Optimal Incentives for Corporate Innovation

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February 14, 2023

Abstract

We propose a simple model to analyze the optimal provision of incentives for corporate innovation. In our model, a manager must be motivated to exert R&D effort and to decide optimally whether to innovate conditional on the information generated by her effort. Importantly, we assume that the manager's decision whether to innovate is observable, so the contract can condition pay not only on outcomes but also on whether the manager innovates. We show that the optimal contract makes pay-performance sensitivity higher if the manager decides to innovate. We also show that the optimal contract depends on factors not considered in prior work on the motivation of innovation.

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One of the most important questions faced by firms is whether to further exploit their current products or technologies or instead innovate by launching new products, entering new geographic markets, or adopting new technologies. Since the returns from innovation are often difficult to assess by firm owners, it is crucial that managers have the right incentives to make optimal innovation decisions on their behalf.

Making optimal innovation decisions requires costly effort in R&D. Managers have to invest time and effort in acquiring the knowledge necessary to innovate or in setting up and overseeing research teams and evaluating their proposals. Therefore, managers' incentives should motivate them to exert R&D effort.

However, motivating R&D effort is not enough to guarantee optimal innovation decisions. Managers should should also have the incentives to make the correct decisions conditional on the information they acquire as a result of their R&D effort.

To motivate R&D effort and optimal innovation decisions, a principal can condition the manager's compensation on the firm's financial performance. However, a key aspect of innovation decisions is that they are often observable. For example, owners can observe whether the firm launched a new product or entered a new market. Even the adoption of new production technologies or management practices can be to a great extent observable in many cases. Therefore, managerial compensation can be made to depend on the innovation decision itself. That is, the level or performance sensitivity of pay can depend on whether the manager innovates.

In this paper, we propose a simple model to analyze the optimal provision of innovation incentives. Our model incorporates the three ingredients described above. First, the manager must exert R&D effort to evaluate the profitability of innovation. Second, the manager decides whether to innovate conditional on the information acquired as a result of her effort. And third, the principal can condition the manager's compensation not only on financial performance but also on the manager's innovation decision.

Our model yields novel results about the optimal way to provide incentives for innovation. In particular, our main result is that the optimal contract provides low-powered incentives to the manager if she decides not to innovate but makes the manager's pay depend more strongly on performance if she innovates. Importantly, this optimal contract should not be interpreted as implying that high-powered incentives with respect to financial performance are optimal to encourage innovation. Instead, the optimal contract is such that the strength of incentives should depend on whether the manager is observed to innovate (in which case incentives should be strong) or not (in which case incentives should be muted). This distinction is important when interpreting observational empirical findings about the relation between financial incentives and innovation.

In our model, a manager must decide whether to innovate (take the innovative action) or continue with business as usual (take the status quo action). Adopting the characterization by Manso (2011), we characterize the status quo action as one whose distribution of returns is known ex ante. However, the probability of success of the innovative action is not known ex ante. By exerting R&D effort, the manager can obtain a signal about the probability of success of the innovative action. Therefore, the manager can condition her innovation decision on this information if she exerts R&D effort. We assume that neither the manager's effort nor the information that she acquires as a result of that effort are observable, but the manager's principal can observe the manager's decision whether to innovate and the financial performance that results from her action. Therefore, the manager's compensation contract can depend both on financial performance and the innovation decision.

We show that it is optimal for the principal to make the manager's pay depend on the innovation decision. A contract that simply conditions the manager's compensation on financial returns is not optimal. We characterize the optimal contract and show that even if the manager is risk neutral there is an optimal contract that makes the manager's pay flat if she chooses not to innovate but makes pay contingent on performance if the managers decides to innovate. As long as the manager is minimally risk averse, such contract is the unique optimal contract.

Our paper contributes to the literature analyzing the optimal provision of incentives for innovation. Following Bergemann and Hege (1998) and Bergemann and Hege (2005), much of this literature models innovation as a repeated experimentation process. In each period the agent learns about the profitability of a project by investing in (or working on) it but the agent's action is typically the agent's private information. The main goal of this literature is to derive the optimal contract to motivate the agent to experiment an optimal number of periods and can therefore shed only limited light on the problem we address in this paper.[1]

In an influential paper, Manso (2011) departs from this literature by considering an agent who each period decides whether to follow a conventional work method, a new work method, or shirk. The agent's action, which is not observable, determines the period outcome, which is observable, and allows the agent to update her prior about the probability of success of the chosen work method. In this context, Manso (2011) finds the optimal contracts that implement either exploration (that is, that induce the agent to follow the new work method) or exploitation (that is, that induce the agent to follow the conventional work method). Our model differs from Manso's (2011) in two main ways. First, Manso (2011) derives the optimal contract in two different cases: the case in which the principal wants to encourage innovation and the case in which the principal wants to encourage exploitation. We characterize instead the optimal contract when the principal does not know whether innovation or exploitation is optimal and instead wants to ensure that the manager chooses optimally between the two alternatives.

[1]See also Gerardi and Maestri (2012) or Hörner and Samuelson (2013). Recent entriest to this literature, such as Drugov and Macchiavello (2014), Halac et al. (2016), or Khalil et al. (2020) also allow for asymmetric information about the agent's ability to learn.

