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Abstract

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Non-technical Abstract

1 Introduction

[1] According to Saxenian (1994, p.34), labor turnover in Silicon Valley's electronic industry reached 35 percent a year on average during the Seventies.

[2] Innovations created by an employee in its working hours also belong to the employer according to trade secret laws.

[illegible] *de facto* [illegible][3]

[illegible][4] [illegible]

[illegible][5] [illegible]

[illegible][6]

[3] This "inevitable disclosure doctrine" was first proposed by a US court in the PepsiCo case. See Gilson (1999), and Hyde (2001, part III, page 5) for a critique of this doctrine.

[4] Saxenian compares Silicon Valley's performance with Massachusetts' Route 128. The stronger development of the former over the latter is attributed to the higher mobility of workers, itself explained by social reasons as mentioned above. Gilson and Hyde show that the legal infrastructure in California favors spillovers whereas in Massachusetts it does not.

[5] Note that we consider only the ex-ante effects of labor contracts on innovation. For the argument that knowledge spillovers are beneficial if they are large enough to outweigh the detrimental effects on the incentives to innovate, see Gilson (1999).

[6] The compensation to scientists may take many forms, reflecting the fact that scientific personnel are often as much driven by professional curiosity and recognition as by monetary incentives. Examples are: promotions, additional R&D funds, freedom to pursue pet projects,

luncheons and other recognition events. See also Chester (1995) on these issues. For an empirical analysis of compensation schemes in pharmaceutical research, see Cockburn et al. (1999).

[7] See also Hyde (2000) for a critical discussion of the possible application of Aghion and Tirole's model to the analysis of CNCs, especially as regards shared ownership rights. Merges (2001) also uses the Grossman and Hart's theory to discuss who should own property rights of innovations.

[8] See, for example, Fosfuri et al. (2001) and Rønde (2001).

[illegible]

2 The model

[illegible]

2.1 The Game

(1) The contract offered [illegible] 1 [illegible] (s, i, b) [illegible] 1 [illegible]

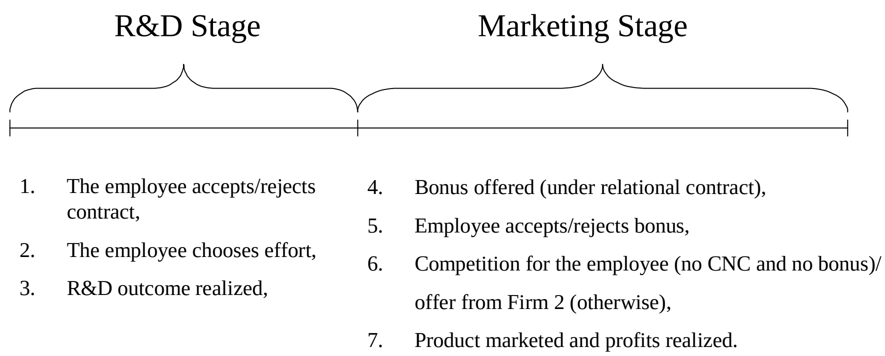
[illegible] s [illegible] $i = CNC$ [illegible] $i = \emptyset$ [illegible] 1.[9]

[illegible] $b > 0$ [illegible]

[9] After the first market realisation, the current innovation loses value. Therefore, we can restrict our attention to one-period covenants.

[illegible][10]

[illegible]



[illegible]

(2) The research stage [illegible][11] [illegible] w_a [illegible] $w_a = 0$[12] [illegible] a [illegible] $1 - a$ [illegible] 0 [illegible] γa^2 for the employee. We will refer to a as the employee's 'effort'.[13]

[10] In other words, we do not consider the component β of the compensation scheme analysed by Baker et al. (1994, 2001).

[11] Here, there is a difference between the first and later periods. In the first period, the employee accepts or rejects the contract. In later periods, he decides whether to continue working for the firm given the conditions of the contract. In most parts of the paper, however, the employee earns zero every period, so this difference between the first and the later periods is inessential.

[12] This might not appear as a completely innocent assumption, since Baker et al. (1994) showed that the value of the reservation wage affects the sustainability of the relational contracts. However, in a previous draft of the paper we have analysed the case where $w_a \geq 0$, only to find that it does not affect the comparison between CNCs and no-CNCs. Since assuming zero reservation wage makes the analysis considerably neater, we have adopted this assumption.

[13] Of ocurse, one should interpret a as the effort made by the employee above a minimal effort which could specified contractually (number of hours worked, verifiable tasks to be

Finally, at the end of the research stage, the outcome of the employee's effort is observed by all relevant agents in the economy. We assume that an innovation has only commercial value for one period. Afterwards, it either becomes obsolete or is imitated by competitors. Suppose first that the employee is unsuccessful. Then, no bonus is offered and the employee continues in the firm (whether it stays or leaves is immaterial). The game continues to the next period. On the other hand, if the employee is successful, there is a marketing stage.

(3) The marketing stage First, it is decided whether the employee stays with Firm 1 or leaves to Firm 2. We need to consider separately the case with and without a CNC. If there is a CNC, the timing is the following. Firm 1 decides whether to offer a bonus. If a bonus is offered, the employee accepts it, as he has no other possibility of capitalizing on the innovation. Afterwards, although the CNC prevents the employee from leaving, Firm 1 might decide to let him go if it receives a suitable compensation in exchange. Therefore, firm 2 decides whether it wants to make an offer to Firm 1 to hire the employee. This offer is either accepted or rejected.

If there is no CNC, the timing is similar. First, Firm 1 decides whether to offer the bonus, b. Next, the employee decides on whether to accept or reject the bonus. If he accepts the bonus, he has to stay until the end of the period in return (i.e. until after market realization). If the employee rejects the bonus, or no bonus is offered, the firms compete for the employee's services. We model the competition, which is discussed in detail in point 5 below, as a first price auction.

The profits depend on whether the employee stays with Firm 1. If the employee stays, Firm 1 can market the innovation as a monopolist. The gross monopoly profits (i.e. gross of wages) are normalized to 1. If the employee leaves, we assume that both firms can market the innovation. The underlying assumption is that the innovation remains within Firm 1, so it needs only to hire a 'production' employee (at the reservation wage) to produce (see section 3.4 for the case where the innovation is the employee's private information). In case the employee leaves, Firm 1 and 2 thus both earn gross duopoly profits of ϕ, ϕ □ 1.

performed, and so on). Therefore, when we talk of 'zero effort' which leads to 'zero profits', these terms need not be taken literally.

(4) Infinite repetition of the game The game continues like in 2-3 every period for an infinite number of periods.[14] There is no discounting within a period, but a discount rate of r between periods.

(5) The competition for the employee The competition for the employee, if there is no CNC and the bonus is rejected, is modeled as a first price auction. We will here describe the auction and derive the static Nash equilibrium for future reference. The first step is to find the value of the employee for the firms. There is a pool of identical employees that the firms can hire from. The value of the employee stems only from the innovation that he has made.

If Firm 1 loses the employee it gets ϕ whereas it gets 1 if keeps it. Hence its willingness to pay is $1 - \phi$. As for Firm 2, it gets ϕ if it is hires the employee and 0 otherwise. Hence, the willingness to pay is ϕ. As tie-breaking rule, we assume throughout the paper that the firm with the highest valuation hires the employee. This ensures an equilibrium in pure strategies. Furthermore, we do not consider equilibria in weakly dominated strategies. This implies that the firm with the higher willingness to pay will get the employee by paying a wage equal to the valuation of the other. Therefore, the firm will keep the employee (no job turnover arises) if $1 - \phi \geq \phi$, or $\phi \leq 1/2$. In this section, we restrict our attention to $\phi \leq 1/2$, but $\phi > 1/2$ is analyzed in section 3.1. We will say that the 'efficiency effect' holds if $\phi \leq 1/2$.[15]

Suppose first that no CNC is in place. Since $\phi \leq 1/2$, the employee stays with Firm 1 and receives a wage equal to ϕ. Suppose instead that there is a CNC. Here, the employee also stays, as Firm 2 cannot (profitably) pay Firm 1 enough to compensate for the loss incurred if the employee leaves.

2.2 Spot and relational contracts

We are now ready to analyze the complete model. We consider two types of contracts. First, we look at employment contracts containing only explicit elements, i.e., the fixed wage, s, and possibly a CNC. Following Baker et al. (2001), we denote these 'spot contracts'. Afterwards, we consider contracts where an implicit bonus, b, is added to the contract. These are called 'relational contracts'

[14] We assume that innovations are non-cumulative: the probability of getting an innovation in the following period(s) is the same no matter what has happened in the present period. This, admittedly strong, assumption simplifies the analysis greatly, and relaxing it is unlikely to change the analysis of CNCs qualitatively.

[15] In the industrial organization literature, the term "efficiency effect" has been used to describe a situation where the monopoly profit is higher than the sum of the duopoly profits. See for instance Tirole (1988, page 348-50).

as they only can be sustained in a long-term relation. Therefore, a contract $(s, i, 0)$ is 'Spot' and a contract $(s, i, b > 0)$ is 'Relational'.

We denote $V_{i,j}$ as the per period profits, where $i \in \{CNC, \emptyset\}$ and $j \in \{S(pot), R(elational)\}$. $V^*_{i,j}$ denotes the equilibrium profits. Finally, $U(a)$ is the utility of the employee in the relevant period as a function of a (the probability an action results in an innovation).

Before turning to the different contracts, we first analyze a benchmark case where it is possible to contract upon the outcome of the employee's effort.

2.2.1 Benchmark: first best

As a benchmark, it is useful to find the optimal contract when the outcome of the innovation is contractible. The firm can thus commit to paying a bonus if an innovation is made. Under contractible outcomes, it is efficient to include a CNC in the employment contract. The reason is twofold. First, since $\phi \leq 1/2$, the employee stays with the firm with and without a CNC. Second, including a CNC in the contract increases the a chosen by Firm 1 (through its choice of b), as it does not have to protect the innovation from Firm 2 ex-post.

Suppose the employee is offered the contract (b, s, CNC). Assuming that the employee accepts the contract, it chooses the a that maximizes its utility $U(a) = ab - \gamma a^2 + s$, which gives the solution $a = b/(2\gamma)$.

