Incentivizing Innovation Under Ambiguity

Seong Byun*

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*University of Mississippi, School of Business Administration. E-Mail: sbyun@bus.olemiss.edu. I am deeply indebted to my advisors Michael Rebello and Robert Kieschnick for their guidance. I also thank Jing Zeng (discussant, FIRS), Nina Baranchuk, Bernhard Ganglmair, Jong-Min Oh, Valery Polkovnichenko, Lord Wardlaw, Harold Zhang, and the seminar participants at The University of Texas at Dallas and 2015 Financial Intermediation Research Society Annual Meeting (Reykjavik) for their valuable comments. I also thank Amanda Besch for editorial assistance.
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Abstract

This paper highlights the limits of high-powered incentives to motivate innovation in an uncertain environment in which the risk of innovation is ambiguous. We show that implementing innovation under ambiguity requires the use of low-powered incentives, such as guaranteed salary, unconditional tolerance for failure, and reliance on intrinsic motivation. The low-powered incentives are optimal even when there exist measurable and contractible signals of innovation’s success. The results generate implications for optimal organizational structures for innovation, and highlight the importance of alternative devices, such as firms’ screening and hiring practices, and the ideal managerial preferences and styles in implementing innovation.

Key Words: compensation; optimal contracting; ambiguity; uncertainty; innovation.

JEL: D86, G30, O32.
What is the optimal incentive scheme that encourages people to take on innovative and creative endeavors? The question requires one to first think about what the process of innovation actually entail. If innovation is viewed simply as a task that requires costly effort, then the traditional principal-agent models would suggest that conventional pay-for-performance scheme is necessary to induce innovation ((Arrow (1974), Harris and Raviv (1978), Holmstrom (1979), Grossman and Hart (1983), and Mirrlees (1999)). On the other hand, others have examined innovation as a process that involves experimentation and learning over time, in which case the tolerance for failures in the short-term and the greater reward for long-term performance, such as equity options that vests over multiple years, may be optimal to induce agents to experiment and learn, which involves potential failures (Manso (2011), Ederer and Manso (2013), Francis, Hansan, and Sharma (2010), Baranchuk, Kieschnick, and Moussawi (2013), Tian and Wang (2014)).

While these existing views highlight the potential value of designing the right extrinsic incentives in motivating innovation, this paper gives an alternative view by showing the limitations of extrinsic incentives and the adverse effects they can have on the incentive to innovate. To do so, we propose to view innovation in a different light: innovation is a process that involves ambiguity, in which the manager has incomplete information about the underlying risk associated with innovation. We show that high-powered and extrinsic incentives may actually discourage innovation, and that incentivizing innovation under ambiguity requires more reliance on low-powered incentives, such as boosting intrinsic motivation and providing unconditional tolerance for failures to the agents. Furthermore, we show that the limits on extrinsic incentives to motivate innovation is determined by a) the degree of ambiguity associated with innovation, b) the difficulty of implementing innovation, c) the relative profitability of alternative projects, and d) the level of agent’s intrinsic motivation.

The main idea of this paper is consistent with Holmstrom (1989) and Holmstrom and Milgrom (1991), which have shown that low-powered incentives are optimal when the performance of innovative and creative endeavors cannot be measured or be contracted upon. In such cases, providing high-powered incentives can disincentive the agent away
from creative but hard to quantify tasks to tasks that are more visible and easier to measure. This paper extends this idea into a broader and more realistic spectrum by showing that high-powered incentives may not be optimal even when innovation is measurable and contractible. For example, even when the principal can encourage innovation by rewarding the manager based on the number of patents generated by the manager, it may still be optimal to forgo such contract in favor of paying the manager equally regardless of the outcome. In the presence of ambiguity, designing the agent’s compensation to be performance-sensitive encourages the agent to implement less ambiguous method to achieve the same mean while forgoing ambiguous but potentially more profitable method.

To study the ambiguous nature of innovation, we model the agent’s belief about innovation’s likelihood of success as a set of distributions rather than as a single value. Specifically, we consider an innovative project which will either be a success with a probability $p \in [\underline{p}, \bar{p}]$ and a failure with a probability $1 - p$. In the special case where $\underline{p} = \bar{p}$, the project follows a single Bernoulli distribution. In contrast, when $\underline{p} < \bar{p}$, the probability is a set, rather than a singleton. Hence, the manager has multiple distributions in mind and does not know the exact distribution associated with the project. Furthermore, we model the manager’s preference (distinguished from simply his beliefs) using Gilboa and Schmeidler’s (1989) multiple-priors utility. With these preferences, the manager assumes his utility for each possible prior, and maximizes his utility based on the prior with the lowest utility. Thus, he behaves as if he believes in the worst possible prior from his set of beliefs. The size of the set $[\underline{p}, \bar{p}]$ reflects the level of manager’s ambiguity towards the project.

To examine the optimal incentives for innovation, we utilize a principal-agent framework where the agent faces the choice of hidden action on whether to work on an innovative project, in which exact probability of success is unknown (ambiguity), or on a conventional project, in which the probability is known (risk). The project choice reflects the tension between the choice to stay with a convention or to innovate. In addition to the project choice, the agent also takes a hidden action on his effort level, which reflects the traditional agency conflict in which exerting effort is costly to the agent. Given the
two dimensions to the agent’s hidden action, motivating innovation requires the principal to incentivize the agent not only to exert high effort, but also to choose innovation over conventional project. To examine the agency cost arising from ambiguity-aversion, we consider the problem where the principal is ambiguity-neutral and makes decision based on her subjective prior. Therefore, the principal and the agent share the same information set, but their preferences towards ambiguity are different. This generates an additional agency costs.

The optimality of low-powered incentives in this paper does arise with alternative preferences such as simply risk-aversion or disagreement models, and are unique to the setting with ambiguity. The key result with ambiguity is that ambiguity-averse agent behaves as if he always believes in the worst possible outcome, and therefore, the agent’s belief under ambiguity appears as if it is endogenous to the wage scheme set by the principal, rather than being a fixed prior. If the principal rewards the agent for a success, then the agent associates innovation with a low probability of success. On the other hand, if the principal rewards the agent for a failure, the agent then associates innovation with a high probability of success. Consequently, in both cases, the use of performance-based reward incentivizes the agent to choose convention. Therefore, the optimal contract for motivating innovation in the case of high ambiguity is to provide no incentive at all. With risk-aversion models, the risk-aversion effect is second-order and does not come into play at low levels of incentives. With disagreements where the principal and the agent agree-to-disagree on the best course of action, the principal can still implement the desired action by rewarding the agent to fail, in which case the agent may implement the worst perceived course of action, which the principal may perceive as the best course of action.