Second, Manso (2011) assumes that the manager's action (choosing the innovative or the status quo project) is not contractible and uses the sequence of outcomes induced by the manager's sequence of actions to infer whether the manager opted for one or the other project. We assume instead that the principal observes whether the manager innovates and can condition the manager's pay on her decision. Therefore, our analysis describes situations in which there is ex ante uncertainty as to whether exploitation or innovation is optimal and in which it is possible to determine whether the manager opted for the former or the latter. Manso's (2011) model describes instead situations in which shareholders know the type of project they want to implement but have no direct way to determine whether the manager innovated.[2]

Our paper is also related to the literature on the optimal provision of incentives to experts initiated by Lambert (1986) and Demski and Sappington (1987). In this literature, the principal delegates to the expert agent decision making and the acquisition of information. Within this literature, Inderst (2009) analyzes the model most related to ours. However, the focus (on the optimality of delegation) and structure of this model is very different from ours and, crucially, Inderst (2009) does not consider the innovation to be contractible.

The paper is organized as follows. Section 1 describes the model. Section 2 derives the optimal contract, describe the factors that affect the form of the optimal contract and discusses some extensions. Finally, Section 3 concludes.

[2] Bernardo et al. (2009) also study incentives for entrepreneurial activity within firms, but in a different context in which the problem is how much to invest in a certain project of unknown quality and in which the manager's entrepreneurial effort determines the distribution of quality levels from which the project's quality is drawn.

1 The Model

1.1 Innovation vs. exploitation

We consider a manager (the agent) who must decide whether to exploit the firm's current product line or technology (the status quo action O) or opt for a new product line or technology (the innovative action N). Either action can result in success (S) or failure (F). We denote by $r_i \in \{S, F\}$ the return of action $i = O, N$.[3]

Following Manso (2011), we characterize the status quo action as one whose distribution of returns is known. Thus, the probability of success of the status quo action is known to be $p_O > 0$.

In contrast, the probability of success of the innovative action (p_N) is not known ex ante. There are two possible states for this distribution. In state $s = G$, the probability of success of the innovative action is higher than the probability of success of the status quo action ($p_N^G > p_O$), while in state $s = B$, the converse is true ($p_N^B < p_O$). The probability that the state is G is g. Thus, at the outset, the manager and the principal expect the probability of success of the innovative action to be $p_N^e = gp_N^G + (1-g)p_N^B$.

We assume that successful innovation requires costly R&D effort, so innovating without R&D effort is unlikely to succeed. Therefore, we assume, as Manso (2011), that $p_N^e < p_O$, although we also discuss the possibility that the status quo is sufficiently unattractive that ex ante it is optimal to innovate.

1.2 The R&D effort

If the manager exerts effort in R&D, she obtains a private signal σ about probability of success of the innovative action (that is, about the state s). If the manager does not exert effort, she obtains no signal before taking the action. Neither the manager's

[3] Assuming that the returns of success and failure are the same for both actions is for simplicity only. All our results go through if one allows the returns to differ across actions.

research effort nor the signal obtained by the manager are observed by the principal. Exerting effort has a cost of $c > 0$ that is privately borne by the manager.

The manager's effort admits different interpretations. It can be understood as the effort necessary to develop an idea into a marketable product or a useful technology. It can also be understood as the research necessary to determine the demand for a new product or the costs and benefits of adopting a new production technology or management practice.

Importantly, the cost c is the cost of carrying out the research effort that is privately borne by the manager, not the R&D expenses incurred by the firm. We could incorporate R&D expenses in the model simply by letting the returns from success and failure differ for the different actions in a way that reflects their expected revenues and costs (including R&D expenses).

The signal σ can take one of two values, high (H) or low (L). The probability distribution of the signal conditional on the state is

$$\Pr(\sigma = H \mid s) = \begin{cases} \lambda & \text{if } s = G \\ 1-\lambda & \text{if } s = B, \end{cases} \tag{1}$$

so $\sigma = H$ is a favorable signal about the distribution of the innovative action and $\sigma = L$ an unfavorable signal. The parameter $\lambda \in (\frac{1}{2}, 1)$, which we refer to as the *precision* of the signal, is the probability that the signal is correct ($\sigma = H$ when $s = G$ or $\sigma = L$ when $s = B$). We let

$$\pi^H \equiv Pr(\sigma = H) = g\lambda + (1-g)(1-\lambda) \tag{2}$$

denote the (unconditional) probability of observing $\sigma = H$ and define π^L analogously. Throughout the paper we use subscripts to denote the contractible variables—namely, the action $i \in \{O, N\}$ and the return realization $r \in \{S, F\}$. We use superscripts to denote the noncontractible realizations of the private signal received by the manager. We use the following notation for the probability of success of the innovative action conditional on the realization of the signal:

$$p_N^k \equiv \Pr\left(r_N = S|\sigma = k\right), \text{ for } k \in \{L, H\}. \tag{3}$$

For the problem to be interesting, we assume that the manager's signal is sufficiently precise that

$$p_N^H > p_O > p_N^L, \tag{4}$$

so the innovative action is optimal conditional on observing the good signal and the status quo action is optimal conditional on observing the bad signal.

