

Management of Knowledge Workers*

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Abstract

We study how complementarities and intellectual property rights affect the management of knowledge workers. The main results relay when a firm will wish to sue workers that leave with innovative ideas, and the effects of complementary assets on wages and on worker initiative. We argue that firms strongly protected by property rights may not sue leaving workers in order to motivate effort, while firms weakly protected by complementary assets must sue in order to obtain positive profits. Firms with more complementary assets pay higher wages (and have lower turnover), but such higher pay has a detrimental effect on worker initiative. Our analysis suggests that strengthened property rights protection reduces turnover costs but weakens worker initiative.

Keywords: Entrepreneurship, Innovation, IPP, Litigation, Personnel economics, R&D, Start-ups.

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To make knowledge-work productive will be the great management task of this century, just as to make manual work productive was the great management task of the last century (Peter Drucker, 1969, p.290).

1 Introduction

Knowledge workers make up a significant fraction of the workforce in advanced economies (some estimates loom as high as 25-30%). Their expertise determines the success of countless organizations around the world, but still we have limited insight on the management of such workers.¹ The paper aims to fill this void in a context where worker initiative stems from the possibility of leaving its employer carrying valuable ideas, and firms are imperfectly protected by complementary assets and property rights. Our analysis addresses two questions. When will a firm take legal action and sue its leaving workers? How do complementary assets and property rights influence a firm's wage policy and worker initiative?

The crux of the paper is twofold. We argue that a firm weakly protected by complementary assets should sue its leaving workers, while a firm strongly protected by property rights may not. A firm weakly protected by complementary assets must sue in order to avoid having only unproductive workers stay on in the firm. A strongly protected firm may not sue because suing would eliminate worker initiative. Second, we argue that firms with more complementary assets should pay higher wages, and will as a result experience less worker initiative. The intuition is that a firm with more complementary assets has a higher marginal value from workers staying on, and will therefore pay higher wages in order to keep more workers. However, such higher pay will serve as a cushion that weakens worker initiative.

In the model, firms are exposed to both moral hazard in that workers exert unobservable effort to generate ideas, and adverse selection in that workers observe their ideas privately. After a worker has generated an idea, the firm offers a continuation wage which the worker may accept and stay on in the firm, or reject and start up his own business. If

¹See the January 2006 survey of the Economist, Roberts (2004), or Neef (1999) for evidence on the importance of knowledge workers.

the worker leaves, the firm may sue the worker. Complementarities play a role in determining the value of the idea to the firm. Property rights play a role in determining how likely it is that the firm wins a litigation case against the worker.

The worker's motivation to exert effort stems from being able to capture a fraction of the value of the idea if leaving. The worker has stronger incentives to exert effort if he expects the firm not to sue, since this fraction then becomes larger. The firm's litigation policy therefore balances the benefits from more motivated workers with the costs from more workers leaving. At a casual level, this trade-off accords with the personnel policy at Hewlett Packard, which in addition to encouraging workers to start up their own companies had a reputation for the employees being highly motivated.

We find that a firm strongly protected by strong property rights may not sue leaving workers. The reason is that suing would be a "too powerful" instrument under strong property rights and may ruin worker initiative. We find that a firm not protected by complementary assets must sue in order to get positive profits. The intuition is that if the firm does not have complementary assets, not suing will lead to adverse selection where only workers not worth the wage they are paid will stay on in the firm.

Our analysis suggests that firms more strongly protected by complementarities pay higher wages, has less turnover and has less motivated workers. Stronger complementarities imply that a given idea has a higher value inside the firm, and the firm decreases turnover by paying more. Lower turnover implies less motivated workers, because the entrepreneurial option becomes less attractive relative to staying on in the firm. If we assume that larger firms have stronger complementarities, these findings are consistent with evidence from labor economics that larger firms pay higher wages (see e.g., Fox, 2004, for an overview) and have lower turnover (Even & MacPherson, 1996, Kim & Marschke, 2005).

Finally, our analysis suggests that weakened property rights protection increases worker initiative but may waste synergies. We note that the existing literature (e.g., Schotchmer, 2004) argues that intellectual property rights should be strong when ex-ante effects (on firms' R&D investments) are important relative to ex-post effects (on the use of innovations). In contrast, we suggest that intellectual property rights should be *weak* when the ex-ante effects (on worker initiative) are relatively important and *strong* when the ex-post

effects (on the use of complementary assets) are important.

The paper is structured as follows. The next subsection discusses related literature. Section 2 contains the model setup, Section 3 the analysis, and Section 4 concludes. The appendix contains proofs.

1.1 Related literature

The empirical motivation for the paper comes from several sources. Bhide (2000) finds that 71% of entrepreneurs in his sample replicated or modified an idea encountered through previous employment, which echoes earlier research by Cooper (1984).² Marschke & Kim (2005) finds that firms located in industries with higher worker turnover rates patent more, which suggests that patenting may partly be a protective measure against employees. This evidence suggests that knowledge workers pose a threat in addition to being a crucial input.³ On the prevalence of workers leaving their employer, Stone (2002) reports that the number of court cases involving covenants not to compete and trade secrets has increased sharply over the last decades. Similar findings are reported by Lowry (1988). At a case level, Hewlett-Packard institutionalized a famous policy where workers were encouraged to leave and start up their own companies, often with ideas based in their employment at Hewlett-Packard.⁴ On the other hand, in a much-publicized case where workers from the electronics company Cadence founded a company based on software programs and customer relations developed at Cadence, Cadence sued the workers and several of the previous employees received fines and prison sentences (Glynn & Mukherjee, 2003).⁵ This anecdotal evidence suggests, but obviously does not prove, a considerable heterogeneity in the suing policy of R&D intensive firms.

We are not aware of closely related theoretical papers. There are three branches of

²Cooper (1985) finds that 70% of founders of new firms in a broad cross-section of industries where previously employed in the same industry.

³There is a long range of anecdotal evidence that gives the same picture. A fascinating historical account is given by Fisk (2001).

⁴The response of Dave Packard, one of the two founders of Hewlett-Packard, was, "Are we upset that they left us? On the contrary, Bill and I understand and respect their entrepreneurial spirit." (Packard, 1995)

⁵Among more well-known companies, Intel and Microsoft have a reputation for being uncooperative with leavers, and the same goes for a range of Route 128 companies as described by Saxenian (1994).

the literature that address related issues: the management of innovation, the economics of litigation, and the industrial economics of R&D.