The problem of the firm is to maximize its profits subject to the participation and incentive constraint of the employee:

$$\max_{b,s}\{(1-b)a - s\} \quad subject\, to: \quad ab + s - \gamma a^2 \geq 0 \text{ and } a = b/(2\gamma).$$

which can be rewritten, after noting that the participation constraint is binding, as: $\max_b\{b(1 - b/2)/(2\gamma)\}$. The solution is $b^{fb} = 1$, $s^{fb} = -1/(4\gamma)$, and $a^{fb} = 1/(2\gamma)$. It can easily be verified that this is also the outcome if it is possible to contract directly on a.

In order to avoid corner-solutions, we assume that $\gamma > 1/2$. This ensures that a is smaller than 1 in equilibrium.

2.2.2 Spot Contracts

We now turn to the case where it is not possible to contract upon the outcome of the innovation. We first look at spot contracts $(s, i, 0)$.

A covenant not to compete Suppose first that there is a CNC. Since the employee cannot leave, he cannot rely on outside offers to increase his wage after

an innovation. His problem is: $\max_a U(a) = (s - \gamma a^2)$, leading to the optimal effort $a = 0$. The firm anticipates that the employee makes zero effort and pays him no more than $s = 0$. Firm 1's expected payoff in this case is

$$V^*_{CNC,S} = 0. \tag{1}$$

No covenant Suppose now that a CNC is included in the employment contract. From the analysis of the hiring process in the previous subsection, we know that *if* the effort leads to an innovation, the firm will pay ϕ to the employee to make him stay. The employee's expected payoff at the moment of deciding its effort is therefore $U(a) = (s + a\phi - \gamma a^2)$, leading to optimal effort $a = \phi/(2\gamma)$.

The problem of Firm 1 is to find the optimal fixed salary given the anticipation that the employee earns ϕ from an innovation. Hence, it solves:

$$\max_s V_{\emptyset,S}(s) = a(1 - \phi) - s, \quad subject\,to: \quad s + a\phi - \gamma a^2 \geq 0 \text{ and } a = \phi/(2\gamma),$$

where the first constraint ensures the participation of the employee. Clearly, this problem is solved by paying him a salary that will give him the reservation wage, that is: $s = -a\phi + \gamma a^2 = -\phi^2/(4\gamma)$. The expected profits of Firm 1 are:

$$V^*_{\emptyset,S} = \frac{\phi(2 - \phi)}{4\gamma}. \tag{2}$$

Note that the fixed wage is lower than the reservation wage (i.e., negative). Firm 1 is able to appropriate all monetary rents as the employee is risk-neutral and is not credit and wealth constrained.[16]

From the discussion above, the next lemma follows immediately:

Lemma 1 *If only spot contracts are available, it is optimal not to include a covenant not to compete in the employment contract.*

Under spot contracting, if there is a covenant not to compete the firm is not able to reward a successful employee. If there is no covenant in the contract, the firm is forced to pay at least *some* reward to the successful employee (as he otherwise leaves for a competitor). Letting the employee be free to leave thus partly overcomes the commitment problem of the firm, and this is the intuition why it is optimal not to include a CNC in the contract.

[16] If either one of these two assumptions is relaxed, some of the monetary rents will go to the employee. See section 3.2.

2.2.3 Relational Contracts

A covenant not to compete Let us start with the case where a CNC exists. Recall that under a relational contract, Firm 1 promises to pay the employee a bonus, b, if an innovation is made. Suppose that the employee expects the bonus to be paid. The optimal effort is found from the program: $\max_a U(a) = s + ab - \gamma a^2$, which leads to $a(b) = b/(2\gamma)$. The employee has the participation constraint $s + a(b)b - \gamma\left(a(b)\right)^2 \geq 0$, so the firm offers him the wage $s(b) = -b^2/(4\gamma)$. (Note that sofar the role of b is precisely the same as ϕ in the analysis above.) The per period payoff of the firm, as a function of b, is:

$$V_{CNC,R}(b) = a(b)(1-b) - s(b) = \frac{b(1-b)}{2\gamma} + \frac{b^2}{4\gamma} = \frac{b(2-b)}{4\gamma}$$

However, the key issue here is to understand whether the implicit contract is self-sustainable or not. Indeed, $V_{CNC,R}(b)$ can be the payoff only if the employee anticipates that the firm will pay the bonus. Else, he rejects the contract. Let us look then at the incentive constraint of the firm. The firm, after observing an innovation, has to compare the payoffs from paying the bonus and from reneging.

We consider an equilibrium sustained by 'grim' trigger strategies. We assume that if the firm deviates and chooses not to pay the bonus, it loses its reputation not only with the current employee but also with all potential employees.[17] [18] After a deviation, the firm has thus to use spot contracts in all future. It prefers thus to give up the covenant, as this gives a higher payoff under spot contracting.[19] Therefore, the incentive constraint (IC) is determined by the following condition:

$$(1-b) + \frac{V_{CNC,R}(b)}{r} \geq 1 + \frac{V^*_{\emptyset,S}}{r},$$

[17] Hyde brings an illustration of such a reputation mechanism at play (http://www.andromeda.rutgers.edu/~hyde/WEALTH3.htm). Intel sued in 1989 Chan, an engineer, for having misappropriated some of Intel's intellectual property related to the 80387 mathematical co-processor. This was a highly unusual step in Silicon Valley, and was perceived as unfair by the community of research engineers. As a result, Intel suffered serious recruitment problems. Apparently, this led Intel to abandon the practice of suing departing employees.

[18] If one is not comfortable with the hypothesis of reputational effects in the labor market, one can think that because of lock-in effects there can be a relationship only between the firm and a particular employee. After not receiving the bonus, this employee will not be willing to enter a relational contract any longer.

[19] After a deviation, the firm and the employee renegotiate the contract, as the employee gets a negative pay-off under the initial contract in the continuation game following a deviation where no bonus is paid (the employee would otherwise leave). The employee has no bargaining power, and the firm chooses the spot contract that maximizes its expected profits.

where the left hand side (LHS) are the profits of the firm if it pays the bonus, and the right hand side (RHS) are the profits if it deviates, pays no bonus, and continues with spot contracting and no CNC. Therefore, the problem of the firm is (after rewriting the IC):[20]

$$\max_{b} V_{CNC,R}(b), \quad subject\ to: \ V_{CNC,R}(b) \square rb + V^*_{\emptyset,S}$$

The objective function finds its maximum in the unconstrained problem for $b^{fb} = 1$ (that leads to the first best effort $a^{fb} = 1/2\gamma$). However, the constraint might be binding, or there could be no value of b satisfying it. The following proposition summarizes the solution of this program:

Lemma 2 *(Relational contract and a covenant not to compete)*
For $1/2 \square \phi$, the optimal relational contract with a covenant is characterized as follows:
i. If $r \square \frac{(1-\phi)^2}{4\gamma} \square \widehat{r}_{fb}$, then $b^* = 1$ (the relational contract attains first best).
ii. If $\widehat{r}_{fb} < r \square \frac{1-\sqrt{\phi(2-\phi)}}{2\gamma} \square \widehat{r}_o$, then $b^* = \widehat{b} = 1 \square 2\gamma r + \sqrt{(1 \square 2\gamma r)^2 \square \phi(2 \square \phi)}$ (the relational contract attains second best).
iii. If $r > \widehat{r}_o$, then the problem has no solution (only spot contracts exist).

Proof. For $b^* = 1$, the incentive constraint is $V(1) = 1/(4\gamma) \square r + \phi(2 \square \phi)/(4\gamma)$, which is satisfied iff. $r \square \widehat{r}_{fb}$. For higher values of r, b^* does not satisfy the incentive constraint. Therefore, the firm chooses the highest possible value of b that satisfies the incentive constraint with equality. This is a standard second order equation, whose higher root is $\widehat{b} = 1 \square 2\gamma r + \sqrt{(1 \square 2\gamma r)^2 \square \phi(2 \square \phi)}$. This root exists only if $(1 \square 2\gamma r)^2 \square \phi(2 \square \phi) > 0$, i.e. $r \square \widehat{r}_o$. ■

Lemma 2 states only the optimal bonus, but the corresponding effort and fixed wage are easily derived from the incentive and participation constraint of the employee. Note that when the relational contract is feasible, the firm always prefers it over spot contracts. This can be observed from the fact that a necessary condition for the incentive constraint of the firm to hold is $V_{CNC,R}(b) \square V^*_{\emptyset,S}$ $(> V^*_{CNC,S})$.

Observe that other things equal, the lower the discount rate r (i.e., the more weight attached to the future) the more likely that the relational contract can be sustained and lead to the first best. For intermediate values of the discount rate, a relational contract can be sustained, but only the second best solution $\widehat{b}$

[20] The problem is written for simplicity as in Baker et al. (1994). See that paper for a graphical analysis.

can be obtained. If the discount rate is too large, only the spot contracts arise (and the firm gives up the covenant to increase its payoff).

The following comparative statics result are easily obtained: $\partial b^*/\partial r \;\Box\; 0$ and $\partial b^*/\partial \phi \;\Box\; 0$. If the interest rate increases, it becomes more attractive for the firm to deviate from the relational contract because future benefits from the contract (relative to spot contracting) are valued less. Therefore, the bonus has to decrease to sustain cooperation. Higher duopoly profits have a similar effect on the equilibrium bonus, as they increase the profits from deviating through $V^*_{\emptyset,S}$.

It is interesting to note that the firm is hurt by the fact that it is able to give it up the CNC after reneging on the relational contract. This increases the payoff from deviating and makes it harder to sustain the more profitable relational contract.[21]

No covenant Let us now look at the relational contract under the assumption that there is no covenant. This gives the employee the possibility to get an outside offer (but recall we assume that he cannot leave if he accepts the bonus). Everything is as above, except that the employee may threaten to leave if no bonus is paid or it is rejected. The outside offer is ϕ. Therefore, the employee only accepts the bonus, and refrains from getting outside offers, if $b \;\Box\; \phi$. We only consider contracts where the bonus is accepted, as the contract otherwise is equivalent to a spot contract.

The incentive constraint of the firm is then:

$$(1 \,\Box\, b) + \frac{V_{\emptyset,R}(b)}{r} \;\Box\; 1 \,\Box\, \phi + \frac{V^*_{\emptyset,S}}{r},$$

where the LHS are the profits if the bonus is paid, and the RHS are the profits if the firm deviates, the employee is hired at the wage ϕ, and the employment is continued under spot contracting with no CNC.