To clarify the mechanisms driving our results, we initially assume that the manager is risk neutral and then consider the case of a risk-averse manager. We also assume initially that the cost to the manager of implementing either action is the same (which we normalize to zero), so the manager does not have a preference for one of the actions. We consider the implications of relaxing this assumption. Finally, we assume that the manager is protected by limited liability and, for simplicity, that she has no wealth and has a zero reservation utility.

1.3 The manager's action choice

After observing the signal, or having observed no signal if she did not exert effort, the manager chooses either the status quo or the innovative action. The manager's choice of action is public information.

1.4 Contracts

The manager's action choice and the realized return of the chosen action are observable and contractible. However, the manager's choice of effort and the realizations of the signal that she obtains if she exerts effort are her private information. No one observes the return realization of the action not taken by the manager.

A contract is a vector $w = (w_{OF}, w_{OS}, w_{NF}, w_{NS})$ that specifies a payment for each possible combination of action and realized return.

2 The Optimal Contract

We derive the contract that minimizes the expected payment to the manager among all contracts that induce the manager to exert R&D effort and take the optimal action conditional on the signal she receives.

We denote by $\mathbb{E}^*(w)$ the expected payment to the manager if the contract is w and the manager exerts effort and chooses optimally conditional on the signal.

$$\mathbb{E}^*(w) \equiv \pi^H (p_N^H w_{NS} + (1 - p_N^H) w_{NF}) + (1 - \pi^H) \left(p_O w_{OS} + (1 - p_O) w_{OF} \right). \qquad (5)$$

The optimal contract is the contract that minimizes $\mathbb{E}^*(w)$ subject to three sets of constraints. First, the contract must satisfy the *R&D effort constraints*, which ensure that the manager prefers to exert R&D effort and choose optimally than to exert no effort and take either action.

$$\mathbb{E}^*(w) - c \geq p_N^e w_{NS} + (1 - p_N^e) w_{NF}, \qquad (IC_N)$$

$$\mathbb{E}^*(w) - c \geq p_O w_{OS} + (1 - p_O) w_{OF}. \qquad (IC_O)$$

The contract also needs to meet the manager's *decision constraints* (one for each realization of the signal σ), which induce the manager to take the optimal action conditional on each realization of the signal:

$$p_O w_{OS} + (1 - p_O) w_{OF} \geq p_N^L w_{NS} + (1 - p_N^L) w_{NF} \qquad (IC^L)$$

$$p_O w_{OS} + (1 - p_O) w_{OF} \leq p_N^H w_{NS} + (1 - p_N^H) w_{NF}. \qquad (IC^H)$$

Finally, the contract must satisfy the manager's *limited liability constraints*:

$$w_{ir} \geq 0, \quad i \in \{O, N\} \text{ and } r \in \{F, S\}. \qquad (LL_{ir})$$

Together, the effort and limited liability constraints imply that the optimal contract must yield the manager an expected utility greater than her zero reservation utility, so we disregard the manager's participation constraint.

2.1 The optimal contract

To derive the optimal contract it is useful to first consider contracts that do not condition pay on the manager's action choice, that is, contracts such that $w_{OS} = w_{NS} = w_S$ and $w_{OF} = w_{NF} = w_F$. For such contracts to induce the manager to exert effort and take the optimal action conditional on the signal, the pay following success must be greater than the pay following failure ($w_S > w_F$). Therefore, we can label these contracts unconditional bonus contracts. Further, rewarding the manager for failure (that is, having a positive w_F) is costly for the principal and is not necessary to induce the manager to exert effort and choose optimally. Therefore, it is optimal for the principal to set $w_F = 0$. The optimal unconditional bonus contract is thus the one with the minimum bonus w_S that satisfies all incentive constraints.

The principal can reduce the bonus without affecting the manager's decision incentives, since for any unconditional bonus contract, the manager strictly prefers to take the action with the higher probability of success (that is, the decision constraints are slack). Therefore, the only constraints that limit the reduction in the bonus are the effort constraints. Since the status quo action has a higher prior probability of success, it follows that if pay is not conditional on the action and the manager does not exert effort, she will prefer to take the status quo action over the innovative action. Therefore, the minimum incentive-compatible bonus is the one that makes the manager indifferent between acting optimally and not exerting effort and sticking to the status quo action. If the principal sets this bonus, all the other incentive constraints are slack.

It is straightforward to see that this least-cost unconditional bonus contract is not optimal. Starting from such contract, a marginal reduction in the bonus for success if the manager chooses the status quo action reduces the expected cost of the contract. At the same time, the reduction in w_{OS} makes choosing the status quo action relatively less attractive for the manager than exerting effort and choosing optimally, since in the latter case the manager suffers from the reduction only if the signal recommends choosing the status quo action. Therefore, the reduction in w_{OS} relaxes the only incentive constraint that was initially binding. Since all the other incentive constraints were slack, they still hold if the reduction in w_{OS} is sufficiently small, so the new contract is both less costly and incentive compatible. Therefore, the least-cost unconditional bonus contract is not optimal.

