Covenants not to Compete, Labor Mobility, and Industry Dynamics

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Abstract

Conventional wisdom among legal scholars is that contractual restrictions on employee mobility affect turnover and led to the overtaking of Massachusetts' Route 128 by Silicon Valley. We study a model of employee mobility in the spirit of Pakes and Nitzan (1984) to see when this can be the case. We show that, in fact, with certain frictions taken into account, a model of employee mobility can not only replicate the overtaking by Silicon Valley, but it can also help to explain Route 128's early dominance. Further, the model explains the relative success of firms that start as, or generate, spin-outs.

1 Introduction

One of the most common statutory forms of intellectual property protection protects firms from competition from former employees. States provide varying degrees of protection. In some states, it is possible to add a limited provision of non-competition to an employment contract (a non-compete clause or "covenant not to compete," or CNC), whereby the employee is

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forbidden from working for any other firm in the same industry (including a start-up of her own) for a fixed length of time, while in other states, most notably California, these contracts are unenforceable.

Starting with Gilson (1998), and Hyde (2003), there has been a long-standing conjecture in the legal and sociological scholarship that suggests that outcomes will differ depending on the enforcement of CNC's. In particular, Gilson and Hyde suggest that the main reason for the success of the high technology industrial district in Silicon Valley and the failure of the one in Massachusetts' Route 128 was the differential enforcement of CNC's. They argue that the different legal environments led to more turnover, and ultimately more firms in California.

We formalize such a story in an economic model of employee mobility. There are several stylized facts, documented by authors such as Saxenian (1994), that the model has the potential to explain. Broadly speaking, Massachusetts, the region with CNC's, was relatively successful early on, but was later leapfrogged by California, the region without CNC's. In 1965, Route 128 had approximately three times more total technology employment compared to Silicon Valley. But by 1975, Silicon Valley's employment had quintupled, while Route 128 had only tripled, resulting in 15% higher total employment in Silicon Valley. From 1975 to 1990, Silicon Valley had tripled Route 128's new job creation. If attention were focused only on semiconductor and electronic component jobs, the same pattern appears. The fields that contributed to Silicon Valley's strongest growth were software and multimedia, but excluding even these areas, Silicon Valley exported double the quantity of electronics when compared to Route 128. The overtaking by Silicon Valley was remarkable. Finally, work by Stuart and Sorenson (2003) shows that CNC's tend to moderate the impact of IPO's and acquisitions of firms within or near an MSA on the creation of new firms in that MSA.

A primary reason for the growth of Silicon Valley was the emergence of spin-outs. A "spin-out" is a new firm founded by employees of an incumbent firm in the same industry. Unlike a "spin-off," the choice to form the firm in a spin-out is made by the employee, not the employer. A subset of firms in Silicon Valley were responsible for the emergence of many new firms. Franco and Filson (2006) document approximately 40 spin-outs in a 20 year period in the rigid disk drive industry. These firms account for approximately 25% of the entering firms. In Christensen's 1993 study of this industry, he notes that one firm, Shugart, had seven descendants and of these, six were in operation in 1991 and included the U.S. original equipment market's four largest firms.[1] Christensen also shows that descendants of Memorex and Shugart were the most productive, accounting for 64% of the cumulative revenues of the start-ups. This type of activity is also documented in the semiconductor industry. In the period from 1955 to 1976, at least 29 entering firms had at least one founder who worked for Fairchild Semiconductor (Braun and MacDonald (1982)). Fairchild itself was a spin-out of Shockley.[2] Other work has documented the fact that firms that are spin-outs are more successful than other entrants, in terms of survival and performance, and the firms that generate spin-outs also dominate other incumbents (See Franco and Filson (2006), Agarwal, Echambadi, Franco and Sarkar (2004) for evidence from the hard drive industry, Klepper and Sleeper (2005), laser printer industry, and Klepper (2002), the automobile industry). In addition, empirical work has pointed to the importance of social ties in determining the success of new firms and the importance of tacit knowledge in determining the persistence of geographic concentration of industries (See Dahl and Sorenson (2007), and Sorenson and Audia (2000).).

Our goal is to examine the idea that legal restrictions might explain the observed differences. In order to do so, we start with a situation where a worker has private information over whether or not he has learned the production process of an employer. We study an optimal contracting problem, determining if the contract calls for the employee to start a new firm, and what compensation should be. We find important differences between environments where CNC's are allowed (so that the employer can always get at least as much surplus as if the employee doesn't start a firm) and ones where CNC's are not allowed (so that the employee can always get as much as if he starts a firm). In particular, the contract always maximizes joint surplus in the former case, but in the latter there is sometimes spin-out formation when it is not in the interest of the joint surplus maximization. Moreover, turnover is uniformly higher without CNC's, as suggested by Gilson (1998) and Hyde (2003). These differences arise due to the asymmetric information.

Our point of departure in Section 2 is an environment similar in spirit to Pakes and Nitzan (1984). In Pakes and Nitzan, firms cannot use CNC's; the only way to protect themselves from competition from former employees is to compensate those employees sufficiently to prevent them from starting

[1] Shugart was a spin-out of IBM.

[2] Robert Noyce, one of the "treacherous eight" who founded Fairchild, is credited with being the co-inventor of the integrated circuit, for which Jack Kilby received the Nobel prize in Physics in 2000, ten years after Noyce's death.

a new firm. This is, however, sufficient to make moot the force stressed in papers like Gilson (1998) and Hyde (2003). There are several key differences in our approach. First, we have an asymmetry of information: the employer does not know if the employee has learned. Second, we study optimal contracts, but do not endow the employee and employer with enough commitment power for workers to take below-market wages in the first period as a sort of bond posting, to be recouped later, as a way to enforce employee mobility restrictions without formal CNC's. As a result, whereas in Pakes and Nitzan, the legal structures we consider do not affect turnover, in our environment they can. We can therefore study the optimal contract under different legal structures, which affect the outside options of the parties. In a sense, our paper is an application of bargaining problems with adverse selection, as reviewed in Kennan and Wilson (1993). We view the legal structure as impacting the participation constraints of the parties, but it has a similar impact to the timing of bargaining, which is known to be important in determining efficiency.

In Section 3, we embed the contracting problem into an industry equilibrium model to determine the life-cycle effects of having two regions with differential enforcement of CNC's. We consider the life-cycle of firms, as well as their size distribution in cross section, when there are two regions, one where CNC's are enforced and one where they are not. We compare our results to the history of Silicon Valley and Route 128. While authors such as Gilson (1998) and Hyde (2003) stress that legal differences led to Silicon Valley's growth, the model can also use the different legal environments to explain the early advantage of Route 128, where CNC's were available.

We find that the region with CNC's initially dominates the non-CNC region, because the value that firms can appropriate in the CNC region is higher than that in the non-CNC region. The reason is a standard one: greater protection of intellectual property creates a greater reward. In the early period, when the few new firms must be non-spin-outs, the greater intellectual property protection in Massachusetts invites more entry. However, over time, the non-CNC region can overtake the CNC region.