Proceeding as above, the problem of the firm is:

$$\max_b V_{\emptyset,R}(b) = V_{CNC,R}(b) = \frac{b(2 \,\Box\, b)}{4\gamma} \quad s.\ to: V_{\emptyset,R}(b) \;\Box\; rb \,\Box\, r\phi + V^*_{\emptyset,S} \ and\ b \;\Box\; \phi.$$

The following proposition summarizes the solutions of the firm's program:

[21] In section 5, we analyze an extension of the model where firms can protect their knowledge by locating far away from competitors. The crucial difference between a CNC and an isolate location is precisely the possibility of giving up the protection after deviating.

Lemma 3 *(Relational contract and no covenant not to compete)*
For $1/2 \square \phi$*, the optimal relational contract without a covenant is characterized as follows:*
i. If $r \square \frac{(1-\phi)}{4\gamma} \square \widetilde{r}_{fb}$*, then* $b^* = 1$ *(the relational contract attains first best).*
ii. If $\widetilde{r}_{fb} < r \square \frac{(1-\phi)}{2\gamma} \square \widetilde{r}_o$*, then* $b^* = \widehat{b} = 2 \square \phi \square 4\gamma r$ *(the relational contract attains second best)*
iii. If $r > \widetilde{r}_o$*, then the problem has no solution (only spot contracts exist).*

Proof. At $b^* = 1$, the incentive constraint is: $V_{\emptyset,R}(1) = 1/4\gamma \square r \square r\phi + \phi(2 \square \phi)/(4\gamma)$, which is satisfied iff $r \square \widetilde{r}_{fb}$. For higher values of r, the incentive constraint binds and the firm chooses the highest bonus solving: $b/(2\gamma) \square b^2/(4\gamma) = rb \square r\phi + \phi(2 \square \phi)/(4\gamma)$, whence $\widehat{b} = 2 \square \phi \square 4\gamma r$. Since we require that $b \square \phi$, it must be that $r \square (1 \square \phi)/(2\gamma)$. For higher values of r, there is no solution to the constrained program. ■

We have as above, and for the same reasons, $\partial b^*/\partial r \square 0$ and $\partial b^*/\partial \phi \square 0$. Comparing the incentive constraint of the firm with and without a CNC, we see that the constraint is looser if there is no covenant (the only difference between the two constraints is ϕ that is substracted on the RHS when there is no CNC.) The absence of a covenant endows the employee with the threat to leave the firm. This decreases the payoff of the firm from deviating, so a relational contract can be sustained for a larger region of parameters and with higher powered incentives. The next lemma shows this formally.

Lemma 4 *For* $1/2 \square \phi$*, the region of parameters for which a relational contract exists is larger if there is no covenant not to compete included in the employment contract. Furthermore, whenever a relational contract exists both with and without a covenant, both the profits of the firm and the effort of the employee are (weakly) greater with no covenant.*

Proof. To prove this proposition, we just have to compare the results obtained in Lemma 2 and 3. We start by comparing the threshold values. It is straightforward to show that $\widehat{r}_{fb} < \widetilde{r}_{fb}$ and $\widehat{r}_o < \widetilde{r}_o$. Therefore, if $r \square (0, \widehat{r}_{fb}]$, the profits are the same with and without a covenant, as the first best bonus can be implemented. If $(\widetilde{r}_o, \square)$, no relational contract exists (and Lemma 1 establishes that profits are higher if there is no covenant). If $r \square (\widehat{r}_{fb}, \widetilde{r}_{fb}]$, it is optimal to have no covenant as this is the only way that b^{fb} can be implemented. Similarly, if $r \square (\widehat{r}_o, \widetilde{r}_o]$, it is optimal to not to have a covenant as there otherwise exists no relational contract. Finally, consider $r \square (\widetilde{r}_{fb}, \widehat{r}_o]$ where a second best relational contract exists with and without a covenant. Here, the

equilibrium effort under the covenant ($\widehat{b}_c$) is lower than without the covenant ($\widehat{b}_{nc}$): $\widehat{b}_c = 1 - 2\gamma r + \sqrt{(1 - 2\gamma r)^2 - \phi(2 - \phi)} < \widehat{b}_{nc} = 2 - \phi - 4\gamma r$. Since $V_{i,R}(b)$ is increasing for $b < 1$, it is optimal not to have a covenant in this region. ■

Combining the previous results, we obtain the following proposition, which is one of the main results of the paper:

Proposition 5 *When the innovation depends only on the employee's effort, it is always (weakly) better for the firm not to include a covenant not to compete in the employment contract.*

Proof. There are three situations possible: 1) only spot contracting is possible whether or not a covenant is included ($r \in (\widetilde{r}_o, \infty)$); 2) a relational contract exists only if there is no covenant ($r \in (\widehat{r}_o, \widetilde{r}_o]$); and 3) a relational contract exists with and without a covenant ($r \in (0, \widehat{r}_o]$). Since a relational contract always dominates spot contracts when it exists, the proof follows directly from Lemma 1 and 5. ■

This intuition behind this result is, as explained above, that having no covenant alleviates the commitment problem of the firm. The firm would like to commit to rewarding the employee for innovating but doing so is difficult. Under spot contracting, the only way to credibly promise to reward a successful employee is not to include a CNC. Under relational contracting, the commitment problem is less severe, as the threat of reversion to spot contracting makes it costly for the firm to renege on its (implicit) promises. However, even in a relational contract, it is (weakly) better not to include a CNC, as it relaxes the incentive constraint of the firm by increasing the cost of deviating.

3 Robustness of the results

In this section, we relax (one at a time) some of the assumptions we have made so far. First, we examine the case where the efficiency effect does not hold ($\phi > \frac{1}{2}$); second, we study the case where the employee is credit constrained; third, we discuss alternative assumptions about the nature of the hiring process; fourth, we study the case where the innovation is private information of the employee.

3.1 The efficiency effect does not hold ($\phi > \frac{1}{2}$)

Up to now, we have considered only the case where the so-called efficiency effect holds. Now, we analyze the case where $\phi > \frac{1}{2}$. Here, the outside firm has the highest valuation of the employee (said otherwise, the firm loses relatively little

from letting the employee go). If the employee is free to leave, the outside firm (Firm 2) hires the employee paying a wage of $1 - \phi$. If the employee cannot leave, either because of a CNC or because it has accepted a bonus, Firm 2 gives a take-it-or-leave-it offer to Firm 1.[22] In equilibrium, Firm 2 hires the employee paying $1 - \phi$ to Firm 1. The outside firm thus always hires the employee paying $1 - \phi$. However, the payment goes to the employee only if he is free to leave. Otherwise, it goes to the firm.

Spot contracts Following an innovation, the employee receives a wage of 0 is there is a covenant and $1 - \phi$ if there is none. Therefore, the effort of the employee is 0 and $(1 - \phi)/(2\gamma)$ with and without a covenant, respectively. Proceeding as in the base model, we have:

$$V^*_{CNC,S} = 0 \text{ and } V^*_{\emptyset,S} = \frac{1 - \phi^2}{4\gamma}.$$

Hence, the firm prefers to have no CNC under spot contracting. Notice that $V^*_{\emptyset,S}$, unlike in the previous section, is decreasing in ϕ. The reason is that the wage is decreasing in ϕ, which in turn decreases the effort of the employee.[23] Note that the higher ϕ the less the firm is willing to pay to keep the employee. In the limit, $\phi = 1$, the firm is not willing to pay anything, as the outside firm uses the innovation in an independent product market. Therefore, the employee receives a zero wage, also if there is no CNC, and exerts no effort.

Relational contracts First, we look at relational contracts where a CNC is included. The problem of choosing the optimal contract is similar to the one in the base model. As before, the key constraint is the incentive constraint of the firm. Suppose thus that an innovation has been made. If the firm pays the bonus, the employee always accepts it, as he cannot threaten to leave for a competitor. Afterwards, the outside firm offers to pay $1 - \phi$ to hire the employee. Since the employee has been paid the bonus, it is the firm that decides whether to accept or reject this offer. It will accept, as the efficiency effect does not hold. Hence, the firm lets the employee go, and hires another worker to do the production. In the present period, the firm earns: $-b + 1 - \phi + \phi = 1 - b$. The

[22] The results are robust to different specifications of the bargaining game as long as the employee earns a lower wage with a CNC than without; see discussion in next subsection.

[23] Suppose that the employee's outside option instead would be to set up its own business. Disregarding any fixed costs of starting the business, this option would have the value ϕ (i.e., the duopoly profits). For $\phi \leq 1/2$, it doesn't matter whether the outside option is to start up a business or to leave for a competitor. For $\phi > 1/2$, however, the value of the outside option is decreasing in ϕ if the employee receives an offer from a competitor whereas it is increasing if the employee can start up a new business. However, considering a startup as the outside option would not affect the basic trade-off between having a CNC or not.

following period, the firm can start a relational contract with another worker, as it has honored the contract and kept its reputation intact. If the firm does not pay the bonus, the firm earns 1 this period (i.e., $1 - \phi + \phi$). However, it has lost its reputation in the labor market and has to continue with a spot contract. The problem of the firm is thus:

$$\max_b V_{CNC,R}(b) = \frac{b(2-b)}{4\gamma}, \quad \text{subject to}: V_{CNC,R}(b) \geq rb + V^*_{\emptyset,S}$$

The next lemma states the solution to this problem. Since the problem is almost identical to the one in the base model, the proof has been left out.