Proposition 1. *If* $w^* = (w^*_{OF}, w^*_{OS}, w^*_{NF}, w^*_{NS})$ *is an optimal contract, then either* $w^*_{OF} \neq w^*_{NF}$ *or* $w^*_{OS} \neq w^*_{NS}$*.*

As the above argument suggests, the principal can reduce w_{OS} in an incentive-compatible way. Further, doing so allows the principal to reduce w_{NS} as well while maintaining incentives. The principal can keep reducing the bonuses for success until both effort constraints are binding. As we show in the Proposition 2 below, the contract that results from this process is optimal. However, it is not the unique optimal contract.

Inspection of the incentive constraints and the definition of $\mathbb{E}^*(w)$ reveals that the particular values of w_{OF} and w_{OS} are irrelevant for incentives. Only the expected pay $W_O \equiv p_O w_{OS} + (1-p_O)w_{OF}$ if the status quo action is chosen matters. Therefore, if W_O^* is the value of this expected pay at an optimal contract, any other contract with the same payments following the innovative action and with payments for the status quo action w_{OF} and w_{OS} such that $p_O w_{OS} + (1-p_O)w_{OF} = W_O^*$ will also be optimal. In particular, there is an optimal contract with $w_{OF} = w_{OS}$. The intuition for the optimality of this contract is that for the manager to choose optimally it is necessary that her expected pay when the probability of success of the innovative action is high (that is, following the signal H) be higher than when the probability of success is low (that is, following the signal L). However, a positive pay-performance sensitivity if the manager takes the status quo action is not necessary to induce the correct decision. The next proposition formally states these results (all proofs are in the appendix).

Proposition 2.

1. *The contract $w' = (w'_{OF}, w'_{OS}, w'_{NF}, w'_{NS})$, with $w'_{NF} = 0$,*

$$w'_{NS} = \frac{c}{(p_N^H - p_N^L)\pi^L \pi^H} = \frac{c}{(p_N^G - p_N^B)g(1-g)(2\lambda - 1)}, \tag{6}$$

   and

$$w'_{OF} = w'_{OS} = w'_O = p_N^e w'_{NS}, \tag{7}$$

   is optimal.

2. *A contract w^* is optimal if and only if $w^*_{NF} = 0$, $w^*_{NS} = w'_{NS}$, $w^*_{OF} \in \left[0, \frac{w'_O}{1-p_O}\right]$, and $w^*_{OS} = \frac{w'_O}{p_O} - \left(\frac{1-p_O}{p_O}\right) w^*_{OF}$ (so that $p_O w^*_{OS} + (1-p_O)w^*_{OF} = w'_O$).*

3. *The two effort constraints are binding for any optimal contract.*

Proof. The proof is in Section A of the Appendix. □

Part 1 of Proposition 2 shows that contract w', which gives the manager a flat pay w'_O if she chooses the status quo, is optimal. Part 2 shows that there is also a continuum of optimal contracts with $w^*_{OS} \neq w^*_{OF}$ and expected cost if the manager takes the status quo action equal to the flat pay w'_O. Among the optimal contracts with $w^*_{OS} \neq w^*_{OF}$ is the one discussed above, where $w^*_{OF} = w^*_{NF} = 0$ and the other two payoffs are such that both effort constraints are binding.

However, the optimality of the contracts with $w^*_{OS} \neq w^*_{OF}$ hinges on the assumption that the manager is risk neutral. If the manager is minimally risk averse, it is not optimal to unnecessarily expose the manager to risk, so the unique optimal contract gives the manager a flat pay if she chooses the status quo action, as we show in the following proposition.

Proposition 3. *Suppose that the manager is strictly risk averse with Bernoulli utility function $U(w, e) = u(w) - c(e)$, where $u(0) = 0$, $u' > 0$, $u'' < 0$, and $c(e) = c$ if the manager exerts effort and $c(e) = 0$ otherwise. Then, the unique optimal contract w^* satisfies*

$$w^*_{NF} < w^*_{OF} = w^*_{OS} = w^*_O < w^*_{NS}, \tag{8}$$

where

$$u(w^*_{NS}) = w'_{NS} \tag{9}$$

$$u(w^*_O) = w'_O \tag{10}$$

for w'_{NS} and w'_O defined in (6) and (7), respectively.

Proof. The proof is in Section B of Appendix. □

2.2 Determinants of the optimal contract

Inspection of equation (6) reveals, expectedly, that the optimal bonus (in either monetary or utility terms) is increasing in the cost of the R&D effort for the manager. Equation (6) also reveals that that the optimal bonus depends on the informativeness of the manager's R&D effort. This is clearly shown by the first equality in (6). This equality shows that the bonus for success if the manager innovates is decreasing in difference between the conditional probabilities if the signal is high and low ($p_N^H - p_N^L$). This difference captures the relevance of the information that the manager can obtain. The other term in the denominator in (6) (the product of the probabilities of the good and bad signals) captures the unpredictability of the signal. This term is large when the realization of the signal is less predictable (that is, for π^H near $\frac{1}{2}$) and small when the realization of the signal is more predictable (that is, for π^H near 0 or 1).

Therefore, propositions 2 and 3 show that the manager's bonus (and the cost of the contract) is decreasing in the informativeness of the manager's R&D effort. The intuition for this result is that a more informative signal increases the probability of success if the manager takes the optimal action and therefore makes it possible to give the manager a high expected pay if she chooses the optimal action even with a relatively low bonus.