The main contribution of this paper is to the literature on motivating innovation. In regards to the theoretical work (Holmstrom, 1989; Holmstrom and Milgrom, 1991; Aghion and Tirole, 1994; Manso, 2011), by modeling innovation as a process involving ambiguity rather than risk alone, this paper shows that low-powered incentives are optimal even when innovation is measurable and contractible, and that uncertainty can have
a first-order effect on the optimal incentive scheme.

In regards to empirical studies related to compensation features that correlates with innovation, this paper contributes to the studies on intrinsic motivation and non-pecuniary compensation in practice (Maslow, 1943; Hertzberg, 1959; McGregor, 1960; Rajan and Zingales, 1998; Carlin and Gervais, 2009; Berk, Stanton, and Zechner, 2010; Zingales, 2000; Edmans, 2011, 2012) by showing that intrinsic incentives are not just simple substitutes for extrinsic compensation, but that they play an important role for motivating innovation that extrinsic incentives cannot satisfy. In regards to the studies examining various compensation features and innovation (Ederer and Manso, 2013; Francis, Hasan, and Sharma, 2010; Baranchuk, Kieschnick, and Moussawi, 2013; Tian and Wang, 2014; Seru, 2014), this paper predicts positive relation between innovation and unconditional, rather than just short-term, tolerance for failure, which seem to be the characteristic of many of the entrenchment devices present in corporations. Also, this paper would suggest caution in interpreting the positive relation between innovation high-powered incentives. If we conjecture that radical and novel innovation are more likely to be more ambiguous, then empirical tests may simply be capturing the positive association between high-powered incentives and incremental innovation, and thus, may fail to give a full picture of the overall relation between incentives and innovation.

Secondly, given the long recognition that the incentives problem arising from agency conflicts can determine the structure of organizations (Arrow (1974) and Jensen and Meckling (1976)), this paper is also related to the literature studying the effects of the organizational forms and the boundaries of the firm on firm’s innovation (Gompers, Lerner, and Scharfstein, 2005; Robinson, 2008; Seru, 2014), and more broadly to the efficiency of investments in conglomerates and diversified firms (Lang and Stulz, 1994; Stein, 1997; Rajan, Servaes, and Zingales, 2000; Scharstein and Stern, 2000; Schoar, 2002; Ozhus and Scharfstein, 2010). If novel and radical innovations are associated with higher ambiguity, then ambiguity-averse agents will forgo radical innovations in favor of conventional projects with less ambiguity, and this agency cost, as we show, cannot be solved by optimal contracting within corporations. Hence, the agency cost associated
with innovation under ambiguity can also determine the boundary of the firm.

Thirdly, by pointing out the limits of contracting with incentives to solve the agency problem in inducing innovation, the paper highlights the importance of alternative devices in implementing innovation. When innovation is ambiguous, screening of managers and employees with less aversion to ambiguity may be the only way to implement innovation. Thus, examining firms’ and boards’ hiring practices, managerial/employee turnovers, CEO preferences and styles (Bertrand and Schoar 2003) may provide greater explanatory power for firm’s innovative output and quality than studying the compensation features alone.

Lastly, this paper also extends the existing work examining the effects of ambiguity in the contracting literature (Mukerji(1998, 2003), Lopomo, Rigotti, and Shannon(2011), and Weinschenk(2010)). While the existing studies focus on a single ambiguous project, this paper studies the situation in which there are mix of ambiguous and non-ambiguous projects, which allows us to study the tension between choosing to innovate versus choosing to stick with a conventional alternative, similar to extending the principal-agent model to multi-tasking framework. As a consequence, low-powered incentives arise as optimal contract even when high-powered incentives may be optimal for both conventional and ambiguous projects if they are contracted upon independently. Hence, the situations in which low-powered incentives are optimal are much more prevalent than suggested before.

1 Model

In this section, we introduce the agency conflict that arises from tension between innovation and convention in the principal-agent framework. A principal hires an agent to work on a project with a payoff $S$ in case of a success and $F = 0$ in case of a failure. The principal is neutral to ambiguity, but the agent is ambiguity-averse.¹ However, both the principal and the agent are risk-neutral.²

¹The opposite case is possible, but with ambiguity-averse principal, we can end up with non-participation so that there is no agency conflict to begin with. Further implications are discussed in Section 3.

²This is to highlight the effect of ambiguity-aversion on incentives. In Section 3, we show that the results are qualitatively similar if we incorporate risk-aversion.
In carrying out the project, the agent makes decisions along two dimensions: a method choice and an effort choice. The principal does not observe the actions taken by the agent, so that the principal offers a wage contract contingent on the project outcome, i.e., whether the project is a success or a failure, which provides a contractible signal of innovation in this model.\(^3\) The contract involves setting the wage conditional on success, \(w_S\), and on failure, \(w_F\). The agent has limited liability, so the wage cannot be negative.

First, in implementing the project, the agent makes a decision whether to innovate or choose a conventional method (method choice, \(m \in \{i, c\}\)). The two action choices differ in their expected probability of success, \(p(m)\). Convention \((m = c)\) is associated with the expected probability of success \(p(m = c) = p_c\) and the effort cost \(C(m = c) = C_c\).

On the other hand, innovation \((m = i)\) is associated with the expected probability of success \(p(m = i) = \tilde{p}_i \in [p_i^L, p_i^H] = [\overline{p}_i - \epsilon, \overline{p}_i + \epsilon] \equiv \mathcal{P}_i\) and the effort cost \(C(i) = C_i\). The tilde notation \(\tilde{\cdot}\) denotes the presence of ambiguity.

![Figure 1: The Decision Sequence](image)

The expected probability of success for innovation is a set of possible values rather than a singleton. Hence, the agent perceives the risk associated with innovation to follow one of many possible distributions rather than a single known distribution. The parameter \(\epsilon\), which describes the size of the set \(\mathcal{P}_i\), reflects the amount of ambiguity associated with innovation. When \(\epsilon = 0\) so that \(p_i^L = p_i^H\), the agent has a single prior, and therefore, perceive innovation simply as a risky, not but ambiguous, choice of action.

In addition to the choice between innovation and convention, the agent also can

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\(^3\)If there exists alternative signals of agent’s action other than the outcome, then the optimal contract will be contingent on those signals, but as long as the observed signal is imperfect, the optimal contract will be a function of the outcome.
choose to put in high effort or to shirk. With high effort, the agent incurs the aforementioned effort cost and the expected probability of success. The relative effort costs can vary depending on the project and on the agent’s preference. If innovation demands significantly more resources and time, then the agent associates higher effort cost with innovation, i.e., \( C(m = i) > C(m = c) \). On the other hand, if the agent inherently enjoys working on new ideas rather than on repetitive tasks, then the agent may associate lower cost of effort with innovation \((C(m = i) < C(m = c))\). This may be the case for young and creative individuals who prefer to work on new projects rather than repeating the same projects. The agent can also choose to exert low effort (shirk) in carrying out either convention or innovation. In this case, the agent incurs zero effort cost. As such, there are four possible implementable methods for the principal: convention with high effort, \( m = c \), or a low effort, \( m = c \mid l \), and innovation with high effort, \( m = i \), or a low effort, \( m = i \mid l \).