Lemma 6 *(Relational contract and a covenant not to compete) For* $\phi > 1/2$*, the optimal relational contract with a covenant is characterized as follows:*
i. If $r \leq \frac{\phi^2}{4\gamma} \equiv \widehat{r}_{fb}$*, then* $b^* = 1$ *(the relational contract attains first best[24]).*
ii. If $\widehat{r}_{fb} < r \leq \frac{1-\sqrt{1-\phi^2}}{2\gamma} \equiv \widehat{r}_o$*, then* $b^* = \widehat{b} = 1 - 2\gamma r + \sqrt{(1-2\gamma r)^2 - 1 + \phi^2}$ *(the relational contract attains second best)*
iii. If $r > \widehat{r}_o$*, then the problem has no solution (only spot contracts exist).*

We now turn to contracts where there is no CNC. Consider the incentive constraint of the firm. If the firm pays the bonus, the profits are the same as with a CNC. If the firm does not pay the bonus, they are not. In this case, the firm loses the employee to the outside firm and earns duopoly profits in the present period. Afterwards, the firm continues with a spot contract because no worker in the pool is willing to accept a relational contract. The problem of the firm is thus:

$$\max_b V_{CNC,R}(b) = V_{\emptyset,R}(b) = \frac{b(2-b)}{4\gamma}, \quad \text{s. to}: 1 - b + \frac{V_{CNC,R}(b)}{r} \geq \phi + \frac{V^*_{\emptyset,S}}{r}$$

The firm earns monopoly profits after reneging on the bonus if there is a CNC, but only duopoly profits if there is no CNC. Therefore, the incentive constraint of the firm is laxer if there is no CNC. The study of the firm's program when there is no covenant is very similar to the problem analyzed in the previous section, and we omit the derivation.

Lemma 7 *(Relational contract and no covenant) For* $\phi > 1/2$*, the optimal relational contract without a covenant is characterized as follows:*
i. If $r \leq \frac{\phi}{4\gamma} \equiv \widetilde{r}_{fb}$*, then* $b^* = 1$ *(the relational contract attains first best).*

[24] The first best effort is here defined as the one that maximizes the profits of Firm 1. For $\phi > 1/2$, however, Firm 2 also benefits from the innovation. The bonus that maximizes the joint profits of the two firms is thus $b = 2\phi$.

ii. If $\widetilde{r}_{fb} < r \,\square\, \frac{\phi}{2\gamma} \,\square\, \widetilde{r}_o$*, then* $\widehat{b} = 1 + \phi \,\square\, 4\gamma r$ *(the relational contract attains second best)*
iii. If $r > \widetilde{r}_o$*, then the problem has no solution (only spot contracts exist).*

Armed with these results, we can now proceed to confirm the main result that we obtained in the previous section:

Proposition 8 *For* $\phi > 1/2$*, it is always (weakly) better for the firm not to include a covenant not to compete in the employment contract.*

Proof. In appendix. ∎

Proposition 8 summarizes the analysis for $\phi > 1/2$ where the employee leaves for the outside firm and technology spillovers arise. It is optimal, as it is for $\phi \,\square\, 1/2$, not to include a CNC in the employment contract. The employee exerts a higher effort under spot contracting if there no CNC. Furthermore, it is easier to sustain a relational contracts if there is no CNC, as it is more costly for the firm to renege on the contract.

Note that under the assumption that $\phi > 1/2$ job spillovers arise at equilibrium, whereas in the base model (where the efficiency effect held) the employee was kept within firm 1 at equilibrium. Therefore, it is not the actual job turnover that matters, but rather the possibility of it (whether the outside offers are matched or not is immaterial, although of course the level of the outside offer matters).

3.2 Credit constrained employee

Throughout the paper we have assumed that the firm can extract all rents by using a negative, fixed wage. In this section, we study the case where the employee is wealth and credit constrained. In particular, we assume that the firm has to offer a wage $s \,\square\, 0$ every period.[25] This can also be thought of as a situation where there is a minimum wage of 0. We consider only $\phi \,\square\, 1/2$.

Spot contracts The employee receives an additional wage of ϕ if it makes an innovation and there is no CNC. Therefore, it exerts the effort $\phi/(2\gamma)$. The firm can no longer extract all rents ex-ante, but it chooses the lowest fixed wage

[25] Another possibility is that the employee is credit constrained at the beginning of the game, but not necessarily later if it is successful and earns more than the expected wage of 0. This problem is technically quite difficult, as it is not stationary, so we restrict attention to the simpler variant where $s \geq 0$ every period. This can be thought of as the other extreme case relative to the base model where the employee is credit constrained in any one period. Our speculation is that in an intermediate situation where the employee is constrained only in the first period the qualitative results would not change.

possible, $s = 0$. The employee chooses $a = 0$, if there is a CNC, as an innovation does not increase the employee's wage bill. Hence, $s = 0$ is optimal. From this discussion follows:

$$V^*_{CNC,S} = 0 \text{ and } V^*_{\emptyset,S} = \frac{\phi(1 \square \phi)}{2\gamma}.$$

Under spot contracting, it is thus optimal to have no covenant, as the employee otherwise chooses the minimal effort.

Relational contracts Suppose that there is a CNC in place. The employee is paid b if he innovates and chooses the effort $b/(2\gamma)$. The firm offers $s = 0$ to minimize the employee's rents. Therefore, the expected profits per period are $(1 \square b)b/(2\gamma)$. The bonus that solves the unconstrained problem of the firm is $b^* = 1/2$. Since the firm cannot use the fixed wage to extract the surplus of the employee, it offers a lower bonus in order to capture some of the rents created by the innovation. (Indeed, if it offered $b = 1$, which is the first best bonus when the employee is not credit constrained, it would earn zero profits). Abusing notation slightly, we denote $\widetilde{b}$ the first best bonus, as it solves the firm's unconstrained problem.

The firm's incentive constraint has the same form as in the base model, so the problem of the firm can be written as:

$$\max_b V_{CNC,R}(b) = \frac{b(1 \square b)}{2\gamma} \quad \text{subject to: } V_{CNC,R}(b) \square V^*_{\emptyset,S} \square rb.$$

The following lemma summarizes the solution to this program:

Lemma 9 *(Relational contract with a covenant and a credit constrained employee) For $1/2 \square \phi$, the optimal relational contract with a covenant is characterized as follows:*
i. If $r \square \frac{(1-2\phi)^2}{4\gamma} \square \widehat{r}_{fb}$, then $b^* = 1/2$ (the relational contract attains first best given the credit constraint).
ii. If $r \square \frac{1-2\sqrt{\phi(1-\phi)}}{2\gamma} \square \widehat{r}_o$, then $\widehat{b}_o = \left(1 \square 2\gamma r + \sqrt{(1 \square 2\gamma r)^2 \square 4\phi(2 \square \phi)}\right)/2$ (the relational contract attains second best).
iii. If $r > \widehat{r}_o$, then the problem has no solution (only a spot contract exists).

If there is no covenant, it is costlier to renege on the bonus, as the firm has to pay ϕ to keep the employee. Therefore, the problem of the firm is:

$$\max_b V_{CNC,R}(b) = \frac{b(1 \square b)}{2\gamma} \quad \text{subject to: } V_{CNC,R}(b) \square V^*_{\emptyset,S} \square r(b \square \phi).$$

The solution to this program is:

Lemma 10 *(Relational contract, without covenant and with a credit constrained employee) For $1/2 \square \phi$, the optimal relational contract without a covenant is characterized as follows:*

i. If $r \square \frac{1-2\phi}{4\gamma} \square \widetilde{r}_{fb}$, then $b^* = 1/2$ (the relational contract attains first best given the credit constraint).

ii. If $r \square \frac{1-2\phi}{2\gamma} \square \widetilde{r}_o$, then $\widetilde{b}_o = 1 \square 2\gamma r \square \phi$ (the relational contract attains second best)

iii. If $r > \widetilde{r}_o$, then the problem has no solution (only a spot contract exists).

The next proposition shows that it is optimal not to include a CNC in the employment contract. (We omit the proof because it follows the same steps as above.)

Proposition 11 *Suppose that the employee is wealth and credit constrained and $1/2 \square \phi$. Then, it is always (weakly) better for the firm not to include a covenant not to compete in the employment contract.*

As above, the intuition is that having no covenant both relaxes the firm's incentive constraint under relational contracting and gives the employee better incentives under spot contracting. The outcome is less efficient if the employee is credit constrained, as the firm has to offer a lower bonus to capture some of the rents accruing from the innovation, but it does not change the conclusion of the base model that it is optimal not to include a CNC in the contract.

3.3 Different bargaining rules

We have sofar modeled the hiring process of the employee as a first price auction. In this section we show that our qualitative results (in particular, about the effect of CNCs) are robust to different assumptions concerning the bargaining game. We restrict attention to $\phi \square 1/2$ and assume that the employee is not credit constrained. The effects at play are easily understood from the base model, so we keep the analysis verbal.

Under spot contracting, the bargaining game is irrelevant if there is a covenant in place. Firm 1 has the highest valuation of the employee, so there are no gains from trade to be realized. Hence, after an innovation is made, Firm 1 keeps the employee without paying anything. Foreseeing this, the employee exerts no effort and $V^*_{CNC,S} = 0$.

When there is no CNC, the bargaining rule affects the solution under spot contracting. The employee receives an outside offer of ϕ from Firm 2. However, it may try to increase its wage further by threatening to leave. If the

employee leaves, both the firm and the employee receive ϕ. If, on the other hand, the employee stays, the firm earns monopoly profits of 1. Depending on the bargaining power of the two parties, the employee obtains a wage $w \in [\phi, 1 - \phi]$.[26,27] The employee exerts the effort $w/(2\gamma)$, which is greater than (or equal to) the effort in the base model. The profits of the firm are also higher: $V^*_{\emptyset,S} = w(2 - w)/(4\gamma) \geq \phi(2 - \phi)/(4\gamma)$. The conclusion in the previous section that it is optimal to have no CNC under spot contracting holds thus a fortiori.

Under relational contracting, a different bargaining rule affects the incentive constraint of the firm. The incentive constraint is $V_{CNC,R}(b) - V^*_{\emptyset,S}(w) \geq rb$ if there is a CNC and $V_{\emptyset,R}(b) - V^*_{\emptyset,S}(w) \geq r(b - w)$ if there is none. A higher wage affects the incentive constraints through two channels. First, by increasing the spot market payoff, $V^*_{\emptyset,S}$, it makes the incentive constraint tighter with and without a covenant. Second, if there is no covenant, a higher wage increases the cost of keeping the employee after reneging on the bonus (w on the right hand side of the constraint). This is a countervailing effect that makes the incentive constraint slacker. In total, the incentive constraint is tighter if the wage is higher both with and without a CNC.[28] However, the relational contract without a covenant still does better than the contract with a covenant due to the second effect. A higher wage decreases the profits under relational contracting, but it does not change the relative ranking between a relational contract with and without a CNC.

We have, as in the previous section, three cases to consider. If the discount rate is high (low), there exists a relational contract (no relational contract) independently of whether a CNC is included in the contract. Finally, for intermediate discount rates, a relational contract exists only if there is no CNC. It follows from the discussion above that it is optimal to have no CNC in all three cases.