We model competition between spin-outs and the firms that generate them as relatively "tough" competition relative to competition with other firms. As a result, firms in the CNC region who form spin-outs charge a lower price. If demand is sufficiently elastic, this leads to enough extra quantity to make up for the initially lower number of firms in the non-CNC region. We also show that as long as demand is sufficiently inelastic, the size of firms that either create spin-outs or are spin-outs is larger than those incumbents which do not generate spin-outs. This accords with cases like the hard-drive industry described above, and does not rely on the inclusion of any externalities between firms, although our results would only be enhanced by including spillovers. We show that the logic can be applied both to cases where spin-outs are imitators and when they are technological improvements over their parents due to innovation.

This work is related to several streams of literature. First is works on the trade-off between internal and external implementation of ideas. In Anton and Yao (1995), the parent firm can protect itself with patents while we assume that the parent firm cannot protect itself in this way.[3] As a result, our story of spin-outs contrasts with theirs. In their model, the employee is concerned about disclosing the idea to his employer, for fear that the idea will be appropriated. Here the idea cannot be implemented within the employer's firm. We take as given the existence of some friction along the lines of the ones studied elsewhere that makes implementation within the parent firm impossible.[4] Another paper in this stream is Hellman (2007). There are two key differences. First, Hellman considers the case where generating innovations that lead to spin-outs by the employee is rivalrous with other activities profitable to the firm. Here we focus only on the decision to leave or not; learning is "free." On the other hand, production is strongly rivalrous in our model, in the sense that the idea cannot be implemented within the parent firm. Thus, we consider optimal contracts that maximize joint surplus, and allow the employee to buy his way out of a contract to start his own firm.

Other recent work on labor mobility restrictions by Lewis and Yao (2001) considers an employment relationship where an employee's research might lead to profitable outside opportunities. In their model, information is symmetric and restrictions on mobility are always surplus reducing, because they reduce the total surplus from the innovation. A key difference is that our contract allows for employees to "buy out" CNC rights, where theirs does not. Like us, Lewis and Yao (2001) explicitly rule out payments from workers to firms as a way to limit mobility. Worker mobility in their model is determined by equalizing surplus across workers and firms.

Pakes and Nitzan (1984) is part of a larger literature studying the degree

[3] Kim and Marschke (2005) provide evidence that firms sometimes do use patents to protect themselves from knowledge outflow via employees.

[4] Klepper and Sleeper (2005) argue that parents do not always recognize the value of the employee's idea, and spin-outs are the result, as they can be here.

to which intellectual property can have value without statutory protection. Other papers include Anton and Yao (1994), Baccara and Razin (2002), and Boldrin and Levine (2003). We incorporate information frictions to a similar environment, to see how effective future employment offers are in protecting the value of firms. We show that future employment may not be very useful, relative to CNC's, in maintaining the value of innovation under the set of frictions we study.

There are several related papers in the literature on clusters like those found in Silicon Valley. These papers focus on competition between existing firms rather than new firm formation, and place special emphasis on the market for ideas in the location decision of firms. They do not study the sort of contracting problem between workers and firms that we focus on. Combes and Duranton (2006) study a duopoly game between firms that compete for workers with knowledge. Like us, they focus on a case where workers cannot be made to post bonds, and where the degree of elasticity of substitution is important. Cooper (2001) also focuses on labor mobility between firms and the market for workers, in a model of perfect competition. Fosfuri and Ronde (2004) study a duopoly game of cumulative innovation where laggard firms can catch up by hiring leading the leading firm's employee. Their results are most similar to ours, in that they study the impact of labor mobility laws. They study both policies that explicitly limit mobility (like CNC's) and policies like trade secrets laws that award damages to firms that lose employees. They find that damages raise profits and typically still allow for spillovers, but that CNC's lower profits by lowering spillovers. In contrast, our results show that CNC's might raise profits, by solving an inefficiency due to asymmetric information. However, our results are similar to theirs in that CNC's limit mobility.

2 A Contracting Problem

We study a contracting problem between an employer and her employee, who might have learned the employer's technology. The worker, if he has learned, might make some profits from a startup. The startup, however, could lower the profits of the employer; whether or not the sum of profits between the two has increases (perhaps because of the employee's idea being an improvement) or decreases (due to competition between them) are cases we consider in turn. The asymmetric information friction is that the learning is private information of the employee. Intuitively, without a CNC, the employer must trade off the benefits of keeping the worker if he has learned, against the fact that, in order to do so, she will have to pay a high wage. In particular, she will be paying more than would have been necessary to keep a worker who had not learned. If the probability of learning is low, the employer cannot be convinced to make such a payment, and would rather take the chance that the employee has learned, even though that might lower the employer's profits by becoming a competitor. With a CNC, the employer would keep the worker from becoming a competitor any time the worker's departure lowered their joint profits.

2.1 The Players and the Objective

An employer hires an employee. During the first period of employment, the employee may or may not learn something valuable. An employee that learns something can potentially start a firm of their own. For now, we focus on the contracting problem at the start of the second period; that is, after the learning may or may not have happened. This contrasts with the Pakes and Nitzan (1984) approach, where a two period contract may allow for low wages in the initial period (backloading) as a way to protect the employer. We assume that there is no power to commit to second period payments or actions in the first period, and therefore the long term contract cannot be written. The intuition for our result will hold with any (less severe) restriction on backloading, such as the ones suggested by Pakes and Nitzan.

In the second period, the employee can either leave ($a = 1$) or stay ($a = 0$). The employee may have learned ($\theta = 1$) or not ($\theta = 0$)[5]; learning occurs with probability λ (which is common knowledge after the employee begins to work at the firm),[6] and the outcome θ is private information of the employee.[7] The

[5]This can also be interpreted as whether or not the employee has sufficient financial backing to start a firm. The employee would know the outcome of conversations with potential financial backers, while the employer would not.

[6]One could imagine implementing this situation in cases where λ was a subjective belief; however, for the purposes of defining a joint surplus objective, we assume that this probability is objective and known.

[7]Although we assume learning is completely unobserved, one could imagine adding a noisy signal for the firm about the employee's success or failure. As long as some uncertainty remains, the trade-off we study will still be in effect. In that sense our asymmetry is similar to the idea in Klepper and Sleeper (2005) that sometimes employers do not fully appreciate the ideas of their employees.

profits from operating firms in the second period are $\pi_p(a, \theta)$ for the employer (parent) and $\pi_c(a, \theta)$ for the employee (child), gross of any payments they receive from one another. We assume that

Assumption 1. $\pi_c(a, 0) = \pi_c(0, \theta) = 0$

The employee can only make profits if he both learns and starts a firm. The employee also may get a payment $w(\theta)$ in the second period. This payment can be either positive or negative, so that it is in fact a transfer to the original firm. We further denote by $a(\theta)$ the contract's prescribed spin-out decision for the employee.

Note that although the language of this mechanism design approach is to imagine the employee "announcing" whether or not he has learned, it is enough for the employer to post a second period wage $w(0)$ for employees who continue, and a buyout amount $w(1)$ for agents who leave. Then the employee chooses whether to stay or leave according to maximizing their private return. As such, no explicit announcement is required. One could imagine a firm deciding on its wage-tenure policy either with an eye to retaining workers, or deciding that such a profile is too expensive, and setting the profile in such a way that they realize those that have special ideas will leave the firm.