When the agent puts in low effort, he faces the expected probability of success that is lower by a fixed amount \( \tau \), which results in the probability of success \( p_{c \mid l} = p_c - \tau \) for convention and \( \tilde{p}_{i \mid l} \in [p^L_i - \tau, p^H_i - \tau] = [\tilde{p}_{i \mid l} - \epsilon, \tilde{p}_{i \mid l} + \epsilon] \equiv \mathcal{P}_{i \mid l} \) for innovation. If the expected payoff for low effort is equivalent for convention and innovation, we assume that the agent will choose the task that is desirable to the principal. Hence, low effort can be interpreted as the minimum level of work that the agent is willing to do from his intrinsic motivation as in Holmstrom (1989) and Holmstrom and Milgrom (1991).

The agent’s expected wage when he implements a given method \( m \) is then

\[
\tilde{W}(m) = \tilde{p}_m w_S + (1 - \tilde{p}_m) w_F.
\] (1)

When the agent implements innovation, he faces a set of possible expectations over \( \mathcal{P}_i \), rather than a single expected value. We model the agent’s aversion to ambiguity by utilizing the multiple-priors utility (MPU) from Gilboa and Schmeidler (1989).
Under MPU, the agent derives his utility based on each possible prior, and takes action based on the prior with the lowest possible payoff. In other words, he behaves as if he believes in the worst-case prior: We denote the solution to the minimization problem over \( P_i \) as \( p_i' \):

\[
p_i'(m) = \arg \min_{\tilde{p}_i \in P_i} \{ [W(m|\tilde{p}_i) - C(m|\tilde{p}_i)] \}.
\] (2)

Then, the agent’s problem is to maximize his utility based on the worst-case prior:

\[
\max_m \tilde{U}^a(m) = \max_m \min_{\tilde{p}_i \in P_i} \{ U^a(m|\tilde{p}_i) \} = \max_m U^a(m|p_i').
\] (3)

While the worst-prior behavior of the agent under MPU may seem extreme at first sight, the MPU model is very general and can incorporate various degrees of ambiguity.

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### Table: Expected Payoffs from the Project

<table>
<thead>
<tr>
<th>Effort</th>
<th>Convention</th>
<th>Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>( p_c )</td>
<td>( \tilde{p}_i \in [p_i^L, p_i^H] )</td>
</tr>
<tr>
<td></td>
<td>( 1 - p_c )</td>
<td>( 1 - \tilde{p}_i )</td>
</tr>
<tr>
<td>{ ( m = c } )</td>
<td>( F )</td>
<td>{ ( m = i } )</td>
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<table>
<thead>
<tr>
<th>Effort</th>
<th>Convention</th>
<th>Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>( p_{cl} = p_c - \tau )</td>
<td>( \tilde{p}_{il} \in [p_i^L - \tau, p_i^H - \tau] )</td>
</tr>
<tr>
<td></td>
<td>( 1 - p_{cl} )</td>
<td>( 1 - \tilde{p}_{il} )</td>
</tr>
<tr>
<td>{ ( m = c</td>
<td>l } )</td>
<td>( F )</td>
</tr>
</tbody>
</table>

Figure 2: The Expected Payoffs from the Project
aversion. If one interprets the set $\mathcal{P}_i$ as the agent’s subjective priors, and distinguishes it from the set of all logically possible probability distributions, say $\mathcal{P}_i^*$, with $\mathcal{P}_i \subseteq \mathcal{P}_i^*$, then the degree of ambiguity aversion can be incorporated through the size of the set $\mathcal{P}_i$.

For example, if the success probability of innovative project, $p_i$ lies within zero and 1, then a moderately ambiguity-averse agent may have a subjective prior $p_i \in [\frac{1}{3}, \frac{2}{3}]$ while extremely ambiguity-averse agent may have a subjective prior $p_i \in [\frac{1}{10}, \frac{9}{10}]$.

An alternative way to model ambiguity aversion is by using smooth ambiguity model of Klibanoff, Marinacci, and Mukerji (2005), which assigns an additional probability distribution $\mu$ on the set of possible priors $\mathcal{P}_i^*$. The agent’s utility under smooth ambiguity model is given as follows:

$$\tilde{U}_{KMM}^a(m) = \int_{\mathcal{P}_i^*} \phi(U^a(m|p_i)) \, d\mu,$$

(4)

where $\mu$ captures agent’s subjective prior over a set of all possible distributions $\mathcal{P}_i^*$ and $\phi$ is a function that maps agent’s expected utility to a real line, and captures the agent’s attitude towards ambiguity. When $\phi$ is concave, then the agent is ambiguity-averse in a sense that the certainty equivalent payoff for a set of uncertainty priors $\mathcal{P}_i^*$ is lower than an ambiguity-neutral agent with a linear $\phi$. Thus, KMM is able to distinguish between the existence of ambiguity through the set $\mathcal{P}_i^*$ and the individual’s attitude towards ambiguity through the function $\phi$. However, given any degree of ambiguity aversion in KMM framework, we can find an agent under the MPU framework with equivalent degree of ambiguity-aversion by setting the right subjective priors for the agent in MPU, i.e., agent’s subjective prior $\mathcal{P}_i$ is such that $\min \mathcal{P}_i = p_i^L = \int_{\mathcal{P}_i^*} \phi(U^a(m|p_i)) \, d\mu$. Hence, we will utilize the framework of MPU to model ambiguity throughout the paper, but our results are similar under the smooth ambiguity models of KMM.

The principal can incentivize the agent to implement a desired action by setting the wage scheme $\vec{w} = \{w_S, w_F\}$. When designing the wage scheme, the ambiguity-neutral principal maximizes her utility based on the expected utility with prior $E[p_i]$. Without further information on the likelihoods of the set $\mathcal{P}_i$, the principal puts equal weight on possible priors, such that $E[p_i] = \bar{p}_i$. In the alternative framework of KMM, the principal
is ambiguity-neutral with a linear $\phi$ function in Equation 4. To study the agency cost arising from implementing innovation, the principal in the absence of agency conflict always wishes to implement innovation, i.e. $p_i > p_c$. Lastly, the agent’s reservation utility is normalized to zero, and so the individual rationality constraint is non-binding.