[26] There are, as mentioned in text, other equilibria in the first price auction than the one considered. These involve: Firm 2 bidding between its own and Firm 1's evaluation of the employee (i.e., $w \in [\phi, 1-\phi]$); Firm 1 matching the bid of Firm 2. Up to now, we have ignored these equilibria, as they are in weakly dominated strategies. The analysis in this section deals with alternative bargaining rules, but it can be reinterpreted as the outcome if these other equilibria are played.

[27] In the base model, $w = \phi$ and this corresponds to a situation where the firm has all bargaining power ex-post (i.e., after the innovation is made).

[28] Consider the contract with no CNC. Following the step in previous section, it can be shown that a relational contract exists if and only if $r \leq (1 - w)/2\gamma$. However, for these parameters, we have: $\partial(V_{\emptyset,R}(b) - V^*_{\emptyset,S} - r(b - w))/\partial w < 0$. Hence, the incentive constraint is tighter for $w > \phi$. The first effect thus always dominates the second.

3.4 The innovation is private information

In the base model, it is assumed that the firm keeps the innovation if the employee leaves. This requires that there is a control system in place to ensure that the work of the employee is kept inside the firm, or that the employee works in a team, so that he could not have an informational monopoly on an innovation.[29,30] In some circumstances, it is difficult to put such a control system in place (it would be, for example, very difficult to force an employee to reveal a new idea that exists only inside his head), or there might be no team-work. In this section, we analyze a set-up where the innovation is private information to the employee with a positive probability (while assuming $\phi \leq 1/2$ and no credit constraints).

Suppose that if the employee leaves, the firm keeps the innovation only with the probability $1 - \theta$.[31] The value of the employee who has made an innovation is thus $1 - (1 - \theta)\phi$ for Firm 1. The value of the employee is $\theta + (1 - \theta)\phi$ for Firm 2. First, suppose that there is a CNC in place. Since $\phi \leq 1/2$, Firm 1 has the higher valuation of the employee ($1 - (1 - \theta)\phi \geq \theta + (1 - \theta)\phi$ when $\phi \leq 1/2$). If there is a CNC, Firm 1 keeps the employee paying nothing additional. If there is no CNC, Firm 1 also keeps the employee but has to pay $w(\theta) = \theta + (1 - \theta)\phi$.

First notice that for $\theta > 0$, the employee earns a higher wage than in the base model, as it has a monopoly on the innovation with a positive probability. The game is thus formally equivalent to the one considered above where the employee has more bargaining power ex-post. It follows that it is optimal not to include a CNC in the employment contract.

4 Two-sided investments

In this section, we extend the analysis by considering the case where not only the employee but also the employer invest in creating the innovation. We therefore modify slightly the game analyzed sofar by assuming that in the second stage of each period the firm also makes an investment, I. More specifically, we assume that the probability of an innovation is $\lambda a + (1 - \lambda)I$ where a and I are the

[29] These control mechanisms can take many forms: the employees may have to write diligent lab notes and periodical progress reports; so-called 'trailer clauses' may be included in the contracts (such clauses assign the current employer user rights to innovations that the employee makes shortly after leaving the firm).

[30] The degree of control may clearly be an endogenous variable. However, if control can be given up at no cost, there is no trade-off inside this model: It is optimal to choose as little control as possible, as it helps the firm to commit to rewarding a successful employee. This true both with a relational and a spot contract.

[31] The firm may either obtain the innovation through an internal control mechansim or recover it after the employee has left due to a trailer clause.

investments of the employee and the firm, respectively. λ is thus a measure of how important the employee's investment is relative to the firm's. In the extreme cases, if $\lambda = 1$, only the employee's investment matters, whereas if $\lambda = 0$ only the firm's investment matters. The cost of investing is given by $\gamma(i)^2$ $(i = a, I)$ for both agents. We assume that $\phi \square \frac{1}{2}$ and that the employee is not credit constrained.

4.1 Benchmark: first best

We first determine the optimal contract when it is possible to contract upon the worker's contribution to the innovation, so the firm can commit to paying b if he is successful. In this case, at the innovation stage the employee solves $\max_a \left\{(\lambda a + (1 \square \lambda)I)b \square \gamma(a)^2 + s\right\}$, which leads to the effort $a(b) = \lambda b/(2\gamma)$; the firm solves $\max_I \left\{(\lambda a + (1 \square \lambda)I)(1 \square b) \square \gamma(I)^2 \square s\right\}$, resulting in the investment $I(b) = (1 \square \lambda)(1 \square b)/(2\gamma)$.

The firm maximises its profit subject to the participation constraint of the employee: $\max_{b,s} \left\{(\lambda a(b) + (1 \square \lambda)I(b))(1 \square b) \square \gamma(I(b))^2 \square s\right\}$, subject to $s \square \gamma(a(b))^2 \square (\lambda a(b) + (1 \square \lambda)I(b))\, b$. After substituting and noting that the participation constraint will bind, this can be rewritten as:

$$\max_b V(b) \square \left\{\frac{\lambda^2 b(2 \square b)}{4\gamma} + \frac{(1 \square \lambda)^2(1 \square b^2)}{4\gamma}\right\}.$$

Solving this problem, we obtain:

$$b^{fb}(\lambda) = \frac{\lambda^2}{\lambda^2 + (1 \square \lambda)^2}.$$

It can be checked that the second order condition is satisfied, so b^{fb} is a global maximum. It is not possible to increase the incentives of the firm and the employee at the same time, as a higher bonus to the employee leads to lower profits for the firm. The optimal bonus has thus to trade-off the incentives of the firm and the employee. b^{fb} is increasing in λ, because the incentives of the employee become more important (relative to the firm's) when the employee contributes more to the innovation.

4.2 Spot contracts

4.2.1 Covenant not to compete

Suppose first that there is a CNC, so the employee cannot leave following an innovation. Under spot contracting, the firm does not pay the employee extra if there is an innovation. Therefore, as in the base model, we have: $a = s = 0$.

The firm receives profits 1 if it innovates. The problem of the firm can thus be written as $\max_I V_{CNC,S} = (1 \square \lambda)I \square \gamma(I)^2$, which results in $I = (1 \square \lambda)/(2\gamma)$ and $V^*_{CNC,S} = V(0) = (1 \square \lambda)^2/(4\gamma)$.

4.2.2 No covenant

We now turn to the case where there is no CNC. In equilibrium, the firm pays ϕ to the employee, if there is an innovation, to avoid him leaving. The employee takes the effort $a = \lambda\phi/(2\gamma)$, and the firm extracts all expected rents by offering $s = \square\lambda^2\phi^2/(4\gamma) \square (1 \square \lambda)^2(1 \square \phi)\phi/(2\gamma)$. The expected profits of the firm are: $V^*_{\emptyset,S} = \lambda^2\phi(2 \square \phi)/(4\gamma) + (1 \square \lambda)^2(1 \square \phi^2)/(4\gamma)$.

Comparing the profits with and without a covenant, we have the following result:

Lemma 12 *Under spot contracting, the firm chooses to have a covenant not to compete if and only if*

$$\phi \square 2b^{fb}(\lambda).$$

Proof. Follows directly from comparing profits above. ■

In order to understand the lemma, note that the condition $\phi \square 2b^{fb}(\lambda)$ is equivalent to $\lambda \square \widetilde{\lambda}(\phi)$,where $\widetilde{\lambda}(\phi)$ (with $\partial\widetilde{\lambda}/\partial\phi > 0$) is implicitly given by the solution of $\phi = \frac{2\lambda^2}{\lambda^2+(1-\lambda)^2}$. In general, the firm chooses a covenant if the effort of the employee is relatively unimportant for the R&D outcome (λ low) and competition in the product market is weak (ϕ is high). In this case, the employee would be paid too high a reward for an innovation if there were no CNC, and this would destroy the (more important) incentives of the firm.[32] This result is in the spirit of Grossman and Hart (1986) showing that the residual rights of control should be owned by the party whose investment is more important.[33]

In the base model, where only the employee's effort matters for R&D ($\lambda = 1$), it is optimal to have no CNC to provide incentives to the employee. In the other extreme case where only the firm's investment matters ($\lambda = 0$), it is optimal to have a covenant. (This is easily seen from Lemma 12 as $b^{fb} = 0$ for $\lambda = 0$.) The reason is that a covenant maximizes the incentives of the firm by minimizing the reward to the employee.

[32] Notice that $\frac{1}{2} \geq \phi \geq 2b^*$ is feasible if and only if $\lambda \leq (\sqrt{3} - 1)/2$.

[33] Unlike Grossman and Hart, in this paper there is not a choice between giving the control rights to either the firm or the employee. Rather, there is a choice between giving the control rights to the firm (a covenant) or sharing them (no covenant).

4.3 Relational Contracts

We now consider the possibility of relational contracts. Reassuringly, the conclusion of Lemma 12 will not change. It is optimal to include a CNC in the employment contract if and only if $\phi \square 2b^{fb}$. However, the analysis of relational contracts with two-sided investment is rather long, so the reader may consider skipping it at a first reading.

4.3.1 A covenant not to compete

In the analysis, we need to consider $\phi < 2b^{fb}$ and $\phi \square 2b^{fb}$ separately, as the spot contract that the firm would choose after reneging on the relational contract is different (see Lemma 12).