For the employer, we assume

Assumption 2. $\pi_p(a, 0) = \pi_p(0, \theta) = \bar{\pi}_p$

Assumption 2 implies that the employee's spin-out decision only matters if he has learned, and his learning only matters if he forms a firm. As such, it is without loss of generality to normalize $a(0) = 0$. Finally, for there to be any tension in the problem, we let $\pi_p(1, 1) < \bar{\pi}_p$; in other words, an employee leaving the firm lowers the profits of the parent firm.[8]

Rather than take a stand on surplus division, we study optimal contracts. The optimal contract orders action a to maximize expected combined profits:

$$\lambda\left(\pi_p(a(1), 1) + \pi_c(a(1), 1)\right) + (1 - \lambda)\left(\pi_p(a(0), 0) + \pi_c(a(0), 0)\right) \qquad (1)$$

Under our assumptions, this is equal to $\lambda\left(\pi_p(a(1), 1) + \pi_c(a(1), 1)\right) + (1 - \lambda)\bar{\pi}_p$. Since the last term is a constant, maximizing this is equivalent to maximizing

$$S(a(1)) \equiv \pi_p(a(1), 1) + \pi_c(a(1), 1)$$

[8]Without this assumption, it is clear that employees should always leave.

Define the solution to unconstrained maximization of S by $a^*(1)$; $a^*(1) = 1$ if and only if joint profits are greater when the employee leaves (i.e. $\pi_p(1,1) + \pi_c(1,1) > \pi_p(0,1)$).

Since θ is private information of the employee, there are constraints in the maximization of S by the optimal contract. First, there is an incentive compatibility constraint for the employee:

$$\theta = \arg \max_{\hat{\theta} \in \{0,1\}} \left(\pi_c(a(\hat{\theta}), \theta) + w(\hat{\theta}) \right) \tag{2}$$

There are also participation constraints which differ depending on the legal environment assumed; we discuss those in the next sections. The optimal contracting problem is

$$\max_{a(1), w(\theta)} S(a(1))$$

subject to (2) and these participation constraints. As is common in this sort of contracting problem, all of the structure is assumed common knowledge.

2.2 Legal Environments

We assume that the firm cannot protect itself against competition from a spin-out through a patent. If such enforcement were available, clearly CNC policy would be moot. We take the existence of spin-outs as at least indirect evidence that patents do not provide complete protection for parents. Moreover, we assume that the employee's idea can not simply be implemented in parallel to the firm's existing business, as might be the case if the knowledge were codifiable. We view this assumption as the natural complement to the assumption of asymmetric information; the employer does not understand the employee's idea as well as the employee does, and therefore might not be able to implement it in the same way. Other models, such as Anton and Yao (1995) and Hellman (2007), study this trade-off. One can think of our analysis as a deeper study of the subgame where the idea is developed outside the firm. Both papers include important cases where that is the case. Moreover, Jaffe et al.(1998) argues that an important component of know-how is tacit, and therefore might be hard to simply implement at arms length.

2.2.1 Covenants not to Compete allowed

When covenants not to compete are allowed, the participation constraint for the employee is

$$\pi_c(a(\theta), \theta) + w(\theta) \geq 0 \ \forall \theta \tag{3}$$

Since the employee can be excluded from spinning out, the contract simply needs to guarantee that he can make at least his outside option from quitting but not starting up a firm, which is normalized to zero. Since the employee can never be compelled to work, this constraint must be met for each θ.

The participation constraint for the employer is

$$\lambda \left(\pi_p(a(1), 1) - w(1)\right) + (1 - \lambda) \left(\bar{\pi}_p - w(0)\right) \geq \bar{\pi}_p \tag{4}$$

Since this constraint is in expectation, we are allowing the firm to commit to payments conditional on reports of θ when the second period begins. The employer can always employ the worker in the first period (for the outside option), and then exclude the employee in the second period when CNC's are allowed. In that case, he makes $\pi_p(0, 0)$ in the second period. Exclusion is not the only option; that is, we allow $a(1) = 1$, and the employee forms a firm. However, to the extent that this action lowers expected profits for the employer (the left hand side of (4)), the employer must be compensated. It is as if the employer had written in a CNC, but then the employee pays a buyout $w(1) < 0$ to eliminate enforcement of the clause.

When CNC's are allowed, the optimal contract can in fact implement $a^*(1)$:[9]

Proposition 1 *Suppose the participation constraints are (3) and (4). Then an optimal contract* $(a(1), w(\theta))$ *satisfies* $a(1) = a^*(1)$ *and*
(a) If $\pi_p(1, 1) + \pi_c(1, 1) < \bar{\pi}_p$, $w(\theta) = 0$.
(b) If $\pi_p(1, 1) + \pi_c(1, 1) > \bar{\pi}_p$,
(i) $w(0) \in [0, \pi_c(1, 1) + w(1)]$
(ii) $w(1) \geq -\pi_c(1, 1)$
(iii) $\lambda(\pi_p(1, 1) - \bar{\pi}_p) \geq \lambda w(1) + (1 - \lambda) w(0)$

The employee cannot be compensated beyond the outside option when $\theta = 0$ and CNC's are allowed. In the optimal contract, either (in (a)) the employee can never start a firm and is compensated the outside option, or

[9] All proofs are contained in the appendix.

(in (b)), the firm allows its employee to leave if he learns, but the employee pays compensation, since learning creates value. That compensation cannot be too large, or else the employee would rather forgo the value created by leaving, and cannot be too small, since it must compensate for (expected) lost revenue of the firm. The easiest case to see is where $w(0) = 0$, so that the restrictions are simply $w(1) \geq -\pi_c(1,1)$ (compensation cannot exceed employee's profits) and $\pi_p(1,1) - \bar{\pi}_p \geq w(1)$ (compensation must be sufficient to cover lost profits of the employer). This represents, intuitively, a buyout of the CNC clause by the employee, in the amount of $-w(1)$.

2.2.2 Covenants not to Compete not allowed

If CNC's are not allowed, the employee is free to leave in the second period. In other words, his participation constraint is

$$\pi_c(a(\theta), \theta) + w(\theta) \geq \pi_c(1, \theta)\ \forall \theta \tag{5}$$

In effect, his outside option is that he can leave and earn $\pi_c(1, \theta)$. This differs from (3) only when $\theta = 1$, so that the worker has learned something of value.

On the other hand, the employer is not under any obligation to employ the worker, or enter into any particular contract for the second period; he could have just employed the worker in period one, paying the outside option, and then let the worker leave:

$$\lambda\left(\pi_p(a(1), 1) - w(1)\right) + (1 - \lambda)\left(\bar{\pi}_p - w(0)\right) \geq \lambda \pi_p(1,1) + (1 - \lambda)\bar{\pi}_p \tag{6}$$

In this case, the employer takes the chance that the worker has learned, and that his profits will be lowered to $\pi_p(1,1)$ if he has.