The second equality in equation (6) shows how the bonus for innovation success depends on the underlying parameters. First, if the potential innovation can have very disparate results, with either a very high or a very low probability of success (i.e., when $p_N^G - p_N^B$ is high), the bonus will be low. If one interprets the difference $p_N^G - p_N^B$ as capturing how radical the innovation is, propositions 2 and 3 imply that (all else equal) more radical innovations require weaker incentives. Second, the more the manager is able to learn about the innovation (that is, the higher is the precision λ of the signal) the weaker are the optimal incentives. Finally, the greater the ex ante uncertainty about the desirability of the innovation (as captured by the product $g(1-g)$), the weaker are the optimal incentives. However, these results have to be interpreted with care, since they are all obtained holding all else equal and different parameters could be correlated in practice. For example, it could be that a very disruptive innovation involves a large difference $p_N^G - p_N^B$ (which drives the bonus down) and a very low probability of success (which would drive the bonus up by leading to a very low value of the product $g(1-g)$) or a large R&D effort (which would also drive the bonus up).

Focusing on the contract with a flat salary in the absence of innovation, to derive the determinants of this salary it is useful to rewrite equation (7) as follows.

$$w_O' = p_N^e w_{NS}' = \frac{c}{(1-g)(2-\lambda)} \left(1 + \frac{p_N^B}{g(p_N^G - p_N^B)}\right). \tag{11}$$

Inspection of equation (11) reveals that the salary in the absence of innovation is decreasing in the precision of the manager's signal and the relative difference of the probabilities of success in the good and bad states ($\frac{p_N^G - p_N^B}{p_N^B}$). Differentiating w_O' with respect to g one obtains that w_O' is increasing in g as long as g is greater than a threshold $g_O < \frac{1}{2}$. Therefore, for sufficiently low g, both the bonus if the innovation is successful and the salary in the absence of innovation move in the same direction as a response to any parameter change.

Importantly, if we restrict attention to the contract with a flat salary in the absence of innovation, the probability of success with the status quo action does not have any effect on the optimal contract as long as it is optimal to induce the manager to exert R&D effort. Therefore, even if we have assumed throughout that it is not optimal to innovate without exerting R&D effort (i.e., $p_O > p_N^e$), the optimal contract has the same form if the expected profitability of the status quo action is sufficiently low that it is preferable to take the innovative action even in the absence of R&D effort.

However, the probability of success of the status quo action does have an obvious effect on the optimal contract. For any combination of the other parameters, if p_O is sufficiently high, then it is not optimal to induce the manager to exert R&D effort, so the optimal contract simply pays the manager a flat wage equal to her reservation wage (which we have normalized to zero).

The following corollary summarizes the comparative statics results described above.

Corollary 1. *Suppose that it is optimal to induce the manager to exert R&D effort.*

1. *The bonus if the manager innovates is decreasing in the precision λ of the manager's signal, the relevance of the manager's information (as captured by the difference $p_N^G - p_N^B$), and the uncertainty about the optimality of innovation (as captured by the product $g(1-g)$). The last result implies that the bonus is decreasing in the probability g that the innovation is optimal if and only if $g < \frac{1}{2}$.*

2. *The flat salary if the manager chooses the status quo action is decreasing in the precision λ of the manager's signal and the relevance of the manager's information (as captured by the ratio $\frac{p_N^G - p_N^B}{p_N^B}$). The salary is decreasing in the the probability g that the innovation is optimal if and only if $g < g_O$,where $g_O < \frac{1}{2}$.*

3. *The probability of success of the status quo action p_O does not affect the optimal contract.*

2.3 Implementation effort

So far, we have assumed that the manager only needs incentives to exert R&D effort and take the optimal action, but does not have to be motivated to exert effort when implementing the chosen action. It is straightforward to extend the model to incorporate the need to motivate the manager to implement optimally the chosen action (that is, to exert implementation effort). To do so, assume that the probabilities of success under each action considered in previous sections are the probabilities of success if the manager exerts implementation effort, but that the probability of success of each action is reduced by δ_i if the manager does not exert implementation effort and that exerting this effort has a private cost for the manager of e_i (for $i \in \{O, N\}$), where we allow both the effect and cost of the manager effort to depend on the action being implemented.

Assuming that it is optimal to induce implementation effort, the contract has to satisfy two additional incentive (implementation effort) constraints, namely

$$p_O w_{OS} + (1 - p_O) w_{OF} - e_O \geq (p_O - \delta_O) w_{OS} + (1 - p_O + \delta_O) w_{OF} \tag{12}$$

$$p_N^H w_{NS} + (1 - p_N^H) w_{NF} - e_N \geq (p_N^H - \delta_N) w_{NS} + (1 - p_N^H + \delta_N) w_{NF}, \tag{13}$$

which can be rewritten

$$w_{OS} - w_{OF} \geq \frac{e_O}{\delta_O} \tag{14}$$

$$w_{NS} - w_{NF} \geq \frac{e_N}{\delta_N}. \tag{15}$$

Therefore, as long as the pay-performance sensitivity required to motivate implementation effort is not greater than the one required to motivate optimal innovation decisions, the optimal contract is still the one derived in the absence of the need to motivate implementation effort.