Pakes & Nitzan (1983) considered a moral hazard problem where firms have no formal property rights protection and workers can appropriate part of their output. Such appropriation provides workers with an incentive to provide effort. While our model shares this feature of Pakes-Nitzan, their paper does not consider workers having private information about output, which drives turnover in our model, nor the possibility of firms suing leaving workers.⁶

Anton & Yao (1994, 2002) asks how a privately informed inventor might sell an idea when formal property rights are non-existing. Anton & Yao (1994) argues that the threat of selling off the idea to a competitor may give the inventor some rents from bargaining with an incumbent firm, and Anton & Yao (2002) argues that a partial disclosure of the idea can be beneficial to the inventor.⁷ We use the insight from Anton-Yao that an inventor may be reluctant to reveal the content of an idea to motivate our assumption that workers have private information about their innovations, but we do not explore mechanisms in which the worker can transmit his private information. This question is briefly discussed in Section 3.5.

In the incomplete contract setting of Aghion & Tirole (1994), the problem is how to allocate ownership to alleviate hold-up problems between a research unit and a customer. Their assumption that ownership rights over an invention are contractible eliminates most of the issues we are concerned about, in particular turnover.⁸

⁶The same holds for Kim & Marschke (2005). Hvide (2005) considers a Pakes-Nitzan type of model where workers have private information about the value of their output. Hvide (2005) does not consider workers' effort decision, nor firms' suing decision.

Møen (2005) considers labor mobility in a sample of firms with varying R&D intensity. Møen finds, consistent with the Pakes-Nitzan view that wage setting in R&D intensive firms is geared to retain workers, that the steepness of wage profile is positively related to a firm's R&D intensity. Oyer & Schaefer (2005) finds evidence that option-based compensation is geared to retain workers rather than to elicit effort.

⁷A related literature considers how to protect innovations from product-market competitors (e.g., Anton & Yao, 2004). The underlying tension is that patents may give stronger formal rights but also disclose more about the innovation.

⁸Hellmann (2003) and Subramanian (2003) consider the multi-tasking problem that ensues if a worker can engage in "private activities" on the job with the intention of creating a start-up later. In contrast to these papers, we assume that the main problem from the principal's viewpoint is workers leaving with ideas generated through their legitimate work.

The incentives to litigate have been studied by several authors, e.g., Bebchuk (1984) and Reinganum & Wilde (1986) on pretrial negotiations, and Priest & Klein (1984) on the probability of succeeding in court. On empirical evidence, Siegelman & Waldfogel (1996) and Lanjouw & Lerner (1998) estimates a Priest-Klein model on data from litigation cases, and finds that intellectual property rights cases are relatively predictable but also quite hard to win (about 35% are ruled in favor of the plaintiff in the former sample).

According to Mansfield (1986) in many industries firms regard complementary assets, rather than property rights, as their main tool for protecting their innovations. The present paper is to our knowledge the first on how complementary assets affect the management of knowledge workers. Most of the industrial economics literature on R&D has considered the firm as a unit and examined how product market competition and patent policy jointly determine R&D investments (Scotchmer, 2004, gives an overview). While this literature provides insight into how a firm's competitive environment stimulates investments in R&D, it has been unable to analyze how successful innovation depends on worker initiative.

2 The model

There is one principal (owner) and one agent (worker). The agent has reservation utility \bar{U} , which we normalize to zero. At date 1, the agent is hired and paid a fixed wage $F \geq 0$. The worker then exerts effort e at a private cost $c(e)$. At date 2, an idea with stand-alone value x is realized, where $x = e + \epsilon$ and ϵ is a random variable with distribution function $G(\cdot)$. The agent learns x , whereas the firm does not. The firm then offers a continuation wage $B \geq 0$ based on its conjecture about x . The agent accepts or rejects B . Accepting B means signing an extension of the employment contract, in which case the final payoffs become $\theta x - B$ to the firm and B to the agent, where $\theta \geq 1$. If the agent rejects, he quits the firm and develops a start-up based on x . The parameter θ reflects the gains from developing the idea inside the firm due to complementary assets (such as equipment, sales channels, or co-workers). A situation with weak complementarities corresponds to θ close to 1 and a situation with strong complementarities corresponds to $\theta \gg 1$. Initially we treat θ as given and briefly discuss investments in θ in Section 3.3.

The worker's payoff from leaving with the idea depends on whether the firm sues the worker at date 3 or not. At date 3, the idea has matured into something more "physical" (like technical drawings or a prototype) that - although its value is not verifiable - the court can transfer from the worker to the firm. If the firm does not sue, the final payoffs become 0 to the firm and x to the worker. If the firm sues, the payoffs depend on the court outcome. If the court rules in favor of the firm, the firm gets $\theta x - v$, where $v \geq 0$ is the cost of litigation. The worker gets zero. If the court rules in favor of the worker, the worker keeps the idea and develops it independently of the firm. The firm then gets $-v$ and the worker gets x .⁹

As evidenced by a large legal literature (see e.g., Kim & Marschke, 2005, page 299, for references) firms and employees cannot easily contract around the problem of workers leaving with innovations, an important reason being that broad non-compete contracts will be voided by courts. We therefore assume that enforcement by courts is probabilistic, in that the firm wins the litigation trial with probability $\phi \in [0, 1]$.¹⁰

A low (high) ϕ corresponds to a situation where the court enforcement is weak (strong). We think of ϕ as partly being determined by industry characteristics such as difficulty in assessing the nature of early-stage innovations, and partly by legislation. Stone (2002) discusses various aspects of the law of post-employment restraints and argues that the courts' enforcement of such restraints varies from state to state and even from case to case. For example, courts differ in their interpretation of whether negative knowledge qualifies as a trade secret (Stone, 2002, p. 756) or more generally in their emphasis of protection of firms' R&D investments versus the protection of free worker mobility and the right to start up a new company.

We make two convenience assumptions. First we assume that the firm chooses a (deterministic) litigation policy at date 0. One way to justify commitment is that it is observable to outsiders whether the worker leaves or not, so that the firm can have a reputation for being tough or lenient with leavers, or even write a formal contract upon

⁹We assume that the litigation cost of the worker is zero. Altering this assumption has no qualitative impact on the results.

¹⁰The idea that court outcomes are probabilistic has substantial empirical support, see e.g., Lemley & Shapiro (2005).

it.¹¹ Throughout, we assume that $G(\cdot)$ is such that the profit function is globally concave in B .

An overview of the timing appears in Figure 1.