Unlike the last case, the optimal contract cannot always implement $a(1) = a^*(1)$. In particular, when $\pi_p(1,1) + \pi_c(1,1) < \bar{\pi}_p$, so that joint surplus would be maximized by $a(1) = 0$, the contract sometimes allows the worker to leave.

Proposition 2 *Suppose the participation constraints are (5) and (6). Then the optimal contract* $(a(1), w(\theta))$ *satisfies*
(a) If $\pi_p(1,1) + \pi_c(1,1) < \bar{\pi}_p$,
(i) if $\pi_c(1,1) \leq \lambda(\bar{\pi}_p - \pi_p(1,1))$, $\quad a(1) = 0$, $w(\theta) \in [\pi_c(1,1), \lambda(\bar{\pi}_p - \pi_p(1,1))]$
(ii) if $\pi_c(1,1) > \lambda(\bar{\pi}_p - \pi_p(1,1))$, $\quad a(1) = 1$, $w(\theta) = 0$
(b) If $\pi_p(1,1) + \pi_c(1,1) > \bar{\pi}_p$, $a(1) = 1$ *and* $w(\theta) = 0$.

Notice that, when $\pi_p(1,1) + \pi_c(1,1) < \bar{\pi}_p$, spin-outs can arise from firms where $\pi_c(1,1) > \lambda(\bar{\pi}_p - \pi_p(1,1)))$. In other words, in that case, spin-outs come from firms with relatively low λ. Firms that are likely to have employees who learn pay to keep the employees from competing. If the firm were to follow a policy of always retaining workers, incentive compatibility requires that the worker be paid regardless of θ, and the payment must be enough to retain the worker when $\theta = 1$. For low λ, the worker is not likely to have learned, so the firm would rather "take its chances" with the facing a spin-out if $\theta = 1$, even though that case results in a reduction of profits and no compensation.

When $\lambda = 0$ or $\lambda = 1$, there is no private information, and hence no difference between the choice $a(1)$ under the two legal environments. This is as in Pakes and Nitzan.

2.3 Implications

In this environment, CNC's lead to implementing the full-information surplus maximizing outcome. Without CNC's, there are cases where that does not occur. We explore this implication in more detail below, in trying to explain the early advantage of Massachusetts in the computer industry; our story is that higher returns to entry, stemming from the ability to use CNC's, made entry more attractive in Massachusetts.

Moreover, as stressed in the legal literature, turnover is greater without CNC's. When $\pi_p(1,1) + \pi_c(1,1) < \bar{\pi}_p$ and $\pi_c(1,1) > \lambda(\bar{\pi}_p - \pi_p(1,1))$, the optimal contract with CNC's (and the full information joint profit maximizing outcome) would keep the employee from starting a competing firm, but that outcome is impossible without CNC's.[10]

Note that, in contrast with the conventional wisdom as in Gilson, CNC's (weakly) raise the profit for the employer regardless of whether we are in case (a) or (b). Moreover, the benefit of CNC's is strict when we are in case (a), regardless of whether $\pi_c(1,1)$ is greater or less than $\lambda(\bar{\pi}_p - \pi_p(1,1))$. In other words, regardless of whether CNC's increase turnover, they still benefit the employer. This contrasts Gilson, who has in mind that turnover generates a spillover that makes California attractive to all firms. We will show in

[10] Note that we did not allow the contract to order the original firm to *exit* for some reports of θ. If this were possible, then there is essentially no friction from the asymmetric information; the planner can make either firm the residual claimant on all joint profits.

the next section that the rise of California can be explained without such a spillover.

We do not allow employers to "charge" employees for learning by offering below market wages. Without CNCs and for $\lambda < 1$, sufficient backloading of wages (charging in the first period, paying high wages in the second) would effectively be a CNC, since it could make leaving prohibitive. We assume commitment is infeasible, so that below market wages are not possible (although above market wages are). Combes and Duranton (2006) point out that minimum wage laws and financing constraints on employees could deliver this limit to feasible contracts.

In the next section we develop an industry equilibrium model that incorporates the contracting problem described by the propositions of this section. In doing so, we are assuming that below market wages in the first period are impossible.

3 An Equilibrium Model of Spin-outs

In this section we embed the contracting problem of the previous section into an industry equilibrium model. The goal is to see how spin-out formation can be affected by legal restrictions, and how industry evolution can in turn differ across locations with different restrictions.

The model starts from the idea that different varieties are produced first by parents, as monopolistic competitors. We then assume that spin-outs produce identical varieties to their parents (although perhaps a higher quality or lower cost, as discussed at the end of the section). This amounts to assuming that parents and children are tougher competitors than any two firms chosen at random – which seems reasonable given the similarity, typically, of the products produced by spin-outs and their former employers.

We show that, in such a case, firms with low λ allow spin-outs only if there is not CNC enforcement. We further show that while rewards at the moment of entry are higher with CNC enforcement, the non-CNC region can eventually overtake the CNC region in output terms, if the elasticity of substitution between varieties is nearly one. The intuition is that, in such a case, differences across varieties are large relative to the amount of competition within a given variety, and therefore varieties with a spin-out produce more output than firms that only face competition from outside varieties. Note that the result requires only that the elasticity across varieties get close to one and not something more extreme.

3.1 Preferences

A representative consumer has income I in each of two periods to spend on an industry of differentiated products. When a mass N of products is available, consumption of product j is x_j. The representative consumer has utility function

$$\left(\int_0^N x_j^\rho dj\right)^{1/\rho}$$

where $\rho \in (0,1)$, i.e. demand is elastic.[11]

3.2 Technology

Products are produced in two locations. Location 1 allows covenants not to compete. Location 2 does not allow such covenants.[12] There are two periods. In period one, each product is produced by one firm, which are called entrants. Let E_i be the number of such firms in location i. The number of products is then $N = E_1 + E_2$. Firms hire a single worker that might learn the technology (regardless of the amount produced), and then produces output at constant marginal cost normalized to 1. This marginal cost can be thought of as relating to inputs that do not have the potential to learn from employment, including capital.

As described in the previous section, we rule out backloading of wages; firms cannot commit to payments in the second period above what is in their static second period interests. As a result, workers are paid at least their outside option (normalized to zero) in the first period. Denote the first period wage in region i by w_i^1

In the second period, the employer in the first period can either retain the worker and pay a wage w_i^2, or allow the worker to leave and potentially form a spin-out producing an identical product to its employer. The two compete by simultaneously choosing quantities, in Cournot competition.

[11] We could allow the consumer to substitute intertemporally; it would only strengthen our results, as the consumer would consume more in period 2 (when goods are relatively cheap), further aiding in the growth of the region that does not allow CNC's.

[12] There is no difficulty in adding more locations, but since only two legal environments are to be considered, there are only two meaningful regions in the model.

Our assumption implies that spin-outs and the firms that create them are tougher competitors for one another than they are for the average firm in the industry. We think this is a reasonable depiction of such firms, since the spin-outs are often making a particularly similar product to its parent firm. The elasticity parameter ρ dictates this difference: for ρ near 1, demand is nearly perfectly elastic across products, so there is little difference between competition between spin-outs and their parents, and the competition across firms that are unrelated. When ρ is near zero, competition between unrelated firms becomes nearly Cobb-Douglas, while spin-outs and their parents remain perfect substitutes. This makes competition between spin-outs and their parents relatively tough. In the following section, we let the spin-out produce an improved version of the product, either in terms of quality or cost.