If the manager is risk neutral, Proposition 2 thus implies that if

$$\frac{p_N^e}{p_O} w'_{NS} \geq \frac{e_O}{\delta_O} \tag{16}$$

$$w'_{NS} \geq \frac{e_N}{\delta_N}, \tag{17}$$

the set of optimal contracts is equal to the subset of the set of optimal contracts derived in Proposition 2 such that $w^*_{OS} - w^*_{OF} \geq \frac{e_O}{\delta_O}$.

If the manager is risk averse, the contract with a flat salary in the absence of innovation is no longer optimal. One can show that the optimal contract also has $w^*_{NF} = 0$ and $w^*_{NS} = w'_{NS}$, and is such that $w^*_{OS} - w^*_{OF}$ is equal to the minimum amount $\frac{e_O}{\delta_O}$ necessary to induce implementation effort in the absence of innovation.

3 Conclusions

We propose a parsimonious model to analyze the optimal incentives to motivate corporate innovation. In our model, the manager must be motivated to exert R&D effort and to decide optimally whether to innovate conditional on the information acquired thanks to the R&D effort. Both the manager's effort and the information she acquires are privately observed by her. Importantly, we assume, realistically, that the manager's principal can observe whether the manager innovates or continues with business as usual, so the manager's contract can condition her pay not only on outcomes but also on whether the manager innovates.

We show that the optimal contract has two key features. First, the optimal contract conditions pay on the manager's innovation decision. And second, pay-performance sensitivity is higher if the manager decides to innovate than if she continues with the status quo. If no incentives are necessary to motivate the manager to implement optimally the status quo action, the optimal contract actually features a flat salary if the manager decides not to innovate.

We also show that the optimal contract depends on factors not considered in prior work on the motivation of innovation. In particular, we show that pay-performance sensitivity if the manager innovates and the manager's salary in the absence of innovation are lower the more informative the manager's research effort is. Therefore, motivating innovation is less costly if the manager has a greater ability to learn, the innovative action has more extreme outcomes, or there is greater uncertainty about the optimality of innovating.

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Appendix: Proofs

Below, we use the following notation. For a contract $w = (w_{OF}, w_{OS}, w_{NF}, w_{NS})$, we let $W_N^k \equiv p_N^k w_{NS} + (1 - p_N^k) w_{NF}$ denote the expected pay if the manager chooses N after having observed signal $\sigma = k$ (where $p_N^k = Pr(r_N = S|\sigma = k)$, as defined in (3)). We denote by W_i the unconditional expected pay if the manager chooses i (for $i \in \{O, N\}$), so $W_O \equiv p_O w_{OS} + (1 - p_O)\, w_{OF}$ and $W_N \equiv p_N^e w_{NS} + (1 - p_N^e)\, w_{NF}$. By the law of iterated expectations,

$$W_N = \pi^H W_N^H + \pi^L W_N^L \tag{A1}$$

When we use a mark over w to refer to a contract, we denote the analogs to W_i and W_i^k for this contract with the corresponding mark over them. For example, if $\widehat{w} = (\widehat{w}_{OF}, \widehat{w}_{OS}, \widehat{w}_{NF}, \widehat{w}_{NS})$, then $\widehat{W}_N = p_N \widehat{w}_{NS} + (1 - p_N)\, \widehat{w}_{NF}$ and $\widehat{W}_N^k = p_N^k \widehat{w}_{NS} + \left(1 - p_N^k\right) \widehat{w}_{NF}$.

With the above notation, we can rewrite the incentive constraints as

$$\pi^L \left(W_O - W_N^L\right) \geq c \tag{$IC_N - a$}$$

$$\pi^H \left(W_N^H - W_O\right) \geq c \tag{$IC_O - a$}$$

$$W_O \geq W_N^L \tag{$IC^L - a$}$$

$$W_N^H \geq W_O. \tag{$IC^H - a$}$$

We say that a contract is *feasible* if it satisfies the effort, decision, and limited liability constraints.

A Proof of Proposition 2

An optimal contract is a solution to the following problem.[4]

$$\min_{w\in\mathbb{R}^4_+} \quad \pi^H W_N^H + \pi^L W_O \tag{EC}$$

$$\text{s.t.} \quad (IC_N - a),\ (IC_O - a),(IC^L - a),\text{ and } (IC^H - a).$$

Inspection of the incentive constraints $(IC_N - a)$–$(IC^H - a)$ shows that if the effort constraints $(IC_N - a)$ and $(IC_O - a)$ hold, the decision constraints $(IC^L - a)$ and $(IC^H - a)$ are slack. Therefore, we disregard the decision constraints hereafter.