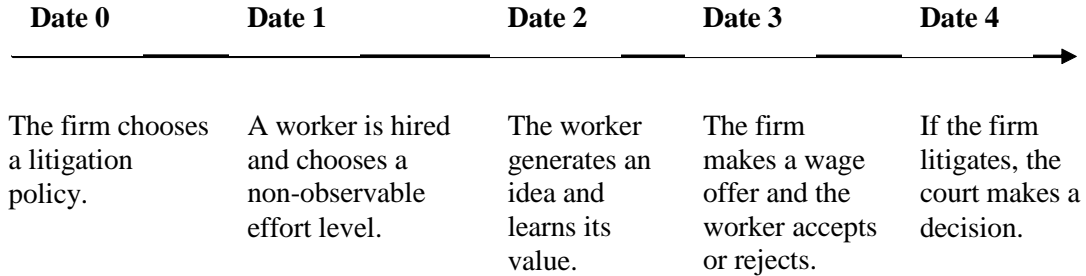


Figure 1: Timing

The basic trade-offs are as follows. The worker chooses an effort level trading off its private cost against a higher value of the idea if he becomes an entrepreneur. The firm sets a wage that trades off the gains from keeping better worker types (ideas) with the cost of paying more for all staying worker types. We focus on Perfect Bayesian equilibria (PBE). A combination of strategies is a PBE if a) the principal sets a wage and its suing policy optimally given its beliefs about effort, b) the worker anticipates the firm's behavior and chooses effort to maximize his utility. This equilibrium notion ensures that the firm's conjecture about effort and the worker's conjecture about the wage setting are fulfilled on the equilibrium path.

Two assumptions underlying the model setup is that (i) the firm (uninformed party) makes the wage offer and (ii) that the firm sets a sequentially rational wage rather than commit to a wage policy up front. Changing these assumptions is unlikely to alter the main insights, as discussed in Section 3.5.

¹¹Another way to justify commitment not to sue is to interpret commitment as granting formal ownership rights up-front to the agent over the innovation.

3 Analysis

We solve the game by in backwards sequence examining the worker's leaving decision, the firm's wage offer, the worker's effort decision, and the firm's suing policy. Then we analyze the effects of changing the level of complementary assets (θ) and strength of property rights protection (ϕ).

3.1 Effort and wages

First we examine effort and wage setting in the subgame reached if the firm litigates. Then we examine the same variables in the subgame reached if the firm does not litigate.

When deciding whether to leave or not, the worker compares what he gets from staying, B , with the expected payoff from leaving and starting up his own company, denoted by U . Since the payoff from leaving increases in x (independently of whether the firm sues or not) the worker leaves if x exceeds some (unique) threshold value. We denote this threshold for z , i.e., $z = \{x : U = B\}$.

Case A. The firm litigates. The worker gets B if he stays in the firm, while the expected payoff from leaving equals $(1 - \phi)x$. Hence $z = B/(1 - \phi)$. For given B and e , the worker's expected utility equals,

$$U = \int_{-\infty}^{z-e} Bg(\epsilon)d\epsilon + (1 - \phi) \int_{z-e}^{\infty} (e + \epsilon)g(\epsilon)d\epsilon - c(e). \quad (1)$$

The first integral is the worker's expected utility when staying ($x < z$) and the latter integral is the worker's utility if he leaves ($x > z$). Let us analyze the worker's effort decision. Suppose that the worker believes that the firm will offer B at date 3 (in equilibrium his conjecture is fulfilled). The marginal utility from exerting effort equals,

$$\begin{aligned} U_e &= -Bg(z - e) + (1 - \phi)(e + z - e)g(z - e) + (1 - \phi) \int_{z-e}^{\infty} g(\epsilon)d\epsilon - c'(e) \quad (2) \\ &= -[(1 - \phi)z - B]g(z - e) + (1 - \phi)[1 - G(z - e)] - c'(e). \end{aligned}$$

Since $B = z(1 - \phi)$, the first term cancels and the optimal effort choice, e^* , is implicitly defined by,¹²

$$(1 - \phi)(1 - G(z - e^*)) - c'(e^*) = 0. \quad (3)$$

The first term represents the marginal gain from effort while the second term reflects the marginal cost. Since $1 - G(\cdot)$ equals the probability that the agent starts up his own company, we see that the agent's motivation to exert effort stems from the possibility of becoming an entrepreneur. All other equal, the worker will be more strongly motivated if property rights are weak, or if he expects a subsequent low wage offer to be made by the firm. The first best level of effort obtains for $c'(e) = 1$. A high ϕ or a high expected wage both contribute to make the worker's effort inefficiently low.

Let us now turn to the firm's choice of B . For given (e, B) the firm's profit equals

$$\Pi = \int_{-\infty}^{z-e} (\theta(e + \epsilon) - B)g(\epsilon)d\epsilon + \int_{z-e}^{\infty} (\phi\theta(e + \epsilon) - v)g(\epsilon)d\epsilon - F. \quad (4)$$

The first integral is the firm's profit from worker types that stay, and the second integral is the firm's profits from suing worker types that leave. Suppose that the firm believes that the worker chooses effort level equal to e (in equilibrium this conjecture is fulfilled). Taking z as the firm's choice variable, the marginal profit equals,

$$\begin{aligned} \Pi_z &= (\theta z - B)g(z - e) - \int_{-\infty}^{z-e} \frac{\partial B}{\partial z} g(\epsilon)d\epsilon - (\phi\theta z - v)g(z - e) \\ &= (\theta z - B)g(z - e) - (1 - \phi)G(z - e) - (\phi\theta z - v)g(z - e) \\ &= [z(\theta - 1)(1 - \phi) + v]g(z - e) - (1 - \phi)G(z - e). \end{aligned} \quad (5)$$

This equation reflects the firm's trade-off when setting a wage offer. An increased wage means that the firm keeps more worker types (the first term), but must also pay more to all types that stay (the second term). We see that a higher θ increases the gain from keeping the marginal worker type. A higher ϕ decreases the gain from keeping the marginal worker type (since the firm gets more from suing) and decreases the wage increase necessary to keep the marginal worker type. The optimal z , denoted by z^* , is implicitly defined by

¹²Second order condition $U_{ee} = (1 - \phi)g(z) - c''(e^*) < 0$.

$$\Pi_z = 0.$$

Case B. The firm does not litigate. If the firm does not litigate, the worker's payoff from leaving equals x . Hence $z = B$. It follows from the same type of derivation as in Case A that the optimal level of effort solves,

$$1 - G(z - e^*) - c'(e^*) = 0. \quad (6)$$

Just as in Case A, the agent's incentive to exert effort stems from the possibility of later becoming an entrepreneur. Since the worker keeps a higher fraction of value upon leaving than in Case A, the worker's incentives to exert effort are stronger (for given z) in Case B than in Case A. The profit given not suing equals

$$\Pi = \int_{-\infty}^{z-e} (\theta(e + \epsilon) - B)g(\epsilon)d\epsilon - F. \quad (7)$$

The firm's marginal profits become,

$$\begin{aligned} \Pi_z &= (\theta z - B)g(z - e) - \int_{-\infty}^{z-e} \frac{\partial B}{\partial z} g(\epsilon)d\epsilon \\ &= (\theta z - B)g(z - e) - G(z - e) \\ &= z(\theta - 1)g(z - e) - G(z - e). \end{aligned} \quad (8)$$

As in Case A, an increased wage means that the firm keeps more worker types (the first term), but must also pay more to all types that stay (the second term). A higher θ increases the gain from keeping the marginal worker type, and ϕ has no effect on the optimal wage policy. The optimal z , denoted by z^* , is implicitly defined through setting $\Pi_z = 0$.

