$. Hence wages are higher with restrictions on β . ■

References

- [1] Acemoglu, D. and J. Pischke (1998), "Why do Firms Train? Theory and Evidence," *Quarterly Journal of Economics* 113: 79-119.
- [2] Akerlof, G. A. (1970), "The Market for Lemons' : Quality uncertainty and the Market Mechanism," *Quarterly Journal of Economics* 84: 288-300.
- [3] Anderson, P. and B. Meyers (1994), "The Extent and Consequences of Job Turnovers," *Brookings Papers on Economic Activity: Microeconomics*: 177-236.
- [4] Angel, D. P. , "The Labor Market for Engineers in the U.S. Semiconductor Industry," *Economic Geography* Vol. 65 No. 2 (1989), 99-112.
- [5] Antelius, J. and L. Lundberg, "Competition, Market Structure and Job Turnover," *FIEF Working Paper Series* 161 (2000).
- [6] Arrow, K. J., "Economic Welfare and the Allocation of Resources for Invention," in *The Rate and Direction of Inventive Activity* (New York, Princeton University Press, 1962).

- [7] Baron, J. N., M. T. Hannan and M. D. Burton, "Labor Pains: Change in Organizational Models and Employee Turnover in Young, High-Tech Firms," *American Journal of Sociology* Vol. 106 (2001), 960-1012.
- [8] Becker, G. S., "Investment in Human Capital : A Theoretical Analysis," *Journal of Political Economy* 70 (1962), 9-49.
- [9] Bernhardt, D., "Strategic Promotion and Compensation," *Review of Economic Studies* Vol. 62 Issue 211 (1995), 315-339
- [10] Bernhardt, D. and D. Scoones, "Promotion, Turnover and Preemptive Wage Offers", *American Economic Review* 83 (1993), 771-791.
- [11] Burdett, K, "A Theory of Employee Job Search and Quit Rates," *American Economic Review* 68 (1978), 212-220.
- [12] Chang, C. and Y. Wang, "Human Capital Investment under Asymmetric Information the Pigouvian Conjecture Revisited," *Journal of Labour Economics* 14 (1996), 505-519.
- [13] Cooper, D. P., "Innovation and Reciprocal Externalities: Information Transmission via Job Mobility," *Journal of Economic Behavior & Organization* Vol. 45 Issue 4 (2001), 403-425.
- [14] Devaro, J. and M. Waldman, "The Signaling Role of Promotions: Further Theory and Empirical Evidence", *mimeo*, Cornell University, 2004.
- [15] Gibbons, R. and L. Katz, "Layoffs and Lemons," *Journal of Labor Economics* 9 (1991), 515-535.
- [16] Golan, L., "Counteroffers and Efficiency in Competitive Labor Markets with Asymmetric Information," *Journal of Labor Economics*, Vol 23, Number 2 (2005), 373-393..

- [17] Greenwald, B., "Adverse Selection in the Labour Market," *Review of Economic Studies* 53 (1986), 325-347.
- [18] Josefek, R. A. and R. Kauffman, "IT Human Capital and the Information Systems Professional's Decision to Leave the Company," Working Paper, Marshall School of Business, University of Southern California, 2003.
- [19] Jovanovic, B., "Job Matching and the Theory of Turnover," *Journal of Political Economy* 87 (1979), 972-990.
- [20] Lewis, T. R. and D. A. Yao, "Information, Knowledge Flow, and Worker Mobility," *mimeo*, War-
rington School of Business, University of Florida, 2003.
- [21] Milgrom, P. and S. Oster, "Job Discrimination, Market Forces, and the Invisibility Hypothesis",
Quarterly Journal of Economics Vol 102, 3 (1987), 453-476.
- [22] Mincer, J. and B. Jovanovic., "Labor Mobility and Wages," in S. Rosen edited, *Studies in Labor
Markets*, (University of Chicago Press, 1981), 21-63.
- [23] Moen, J., "Is mobility of technical personnel a source of R&D spillovers?" *Journal of Labor Eco-
nomics*, Vol. 23 (2005), 81-114.
- [24] Motta, M. and T. Ronde, "Trade Secret Laws, Labor Mobility and Innovations," *mimeo*, European
University Institute, Florence, 2002.
- [25] Owan, H., "Promotion, Turnover, Earnings, and Firm-Sponsored Training," *Journal of Labor Eco-
nomics*, Vol 22, Number 4 (2004), 955-978.

- [26] Parsons, D. O., "Specific Human Capital: An Application to Quit Rates and Layoff Rates," *Journal of Political Economy* 80 (1972), 1120-1143.
- [27] Perri, T. J., "Is there a Winner's Curse in the Labor Market," *Journal of Economic Behavior and Organization* Vol 28 (1995), 79-89.
- [28] Ricart I Costa, J. E., "Managerial Task Assignment and Promotions," *Econometrica* Vol. 56 Issue 2 (1988), 449-466.
- [29] Saxenian, A., "Regional Advantage: Culture and Competition in Silicon Valley and Route 128," (Cambridge Harvard University Press, 1994).
- [30] Shih, J., "Project Time in Silicon Valley," *Qualitative Sociology* Vol. 27 No.2 (2004), 223-245.
- [31] Topel, R.H., and M.P. Ward., "Job Mobility and the Careers of Young Men," *Quarterly Journal of Economics* 107 (1992), 439-479.
- [32] Waldman, M., "Job Assignments, Signalling and Efficiency," *Rand Journal of Economics* 15 (1984), 255-267.
- [33] Zabojnik, J. and D. Bernhardt, "Corporate Tournaments, Human Capital Acquisition, and the Firm Size-Wage Relation," *Review of Economic Studies* 68 (2001), 693-716.
- [34] Zabojnik, J., "A Theory of Trade Secrets in Firms," *International Economic Review* Vol. 43 No. 3 (2002), 831-855.
- [35] "The Competitive Semiconductor Manufacturing Human Resource Project: Second Interim Report," Editor: Clair Brown, Institute of Industrial Relations, University of California at Berkeley, 1996.