Once again, λ denotes the probability of a worker learning; once again this outcome is private information of the employee. When the firm initially enters, it draws λ from some distribution described by c.d.f. $F(\lambda)$. Denote by V_i be the value of starting a new firm in period one at location i. Rather than focus on any specific model of firm entry, we take entry as exogenously determined by $E_i = G(V_i)$, an increasing function. We view this as a minimal structure: higher value to entry in a given region induces more entrants. Since spin-outs do not form new products, we always have N products available.

Our model will not imply that V_i is equated across regions. We have in mind that pioneering a new variety requires the payment of a fixed cost. Further, it could be that pioneering requires some local resources so that, in each region those resources might become more expensive as pioneering in that region increases. Note that the theory only requires that some of the pioneering costs are local; much of them might not be. The value V_i is *gross* of payments to this factor, so that even though V_i differs across regions, the net reward to entry, after payments to the fixed factor, might be identical.[13]

[13]Our assumption that the fixed cost is for market pioneering implies that it will not need to be paid by spin-outs, who produce an identical variety. This assumption makes the analytic results simpler. However, the basic intuition of the model allows for fixed payments to a local factor (say land) that might be made by both spin-outs and parents.

3.3 Equilibrium

3.3.1 Pricing and Profits of Firms

In period one, there are only the entrants, so each product is monopolized. The monopolistic competition outcome has prices equal to the usual markup rule:

$$p(1) = 1/\rho \tag{7}$$

The one in parenthesis denotes the fact that the industry is monopolized. Notice that, regardless of ρ, agents do not consider the other varieties in determining this price. There are two reasons for this in the model. First, all varieties enter the consumer's utility symmetrically, so products with similar indices j are not more similar than products with very different values for j. Secondly, since all the other products are equivalent from the standpoint of the producer of any single variety, and each variety is small relative to the aggregate, nothing the firm does can impact it's residual demand. As a result, from the first order condition for the consumer's problem, the firm faces demand is $p_j = Ax_j^{\rho-1}$, where A is a constant that the firm cannot impact.[14]

In period two, either the employee is retained, in which case the firm remains a monopolist producer of the product and the price is $p(1)$, or the employee leaves. If the employee leaves, he can start a new firm and compete Cournot with the original firm. Denote by x_j^p and x_j^c the quantities produced by the parent and the spin-out in the duopoly respectively, so $x_j = x_j^p + x_j^c$. Using the demand relationship $p_j = Ax_j^{\rho-1}$, revenue for firm p is $p_j x_j^p = A(x_j^p + x_j^c)^{\rho-1}x_j^p$. The first order condition for x_j^p in the duopoly situation sets marginal revenue equal to marginal cost:

$$A\left((\rho-1)\left(x_j^p + x_j^c\right)^{\rho-2} x_j^p + (x_j^p + x_j^c)^{\rho-1}\right) = 1 \tag{8}$$

Solving (8) and the analogous equation for x_j^c,[15] and then substituting in the

[14] One could allow for a sense of "nearby" competitors who are internalized by the producers of a particular variety. We focus on the stark version of the model because of the simple analytics it generates. However, the basic idea that spin-outs are closer competitors to their parents then to other firms would be enough to generate similar results in more general setups.

[15] An alternative solution method is to impose symmetry, $x_j^p = x_j^c$. Symmetry is the only equilibrium, as can be seen by solving the two equations explicitly.

demand function $p_j = Ax_j^{\rho-1}$ simplifies the first order condition to

$$((\rho - 1)(p(2))/2 + p(2)) = 1$$

so

$$p(2) = \frac{2}{\rho + 1} \tag{9}$$

for duopoly provided products.

Denote by $x(1, N, D)$ and $x(2, N, D)$ the quantity consumed for products provided by monopoly and duopoly, respectively, when a total of N products are available, D of which are duopolies, the rest of which are monopolized. The first order condition for the consumer gives

$$\frac{x(1, N, D)}{x(2, N, D)} = \left(\frac{p(2)}{p(1)}\right)^{\frac{1}{1-\rho}} = \left(\frac{2\rho}{\rho + 1}\right)^{\frac{1}{1-\rho}} \tag{10}$$

Let $\Pi(1, N, D)$ be monopoly profits for a given product when a mass N of products is provided, D of which are duopolies and let $\Pi(2, N, D)$ be the duopoly profits, gross of any payments to the employee. Then

$$\begin{aligned} \Pi(1, N, D) &= (p(1) - 1)x(1, N, D) = \frac{1 - \rho}{\rho} x(1, N, D) \\ \Pi(2, N, D) &= (p(2) - 1)\frac{x(2, N, D)}{2} = \frac{1 - \rho}{1 + \rho}\frac{x(2, N, D)}{2} \end{aligned}$$

An important and useful fact is that the ratio of monopoly to duopoly profits is independent of N and D. It results from the fact that, according to (10), the ratio of consumption in the industries with different market structure depends only on ρ:

$$\Pi(1, N, D)/\Pi(2, N, D) = 2\frac{\rho + 1}{\rho}\left(\frac{2\rho}{\rho + 1}\right)^{\frac{1}{1-\rho}} = 2^{\frac{2-\rho}{1-\rho}}\left(\frac{\rho}{\rho + 1}\right)^{\frac{\rho}{1-\rho}} > 2 \tag{11}$$

Spin-out formation depends solely on λ and this ratio, so we can now study spin-outs independently from N and D.

3.3.2 Spin-out Formation

Now we can discuss the issue of spin-out formation for each location and λ. In the language of section 2, we have $\bar{\pi}_p = \Pi(1, N, D)$. If the employee leaves, $\pi_p(1,1) = \pi_c(1,1) = \Pi(2, N, D)$. Since, in every case, industry profits go down as a result of the spin-out ($\Pi(1, N, D) > 2\Pi(2, N, D)$), we are always in the case (a) of Propositions 1 and 2, where $\pi_p(1,1)+\pi_c(1,1) < \bar{\pi}_p$. According to Proposition 1, where CNC's are allowed, spin-outs are never formed ($S_1 = 0$). According to Proposition 2, in region 2, spin-outs are formed if $\pi_c(1,1) > \lambda(\bar{\pi}_p - \pi_p(1,1))$.