3.2 Suing policy

Having characterized the optimal leaving and effort decision by the worker, and the optimal wage offer by the firm, let us now examine the firm's choice of suing policy. We first clarify the trade-off involved when designing a suing policy. The following result follows from a direct comparison of the suing and no-suing subgames.

Lemma 1 Fix θ and ϕ . Effort is lower if the firm sues than if the firm does not sue.

Proof. See Appendix. ■

Lemma 1 clarifies the firm's trade-off the when deciding upon a suing policy. Suing ensures that the firm gets a piece of the cake if the worker leaves, but also reduces the size of the cake since effort decreases. To understand this result, consider Figure 2 which illustrates the worker's best effort response function, $e^*(z; \cdot)$ and the employer's best response function $z^*(e; \cdot)$.

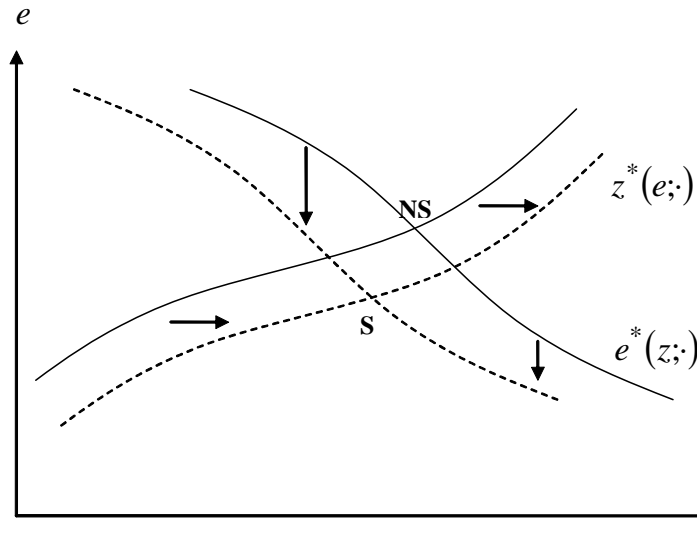


Figure 2: Effects from the firm deciding to sue leaving workers.

$e^*(z; \cdot)$ slopes downward because a higher expected wage offer means that the worker becomes less motivated. $z^*(e; \cdot)$ slopes upward because a higher e means that it will be more attractive to keep the marginal worker type. The unique equilibrium given no suing is given by the intersection of the two solid lines.

When the firm sues, the worker's marginal gain from effort (for a given conjecture about z) is less than if the firm does not sue, since his share of the cake becomes smaller. This reduction in the incentives to supply effort is depicted by the vertical arrows in Figure 2. The firm, on the other hand, will with suing have a higher marginal gain from raising z than under no suing (for a given conjecture about e) since he now avoids the suing costs. This increase in the incentives to pay the agent is depicted by the horizontal arrows in Figure 2. Both effects work in the direction of a lower effort when moving from

a no-suing to a suing regime, as depicted by the move from NS to S in Figure 2. The economic implication is that the firm faces a clear trade-off when choosing a suing policy: suing gives weaker incentives for the worker to leave but also weaker incentives to exert effort.

The net effect on z from suing is ambiguous.¹³ From Figure 2 we see that if the worker's effort only weakly responds to changes in the value of their outside option ($e^*(z; \cdot)$ is flat) then the effect on $z^*(e; \cdot)$ will dominate and, consequently, z decreases if the firm practices a lenient suing policy towards leavers.

The firm's suing decision. We now investigate how θ and ϕ affect the suing decision.

Proposition 1 *(i) A firm not protected by complementary assets ($\theta = 1$) must sue its leaving workers to get positive profits. (ii) A firm strongly protected by property rights ($\phi \approx 1$) may not sue its leaving workers.*

Proof. See Appendix. ■

If a firm not protected by complementary assets does not sue, adverse selection implies negative profits. For any continuation wage level, the firm will only keep worker types with ideas less valuable than the offered wage. In contrast, a firm that is strongly protected through complementarities and intellectual property rights may increase its profit by relinquish its intellectual property rights and not sue. The intuition is simple: a no-suing policy improves the worker's outside option and increases effort. With complementarities, the positive effect on profits from increased effort can be stronger than the negative effect on profits from not suing the leavers. Given this argument, our interpretation of HP's personnel policy is that it was well protected by property rights or by complementary assets, so well that suing leaving workers would seriously impact worker initiative.

¹³The effect on wage setting is ambiguous as well. By suing leaving workers, the firm finds it easier to keep workers by increasing the wage level slightly (the marginal effect on z from an increase in wage B is increased). On the other hand, the firm can reduce its wage offer because it captures value from leaving ideas. Therefore, depending on parameter values of the underlying distribution functions and cost of effort function, suing and wages can be complementary or substitute instruments for the firm when it tries to keep its workers.

3.3 Complementary assets

Let us now evaluate how worker initiative and wages change if the firm holds more complementary assets. The following result holds independently of the firm's suing decision.

Proposition 2 *If the firm holds more complementary assets, then*

- i) wages are higher*
- ii) effort is lower, and*
- iii) turnover is lower.*

Proof. See Appendix. ■

Figure 3 illustrates how an increase in the amount of complementary assets changes the equilibrium outcome.