The principal’s problem is then to choose to implement a method $m$ that maximizes her expected payoffs:

$$
\max_{m \in \{i, il, i|l, c, c|l\}} \bar{p}_m(S - w^*_S(m)) + (1 - \bar{p}_m)(F - w^*_F(m))
$$

where $w^*_S(m)$ and $w^*_F(m)$ are the optimal wages for implementing a given method $m$. The principal’s problem is essentially a two-part problem: first, for each of the possible implementation $m$, we solve for minimum wage scheme that implements the given action. Second, given the expected wage cost of implementing given action, the optimal action is the one that gives the highest expected payoffs to the principal. For the remainder of the paper will focus on the characteristics of the optimal wage scheme that implements innovation, and compare them to the characteristics of wage schemes for implementing convention.\(^4\) To avoid discussing the trivial cases where optimal incentive scheme does not arise, we assume that the expected payoffs associated with high effort is sufficiently high such that relying on intrinsic motivation is the last resort for the principal if both high effort and low effort are feasible and generates positive payoffs for the principal.

2 Incentivizing Innovation

This section examines the optimal wage scheme that motivates innovation. We explore the characteristics of the incentive scheme that motivates innovation under three different degrees of ambiguity present in innovation:

**Definition.** (1) High Ambiguity: $\bar{p}_i - p_{c|l} < \epsilon$ (i.e., $p^L_i < p_{c|l}$). (2) Moderate Ambiguity: $\bar{p}_i - p_c < \epsilon < \bar{p}_i - p_{c|l}$ (i.e., $p_{c|l} < p^L_i < p_c$). (3) Low Ambiguity: $\epsilon < \bar{p}_i - p_c$ (i.e., $p_c < p^L_i$).

\(^4\)The optimal incentive scheme that motivates convention is an orthodox pay-for-performance contract. See Appendix A for details.
There are mainly two ways to implement innovation. First, the principal can induce the agent to innovate with high effort. When the principal wishes to implement innovation with high effort, the principal’s problem becomes

$$\min \limits_{w_S, w_F} \bar{p}_i w_S + (1 - \bar{p}_i) w_F \quad s.t. \quad (6)$$

The left-hand-sides of the IC constraints are the expected utilities from taking on innovation. The first $IC_c$ constraint ensures that the agent’s payoffs from implementing innovation are higher than from implementing convention with high effort. The second $IC_c|l$ and third $IC_i|l$ constraints ensure that the agent’s payoff from innovation is higher than the payoffs from convention with low effort and innovation with low effort, respectively.

Because the agent’s belief about innovation’s probability of success $\tilde{p}_i$ is not fixed, but is endogenous to the wage contract offered by the principal, this is no longer a simple linear programming problem. However, the following lemma simplifies the problem going forward:

**Lemma 1.** The solution, $p'_i$, to the agent’s minimization is $p_i^L$ if $w_S \geq w_F$, and $p_i^H$ if $w_S < w_F$.

This can be seen by rewriting the agent’s expected payoff,

$$\left[ \tilde{W}(i) - C(i) \right] = p_i w_S + (1 - p_i) w_F - C_i.$$

If $w_S \geq w_F$, then the lowest possible $p_i$ minimizes the agent’s payoff. If, otherwise,
$w_S < w_F$, then the highest possible $p_i$ minimizes the agent’s payoff.

Because the optimal contract requires $w_S \geq w_F$, the agent’s belief will become $p'_i|l_i = p^L_i|l_i$. Depending on which method the agent believes to be associated with higher probability of success when he shirks ($p^L_i|l_i < p_{c|i}$, or $p^L_i|l_i > p_{c|i}$), only one of $IC_{c|i}$ and $IC_{c|i}$ will be binding. Thus, there will always be only two IC constraints that are binding, with the other one being slack. We thus denote the binding shirking constraint as $IC_l$, where $l = \{i|l, i|c\}$.

Implementing innovation with high effort, however, may not always be feasible in the presence of ambiguity. In such cases, the principal can only implement innovation with low effort, which results in the following principal’s problem:

$$\min_{w_S, w_F} \bar{p}_{i|i}w_S + (1 - \bar{p}_{i|i})w_F \quad s.t.$$  

$$IC_c : \min_{\bar{p}_{i|i} \in P_{i|i}} \{\bar{p}_{i|i}w_S + (1 - \bar{p}_{i|i})w_F\} \geq p_c w_S + (1 - p_c)w_F - C_c \quad (7)$$

$$IC_l : \min_{\bar{p}_{i|i} \in P_{i|i}} \{\bar{p}_{i|i}w_S + (1 - \bar{p}_{i|i})w_F\} \geq p_{c|i} w_S + (1 - p_{c|i})w_F.$$  

Before we proceed, we define the following terms for the ease of exposition:

$$\beta = \frac{p^L_i - p_i}{p_c - p_i}.$$  

$\beta$ captures the relative profitability of innovation to convention. The numerator is the marginal increase in the probability of success when implementing innovation, and the denominator captures the marginal increase in the probability for implementing convention. We will also use $I(x)$ to denote an indicator function equal to one if statement $x$ is satisfied and zero otherwise.
2.1 High Ambiguity

We first consider the case with high ambiguity, i.e., $p_i - p_l < \epsilon$. In this case, innovation has a lower probability of success than convention with low effort, i.e., $p^L_i < p_l$. If the agent puts in low effort, his prior is $p_{cil}$. But the principal’s prior, on the other hand, does not reflect ambiguity aversion and is $\overline{p}_i$, which is lower than the agent’s prior, $p_{cil}$. The difference in their preferences towards ambiguity generates what appears to be a difference in their priors, even though they share the exact same information set. The following proposition states the optimal contract for innovation under high ambiguity:

**Proposition 1.** Innovation with high effort is infeasible to implement. The optimal contract that implements innovation under high ambiguity is through innovation with low effort, which sets

$$w_S = w_F = 0.$$  \hspace{1cm} (8)

*Proof.* See Appendix C.

The detailed proof is provided in the Appendix C, but the outline of the proof is as follows. If the reward for success is greater than the reward for failure, i.e., $w_S - w_F > 0$, then the agent’s utility is lowest when $\tilde{p}_i$ is minimized, which is achieved when $p'_i = p^L_i$. On the other hand, if the reward for success is lower than the reward for failure, i.e., $w_S - w_F < 0$, then the agent’s utility is lowest when $p_i$ is highest, $p'_i = p^H_i$. Therefore, the ambiguity-averse agent behaves as if he believes in the prior $p^L_i$ if $w_S > w_F$, and with $p^H_i$ if $w_S < w_F$. We can also re-write the incentive compatibility constraint with respect to low effort as follows:

$$IC_l : (p'_i - p_l)(w_S - w_F) \geq C_i.$$  

First, consider the possibility of paying the agent more for success, $w_S > w_F$. Then, the agent’s payoff will be negative since $(p'_i - p_l) = (p^L_i - p_l) < 0$, which violates the IC constraint because the expected payoff is lower than the cost of effort, $C_i$, which
is positive. Consider, then, the alternative case where the principal rewards the agent more for failure, \( w_S < w_F \). The agent’s expected payoff is once again negative since 
\[
(p_i' - p_i) = (p_i^H - p_i) > 0, \quad \text{which makes} \quad (p_i^H - p_i)(w_S - w_F) < 0. \]
Again, the IC constraint is violated for any optimal contract with \( w_S \) and \( w_F \). Hence, any asymmetric reward for either a success or a failure incentivizes the agent towards convention when ambiguity is high. Therefore, innovation with effort, \( m = i \), is in feasible to implement.