Substituting with the values for $\Pi(1, N, D)$ and $\Pi(2, N, D)$ and rearranging we find that spin-outs are formed if $\Pi(1, N, D)/\Pi(2, N, D) < (1 + \lambda)/\lambda$. Replacing from the formula in (11) and solving for λ, a spin-out is formed by an employee who learns at a firm where

$$\lambda < 1/(2^{\frac{2-\rho}{1-\rho}} \left(\frac{\rho}{\rho+1}\right)^{\frac{\rho}{1-\rho}} - 1) \equiv \bar{\lambda}$$

The critical value $\bar{\lambda}$ is an increasing function of ρ ; in the extreme cases, we see that

$$\lim_{\rho\to 0} 1/(2^{\frac{2-\rho}{1-\rho}} \left(\frac{\rho}{\rho+1}\right)^{\frac{\rho}{1-\rho}} - 1) = \frac{1}{3} \tag{12}$$

The implication of (12) is that, for all ρ between zero and one, there are λ that lead to spin-outs in region 2; namely, firms with $\lambda < 1/3$ always let workers go, regardless of ρ. At the other extreme

$$\lim_{\rho\to 1} 1/(2^{\frac{2-\rho}{1-\rho}} \left(\frac{\rho}{\rho+1}\right)^{\frac{\rho}{1-\rho}} - 1) = \frac{1}{4e^{-\frac{1}{2}} - 1} < 1$$

Here the implication is that firms which draw sufficiently high λ will not allow spin-outs, even in region 2.

The number of duopoly industries is also the number of spin-outs in location 2. That number is $D = S_2 = E_2 \int_0^{\bar{\lambda}} \lambda dF(\lambda)$.The number of monopolized industries is everything else; i.e. $E_1+E_2 \left(1 - \int_0^{\bar{\lambda}} \lambda dF(\lambda)\right)$. Firms with $\lambda > \bar{\lambda}$ pay to keep their workers from leaving; we know from Proposition 2 that this payment w_i^2 is greater than or equal to $\Pi(2, N, D)$ and less than or equal to $\lambda(\Pi(1, N, D) - \Pi(2, N, D))$. We don't take a stand on surplus division, and treat the wage as a parameter falling in this interval. All of our analysis is valid for any such wage.

3.3.3 Equilibrium Conditions

We assume a "nationwide" labor market. Although firms cannot commit to future wages, they can use first period wages to entice workers into the region. We therefore assume that expected incomes must be equated across areas in period 1, given the first period wages offered and the second period payoffs foreseen:

$$w_1^1 = w_2^1 + \beta \left(\int_0^{\bar{\lambda}} \lambda \Pi(2, N, S_2) dF(\lambda) + (1 - F(\bar{\lambda})) w_2^2 \right) \tag{13}$$

Working in region 1, the agent gets paid w_1^1 in the first period, and nothing in the second. In region 2, the agent gets first period wages plus either wages or the possibility of profits from establishing a firm in the second period. We assume $\beta \in (0, 1)$ is the discount factor for all agents.

For any N and D, consumers solve

$$\max_{x(1,N,D),x(2,N,D)} ((N - D)x(1, N, D)^\rho + Dx(2, N, D)^\rho) \tag{14}$$

$$\text{s.t.}$$

$$(N - D)p(1)x(1, N, D) + Dp(2)x(2, N, D) = I$$

For any set of parameters, an equilibrium is a list of $\{E_i, V_i, w_i^1, w_i^2, S_2, x(1, N, D), x(2, N, D), \Pi(1, N, D), \Pi(2, N, D)\}$ where $x(1, N, D)$ and $x(2, N, D)$ solve the consumers problem in (14), given I and the prices in (7) and (9), wages w_i^1, w_i^2 satisfy (13), and

$$\begin{aligned} V_1 &= \Pi(1, N, 0) - w_1^1 + \beta \Pi(1, N, S_2) \\ V_2 &= \Pi(1, N, 0) - w_2^1 + \beta \left(\begin{array}{c} \int_0^{\bar{\lambda}} (\lambda \Pi(2, N, S_2) + (1 - \lambda)\Pi(1, N, S_2)) dF(\lambda) + \\ (1 - F(\bar{\lambda}))(\Pi(1, N, S_2) - w_2^2) \end{array} \right) \end{aligned}$$

3.4 Analysis

3.4.1 Value of Firms

A classic question in the literature on innovation is the connection between the reward to innovation (here, entry in the first period) under various legal protections for intellectual property. Note that, for region 2, either $\lambda > \bar{\lambda}$, and the employee retains the worker with $w_2^2 > w_1^2 = 0$ (as implied by Proposition 2), or the firm allows the worker to leave, and the firm makes lower expected profits in period two (as implied by (11)). This force lowers the returns to firms entering region 2. On the other hand, region one must pay higher wages in the first period. The following proposition shows that the total impact is that V_1 is greater than V_2.

Lemma 3 $V_1 > V_2$

The intuition for this result comes from the fact that, according to the previous section, joint surplus is higher in region 1, and strictly so for $\lambda < \bar{\lambda}$. As a result, when workers are indifferent between career paths, firms in region one must be enjoying greater surplus.

3.4.2 Life-Cycle of Output by Region

Since entry is increasing in value, the fact that $V_1 > V_2$ implies

Proposition 4 $E_1 > E_2$

Initially, there are more firms in location 1, where CNC's are allowed. All products are priced identically in period one, so differences in firm numbers are the only source of differences in output across the two regions. As a result, region 1 produces more output in period 1.

In the second period, output in region 1 is $Y_1 \equiv E_1 x(1, N, D)$ and output in region 2 is

$$Y_2 \equiv E_2 \left(\int_0^{\bar{\lambda}} (\lambda x(2, N, D) + (1 - \lambda) x(1, N, D))\, dF(\lambda) + (1 - F(\bar{\lambda})) x(1, N, D) \right)$$

There are three terms. The integrand reflects entrants that allow spin-outs ($\lambda < \bar{\lambda}$). With probability λ, these become duopolized and sell $x(2, N, D)$, and with probability $(1 - \lambda)$, they still produce $x(1, N, D)$. The final term is entrants that have high enough λ that they do not allow spin-outs, and hence continue to produce $x(1, N, D)$.

Output in region 2 divided by output in region 1 is

$$\frac{Y_2}{Y_1} = \frac{E_2}{E_1} \left(\int_0^{\bar{\lambda}} \left(\lambda \left(\frac{2\rho}{\rho + 1} \right)^{\frac{-1}{1-\rho}} + (1 - \lambda) \right) dF(\lambda) + (1 - F(\bar{\lambda})) \right)$$

which simplifies to

$$\frac{Y_2}{Y_1} = \frac{E_2}{E_1}\left(\left(\left(\frac{2\rho}{\rho+1}\right)^{\frac{-1}{1-\rho}} - 1\right)\left(\int_0^{\bar{\lambda}} \lambda dF(\lambda)\right) + 1\right) \tag{15}$$

In period two, region 2 adds S_2 spin-outs. Moreover, in any industry that has a spin-out, becoming a duopoly, the price is lower. This leads to greater output from those products in region 2 where spin-outs occur. We know from (10) that output in duopolized industries is always greater than in monopolized industries. It is easy to compute that $\lim_{\rho\to 0}\left(\frac{2\rho}{\rho+1}\right)^{\frac{-1}{1-\rho}} = \infty$ so that, when demand is nearly unit elastic, output from products that are duopolized is *arbitrarily* bigger than output in monopolized industries. Moreover, since, for all ρ, $\bar{\lambda} \geq 1/3$, we know that the term $\left(\int_0^{\bar{\lambda}} \lambda dF(\lambda)\right)$ is strictly positive if $F(1/3) > F(0)$. Then if E_1/E_2 is uniformly bounded for all ρ, it must be the case that Y_2/Y_1 approaches infinity as ρ approaches zero. We have