A covenant, for $\phi < 2b^{fb}$ The problem of the firm is $\max_{b,s} V(b,s) = \left\{\lambda^2 b(1 \square b)/(2\gamma) + (1 \square \lambda)^2(1 \square b)^2/(4\gamma) \square s\right\}$, subject to the employee's participation constraint $\lambda^2 b^2/(4\gamma) + (1 \square \lambda)^2(1 \square b)b/(2\gamma) + s \square 0$ and the firm's incentive constraint for the payment of the bonus $\left(V(b,s) \square V^*_{\emptyset,S}\right)/r \square b$. This can be rewritten as:

$$\max_b V(b) \qquad s.to: \frac{1}{r}\left(V(b) \square V^*_{\emptyset,S}\right) \square b \tag{3}$$

Except for both parties investing, the problem of the firm is the same as in the base model. Solving the program, we obtain:

Lemma 13 *Under a covenant and $\phi \square 2b^{fb}$,*

i. If $r \square \frac{\lambda^2}{4\gamma}\left(1 \square \frac{\phi}{b^{fb}}\right)^2 \square r_{fb}$, then $b^* = b^{fb}$ (first best).

ii. If $r_{fb} < r \square \frac{\lambda^2}{2\gamma}\left(1 \square \sqrt{\frac{\phi}{b^{fb}}(2 \square \frac{\phi}{b^{fb}})}\right) \square r_{sb}$, then

$$b^* = b^{sb} \square b^{fb}\left[1 \square \tfrac{1}{\lambda^2}\left(2\gamma r \square \lambda^2\sqrt{\tfrac{\phi}{b^{fb}}(2 \square \tfrac{\phi}{b^{fb}}) + \left(1 \square \tfrac{2\gamma r}{\lambda^2}\right)^2}\right)\right] \text{ (second best).}$$

Proof. See Appendix. ■

As expected, a decrease in the interest rate and a decrease in ϕ make the relational contract more likely to be sustained, as they make less attractive for the firm to renege on the contract and continue the relation with a spot contract (and no covenant). One can check that for $\lambda = 1$ (which implies $b^{fb} = 1$), Lemma 13 coincides with Lemma 2 of section 2.

A covenant, for $\phi \square 2b^{fb}$ In this case, the only difference is that after a deviation the firm would keep the covenant. Hence, its programme is:

$$\max_b V(b) \qquad s.to: \frac{1}{r}\left(V(b) \square V^*_{CNC,S}\right) \square b. \tag{4}$$

Lemma 14 *Under a covenant and $\phi > 2b^{fb}$,*

i. If $r \square \frac{\lambda^2}{4\gamma} \square r_{fb}$, then $b^* = b^{fb}$ (first best).

ii. If $r_{fb} < r \square \frac{\lambda^2}{2\gamma} \square r_{sb}$, then $b^* = b^{sb} \square 2b^{fb}\left(1 \square \frac{2\gamma r}{\lambda^2}\right)$ (second best).[34]

Proof. See Appendix. ■

Notice that ϕ does not enter the conditions in Lemma 14: the firm would keep the CNC even after reneging on the contract, so ϕ does not affect the profits from reneging.

4.3.2 No covenant

Like in the previous case, we distinguish between $\phi \square 2b^{fb}$ and $\phi > 2b^{fb}$.

No covenant, for $\phi \square 2b^{fb}$ We have to consider two sub-cases here. The first one is the case where $\phi \square b^{fb}$. Here, a relational contract can only be sustained if $b > \phi$, as a spot contract would otherwise do better. The second one is the case where $\phi > b^{fb}$. In this case, the optimal bonus must be such $b < \phi$, which will raise some new issues: since the outside offer is higher than the bonus, the employee must be given some rents to make him accept the bonus and stay with the firm. Let us start with the first sub-case.

No covenant, for $\phi \square b^{fb}$ The problem facing the firm is similar to (3), except for the incentive constraint, as the firm has to pay ϕ to keep the employee after reneging on the contract:

$$\max_b V(b) \qquad s.to: \frac{1}{r}\left(V(b) \square V^*_{\emptyset,S}\right) \square b \square \phi. \tag{5}$$

The next lemma states the results in this case:

Lemma 15 *If there is no covenant and $\phi \square b^{fb}$,*

i. If $r \square \frac{\lambda^2}{4\gamma}\left(1 \square \frac{\phi}{b^{fb}}\right) \square r_{fb}$, then $b^* = b^{fb}$ (first best).

ii. If $r_{fb} < r \square \frac{b^{fb}(b^{fb}-\phi)}{2\gamma\lambda^2} \square r_{sb}$, then $b^* = b^{sb} \square 2b^{fb} \square \phi \square \frac{4\gamma r \lambda^2}{b^{fb}}$ (second best).

Proof. See Appendix. ■

One can check that the critical values which satisfy Lemma 15 are identical to those found in the base model in section 2 for the special case $\lambda = 1$.

[34] Note that for $\lambda = 0$, the expression could be rewritten as $2b^{fb} - 4\gamma r\left(\lambda^2 + (1-\lambda)^2\right)$.

No covenant, for $b^{fb} < \phi \leq 2b^{fb}$ As anticipated above, there are new issues arising for $\phi > b^{fb}$. A relational contract is only sustainable if it allows the firm to pay a bonus that is lower than ϕ and to strike a better balance between the incentives of the firm and the employee.[35] This, however, raises the problem that the employee may leave for the rival even if offered the bonus. Indeed, if the employee earned a zero expected wage every period, as it was the case up to now, he would find it optimal to reject the bonus and take the outside offer.

The only way to implement a relational contract with $b < \phi$ is thus to ensure that the employee earns rents from staying in the relation.[36] The employee may then accept the bonus, even if the outside offer is higher, because leaving would

i. If $r \square \frac{\lambda^2}{4\gamma}\left(\frac{\phi}{b^{fb}} \square 1\right) \square r_{fb}$, *then* $b^* = b^{fb}$ *(first best).*

ii. If $r_{fb} < r \square \frac{\lambda^2}{2\gamma}\left(\frac{\phi}{b^{fb}} \square 1\right) \square r_{sb}$,
then $b^* = b^{sb} \square 2b^{fb} \square \phi + \frac{4\gamma r b^{fb}}{\lambda^2}$ *(second best).*

Proof. See Appendix. ■

No covenant, for $\phi > 2b^{fb}$ Notice that there is no relational contract with $b > \phi$, as this would be dominated by a spot contract. To sustain a relational contract with $b < \phi$ the firm has to guarantee some rents to the employee in each period - while appropriating them at period $t = 0$. One has then to consider a larger set of constraints, like in the previous case. Fortunately, the problem of the firm simplifies to:

Lemma 18 *If $\phi > 2b^{fb}$ and there is no CNC, the problem of the firm, when choosing the optimal relational contract, reduces to:*

$$\max_b V(b) \text{ subject to: } \frac{1}{r}\left(V(b) \square V^*_{CNC,S}\right) \square \phi \square b. \tag{7}$$

Proof. See Appendix. ■

The following lemma summarizes the results:

Lemma 19 *If there is no covenant and $\phi \square 2b^{fb}$,*

i. If $r \square \frac{\lambda^2}{4\gamma}\left(\frac{b^{fb}}{\phi - b^{fb}}\right) \square r_{fb}$, *then* $b^* = b^{fb}$ *(first best).*

ii. If $r_{fb} < r \square \frac{\lambda^2}{2\gamma}\left(\frac{\phi}{b^{fb}} \square 1 \square \sqrt{\frac{\phi}{b^{fb}}\left(\frac{\phi}{b^{fb}} \square 2\right)}\right) \square r_{sb}$,
then $b^* = b^{sb} \square b^{fb}\left[1 \square \frac{1}{\lambda^2}\left(\sqrt{\left(\lambda^2 + 2\gamma r\right)^2 \square \frac{4\gamma r \lambda^2}{b^{fb}}} \square 2\gamma r\right)\right]$ *(second best).*

Proof. See Appendix. ■

4.4 The optimal choice of a covenant

We are ready to consider the firm's choice of whether including a covenant not to compete in the contract. For $\lambda = 0$, a spot contract with a covenant achieves the first best, so there is no role for a relational contract. In the following, we thus focus on $\lambda > 0$.

First, consider $\phi \square b^{fb}$. Under relational contracting, the firm maximizes $V(b)$. The constraint on the firm's problem depends on whether there is a

covenant or not:

$$\left(V(b) \square V^*_{\emptyset,S}\right)/r \square b \square \phi \text{ (no covenant), or } \left(V(b) \square V^*_{\emptyset,S}\right)/r \square b \text{ (covenant).}$$

The constraint is laxer if there is no covenant, as the firm has to compete with the rival to keep the employee if it reneges on the bonus. It follows from Lemma 13 and 15 that the region of parameters for which a relation contract exists is strictly larger without a CNC. Further, given that the objective function is the same but without covenant the constraint is laxer, when relational contracts exist under both regimes the firm must be (weakly) better off without covenant. Finally, when only spot contracts exist, the firm is better off without a covenant. The following Lemma 20 formalises these intuitions:

Lemma 20 *For $\phi < b^{fb}$, it is (weakly) optimal for the firm not to include a CNC in the contract.*

Proof. See Appendix. ■

Consider now $b^{fb} \square \phi \square 2b^{fb}$. The argument follows closely the one above. Under relational contracting, the firm maximizes $V(b)$, subject to the following constraints:

$$\left(V(b) \square V^*_{\emptyset,S}\right)/r \square \phi \square b \text{ (no covenant), or } \left(V(b) \square V^*_{\emptyset,S}\right)/r \square b \text{ (covenant).}$$

It can be checked that the constraint is again laxer if there is no covenant. Therefore, (i) the region of parameters for which a relational contract exists is strictly larger without a CNC; (ii) given that the objective function is the same but without covenant the constraint is laxer, when relational contracts exist under both regimes the firm must be (weakly) better off without covenant; (iii) when only spot contracts exist, the firm is better off without a covenant. The following Lemma summarises these results:

Lemma 21 *For $b^{fb} \square \phi \square 2b^{fb}$, it is (weakly) optimal for the firm not to include a CNC in the contract.*

Proof. See Appendix. ■

The next lemma shows that it is optimal to include a CNC in the contract for $\phi \square 2b^{fb}$. The intuition is that the outside offer drives up the bonus in the relational contract when there is no covenant (to avoid the employee leaving). The employee thus receives too strong incentives, and the firm too weak, relative to the first best.

Under the relational contract the firm chooses b to maximise the same function $V(b)$, subject to the following constraints:

$$\left(V(b) \square V^{*}_{CNC,S}\right)/r \square \phi \square b \text{ (no covenant), or } \left(V(b) \square V^{*}_{CNC,S}\right)/r \square b \text{ (covenant).}$$

In this region, however, the constraint is laxer under the covenant, as $\phi \square b$ $\square$ b. Therefore, there are parameters where the relational contract exists under the covenant but not without; since the constraint is laxer, it must be that the profit is (weakly) higher under the covenant; and when the relational contract cannot be sustained under either regime, we know from Lemma 12 that with spot contracts the covenant gives the firm a higher payoff. This leads to the following Lemma:

Lemma 22 *For $\phi \square 2b^{fb}$, it is (weakly) optimal for the firm to include a CNC in the contract.*

Proof. Omitted, since it follows the same steps as the previous proofs. ■

The next proposition summarizes this rather long analysis.