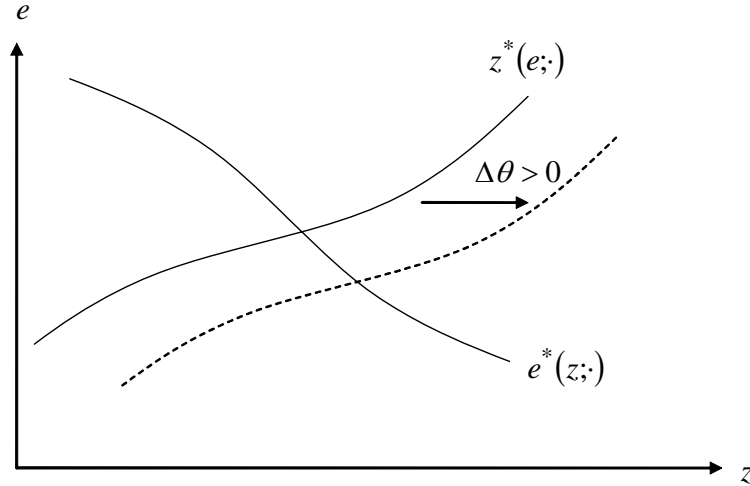


Figure 3: Effects of stronger complementarities.

When θ increases, $e^*(z; \cdot)$ is unaffected (since the entrepreneurial option is unchanged), whereas $z^*(e; \cdot)$ shifts to the right. This is because for any level of effort it will be more beneficial to keep the marginal worker type. Consequently, when θ increases the firm raises its wage offer to keep more worker types. When the wage is raised, the outside option becomes less attractive and worker effort decreases.

We may link θ to firm characteristics such as size.¹⁴ If we assume that large firms have stronger economies of scope than small firms, Proposition 2 suggests that workers

¹⁴One can also relate θ to industry maturity. Initially, firms are small, wages are low and the start-up activities are plentiful. As the industry matures, concentration increases and there are more complemen-

in small firms put in higher effort and create more start-up activities than workers in large firms.¹⁵ The reason is that larger firms have more complementary assets, and pay higher wages to reduce turnover. Our arguments therefore square well with the empirical regularities that larger firms have lower turnover (Oi, 1983, Evan & MacPherson, 1996) and pay higher wages (Fox, 2004).¹⁶

One environment that may serve as a testbed of the theory is firms in the aftermath of mergers and acquisitions. Mergers and acquisitions, particularly in the technology sector, are often motivated by gaining economies of scope. Our predictions would be that after such mergers, wages per worker should increase and turnover due to workers pursuing start-up opportunities should drop. Conyon et al. (2004) finds that wages do tend to increase following mergers.¹⁷

3.4 Property rights protection

In this section we study the effects of changes in property rights protection, interpreted as the probability of the firm winning in court.

Proposition 3 *Stronger intellectual property rights (increased ϕ)*

i) decrease effort

ii) has ambiguous effect on wages and turnover.

Proof. See Appendix. ■

The effects from strengthened intellectual property rights are illustrated in Figure 4.

tary assets inside the firm, workers get better wage offers inside the firm but are less motivated, and fewer workers leave to start up their own businesses. This provides a simple argument for why entry rates are lower in mature industries. We are not aware of direct evidence relating to this question but note that Long & Link (1983) find that firms in more concentrated markets have lower turnover.

¹⁵Economies of scope is the purported motive behind many mergers and acquisitions. Such a motive would generate a positive link between firm size and economies of scope. The extent to which mergers do in fact create economies of scope (rather than say market power) is the topic of a large literature, whose findings are not conclusive. For a recent contribution to this literature, see Gomes & Livdan (2004).

¹⁶Henderson & Cockburn (1996) find a positive relation between economies of scope and R&D success measured by "significant" patents for a sample of biotech companies. This suggest that the direct positive effect on productivity from an increased θ dominates a possible negative effect on productivity from reduced effort in their context.

¹⁷Brown & Medoff (1987) reports a similar finding. Interestingly, Conyon et al. (2004) finds that the increased wage effect is larger for mergers by firms that are in the same industry. Such mergers are arguably where one would expect the complementarity gain to be larger.

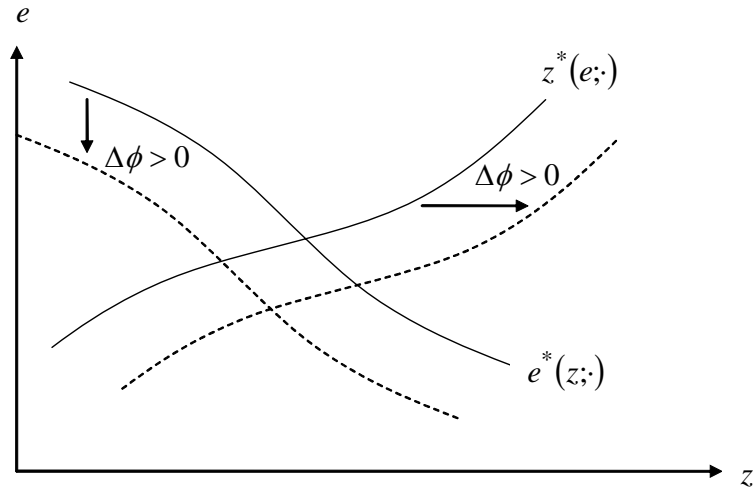


Figure 4: Effects from strengthened intellectual property protection.

When ϕ increases, the worker gets weaker incentives to exert effort because the entrepreneurial payoff is smaller. Hence $e^*(z, \cdot)$ shifts downwards. An increased ϕ makes it cheaper for the firm to keep the marginal worker, because the entrepreneurial option has become less attractive, and $z^*(e; \cdot)$ shifts to the right.¹⁸ Both these two effects pull unambiguously in the direction of a lower worker effort.

Legal scholars argue that the Massachusetts courts are more "pro-firm" while the Californian courts are "pro-employee" (Hellmann, 2002). Proposition 3, part (i), then has resonance in Saxenian (1994), which argues that firms along Route 128 in Massachusetts have fared less well than their counterparts in Silicon Valley.¹⁹

On welfare, we argue based on Proposition 3 that the efficient intellectual property rights from society's viewpoint should balance the beneficial ex-ante effects from motivating workers against the negative ex-post effects on the use of complementary assets.²⁰ We

¹⁸There is also the counter-acting effect of workers leaving becoming less costly when ϕ increases, since more is retained in court. This effect is dominated in optimum.

¹⁹Variation in strength of property rights protection can be related to other variables than geography, such as industry (OECD, 1998, Cohen et al., 2000) or with time. For example, up to the 1980-ies, software innovations were difficult to patent in the U.S. unless embedded in hardware (like mainframe computers or pizza ovens). Landmark court decisions in the mid 90-ies dramatically improved the scope of patenting software (Cohen & Lemley, 2001). Such variation in property rights protection across industries or time may be explored in light of part (i) of Proposition 3.