Thus, the only possible way to induce innovation is to implement innovation with low effort, \( m = i|l \), is to offer low-powered incentives, \( w_S = w_F = 0 \). In this case, the agent is indifferent between the two tasks, and therefore will choose the action that is desired by the principal.

Therefore, when innovation is characterized by high degrees of ambiguity, the agent’s ambiguity-aversion prevents the use of any positive rewards, and the principal must rely on the agent’s intrinsic motivation to work to implement innovation. This is similar to the Holmstrom and Milgrom’s (1991) result, in which the principal must use low-powered incentives to implement innovation when innovation cannot be measured. In their model, low-powered incentives arise only in the limiting case where the signal of agent’s effort in innovation contains infinite noise, such that innovation is not measurable. Such limiting cases are required because, in their model and in the traditional models of moral hazard, the agent’s aversion to the variance of the expected payoffs, which is captured by the degree of his risk-aversion, must be outweighed by the agent’s expected payoff. With finite risk, the principal can always reduce the amount of reward, and therefore, the amount of wealth tied to the project, such that the expected payoff outweighs the risk-aversion effect. In other words, even a risk-averse agent would be risk-neutral towards a small amount of incentive pay given a smooth utility function.

In contrast, in the case of ambiguity-aversion, the agent’s ambiguity is not simply reflected in the variance of the future payoffs, but enters the agent’s expectation directly, which has a first-order effect on agent’s expected utility. Even a small degree of ambiguity therefore can offset the expected payoffs from innovation. Thus, in the presence of high ambiguity, low-powered incentives are optimal for motivating innovation even when
innovation is perfectly measurable and even when the agent is has high tolerance for risk. Also, note that “high ambiguity” is not only a function of innovation itself, but is also a function of the agent’s alternative choices, namely, the expected payoff from convention. Even if the degree of ambiguity associated with innovation, \( \epsilon \), is low, a high expected payoff from convention, \( p_c \), will result in high return from shirking, \( p_{c|l} = p_c - \tau \). Thus, a small degree of uncertainty associated with innovation, in the presence of highly profitable alternatives, will result in a case where low-powered incentives are necessary to induce innovation. Therefore, the presence of even a small degree of ambiguity can potentially render high-powered incentives suboptimal when the agent faces many multiple choices of action. These results thus have implications for the organizational structure and the boundaries of the firm that takes on ambiguous and potentially radical innovation, which will be discussed in Section 5.

2.2 Moderate Ambiguity

Here we consider the optimal incentive schemes under moderate ambiguity, i.e., \( \bar{p}_i - p_c < \epsilon < \bar{p}_i - p_l \). This is the case when convention with high effort has higher probability of success than innovation with high effort in the worst possible case, but innovation is still superior to conventional with low effort, i.e., \( p_c > p_l^L > p_l \). In this case, implementing innovation with high effort becomes feasible. The following proposition derives the optimal contract for incentivizing innovation with high effort under moderate ambiguity:

**Proposition 2.** The optimal contract that implements innovation under moderate ambiguity is such that

\[
w_F = 0,
\]

\[
w_S = \frac{C_i}{p_l^L - p_l} \mathbb{I} \left( \beta - \frac{C_i}{C_c} > 0 \right).
\]

This contract implements innovation with high effort when \( w_S > 0 \) and implements innovation with low effort when \( w_S = 0 \).

**Proof.** See Appendix D.
From the result above, we can see that $w_S$ will be positive if $\beta - \frac{C_i}{C_c}$ is positive, and zero, otherwise. Hence, low-powered incentives can also arise as an optimal incentive scheme to motivate innovation even with moderate ambiguity.

As discussed previously, the agent’s prior on innovation’s expected success depends on whether he is rewarded more for success ($w_S > w_F$) or for a failure ($w_S < w_F$). The incentive compatibility condition associated with shirking can be expressed as

$$IC_l : (p'_i - p_l)(w_S - w_F) \geq C_i.$$

Because we have $(p'_i - p_l) \geq (p'_c - p_c) > 0$ under moderate ambiguity, the agent’s payoff on the left-hand-side will be positive only when the agent is rewarded more for success than failures, $(w_S - w_F) > 0$. Consequently, the only possible way to compensate the agent for high effort is to provide a higher reward for a success than a failure. Then, the optimal contract will set $w_F = 0$ and $w_S > 0$.

The incentive compatibility constraint with respect to convention with high effort can also be expressed as

$$IC_c : (p'_c - p_c)w_S \geq C_i - C_c,$$

but because $(p'_i - p_c) < 0$, the incentive compatibility constraint becomes an upper-bound constraint:

$$IC_c : (p_c - p'_i)w_S \leq C_c - C_i.$$

Along with the IC constraint with respect to low effort, we obtain a lower bound and upper bound constraint on the wage $w_S$:

$$\frac{C_i}{p'_c - p_l} \leq w_S - w_F \leq \frac{C_c - C_i}{p_c - p'_i}.$$

First, if the lower bound value $\frac{C_i}{p'_c - p_l}$ is lower than the upper bound, $\frac{C_c - C_i}{p_c - p'_i}$, then the IC constraint can be satisfied by setting the reward for success at the lower boundary, with
\[ w_S = \frac{C_i}{p_i - \bar{p}_i}. \] In this case, the principal can induce the agent to innovate with high effort by giving him high-powered incentives, but at the same time, the incentives are not enough to incentivize the agent to implement convention over innovation. This \( \frac{C_i}{p_i - \bar{p}_i} < \frac{C_c - C_i}{p_c - \bar{p}_i} \) condition can be rearranged to be written as \( \beta > \frac{C_i}{C_c} \). We can see that this condition is likely to hold when the relative effort cost in implementing innovation is low compared to the effort cost of implementing convention. Such situations are likely in technology industries with high number of young CEOs and employees who inherently enjoy working on new and innovative ideas rather than working on repeated tasks. When innovation is easy to implement, or when convention is difficult to implement for the agent, then high-powered incentives can be used to incentivize innovation because the effect of positive compensation on the agent’s incentive to forgo innovation for convention is offset by the high effort cost. The positive loading on \( w_S \) reflects this possibility.