Proposition 23 *It is optimal to include a CNC in the employment contract if and only if $\phi > 2b^{fb}$.*

The inclusion of relational contracts does not change the conclusion obtained under spot contracting. It is optimal to include a covenant not to compete in the contract if the employee's effort is relatively unimportant compared to the investment of the firm.

5 Location decisions and relational contracts: agglomeration or dispersion?

In this section, we extend the model to get some insights on the implications for firms' location decisions suggested by our approach.

Suppose that a firm has to decide between two alternative locations, one where another firm is already established ('agglomeration'), and another where no firm is present ('dispersion'). Suppose that location decisions neither affect transportation costs (for instance because both firms sell to a market which is located in a third location, equidistant from the two possible firm's locations) nor production costs (costs and reservation wages are identical in the two locations). Assume also that labor is not mobile across the two locations. This can be due, for example, to mobility costs on the side of the employee or to the informational

problem of identifying the 'right' employee in a distant location on the side of the employer. These assumptions make our setting very stylized, but they allow us to focus on the issues brought up in the rest of this paper, and to abstract from all other reasons for agglomeration vs. dispersion which are already well known from the economic geography literature.

In this setting, the firm can protect its intellectual property either through a covenant not to compete or through a distant location. Suppose first that the innovation is determined only by the firm's investment (we shall focus on the extreme cases for simplicity). This case is not particularly interesting: the firm can protect its intellectual property at no cost either using a CNC or choosing a dispersed location.[38]

More interesting is the case where only the employee's contribution to the innovation matters. If only spot contracts were available, again the location problem would be uninteresting: locating away from the other firm would clearly be a self-defeating strategy for a firm. Under spot contracting, outside offers are the only way to motivate the employee to take a higher effort when innovations are not verifiable. Therefore, agglomeration would be the only way to induce positive effort. However, things are less clear-cut when relational contracts are considered. On the one hand, locating away from the other firm tightens the incentive constraint of the relational contract, because it removes the possibility that the employee leaves for a competitor. On the other hand, it relaxes the incentive constraint, because it reduces the future profits after a bonus has been reneged upon.[39] It is therefore not clear what is the overall impact of the location decision on the sustainability of relational contracts, and therefore on the expected innovation outcome.

To study this trade-off, we first look at the equilibrium where the firm decide to locate away from the other (dispersion) and we then compare it with the case where it locates next to the other (agglomeration). We focus on $\phi \,\square\, 1/2$. Except for a superscript a, the notation under agglomeration is the same as in the base model. The per period profits under dispersion are denoted V_i^d, $i \in \{R, S\}$.

[38] If no CNC is available, the firm chooses a dispersed location.

[39] Although it might seem at first sight that the decision to locate far away from another firm is identical to the case where a covenant protects the firm's knowledge, this is not true. Under the covenant regime, it is implausible that a firm could commit to use the covenant forever: after reneging the bonus the firm would just give up the covenant, since it gets higher profit under the spot contracting. But by locating away from rivals, a firm commits to a zero payoff under spot contracts after reneging on the bonus.

5.1 Dispersion: locating away from the other rival

Spot contract. If a firm locates away from the rival, the spot contract equilibrium is identical to the one arising under the covenant regime analyzed above. Since the employee receives no outside offers, optimal effort, wage, and the firm's profits will all be zero in equilibrium: $a = s = V_s^{d,*} = 0$.

Relational contract. An employee who expects a bonus chooses the effort $a^* = \frac{b}{2\gamma}$ and the firm offers the wage $s(b) = \square\frac{b^2}{4\gamma}$. The firm's incentive constraint (IC) is determined by the condition:

$$(1 \square b) + \frac{V_R^d(b)}{r} \square 1 + V_s^{d,*} = 1,$$

since after reneging the firm goes back to a spot contract which gives it $V_s^{d,*} = 0$. The optimal relational contract is thus given as the solution to:

$$\max_b V_R^d(b) = \frac{b}{2\gamma} \square \frac{b^2}{4\gamma}, \quad \textit{subject to}: V_R^d(b) \square rb.$$

Proposition 24 *(Dispersion) The optimal relational contract is characterized as follows:*
i. If $r \square \frac{1}{4\gamma} \square r_{fb}^d$*, then* $b^* = 1$ *(the relational contract attains first best).*
ii. If $r_{fb}^d < r \square \frac{1}{2\gamma} \square r_{sb}^d$*, then* $b^* = \widehat{b}^d = 2(1 \square 2\gamma r)$ *(the relational contract attains second best).*
iii. If $r > r_{sb}^d$*, then only the spot contract exists.*

Proof. At $b^* = 1$, the IC is: $V(1) = \frac{1}{4\gamma} \square r$. For higher values of r, the IC would not be satisfied if $b = 1$. Therefore, the firm would choose the highest possible value of b which satisfies the constraint: $\frac{b}{2\gamma} \square \frac{b^2}{4\gamma} = rb$. Solving this equation gives $\widehat{b}^d = 2(1 \square 2\gamma r)$. This root exists only if $r \square \frac{1}{2\gamma}$. For higher values of r, there is no solution to the constrained program. ■

5.2 Agglomeration: firms locate together

We now have to compare the outcome under dispersion with the one that arises under agglomeration. The setup under agglomeration is identical to the one considered in base model, so by proposition 5 the firm chooses not to have a covenant not to compete. Let us recall the solution in this case (re-labelling the thresholds):

□ If $r \square \frac{(1-\phi)}{4\gamma} \square r_{fb}^a$, then $b^* = 1$.

□ If $r_{fb}^a < r \square \frac{(1-\phi)}{2\gamma} \square r_{sb}^a$, then $b^* = \widehat{b}^a = 2 \square \phi \square 4\gamma r$.

- If $r > r^a_{sb}$, then spot contracts only exist and the employee is paid ϕ if successful.

5.3 Comparing dispersion and agglomeration equilibria

We now compare the profits under agglomeration and dispersion to derive the optimal location of the firm. The next proposition states the results:

Proposition 25 *The optimal location choice is the following:*
i. If $r \leq r^a_{fb}$, the firm is indifferent between dispersion and agglomeration.
ii. If $r^a_{fb} < r \leq r_l = \frac{2-\phi}{4\gamma}$, the firm chooses an isolate location (dispersion).
iii. If $r > \frac{2-\phi}{4\gamma}$, the firm prefers a joint location (agglomeration).

Proof. First, note that $r^a_j \leq r^d_j$, $j \in \{fb, sb\}$. Furthermore, since $\phi \leq 1/2$, we have: $r^a_{sb} \leq r^d_{fb}$. If $r \leq r^a_{fb}$, both dispersion and agglomeration lead to a first best relational contract. If $r^a_{fb} < r \leq r^d_{fb}$, dispersion is preferred as it alone achieves first best. If $r > r^d_{sb}$, only spot contracts exist and agglomeration is optimal. Consider $r^d_{fb} < r \leq r^a_{sb}$ where both dispersion and agglomeration lead to a second best relational contract. The firm chooses dispersion as a higher bonus can be sustained ($\widehat{b}^d > \widehat{b}^a$), which leads to higher profits. Finally, consider $r^a_{sb} < r \leq r^d_{sb}$ where a relational contract is possible only under dispersion. Agglomeration is chosen iff. the outside offer to the employee (ϕ) is higher than the bonus paid under dispersion ($\widehat{b}^d$). We have that $\phi > \widehat{b}^d \Leftrightarrow r \leq r_l$. ■

The equilibrium outcome is summarized in the figure below. The solid and the dotted lines represent the threshold values of r (derived in the analysis above) as a function of ϕ. The solid lines demarcate regions with a different equilibrium choice of location.

[redacted]

[redacted] A ≼ D

[redacted] I: A ~ D

ϕ

effort plays an important role for the success of the firm's R&D program. It is very difficult to verify objectively whether a (valuable) innovation has been made. It is therefore assumed that an employee's effort is not observable (i.e., there is moral hazard) and that the realization of the R&D outcome is observable by all parties but not contractible.

Using this framework, we have shown that when the employee's contribution to the innovation is large enough, a covenant not to compete unambiguously reduces both the employee's effort, the expected number of innovations made, and the firm's profits. This is the case both when the contract between the firm and the employee contains only explicit elements (a spot contract) and when it contains an implicit promise of a bonus (a relational contract). The reason is that having no covenant forces the firm to reward the employee when an innovation is made, as he otherwise walks away to rival. It alleviates thus a commitment problem on the side of the firm and allows for a more profitable, higher powered incentive scheme. However, when the firm's investment is more important than the employee's, there exists a rationale for including a CNC in the contract: since it prevents the employee from leaving for a competitor, a covenant ensures the appropriability of the firm's investment and favors innovation.

In an extension, we compare two different ways of protecting intellectual property: a CNC and an isolate location. We show that if only the firm's investment matters, they are equivalent. However, if the employee's effort matters most, they are not. The firm can give up a CNC after reneging on a relational contract with the employee, but it cannot give up an isolate location (or, only at a high cost). Therefore, relational contracts are easier to sustain with an isolate location, as the costs of reneging are higher. For high discount rates it is thus (weakly) optimal to protect innovations by choosing an isolate location.

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7 Appendix

7.1 Proof of Proposition 8

It is straightforward to check that the conditions for the relational contract to hold and to give rise to the first best are always stricter for the case where a covenant exists: $\widehat{r}_{fb} < \widetilde{r}_{fb}$, and $\widehat{r}_o < \widetilde{r}_o$. This implies that: (a) When the first best is attained under a covenant, it is attained under a no covenant regime as well: both regimes give rise to the same effort levels and profits. (b) There are parameter values where only the second best is attained under a covenant whereas without a covenant a first best is attained: under the latter regime effort and profit are higher. (c) When the second best is attained under a covenant, it is attained under a no covenant regime as well, but the equilibrium effort under the covenant $(\widehat{b}_o)$ is lower than without the covenant $(\widetilde{b}_o)$: : $\widehat{b}_c = 1 \square 2\gamma r + \sqrt{(1 \square 2\gamma r)^2 \square 1 + \phi^2} < \widetilde{b}_o = 1 \square 2\gamma r + \sqrt{(1 \square 2\gamma r)^2 \square (1 \square \phi)(1 + \phi \square 4\gamma r)}$. Since $V(b)$ is increasing for $b < 1$, profit are also higher when a covenant does not exist. (d) There are parameter values where only a fixed wage contract can be attained under a covenant whereas without a covenant a second best relational contract is attained. Since the latter achieves positive effort and profit levels, they are higher than under the former, where effort and profit are zero. (e) There are parameters such that only spot contracts exist, with and without a CNC. Here, as shown in the main text, it is optimal to have no CNC.