²⁰It is worthwhile to note that $\phi = 1$ can never be socially optimal. The intuition is that the marginal gain in effort from decreasing ϕ is large while the marginal turnover cost is small. Our analysis suggests that *neither* firms nor workers would prefer courts to always rule in favor of the firm and that the welfare-maximizing level of ϕ is also intermediate.

note that existing policy literature (see Schotchmer, 2004) typically argues that intellectual property rights should be strong when ex-ante effects (on firms' R&D investments) are important relative to ex-post effects (on the use of innovations). In contrast, our analysis suggests that intellectual property rights should be *weak* when the ex-ante effects (on worker initiative) are relatively important and *strong* when the ex-post effects (on the use of complementary assets) are important.

3.5 Extensions

Let us here discuss some extensions of the framework.

Out-of court settlement: Many intellectual property conflicts are settled before they reach the court. In our context, where the value of the idea is not contractible, it is most natural to think of such pretrial-negotiations as a situation where the firm offers the worker to pay a licensing fee as a compensation for using the idea. Suppose that the firm offers the worker to pay a fixed licensing fee L .²¹ If L is accepted by the worker, the parties save litigation costs and the firm must refrain from suing the worker. If the offer is rejected, the worker and firm meet in court as discussed before. In choosing L , the firm balances the gain from increased licensing fee from accepting worker types and the loss due to lower acceptance rate and consequent litigation costs. Our analysis suggests that the equilibrium outcome splits the value of ideas into three intervals. The first interval consists of workers with the poorest ideas. These workers accept the continuation wage offered and stay inside the firm. The second interval consists of workers with better ideas. These workers leave the firm and are litigated by the firm since they do not accept the suggested licensing agreement (out-of-court settlement). The third interval consists of workers with the best ideas. These workers accept the licensing contract. In an empirical paper, Lerner (2004) studies all litigation cases for a sample of firms from Middlesex, Massachusetts (the borough in which the hi-tech area Route 128 is located). Amongst others, Lerner finds that larger firms are more involved with litigation cases involving intellectual property rights than small firms. Our analysis of pretrial negotiations suggests that the cases

²¹A variable licensing fee depending on sales or profit of the new firm may be more difficult to implement due to problems of verifiability. The effect of a varying licensing fee on worker initiative and turnover can be done in much the same manner as with ϕ .

collected by Lerner (2004) are intermediate in terms of value, and may therefore be the "tip of the iceberg".

The wage offer: We have assumed that the firm does not receive information about the value of the idea before giving a wage offer. There are various ways to make the firm's decision more informed. The most straightforward approach is to let the firm receive a signal about the value of the idea before deciding upon a wage offer. In a previous version of the paper, we showed that if a signal S is generated by the process $s = x + \delta$, where δ is normally distributed, then there exists an easily characterizable equilibrium where the wage offer is increasing in the signal. The signal creates additional incentives to exert effort because the (expected) wage offer increases in the level of effort.

Rather than having the uninformed firm making a wage offer, we could let the informed worker demand a continuation wage. This modeling approach opens up for signaling equilibria where a higher demand from the worker is associated with an idea of better quality (see Hvide, 2005, for a related analysis). We do not believe that such a modified wage bargaining will have important effects on the results we focus on.

Finally, by requiring the wage offer to be sequentially rational, we have implicitly assumed that the firm cannot commit to a wage policy before it hires the worker. The main difference between the commitment and non-commitment cases is that in the former, the principal takes into account the negative effect on effort from increasing the wage. The optimal wage will be lower in the commitment case, and as a consequence turnover will be higher. Apart from this, our analysis of the commitment case has yielded qualitatively the same results as in the present analysis.

Investments in complementary assets: The analysis takes the level of complementary assets as being determined by industry characteristics or size of the firm. We can also think of complementarities as being endogenously determined by firm investments. More complementarities give a negative effect on turnover, by Proposition 2. This accords with evidence from Møen (2005) that turnover rates are lower for more R&D intensive firms. More complementarities also give a negative effect on effort, by Proposition 2, since more complementarities make the worker anticipate a higher wage offer and therefore slacks off. When making an investment decision, the firm therefore trades-off the positive effect on asset deployment with decreased worker initiative. The profit-maximizing level

of investments therefore depends upon the elasticity of effort with respect to increased investments: a firm's profit-maximizing level of R&D investment decreases as a worker's effort becomes more elastically supplied.

4 Conclusion

We have developed a theoretical framework to study how complementarities and intellectual property rights affect the management of knowledge workers. We report three sets of findings. First, firms strongly protected by property rights may not sue leaving workers in order to motivate effort, while firms weakly protected by complementary assets must sue in order to obtain positive profits. Second, firms with more complementary assets pay higher wages and have lower turnover, but such higher pay has a detrimental effect on worker initiative. Third, we suggest that the socially optimal intellectual property rights protection strikes the balance between the efficient use of complementary assets and worker initiative.

We see three areas of application for our work. First, our findings on optimal suing policy might be useful to firms deliberating which attitude to take vis-a-vis leaving workers. Our analysis suggests a clear trade-off: more suing gives the firm a larger piece of the cake if a worker leaves, but also gives less worker initiative and hence a smaller cake. Second, our results that stronger complementarities imply higher wages, less turnover, and less worker initiative gives a set of hypotheses to test for in personnel data on R&D intensive firms. These predictions are not obvious; for example the efficiency wage theory of Shapiro & Stiglitz (1986) predicts that higher wages should lead to workers exerting more effort (because of increased cost to the worker of being fired). Third, our results on the effects of property rights legislation may be of interest to policy makers that aim to better understand the effects of changes in intellectual property rights legislation. One case that comes to mind is the current discussion in Europe on the appropriate patent protection for software innovations: we suggest that strengthened protection may reduce turnover costs but may also decrease the productivity of knowledge-work due to less motivated workers.

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6 Appendix: Proofs

Proof of Lemma 1 (effort and the suing decision): Let us first examine the no suing case (Case B). Equilibrium is then given by (z, e) which simultaneously solves (6) and (8). Consider the "best-response" functions $e^*(z; \cdot)$ and $z^*(e; \cdot)$ that are implicitly defined by (6) and (8). Shorten the notation by writing just g and G instead of $g(z - e)$ and $G(z - e)$. By the implicit function theorem we have that $\frac{\partial e^*}{\partial z} = -\frac{U_{ez}}{U_{ee}}$ and $\frac{\partial z^*}{\partial e} = -\frac{\Pi_{ze}}{\Pi_{zz}}$. Since $U_{ee} < 0$ by the agent's second order condition and, as can easily be shown, $U_{ez} = -\frac{g}{U_{ee}} > 0$, we must have $\frac{\partial e^*}{\partial z} < 0$. Since $\Pi_{zz} < 0$ by the firm's second order condition and $\Pi_{ze} = -\Pi_{zz} + (\theta - 1)g$, we must have that $\Pi_{ze} > 0$ and therefore $\frac{\partial z^*}{\partial e} > 0$. Note that since $\frac{\partial e^*}{\partial z} < 0$ and $\frac{\partial z^*}{\partial e} > 0$ then for any (ϕ, θ) there is a unique equilibrium in (z, e) .