Alternatively, we may have \( \beta > \frac{C_i}{C_c} \). This condition arises when the upper bound on the reward, \( \frac{C_c - C_i}{p_c - \bar{p}_i} \), is actually lower than the lower bound, \( \frac{C_i}{p_i - \bar{p}_i} \). In this case, the incentive compatibility constraints cannot be simultaneously satisfied, which makes high-powered incentives infeasible. In this case, if the principal wishes to implement innovation, the only possible solution would be to implement innovation by allowing shirking, \( m = iI \), which can be implemented by providing low-powered incentives, \( w_S = w_F = 0 \). Then, the agent’s payoff under convention and innovations are equal, and therefore, the agent implements what the principal desires. Therefore, as in the case with high ambiguity, low-powered incentives are necessary to induce innovation.

The existence of alternative methods makes the use of high-powered incentives less likely in two ways: first, the expected probability of success affects the threshold (\( \beta \)) at which high-powered incentives are possible. This threshold is decreasing in convention’s success probability \( p_c \). More profitable alternatives makes the use of high-powered incentives less likely in the presence of ambiguity. Secondly, the agent’s effort cost of implementing convention also affects the threshold. Thus, the existence of alternative action that the agent can take to avoid ambiguous innovation amplifies the effect of ambiguity, which once again exerts a first-order effect on the optimal compensation contract.
2.3 Low Ambiguity

The last case we consider is when ambiguity is low, i.e., \( \epsilon < p_i - p_c \). This condition states that the ambiguity regarding innovation is small enough that the agent, even in the worst-case possible scenario, believes implementing innovation with high effort to be superior to implementing convention with high effort. Therefore, the principal and the agent both believe that innovation has a higher expected probability of success than convention. The following proposition describes the optimal incentives for implementing innovation under low ambiguity:

**Proposition 3.** The optimal contract that implements innovation with high effort under low ambiguity sets

\[
w_F = 0. \tag{10}
\]

\[
w_S = \frac{C_i}{p_i^L - p_l} + \frac{C_i}{p_i^L - p_c} \left( \frac{1}{\beta} - \frac{C_c}{C_i} \right)^+. \tag{11}
\]

*Proof.* See Appendix E.

The optimal contract for inducing innovation under low ambiguity is structured similarly to the optimal contract for inducing convention: the principal provides a positive reward, \( w_S > 0 \). The intuition is that a reward for success incentivizes the agent to forgo shirking and forgo implementing convention because the highest probability of success is achieved by implementing innovation, even under the worst-case belief, \( p_i^L > p_c > p_l \). We can see this from the IC constraints, which can be expressed as

\[
IC_c \quad w_S - w_F \geq \frac{C_c - C_i}{p_c - p_i^L}
\]

\[
IC_l \quad w_S - w_F \geq \frac{C_i}{p_i^L - p_l}
\]

The optimal incentive scheme is the contract with the minimum wage cost that pays enough to compensate the agent to forgoing shirking and implementing convention. Therefore, the \( w_S \) is the maximum of the two lower boundary constraints above.
The high-powered incentives necessary to induce innovation under low ambiguity are similar to the standard pay-for-performance contract. In all these cases, the agent believes that the highest probability of success is associated with innovation: in a standard moral hazard model, exerting effort increases the probability of success; in Manso’s (2011) two-period model, innovation in the long-run, if successful in the short-run, has higher probability of success than shirking or convention. Therefore, positive compensation for performance aligns the interest of the principal and the agent, which is also the case under low ambiguity.

In sum, high-powered incentives are best used to motivate innovation in situations in which the agent knows the precise risk associated with his action, and is able to make a clear trade-off between risk and return. Also, high-powered incentives are optimal when the expected payoff from innovation is high, which moderates the negative effect of ambiguity. However, in situations where the agent is ambiguous about the exact risk associated with his effort, providing the agent with high-powered incentives is detrimental to innovation as the agent substitutes away his effort in favor of less uncertain choices. The latter effect is also more likely to hold for innovations that are marginally profitable compared to existing technology.

3 Robustness and Discussions

The model presented in this paper makes several nontrivial and simplifying assumptions that drive our results. Here we discuss the results with respect to some of model’s key assumptions to first show that the results are unique to the setting with ambiguity and that similar results do not arise with risk-aversion or agree-to-disagree types of preferences. Secondly, we argue that the results presented in the paper are not driven by the simplicity of the model but can be generalized to more complicated settings.
3.1 Ambiguity vs. Risk-Aversion

First, the optimality of low-powered incentives does not arise under risk-aversion alone. Consider the case in which the agent is ambiguity-neutral, and the agent comes up with a subjective prior over the set of all possible distributions \([p_i - \epsilon, p_i + \epsilon]\). If we consider the most naive case where the agent puts equal weights on all possible likelihoods, then the agent’s subjective belief becomes \(\bar{p}_i\). Thus, the principal and the agent have the same prior beliefs about innovation’s success probability. We are then back to the traditional moral hazard model where the principal must compensate the agent for high effort, which can be implemented with high effort.

One may also extend this model to the case where the agent comes up with a subjective prior over the information set. For example, an agent who is averse to the uncertainty arising from multiple priors may place higher weights on low payoff states than on high payoff states. This is the case when the principal and the agent, while sharing the same information set, has a disagreement (agree to disagree) about the future prospect of innovation (e.g., Van den Steen, 2005, 2011). But under this case, the low-powered incentives does not arise as the optimal scheme.

Consider the most extreme case in which the agent takes the most pessimistic view about innovation. Here, the agent comes up with a subjective prior over the set \([\bar{p}_i - \epsilon, \bar{p}_i + \epsilon]\), that puts all weights on the lowest probability, and makes decision as if he believes in the lowest possible prior \(p^L_i = \bar{p}_i - \epsilon\).

Then the incentive compatibility constraints for the agent becomes:

\[
IC_e : \quad p^L_i w_S + (1 - p^L_i)w_F - C_i \geq p_e w_S + (1 - p_e)w_F - C_e
\]

\[
IC_l : \quad p^L_i w_S + (1 - p^L_i)w_F - C_i \geq p_l w_S + (1 - p_l)w_F
\]

These constraints resemble the IC constraints from the original problem. But here, the agent’s minimization problem over the set \(\mathcal{P}_i\) does not exist, which reflects the fact that the agent is ambiguity-neutral. Now, consider the case similar to high ambiguity where
Then, the incentive compatibility constraints become

\[ IC_c \geq (p^L_i - p_c)(w_S - w_F) \geq C_i - C_c \]

\[ IC_l \geq (p^L_i - p_l)(w_S - w_F) \geq C_i. \]

Since the expected probability of success associated with innovation is lower than that of convention, with or without effort, i.e., \( p^L_i < p_c \) and \( p^L_i < p_l \), the principal must pay the agent for a failure more than for success (\( w_S < w_F \)) in order to compensate the agent for forgoing shirking or implementing convention. The optimal compensation contract that minimizes the principal’s expected wage cost while satisfying both IC constraints will be

\[ w_F = \frac{C_i}{p_l - p^L_i} + \frac{C_i}{p^L_i - p_c} \left( \frac{C_c}{C_i} - \frac{1}{\beta^*} \right)^+. \]

\[ w_S = 0 \]

Therefore, the optimal contract under simple disagreement would be a contract that rewards the agent for a failure. Although the incentives are inverted between success and failure, the optimal contract still utilizes high-powered incentives, \( w_F > 0 \), which implements the principal’s preferred choice to implement innovation with high effort. Note that this result relies on the assumption that the principal always prefers to implement innovation with high effort than with low effort, which happens with high return form innovation (\( \tilde{p}_i \)) and low intrinsic motivation (\( -\tau \)), which increases the gap in return from high effort and low effort. If, however, the cost of implementing this contract outweighs the potential return from innovation with high effort, then the principal would prefer to implement innovation with low effort and do not incur any wage cost.