7.2 Proof of Lemma 9

The IC constraint is satisfied for $b^* = 1/2$ iff. $r \square \widehat{r}_1$. For $r > \widehat{r}_1$, the optimal bonus is the highest root that solves the IC constraint with equality as it is closest to $1/2$. This gives $\widehat{b}_0 = \left(1 \square 2\gamma r + \sqrt{(1 \square 2\gamma r)^2 \square 4\phi(1 \square \phi)}\right)/2$. This root exists only if $r \square \widehat{r}_0$.

7.3 Proof of Lemma 10

The IC constraint is satisfied for $b^* = 1/2$ iff. $r \square \widetilde{r}_1$. For $r > \widetilde{r}_1$, the optimal bonus

is the highest root that solves the IC constraint with equality as it is closest to $1/2$. This gives $\widetilde{b}_o = 1 \square 2\gamma r \square \phi$. This root exists only if $r \square \widehat{r}_0$.

7.4 Proof of Proposition 11

It is straightforward to check that the conditions for the relational contract to hold and to give rise to the first best are always stricter for the case where a covenant exists: $\widehat{r}_{fb} < \widetilde{r}_{fb}$, and $\widehat{r}_o < \widetilde{r}_o$. This implies that: (a) When the first best is attained under a covenant, it is attained under a no covenant regime as well: both regimes give rise to the same effort levels and profits. (b) There are parameter values where only the second best is attained under a covenant whereas without a covenant a first best is attained: under the latter regime effort and profit are higher. (c) When the second best is attained under a covenant, it is attained under a no covenant regime as well, but the equilibrium effort under the covenant $(\widehat{b}_o)$ is lower than without the covenant $(\widetilde{b}_o)$: $\widehat{b}_o = \left(1 \square 2\gamma r + \sqrt{(1 \square 2\gamma r)^2 \square 4\phi(2 \square \phi)}\right)/2 < \widetilde{b}_o = 1 \square 2\gamma r \square \phi$. Since $V(b)$ is increasing for $b < 1/2$, profit are also higher when a covenant does not exist. (d) There are parameter values where only a fixed wage contract can be attained under a covenant whereas without a covenant a second best relational contract is attained. Since the latter achieves positive effort and profit levels, they are higher than under the former, where effort and profit are zero. (e) There are parameters such that only spot contracts exist, with and without a CNC. Here, as shown in the main text, it is optimal to have no CNC.

7.5 Proof of of Lemma 13.

For $b^* = b^{fb}$, the incentive constraint is $V(b^{fb}) = b^2(\lambda^2/b^{fb}) + \phi\left(\phi\lambda^2/b^{fb} \square 2\lambda^2\right) + 2b\lambda^2 \square 4\gamma br$ (since $\lambda^2 + (1 \square \lambda)^2 = 1 \square 2\lambda + 2\lambda^2 = \lambda^2/b^{fb}$) which is satisfied iff. $r \square r_{fb}$. For higher values of r, b^* does not satisfy the incentive constraint. Therefore, the firm chooses the highest possible value of b that satisfies the incentive constraint with equality. This is a standard second order equation, whose higher root is b^{sb}. This root exists only if $r \square r_{sb}$.

7.6 Proof of Lemma 14

For $b^* = b^{fb}$, the incentive constraint is $V(b^{fb}) = \square b^2(1 \square \lambda)^2 + b\lambda^2(2 \square b) \square 4\gamma br$, which is satisfied iff. $r \square r_{fb}$. For higher values of r, the firm chooses the highest b that satisfies the incentive constraint with equality, that is b^{sb}. This root exists only if $r \square r_{sb}$.

7.6.1 Proof of Lemma 15

For $b^* = b^{fb}$, the incentive constraint is $V(b^{fb}) = b^2(\lambda^2/b^{fb}) + \phi\left(\phi\lambda^2/b^{fb} \square 2\lambda^2\right) + 2b\lambda^2 \square 4\gamma br \square 4\gamma\phi r$, which is satisfied iff. $r \square r_{fb}$. For higher values of r, the firm chooses the highest b that satisfies the incentive constraint with equality, which is b^{sb}. Note that it must be $b^{sb} \square \phi$, which leads to $r \square r_{sb}$.

7.7 Proof of Lemma 16

The firm's problem with these new constraints is:

$$\max_{b,e,s}\left\{\frac{1+r}{r}\left(\frac{\lambda^2 b(1\square b)}{2\gamma}+\frac{(1\square\lambda)^2(1\square b)^2}{4\gamma}\square s\right)+e\right\} \tag{8}$$

subject to:

$$\frac{1+r}{r}\left(\frac{\lambda^2 b^2}{4\gamma}+\frac{(1\square\lambda)^2(1\square b)b}{2\gamma}+s\right)\square e\ 0\square\quad 0\ (i)$$

5γ2xx1xx20+x4x(1x02x(xxxx20

$$\frac{\lambda^2 b^2}{4\gamma}\square+\ (1\square\lambda)^2(1\square b)b \qquad 0$$

4γ□

/T146 1 Tf 7.0781 0 0 7.0781 247.53 T

7.8 Proof of Lemma 17

For $b^* = b^{fb}$, the incentive constraint is $V(b^{fb}) \square 4\gamma\phi r \square 4\gamma br$, which is satisfied iff. $r \square r_{fb}$. For higher values of r, the firm chooses the lowest b that satisfies the incentive constraint with equality, which is b^{sb}. Note that it must be $b^{sb} \square \phi$, which leads to $r \square r_{sb}$.

7.9 Proof of Lemma 18

The firm's problem is the same as in Lemma (8), the only difference being constraints (iii) and (iv), which are:

$$\begin{aligned} \frac{\lambda^2 b(1 \square b)}{2\gamma} + \frac{(1 \square \lambda)^2(1 \square b)^2}{4\gamma} \square s \square \frac{(1 \square \lambda)^2}{4\gamma} &\quad \square \quad 0 \text{ (iii')}, \\ \frac{1}{r}\left(\frac{\lambda^2 b(1 \square b)}{2\gamma} + \frac{(1 \square \lambda)^2(1 \square b)^2}{4\gamma} \square s \square \frac{(1 \square \lambda)^2}{4\gamma}\right) &\quad \square \quad b \square \phi \text{ (iv')}, \end{aligned}$$

as the firm chooses a CNC under spot contracting. Arguing as in the proof of Lemma 16, it can be shown that constraint (i) binds whereas (ii) and (iv') do not. Using (i), (iii'), and (v), the problem reduces to $\max_b V(b)$ st. $\frac{1}{r}(V(b) \square V(\phi)) \square \phi \square b$.

7.10 Proof of Lemma 19

For $b^* = b^{fb}$, the incentive constraint $V(b^{fb}) \square 4\gamma\phi r \square 4\gamma br$, which is satisfied iff. $r \square r_{fb}$. For higher values of r, the firm chooses the lowest value of b that satisfies the incentive constraint with equality. This is a standard second order equation, whose lower root is b^{sb}. This root exists only if $r \square r_{sb}$.

7.11 Proof of Lemma 20

For $r > \frac{b^{fb}(b^{fb}-\phi)}{2\gamma\lambda^2}$, only spot contracts exist, and Lemma 12 establish that no covenants are better in this region of the parameters' space. For $\frac{b^{fb}(b^{fb}-\phi)}{2\gamma\lambda^2} \square r > \frac{\lambda^2}{2\gamma}\left(1 \square \sqrt{\frac{\phi}{b^{fb}}(2 \square \frac{\phi}{b^{fb}})}\right)$ a second best relational contract is attained without the covenant, which is better than the spot contract under the covenant. For $\frac{\lambda^2}{2\gamma}\left(1 \square \sqrt{\frac{\phi}{b^{fb}}(2 \square \frac{\phi}{b^{fb}})}\right)$ $\square\, r > \frac{\lambda^2}{4\gamma}(1 \square \frac{\phi}{b^{fb}})$ relational contracts exist in both regimes, but a higher bonus is attained without covenant. For $\frac{\lambda^2}{4\gamma}(1 \square \frac{\phi}{b^{fb}}) \square r > \frac{\lambda^2}{4\gamma}(1 \square \frac{\phi}{b^{fb}})^2$ without covenant the first best is attained, whereas under the covenant only a second best is. Finally, if $r \square \frac{\lambda^2}{4\gamma}(1 \square \frac{\phi}{b^{fb}})^2$ the two regimes are equivalent as they both achieve the first best under the relational contract.

7.12 Proof of Lemma 21

For $r > \frac{\lambda^2}{2\gamma}(\frac{\phi}{b^{fb}} - 1)$, only spot contracts exist, and Lemma 12 establish that no covenants are better in this region of the parameters' space. For $\frac{\lambda^2}{2\gamma}(\frac{\phi}{b^{fb}} - 1) \geq r > \frac{\lambda^2}{2\gamma}\left(1 - \sqrt{\frac{\phi}{b^{fb}}(2 - \frac{\phi}{b^{fb}})}\right)$ a second best relational contract is attained without the covenant, which is better than the spot contract under the covenant. For $\frac{\lambda^2}{2\gamma}\left(1 - \sqrt{\frac{\phi}{b^{fb}}(2 - \frac{\phi}{b^{fb}})}\right) \geq r > \frac{\lambda^2}{4\gamma}(\frac{\phi}{b^{fb}} - 1)$ relational contracts exist in both regimes, but a higher bonus is attained without covenant. For $\frac{\lambda^2}{4\gamma}(\frac{\phi}{b^{fb}} - 1) \geq r > \frac{\lambda^2}{4\gamma}(1 - \frac{\phi}{b^{fb}})^2$ without covenant the first best is attained, whereas under the covenant only a second best is. Finally, if $r \geq \frac{\lambda^2}{4\gamma}(1 - \frac{\phi}{b^{fb}})^2$ the two regimes are equivalent as they both achieve the first best under the relational contract.