Let $w = (w_{NF}, w_{NS}, w_{OF}, w_{OS})$ be an optimal contract with $W_O = p_O w_{OS} + (1 - p_O)w_{OF}$ and consider the alternative contract $\widehat{w} = (\widehat{w}_{OF}, \widehat{w}_{OS}, \widehat{w}_{NF}, \widehat{w}_{NS})$, with $\widehat{w}_{NF} = w_{NF}$, $\widehat{w}_{NS} = w_{NS}$, and $\widehat{w}_{OS} = \widehat{w}_{OF} = W_O$. By construction, $\widehat{w} \in \mathbb{R}^4_+$ and

$$\widehat{W}_N^k = W_N^k, \text{for } k = H, L, \text{ and} \tag{A2}$$

$$\widehat{W}_O = W_O. \tag{A3}$$

Equation (A2) implies that the cost of contract $\widehat{w}$ is the same as that of contract w, so if $\widehat{w}$ is feasible, it is also optimal, since w is optimal. (A2) also implies that $(IC_N - a)$ and $(IC_O - a)$ hold for $\widehat{w}$ since they hold for w. Therefore, $\widehat{w}$ is feasible and thus optimal. Moreover, $\widehat{W}_N^H > \widehat{W}_O > \widehat{W}_N^L$, which, together with $p_N^H > p_N^L$ implies that $\widehat{w}_{NS} = w_{NS} > \widehat{W}_O = W_O > \widehat{w}_{NF} = w_{NF} \geq 0$.

Now, if $w_{NF} > 0$, then the contract $(W_O - w_{NF}, W_O - w_{NF}, 0, w_{NS} - w_{NF},)$ satisfies the effort and limited liability constraints and has a lower expected cost than contract $\widehat{w}$, which contradicts the optimality of $\widehat{w}$. Therefore, $w_{NF} = 0$.

Suppose that $(IC_O - a)$ is not binding for w. It follows from (A2) and (A3) that

[4] It is straightforward to show that there exists an optimal contract.

if ($IC_O - a$) is not binding for w, it is also not binding for $\widehat{w}$. Consider contract $\overline{w} = (W_O, W_O, w_{NF}, w_{NS} - \delta)$. If $\delta > 0$ is sufficiently low, $\overline{w}$ satisfies (i) all the limited liability constraints since they hold for $\widehat{w}$ and $\widehat{w}_{NS} = w_{NS} > 0$, (ii) ($IC_O - a$), since ($IC_O - a$) is not binding for $\widehat{w}$, and (iii) ($IC_N - a$), since it holds for $\widehat{w}$ and $\overline{W}_O = W_O = \widehat{W}_O$ and $\overline{W}_N^L < \widehat{W}_N^L$. Thus, $\overline{w}$ is feasible and its expected cost is strictly lower than that of $\widehat{w}$, which contradicts the assumption that w is optimal, since if w is optimal so is $\widehat{w}$.

Analogously, suppose that ($IC_N - a$) is not binding for w and note that if ($IC_N - a$) is not binding for w, it is also not binding for $\widehat{w}$. Consider contract $\widetilde{w} = (W_O - \delta, W_O - \delta, w_{NF}, w_{NS})$. If $\delta > 0$ is sufficiently low, $\widetilde{w}$ satisfies (i) all the limited liability constraints, since they hold for $\widehat{w}$ and $W_O > 0$, (ii) ($IC_N - a$), since ($IC_N - a$) is not binding for $\widehat{w}$, and (iii) ($IC_O - a$) since $\widehat{w}$ satisfies ($IC_O - a$), $\widetilde{W}_N^H = \widehat{W}_N^H$, and $\widetilde{W}_O < \widehat{W}_O$. Therefore, $\widetilde{w}$ is feasible and has an expected cost strictly lower than that of $\widehat{w}$, which contradicts the hypothesis that w is optimal.

Therefore, the optimal contract has $w_{NF} = 0$ and satisfies

$$\pi^L(W_O - p_N^L w_{NS}) = c, \tag{A4}$$

$$\pi^H(p_N^H w_{NS} - W_O) = c. \tag{A5}$$

This system of equations has the unique solution

$$w'_{NS} = \frac{c}{(p_N^H - p_N^L)\pi^L\pi^H}, \tag{A6}$$

$$W'_O = p_N^e w'_{NS}. \tag{A7}$$

Therefore, if w^* is an optimal contract, then $w^* = w(w^*_{OF}) \equiv (w^*_{OF}, w^*_{OS}(w^*_{OF}), 0, w'_{NS})$, where $w^*_{OS}(w_{OF}) = \frac{W'_O}{p_O} - \left(\frac{1-p_O}{p_O}\right) w_{OF}$ (so that $p_O w^*_{OS}(w_{OF}) + (1-p_O)w_{OF} = W'_O$).

By construction, $w(w_{OF})$ has the same expected cost for any w_{OF}. Therefore, a contract w^* is optimal if and only if $w^* = w(w^*_{OF})$ for some w^*_{OF} and $w(w^*_{OF})$ is feasible. Letting $W_{OF} \equiv \{w_{OF} \in \mathbb{R}_+ : w(w_{OF}) \text{ is feasible}\}$, it follows that w^* is optimal if and only if $w^* = w(w^*_{OF})$ for some $w^*_{OF} \in W_{OF}$. By construction, any $w(w_{OF})$ satisfies ($IC_N - a$) and ($IC_O - a$) and limited liability requires that $w^*_{OS}(w^*_{OF}) \geq 0$, which is equivalent to $w^*_{OF} \leq \frac{W'_O}{1-p_O} = \frac{p^e_N w'_{NS}}{1-p_O}$. Thus, $W_{OF} = \left[0, \frac{p^e_N w'_{NS}}{1-p_O}\right]$.