### 3.2 Other Assumptions

The model presented in this paper is a single-period model. Thus, the model does not generate any prediction regarding the potential trade-off between short-term payoff and the long-term payoffs, as it is done in Manso’s (2011) two-period bandit problem. However,
all the results in this paper easily extend to the dynamic settings. As long as the agent is ambiguous about the outcome of innovation whether in the short-run or in the long-run, providing high-powered incentives will be detrimental for motivating innovation.\footnote{In Manso (2011), the optimal contract that motivates innovation is tied only to firm’s long-run performance because the expected probability of success for innovation is lower than the alternative in the short run, i.e., \( p_c > p_i \), but higher in the long-run if innovation is successful, i.e., \( p_i > p_c \). As long as the agent’s ambiguity in the second period contains ambiguity, then low-powered incentives will be optimal to induce innovation. More precisely, \( E[p_c] > E[p_i] \), but \( E[p_i|S,c] > E[p_c|S,i] \).}

The principal in the model is ambiguity-neutral. But one can interpret this assumption to be the normalized level of ambiguity-aversion, so that the model reflects the situation in which the principal is less ambiguity-averse compared to the agent. But there are several reasons why the principal is less ambiguity-averse than the agent. First, the difference in ambiguity-aversion could occur because people have different preferences, just as people may have different degrees of risk-aversion. Secondly, the principal could also be able to hedge her exposure to ambiguity if she is able to invest in multiple projects, similar to the diversification argument in risk models. For example, consider two ambiguous projects that pay \( S \) in the case of success and zero in case of a failure. Both projects have a probability of success either 1 or 0, and thus, the principal is ambiguous about the exact probability. However, if the projects are perfectly negatively correlated, then the principal can completely hedge away the ambiguities by investing in both projects, and obtain an expected payoff of 0.5\( S \). Thus, we model a situation in which the principal has less exposure to ambiguity than the agent, who can only work on a single project.

4 Comparative Statics

This section examines how the characteristics of optimal incentives for innovation change relative to changes in the degree of ambiguity, the expected probability of success for each method, the agent’s cost of effort, and the agent’s intrinsic motivation.
4.1 Degree of Ambiguity

**Corollary 1.** The optimal incentive, \( w_S \) for implementing innovation may decrease with higher degree of ambiguity, \( \epsilon \).

The results can be derived from Propositions 2 and 3, and the fact that \( p_i^L \) and \( \beta \) are decreasing in the degree of ambiguity, \( \epsilon \). In the low ambiguity region, the optimal reward for success (\( w_S \)) is increasing in the degree of ambiguity (\( \epsilon \)). The interpretation is that higher ambiguity lowers the agent’s expectation about the innovation’s success, and therefore, the principal must compensate the agent more to take on innovation. However, if an increase in \( \epsilon \) is large enough to cross into the moderate or high ambiguity region, then the optimal compensation may no longer be positive. Thus, more ambiguity necessitates higher rewards to compensate the ambiguity-averse agent, but a sufficiently large increase in ambiguity can trigger the agent to always prefer to implement convention rather than innovation when given a positive rewards. Therefore, the optimal reward actually goes down as ambiguity prevents the use of high-powered incentives.

4.2 Expected Probability of Success

**Corollary 2.** The optimal incentive for implementing innovation may decrease in convention’s probability of success, \( p_c \). In contrast, the optimal incentive may increase in innovation’s probability of success \( \bar{p}_i \).

When we look at innovation alone, the principal can offer less incentive when the probability of innovation’s success is higher since the agent’s expected reward is increasing in the probability of success. But when we consider the existence of both convention and innovation, the higher probability of success also expands the regions under which high-powered incentives are possible, \( \bar{p}_i + \epsilon = p_i^L > p_c \). Therefore, an increase in the expected probability of success associated with innovation can lead to even greater incentive pay, which contrasts traditional moral hazard framework. In contrast, a higher expected payoff from convention implies a higher opportunity cost for the agent, and thus leads to higher amount of incentives necessary to encourage innovation (we see this from Proposition 3
and 2 that $w_S$ is increasing in $p_c$), which is the intuition from the traditional multi-tasking framework where the presence of alternative tasks makes compensation more costly for the principal. However, if an increase in $p_c$ leads to the moderate ambiguity region or high ambiguity region, then the optimal incentives $w_S$ will actually decrease to zero as high-powered incentives are no longer optimal to induce innovation.

Therefore, when the principal wishes to induce the agent to implement a certain task, the optimal incentive may be to provide less reward when there exist many profitable alternatives. Similarly, this result also suggests that high-powered incentives are likely to be used in situations where the agent is given a clear and limited set of tasks. When the agent’s job involves multiple options and methods of implementing his job, then the use of incentives will encourage the agent to seek less ambiguous and more profitable methods over innovations. On the other hand, if the agent is only given the choice to implement innovation, then high-powered incentives will be optimal to induce high effort. This is similar in concept to Arrow’s (1962) replacement effect in which new technology and innovations are more likely to be successful in an environment where conventional technology is less profitable.

4.3 Effort/Opportunity Cost

**Corollary 3.** The optimal incentives ($w_S$) for implementing innovation may decrease in the relative cost of effort for innovation, $\frac{C_i}{C_c}$.