Proposition 5 *Suppose* $F(1/3) > F(0)$ *and* $\frac{E_1}{E_2}$ *is bounded. Then* Y_2/Y_1 *is arbitrarily large as* ρ *gets close to zero.*

Note that the limit is taken as the elasticity of substitution, $1/(1-\rho)$, gets close to one, so that different products are as differentiated as possible in the range $\rho \in (0,1)$. One natural concern is whether or not, as ρ gets close to zero, we should expect any entry in location 2. However, note $\Pi(1,N,D)/\Pi(2,N,D)$ in (11) is bounded above by four for all ρ between zero and one; the ratio of profits in the two regions is not diverging, even though output is. As such, it is natural to assume that E_1/E_2 is bounded for such ρ; a sufficient condition is that $G(V)$ is a *strictly* increasing function. In that case, if there are any spin-outs ($F(1/3) > F(0)$), then output in region 2 is arbitrarily bigger than that of region 1 as ρ becomes close to zero.

The model predicts that, for sufficiently tough competition between spin-outs and their parents, that regions with CNC's initially dominate, but are eventually overtaken by regions which don't allow CNC's. Note that our model also predicts low profits in the no-CNC region. Many other factors impacted the eventual profitability of Silicon Valley firms; Gilson suggests externalities between firms. We can of course add such an effect (or, for that matter, a variety of possible reasons) to explain profitability in Silicon Valley, without altering the results we stress here. We keep those forces out so that we can isolate the specific forces that come from the contracting problem of the previous section. Moreover, externalities between firms would strengthen the overtaking result, since more spin-outs might create more spillovers and therefore increase output in the no-CNC region even further.

Note that the size of firms that do not create or enter as spin-outs, relative to those that do, is $2x(1, N, D)/x(2, N, D)$, an increasing function of ρ. Whenever $\rho < .633$ firms that either are spin-outs or create spin-outs are larger than their counterparts that do not. This is the stylized fact of the hard drive industry: firms that create or enter as spin-outs are relatively prominent. Once again, the requirement is that demand be nearly unit elastic, or, in other words, that competition between spin-outs and their parents be relatively tough compared to competition across products.

3.5 Innovative Spin-outs

So far, a spin-out has produced the identical variety with the same technology as its parent; it is just an imitation of the parent. In this section we generalize to the case where the child may be a technological improvement over the parent. One can interpret the model we analyze in this section in two possible ways. We will follow the language that the spin-out produces an identical variety, but at a lower marginal cost $m < 1$. However, it is equivalent to think of the spin-out as producing a higher quality version of variety j at the same marginal cost as its parent. Let the effective consumption of x_j be calculated according to $x_j = x_j^p + x_j^c/m$, where x_j^p and x_j^c are physical units of output produced by the parent and child, respectively, at marginal cost 1. Since the spin-out produces the same units of x_j with a fraction m of the units of its parent (due to its higher quality), it is as if it has a lower marginal cost of m and identical quality.[16]

The analogous first order conditions to (8) are

$$\begin{aligned} A\left((\rho-1)\left(x_j^p+x_j^c\right)^{\rho-2}x_j^p+\left(x_j^p+x_j^c\right)^{\rho-1}\right) &= 1 \\ A\left((\rho-1)\left(x_j^p+x_j^c\right)^{\rho-2}x_j^c+\left(x_j^p+x_j^c\right)^{\rho-1}\right) &= m \end{aligned}$$

[16] As before, we assume that the parent cannot incorporate the spin-out's technology into its own. It would be enough for our purposes that the parent cannot fully incorporate the technology, and is left with cost $m' > m$, possibly less than one.

Using the demand curve to solve as in the previous section gives

$$p(2) = \begin{cases} \frac{m+1}{\rho+1} \text{ if } m > \rho \\ \frac{m}{\rho} \text{ if } m \leq \rho \end{cases}$$

When $m \leq \rho$, the spin-out completely eliminates the parent, and charges its own monopoly price. In either case, however, the ratio of prices and quantities in industries with and without spin-outs depends only on ρ and the marginal costs. As a result the profit ratios can be computed independently of N and D.

Duopoly profits are continuous in m and joint surplus is lower for $m = 1$ by the previous section. Therefore we know that, for m sufficiently close to one, the sum of the parent and child's profits is less than the parent's monopoly profits, and all of the qualitative analysis of the earlier parts of the section goes through without change. For very low m, however, spin-outs occur in either region.[17] It is straightforward to show that as ρ goes to zero the range of m such that the sum of parent and child's profits are less than the parent's monopoly profits is the entire interval from zero to one.[18] So, for any m, sufficiently low ρ makes spin-outs unattractive in the CNC region. In other words, the theory of the previous section, which relied on sufficiently low ρ, applies for any $m > 0$.

The intuition for the lack of spin-outs in the CNC region for more moderate m is that the losses due to lost increased competition still make spin-outs less attractive than monopolizing a variety, and therefore parents resist them. Moreover, in these cases the addition of innovative spin-outs furthers the overtaking logic, since in that case the region that enforces CNC's does not have spin-outs CNC's loses out not only additional output due to competition, but also loses additional output due to not adopting the lower cost technology associated with the spin-outs.

In recent work, Fallick, Fleischman and Rebitzer (2006) find that, in the computer industry, there are higher labor mobility rates in California than in other states. According to the model, regardless of whether spin-outs are innovative or not, this suggests that the joint surplus is lower and the probability of an employee copying the firm's technology is low, but due to

[17] To see this, consider $m < \rho$. Then the spin-out becomes a monopolist and can make more profits than the parent alone.

[18] The calculations are significantly less concise than in the previous section. Details are available from the authors.

the differential legal structure, firms in California allow employees to leave. They also find that there is no difference in labor mobility rates in other industries in California compared in other states. Under this framework, this could be a result of a low ρ or high λ.

4 Conclusion

The conventional wisdom of legal scholars on the importance of CNC's for spin-out formation can be rationalized in a standard model of employee mobility, but not without some frictions added. We have incorporated such frictions and shown that, in fact, the model can explain higher turnover in places where CNC's are not allowed, and in fact can have the spin-outs concentrated in a few firms. In addition, we have used the standard economic intuition that higher returns generate greater innovation to explain why, in the early stage, the region which enforces CNC's can have greater firm numbers.

Note that this outcome requires several ingredients. Wages could not be backloaded, so that the employee gets paid below his outside option while learning, in exchange for higher wages if he stays for the second period. Whether employees had learned or not was private information. And the contract could not pre-specify exit by the employer (in exchange for a payment) if the employee learned, so that the employee could obtain higher profits.[19]

The model can deliver both the life cycle facts (initial dominance by the CNC region and eventual overtaking by the non-CNC region), as well as the size distribution fact (large firms are one that either start as spin-outs, or ones that create spin-outs). The essential ingredient is that competition between spin-outs and their parent firm be relatively tough, compared to competition between unrelated firms. Our model does not include any externalities between firms. Such externalities are a central theme in the legal and sociological stories about the role of spin-outs. We view our theory as complementary to those ideas, in the sense that externalities should only

[19]We focus on a particular type of asymmetric information, where the employee knows the outcome of the learning uncertainty. We could do the reverse: consider the case where only the *employer* knows. This is clearly important in many industries where employees seek letters of recommendation to attain future employment; the job market for economists is one example.

further the driving force we highlight.