To evaluate the effect on equilibrium values of (z, e) from the firm changing its suing policy, we evaluate the effects on $e^*(z; \cdot)$ and $z^*(e; \cdot)$ in turn. From equation (6), the agent's marginal gain from exerting effort under the no suing regime equals $1 - G(z - e)$. From equation (3), the agent's marginal gain from exerting effort under the suing regime equals $(1 - \phi)(1 - G(z - e))$. Since $(1 - \phi) < 1$, the agent's marginal incentives (for given z) is stronger under no suing, and e^* is higher under no suing than under suing. Hence when the firm changes its suing policy from no suing to suing, the $e^*(z; \cdot)$ function shifts to the south in the (z, e) space in Figure 2.

Now consider the effect on $z^*(e; \cdot)$ from changing the firm's suing policy. Denote Π_z under no suing, given by equation (8), by Π_z^n , and denote Π_z under suing, given by equation (5), by Π_z^s . Combining (5) and (8) then gives,

$$\Pi_z^s = (1 - \phi)\Pi_z^n + vg. \quad (9)$$

Now denote the optimal z under no suing for z_n^* and the optimal z under suing for z_s^* . By definition, $\Pi_z^n(z_n^*) = 0$. Since $(1 - \phi) < 1$ and $vg > 0$ it follows from the global concavity of Π_z^n that $z_s^* > z_n^*$. Hence when the firm changes its suing policy from no suing to suing, $z^*(e; \cdot)$ shifts to the east in Figure 2.

To summarize, we have shown that moving from the no suing to the suing regime has two effects. First, $e^*(z; \cdot)$ shifts to the south in Figure 2, while $z^*(e; \cdot)$ shifts to the east. The equilibrium level of effort must decrease when the firm moves from a no suing to a suing regime.

Proof of Proposition 1: (i) We show that if the firm does not sue and $\theta = 1$, the firm's profits are negative. First note that if the firm does not sue, then $z = B$. For $\theta = 1$, the profits therefore equal $\int_{-\infty}^{B-e} (x - B)g(\epsilon)d\epsilon$, where $x = e + \epsilon$. This expression is negative because $x < B$ for any $\epsilon \in (-\infty, B - e]$. By continuity, the firm's profits are also negative for θ close to 1. (ii) Suppose that $\phi = 1$. If the firm sues, the worker gets nothing if he leaves. Therefore, all worker types stay for any $B \geq 0$. We can therefore set $z = \infty$, and the firm's profits equal $\int_{-\infty}^{\infty} (x - B)g(\epsilon)d\epsilon$. Since the worker's effort equals zero from equation (3), $\int_{-\infty}^{\infty} xg(\epsilon)d\epsilon = \int_{-\infty}^{\infty} \epsilon g(\epsilon)d\epsilon$. The latter expression is zero since ϵ is white noise. But since $B \geq 0$, the firm's profits $\int_{-\infty}^{\infty} (x - B)g(\epsilon)d\epsilon$ must be non-positive. We now construct an example where not suing leads to positive profits. Let $g(\epsilon)$ be uniformly distributed on $[-\frac{1}{2}, \frac{1}{2}]$ and let $c(e) = \frac{\gamma}{2}e^2$. If the firm does not sue, $z = B$ the profits are $\Pi = \int_{-\frac{1}{2}}^{B-e} (\theta(e + \epsilon) - B)g(\epsilon)d\epsilon$. For a given B , the worker chooses effort to maximize

$$\begin{aligned}
U &= \int_{-\frac{1}{2}}^{z-e} Bg(\epsilon)d\epsilon + \int_{z-e}^{\frac{1}{2}} (\epsilon + e)g(\epsilon)d\epsilon - c(e) \\
&= \int_{-\frac{1}{2}}^{B-e} Bg(\epsilon)d\epsilon + \int_{B-e}^{\frac{1}{2}} (\epsilon + e)g(\epsilon)d\epsilon - \frac{\gamma}{2}e^2 \\
&= B(B - e) - \frac{1}{8}(2B - 2e - 1)(2B + 2e + 1) - \frac{\gamma}{2}e^2.
\end{aligned} \tag{10}$$

Differentiating with respect to e and solving, we have the unique interior solution $e^*(z) = (\frac{1}{2} - z)/\gamma$, with second order condition $\gamma > 1$. Substituting into the profit function, we

get

$$\begin{aligned}
\Pi &= \int_{-\frac{1}{2}}^{B-e} (\theta(e + \epsilon) - B)g(\epsilon)d\epsilon & (11) \\
&= \int_{-\frac{1}{2}}^{z - (\frac{1}{2} - z)/\gamma} (\theta((\frac{1}{2} - z)/\gamma + \epsilon) - z)g(\epsilon)d\epsilon \\
&= \left[\epsilon\theta(\frac{1}{2} - z)/\gamma + \frac{1}{2}\theta\epsilon^2 - z\epsilon \right]_{-\frac{1}{2}}^{z - (\frac{1}{2} - z)/\gamma} \\
&= \frac{1}{8\gamma^2} (\theta - 2z\theta - 4z\gamma - \theta\gamma + 2z\theta\gamma) (2z + \gamma + 2z\gamma - 1).
\end{aligned}$$

Differentiating with respect to z and solving, we obtain the first order condition

$$\frac{1}{2\gamma^2} (\theta + \gamma - 2z\theta - 4z\gamma - \theta\gamma - \gamma^2 - 4z\gamma^2 + 2z\theta\gamma^2) = 0, \quad (12)$$

which implies the unique interior solution $z^* = \frac{(\theta + \gamma)(\gamma - 1)}{2(\theta\gamma - 2\gamma - \theta)(\gamma + 1)}$, with second order condition $\frac{1}{\gamma^2} (\theta\gamma - 2\gamma - \theta)(\gamma + 1) < 0$. Substituting in for z^* into the profit function,

$$\begin{aligned}
\Pi &= \frac{1}{8\gamma^2} (\theta - 2z^*\theta - 4z^*\gamma - \theta\gamma + 2z^*\theta\gamma) (2z^* + \gamma + 2z^*\gamma - 1) & (13) \\
&= -\frac{(\gamma - 1)^2 (\theta - 1)^2}{8(\theta\gamma - 2\gamma - \theta)(\gamma + 1)}.
\end{aligned}$$

Since the denominator is negative by the second order condition, the firm's profits are always positive.