Since there exists an optimal contract, there exists at least one optimal contract with $w_{OF} = w_{OS}$. Since $w^*_{OS}(w_{OF}) = w_{OF}$ if and only if $w_{OF} = W'_O = p^e_N w'_{NS}$, it follows that the unique optimal contract with $w_{OF} = w_{OS}$ is the contract $w' = w(W'_O) = (W'_O, W'_O, 0, w'_{NS})$, where $W'_O = W'_O = p^e_N w'_{NS}$.

After some algebra, one can show that

$$(p^H_N - p^L_N)\pi^L \pi^H = g(1-g)(2\lambda - 1)(p^N_G - p^N_B), \tag{A8}$$

so

$$w'_{NS} = \frac{c}{g(1-g)(2\lambda-1)(p^N_G - p^N_B)}, \tag{A9}$$

$$W'_O = p^e_N w'_{NS}. \tag{A10}$$

which completes the proof. ■

B Proof of Proposition 3

Following Grossman and Hart (1983), we rewrite the principal's problem as the problem of finding the vector of utility levels for the manager that satisfies the manager's incentive compatibility and limited liability constraints at the minimum expected cost. We let x_{ir} denote the payment following action i and return r and $w_{ir} = u(x_{ir})$ denote the manager's Bernoulli utility level corresponding to payment x_{ir}. With this relabeling, the manager's incentive and limited liability (since $u(0) = 0$) constraints are formally identical to the ones of the risk-neutral case considered in Proposition 2 (constraints $(IC_N - a)$,$(IC_O - a)$, $(IC^H - a)$, and $(IC^L - a)$, and the objective function has the form

$$p^*_{NS}v(w_{NS}) + p^*_{NF}v(w_{NF}) + p^*_{OS}v(w_{OS}) + p^*_{OF}v(w_{OF}), \tag{A11}$$

where p^*_{ir} (for $i \in \{O, N\}$ and $r \in \{F, S\}$) is the probability that the manager takes action i and the return is r if the manager exerts effort and chooses optimally conditional on the signal, and $v(w_{ir}) = u^{-1}(w_{ir})$. Since $u' > 0$ and $u'' < 0$, it follows that $v' > 0$ and $v'' > 0$, so that the objective function is strictly convex in w. It follows from the strict convexity of v that if $\alpha w_{iS} + (1 - \alpha)w_{iF} = \alpha w'_{iS} + (1 - \alpha)w'_{iF}$ for $\alpha \in (0, 1)$ and $w_{iF} < w'_{iF} \leq w'_{iS} < w_{iS}$, then $\alpha v(w_{iS}) + (1 - \alpha)v(w_{iF}) > \alpha v(w'_{iS}) + (1 - \alpha)v(w'_{iF})$, so that if $w_{iS} > w_{iF}$, any change that keeps the expected utility if the manager chooses i constant (where the expectation is taken with respect to any arbitrary non-degenerate distribution) and reduces the difference between w_{iS} and w_{iF} reduces the expected (with respect to the same distribution) cost of the manager's pay if she chooses action i.

It follows from the proof of Proposition 3 that the decision constraints are slack at an optimum, so we disregard them.

Let $w = (w_{OF}, w_{OS}, w_{NF}, w_{NS})$ be an optimal vector of utility levels with $W_O = p_O w_{OS} + (1-p_O)w_{OF}$ and let $\widehat{w} = (W_O, W_O, w_{NF}, w_{NS})$. Contract $\widehat{w}$ yields the manager the same expected utility as w, and it follows from the proof of Proposition 3 that $\widehat{w}$ satisfies the effort and limited liability constraints. Hence, if $w_{OF} \neq w_{OS}$, it follows from the manager's strict risk aversion that the expected cost of $\widehat{w}$ is lower than that of w, contradicting the assumption that w is optimal.

Therefore, if $w = (w_{OF}, w_{OS}, w_{NF}, w_{NS})$ is an optimal vector of utility levels, then

$w_{OF} = w_{OS} = W_O$. Further, $W_N^H > W_O > W_N^L$ and thus $w_{NS} > W_O > w_{NF}$. If $w_{NF} > 0$, the utility vector $(W_O - w_{NF}, W_O - w_{NF}, 0, w_{NS} - w_{NF})$ is also feasible and has a lower expected cost. Therefore, $w_{NF} = 0$. Since the argument in the proof of Proposition 2 showing that $(IC_N - a)$ and $(IC_O - a)$ are binding at the optimum applies unchanged if the manager is risk averse, $(IC_N - a)$ and $(IC_O - a)$ are binding at the optimal utility vector. Therefore, it follows from the proof of Proposition 2 that there is a unique optimal utility vector w^*, with $w^*_{NS} = 0$, $w^*_{NS} = w'_{NS}$, and $w^*_{OS} = w^*_{OF} = W'_O$, for w'_{NS} and W'_O defined in expressions (A6) and (A10). Since $u(0) = 0$, $u' > 0$, and $w^*_{NF} = 0 < w^*_{OF} = w^*_{OS} = W'_O < w^*_{NS} = w'_{NS}$, it follows that the optimal contract's ranking of pay levels is $x^*_{NF} = 0 < x^*_{OF} = x^*_{OS} = u^{-1}(W'_O) < x^*_{NS} = u^{-1}(w'_{NS})$, which completes the proof. ■