In California, the debate focusing on the enforcement of CNC's has recently resurfaced, prompted by the California District Court's Electro Optical decision, in which the court determined than if a former employee's position at a "direct competitor" will require "inevitable disclosure" of the former employer's trade secrets, the former employee can be prevented from working for said competitor (Sandberg, 2000.) This has lead to several companies in California to file suits against their competitors. However, when the State Supreme Court depublished the ruling, the decision could not be used as precedent in other cases.

There are several points raised by the model that suggest future possibilities. Since the benefits of CNC protection are decreasing in the degree of competition, firms in concentrated industries would be most interested in locating in CNC enforcing regions, while firms in more competitive industries would be less willing to go out of their way to get the protection. In industries where spin-outs are especially important, this force might be important in determining the location of industries across locations.

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5 Appendix: Proofs

Proof of Proposition 1. If we can show that the unconstrained maximum $a^*(1)$ is feasible, then clearly it is optimal when there are constraints. We need to show that (2), (3), and (4) hold for a^* and the proposed wages, and that $w()$ is as specified.

For (a), the worker is never allowed to leave, and always receives the zero compensation, so $\pi_c(a(\hat{\theta}), \theta) + w(\hat{\theta}) = 0$ for all reports $\hat{\theta}$. Therefore incentive compatibility is trivially hired and the worker earns a payoff of exactly zero, satisfying participation. The employer's participation constraint is immediate. Note that, given $a(1) = 0$, participation of the worker requires $w(\theta) \geq 0$, but participation of the firm requires

$$\bar{\pi}_p - \lambda w(1) - (1 - \lambda) w(0) \geq \bar{\pi}_p$$

This implies $w(\theta)$ must be exactly 0.

For (b), the participation constraint for the employee holds as long as $w(0) \geq 0$ and $w(1) \geq -\pi_c(1, 1)$. Truthful reporting of $\theta = 0$ holds if

$$\pi_c(a(0), 0) + w(0) = w(0) \geq \pi_c(a(1), 0) + w(1) = w(1) \tag{16}$$

Participation of the employer holds if:

$$\lambda(\pi_p(1, 1) - w(1)) + (1 - \lambda)(\bar{\pi}_p - w(0)) \geq \bar{\pi}_p$$

so

$$\lambda(\pi_p(1, 1) - \bar{\pi}_p) \geq \lambda w(1) + (1 - \lambda) w(0)$$

i.e. expected compensation must be no bigger than expected losses would be if the worker were allowed to leave. Since $w(0) \geq w(1)$ from (16),

$$\lambda(\pi_p(1, 1) - \bar{\pi}_p) \geq w(1)$$

The left hand side is negative, so $w(1) < 0$.

Truthful reporting of $\theta = 1$ requires

$$\pi_c(a(1), 1) + w(1) = \pi_c(1, 1) + w(1) \geq \pi_c(a(0), 1) + w(0) = w(0)$$

so $\pi_c(1,1) + w(1) \geq w(0)$. ■

Proof of Proposition 2. We start with (b), where the full information outcome is implemented. Clearly the policy is incentive compatible and satisfies the employee's participation constraint if and only if $w(0) = w(1) \geq 0$. Participation for the employer requires

$$\lambda\left(\pi_p(1,1) - w(1)\right) + (1-\lambda)\left(\bar{\pi}_p - w(0)\right) \geq \lambda\pi_p(1,1) + (1-\lambda)\bar{\pi}_p$$

When $w(0) = w(1)$, this is satisfied only if $w(1) = w(0) \leq 0$, so it must be that $w(\theta) = 0$.

For (a), first consider the situation where $\pi_c(1,1) \leq \lambda(\bar{\pi}_p - \pi_p(1,1))$. Since the employee is never allowed to earn profits ($a(1) = 0$), it must be the case that $w(0) = w(1)$ for incentive compatibility, and $w(1) \geq \pi_c(1,1)$ for employee participation. This leaves employer participation as

$$\begin{aligned}
\lambda\left(\bar{\pi}_p - w(1)\right) + (1-\lambda)\left(\bar{\pi}_p - w(0)\right) &\geq \lambda\pi_p(1,1) + (1-\lambda)\bar{\pi}_p \\
\bar{\pi}_p - w(1) &\geq \lambda\pi_p(1,1) + (1-\lambda)\bar{\pi}_p \\
\lambda(\bar{\pi}_p - \pi_p(1,1)) &\geq w(1)
\end{aligned}$$

so, combining, $\pi_c(1,1) \leq w(\theta) \leq \lambda(\bar{\pi}_p - \pi_p(1,1))$

If $\pi_c(1,1) > \lambda(\bar{\pi}_p - \pi_p(1,1))$, then the same steps imply that it is impossible for all the constraints to be met with $a(1) = 0$. The only alternative is to set $a(1) = 1$; in that case, the same steps as in the proof of (b) imply that $w(\theta) = 0$. ■

Proof of Lemma 3. We can substitute the formula for w_1^1 from (13) to get

$$V_1 = \Pi(1,N,0) - w_2^1 - \beta\left(\int_0^{\bar{\lambda}} \lambda\Pi(2,N,S_2)dF(\lambda) + (1-F(\bar{\lambda}))w_2^2\right) + \beta\Pi(1,N,S_2)$$

and then write the difference between V_1 and V_2 (divided by β) as

$$\Pi(1,N,S_2) - 2\int_0^{\bar{\lambda}} \lambda\Pi(2,N,S_2)dF(\lambda) - \int_0^{\bar{\lambda}} (1-\lambda)\Pi(1,N,S_2)dF(\lambda) - (1-F(\bar{\lambda}))\Pi(1,N,S_2)$$

We can rewrite

$$\begin{aligned}
\Pi(1,N,S_2) &= \int_0^{\bar{\lambda}} \Pi(1,N,S_2)dF(\lambda) + (1-F(\bar{\lambda}))(\Pi(1,N,S_2) \\
&= \int_0^{\bar{\lambda}} \lambda\Pi(1,N,S_2)dF(\lambda) + \int_0^{\bar{\lambda}} (1-\lambda)\Pi(1,N,S_2)dF(\lambda) + (1-F(\bar{\lambda}))\Pi(1,N,S_2)
\end{aligned}$$

This allows us to simplify $(V_1 - V_2)/\beta$ to

$$\int_0^{\bar{\lambda}} \lambda \Pi(1, N, S_2) dF(\lambda) - 2 \int_0^{\bar{\lambda}} \lambda \Pi(2, N, S_2) dF(\lambda)$$

This is strictly positive since $\Pi(1, N, S_2) > 2\Pi(2, N, S_2)$. ■