Proof of Proposition 2 and Proposition 3: We are interested in the effect of a change in θ or ϕ on the equilibrium e, z, T in the case where the firm sues (Case A) and in the case where the firm does not sue (Case B). We label the turnover rate as T , where $T = 1 - G(z - e)$. Let us consider Case A, when the firm sues. On reduced form, we can suppress B and write the two first order conditions (3) and (5) as,

$$\begin{aligned}
\Pi_z(z, e, \phi, \theta) &= 0 & (14) \\
U_e(e, z, \phi) &= 0.
\end{aligned}$$

Denote partials by subscript and totally differentiate (14),

$$\begin{aligned}\Pi_{zz}dz + \Pi_{ze}de + \Pi_{z\phi}d\phi + \Pi_{z\theta}d\theta &= 0 \\ U_{ee}de + U_{ez}dz + U_{e\phi}d\phi &= 0.\end{aligned}\tag{15}$$

We want to examine the effect of changing θ and ϕ , respectively. Solving the system yields.

$$\begin{aligned}\frac{dz}{d\phi} &= \frac{\Pi_{z\phi}U_{ee} - \Pi_{ze}U_{e\phi}}{\Pi_{ze}U_{ez} - \Pi_{zz}U_{ee}}, \quad \frac{de}{d\phi} = \frac{\Pi_{zz}U_{e\phi} - U_{ez}\Pi_{z\phi}}{\Pi_{ze}U_{ez} - \Pi_{zz}U_{ee}} \\ \frac{dz}{d\theta} &= \frac{\Pi_{z\theta}U_{ee}}{\Pi_{ze}U_{ez} - \Pi_{zz}U_{ee}}, \quad \frac{de}{d\theta} = \frac{-U_{ez}\Pi_{z\theta}}{\Pi_{ze}U_{ez} - \Pi_{zz}U_{ee}}.\end{aligned}\tag{16}$$

Let us now evaluate the partials. Differentiating U_e from equation (3),

$$\begin{aligned}U_{e\phi} &= -(1 - G(z - e)) < 0 \\ U_{ee} &= (1 - \phi)g(z - e) - c''(e) < 0 \\ U_{ez} &= -(1 - \phi)g(z - e) < 0.\end{aligned}\tag{17}$$

Note that $U_{ee} = -U_{ez} - c''$. Now the firm. Differentiating Π_z from equation (5),

$$\begin{aligned}\Pi_{z\phi} &= -z(\theta - 1)g + G(z - e) > 0 \\ \Pi_{zz} &= (\theta - 1)(1 - \phi)g(z - e) + (v + z(\theta - 1)(1 - \phi))g'(z - e) - (1 - \phi)g(z - e) < 0 \\ \Pi_{ze} &= -\Pi_{zz} + (\theta - 1)(1 - \phi)g(z - e) > 0 \\ \Pi_{z\theta} &= (1 - \phi)zg(z - e) < 0.\end{aligned}\tag{18}$$

Now return to (16). The denominator equals $\Pi_{ze}U_{ez} - \Pi_{zz}U_{ee}$. This expression is negative given the signs of the partials in (17) and (18). Both terms in the numerator of $\frac{de}{d\phi}$ are positive and hence $\frac{de}{d\phi} < 0$. Both terms in the numerator of $\frac{de}{d\theta}$ are negative and hence $\frac{de}{d\theta} > 0$. Neither $\frac{dz}{d\phi}$ nor $\frac{dz}{d\theta}$ can be signed unambiguously since the terms in the numerator

are of different sign. Now consider turnover. Recall that $T = (1 - G(z - e))$. Therefore

$$\frac{dT}{di} = g(z - e)\left(\frac{de}{di} - \frac{dz}{di}\right), \text{ where } i = \theta, \phi. \quad (19)$$

Denote the denominator of (16) by $D < 0$. Substitute (16) into (19) using $U_{ee} = -U_{ez} - c''$,

$$\begin{aligned} \frac{dT}{d\theta} &= (-U_{ez}\Pi_{z\theta} - \Pi_{z\theta}U_{ee})/D \\ &= -\Pi_{z\theta}(U_{ee} + U_{ez})/D = c''\Pi_{z\theta}/D < 0 \\ \frac{dT}{d\phi} &= (\Pi_{zz}U_{e\phi} - U_{ez}\Pi_{z\phi} - \Pi_{z\phi}U_{ee} + \Pi_{ze}U_{e\phi})/D \\ &= [\Pi_{zz}U_{e\phi} - (-U_{ee} - c'')\Pi_{z\phi} - \Pi_{z\phi}U_{ee} + (-\Pi_{zz} + k)U_{e\phi}]/D \\ &= (kU_{e\phi} + c''\Pi_{z\phi})/D, \end{aligned}$$

where $k = (\theta - 1)(1 - \phi)g(z - e)$. Hence we have established that $\frac{dT}{d\theta} < 0$.

Let us now consider case **B**, when the firm does not sue. In that case the partials are

$$U_{e\phi} = 0 \quad (20)$$

$$U_{ee} = \theta g(z - e) - c''(e) < 0$$

$$U_{ez} = -\theta g(z - e) < 0$$

$$\Pi = \int_{-\infty}^{z-e} (\theta(e + \epsilon) - B)g(\epsilon)d\epsilon - F. \quad (21)$$

The marginal profits are

$$\Pi_z = z\theta g(z - e) - G(z - e), \quad (22)$$

and the partials are,

$$\Pi_{z\phi} = 0 \quad (23)$$

$$\Pi_{zz} = \theta g(z - e) + z\theta g'(z - e) - g(z - e) < 0 \text{ Firm's SOC}$$

$$\Pi_{ze} = -\Pi'_z + \theta g(z - e) > 0$$

$$\Pi_{z\theta} = zg(z - e) > 0,$$

which gives,

$$\begin{aligned} \frac{dz}{d\phi} &= 0, \frac{de}{d\phi} = 0 \\ \frac{dz}{d\theta} &= \frac{\Pi_{z\theta}U_{ee}}{\Pi_{ze}U_{ez} - \Pi_{zz}U_{ee}} \geq 0, \frac{de}{d\theta} = \frac{-U_{ez}\Pi_{z\theta}}{\Pi_{ze}U_{ez} - \Pi_{zz}U_{ee}} < 0, \end{aligned} \tag{24}$$

A changed ϕ has no effect on turnover. The effect on turnover of increased θ is negative as when the firm sues.