With low ambiguity, $w_S$ is increasing in $C_i$, which reflects the fact that the principal must compensate the agent more for putting in costly effort. This is also true under moderate ambiguity when $\frac{C_i}{C_c} \leq \beta$, as $w_S = \frac{C_i}{p'_i - p_i}$ in this case from Proposition 2. However, the effort cost of innovation also affects the region in which high-powered incentive is optimal ($\frac{C_i}{C_c} \leq \beta$). If an increase in $C_i$ crosses the high ambiguity region, then the optimal incentive is decreased as low-powered incentives becomes optimal to induce innovation ($\frac{C_i}{C_c} \geq \beta$). Therefore, high effort costs may make monetary incentives less likely in the presence of ambiguity, which contrasts the conventional intuition from the standard moral hazard model.
**Figure 3: Optimal Incentives.** This figure depicts the optimal incentive compensation \((w_S)\) in response to the changes in the degree of ambiguity, \(\epsilon\), convention’s expected probability of success, \(p_c\), innovation’s average expected probability of success, \(\overline{p}_i\), relative cost of effort, \(\frac{C_i}{C_c}\), and the agent’s intrinsic willingness to work, \(p_l\). The base parameters used for this figures are \(p_c = 0.3\), \(\overline{p}_i = 0.6\), \(\tau = 0.2\), \(C_c = 1\), \(C_i = 0\), and \(\epsilon = 0.3\). For panel 5, \(\epsilon = 0.2\) is used to depict the condition with positive threshold.

Therefore, when there exists a moderate amount of ambiguity, the positives incentives are more likely to be used in situations where innovation requires less effort relative to the alternative action. On the other hand, if innovation requires higher amount of effort, then the use of low-powered incentives are more likely to be used to motivate innovation. If one interprets the cost of effort as an opportunity cost of implementing an action, then positive incentive pays are associated with innovations in situations with low opportunity cost, while non pecuniary incentives are likely to be used when the agent faces a high opportunity cost of working on innovation.
4.4 Intrinsic Motivation

**Corollary 4.** Under low ambiguity, the optimal incentive \((w_S)\) for implementing innovation is increasing in the agent’s intrinsic motivation \(p_l\) (and \(-\tau\)) up to the threshold \(\overline{p}_l = (p_l^L - \frac{C_i}{C_c}p_c)/(1 - \frac{C_i}{C_c})\), but may decrease above the threshold.

We have previously defined that low effort lowers the expected probability of success by \(\tau\). If low effort is interpreted as the minimum amount of effort the agent is willing to put in by his intrinsic motivation, then \(p_l = p_m - \tau\) can be a proxy for the agent’s intrinsic motivation. The more the agent is willing to work without any extrinsic incentives, the higher \(p_l\), and lower \(\tau\) will be. Then, when \(\frac{C_i}{C_c} \leq \beta\), the optimal reward for success \((w_S)\) is increasing in the probability of success under low effort \((p_l)\). This result may be counter-intuitive at first, but it simply states that when the agent is self-motivated, then it requires relatively more extrinsic incentives for the principal to induce even higher level of effort from the agent. But unconditionally, the increase in intrinsic motivation also widens the high ambiguity region \((p_l \geq p_l^L)\), in which high-powered incentives are not optimal for innovation. Furthermore, within the moderate ambiguity region, the increase in \(p_l\) can shift the optimal incentives from \(w_S = \frac{C_i}{p_l - p_l^L}\) to \(w_S = 0\) by changing the size of the \(\beta\) (Proposition 2). Thus, as long as we are within the moderate and high ambiguity regions, an increase in the agent’s intrinsic motivation makes the use of monetary incentives less likely.

Overall, the amount of incentive is increasing in the level of agent’s intrinsic motivation when the degree of ambiguity is low, but with sufficient amount of ambiguity, intrinsic motivation makes the use of high-powered incentives less likely.

5 Empirical Implications

In this section, we discuss various empirical implications and tests arising from the main results.
5.1 Compensation and Governance

One of the implications of the classical moral hazard models is that people are responsive to incentives: By designing the incentives in the right way, the principal can induce the agent to implement an action desired by the principal. However, this paper points out the limits on high-powered incentives to motivate innovation when innovation is ambiguous. Because the agents can become biased towards choosing actions that they are less uncertain of when presented with extrinsic incentives, the optimal incentive scheme in case of high or moderate ambiguity (Propositions 1 and 2) is to provide no incentive at all. In other words, the principal must rely on intrinsic motivation of the agent to implement the desired action. These results show that intrinsic motivation and non-pecuniary compensations observed in practice are not only substitutes for motivating innovation, but are necessary and possibly the only ways to encourage innovation in an ambiguous environment. Hence, this paper provides incentives and contract based rationale for firms’ investments in employee benefits and other non-pecuniary compensation that are consistent with the human relations and stakeholder theories (Maslow, 1943; Hertzberg, 1959; McGregor, 1960; Rajan and Zingales, 1998; Carlin and Gervais, 2009; Berk, Stanton, and Zechner, 2010; Zingales, 2000; Edmans, 2011, 2012).

Likewise, Corollary 4 predicts a positive association between non-pecuniary benefits and ambiguous innovation, and a positive association between pecuniary compensation and less ambiguous innovation. If radical innovations are positively correlated with the degree of ambiguity, then one could potentially examine whether monetary compensation is positively correlated with incremental innovation, but not with radical innovations. It also give caution in interpreting the positive relation between incentive pay and innovative output (Ederer and Manso, 2013; Francis, Hasan, and Sharma, 2010; Baranchuk, Kieschnick, and Moussawi, 2013; Tian and Wang, 2014) as such relation, according to this paper, would likely to be true only for innovations with low degree of ambiguity. The unintended consequence from using high amounts of incentive compensation is that managers may substitute radical and novel innovations with high ambiguity for incremental and safer innovations with low ambiguity, which can have a negative consequence.
for firm value and overall social welfare. Therefore, a possible test for future research is to examine whether stock option grants and other monetary compensation is correlated not only with the quantity of innovation, but also the quality and the types of innovation. While good proxies for ambiguity is still being researched and debated, some asset pricing research have used various measures of volatility to capture ambiguity (e.g., Epstein and Schneider, 2008).

Furthermore, the model predicts that tolerance for failure even in the absence of learning. Manso’s (2011) model for motivating innovation predicts a tolerance for failure in the short-run, but a high sensitivity to long-run performance. Therefore, the persistent use of entrenchment devices in corporate governance, such as classified boards and golden parachutes, even for firms with persistent under-performance may be justified by the presence of ambiguity in the market. Thus, one could test whether entrenchment devices are tied to the level of ambiguity in the market or with the changes in firm’s policy towards new markets that may require a CEO to make choices under ambiguity.

The optimality of low-powered incentives and tolerance for failure necessary to induce innovation in the presence of ambiguity can also justify the use of many empirical proxies that are inconsistent with the existing theoretical explanations for incentivizing innovation. Existing theories on innovation incentives rely on the assumption that the innovative output is either unobservable or indistinguishable from the result of alternative tasks. Yet, many potential empirical signals for innovation exist in the real world that may alleviate this issue. Indeed, many empirical studies testing the implications of the these models use empirical proxies such as R&D expense and the number of patents, which, in theory, could be tied to the manager’s compensation contract. However, this paper points out that a tolerance for failure can arise due to the agent’s ambiguity about innovation. Thus, use of measurable and contractible proxies for testing innovation may be justified. In addition, the model may also explain why many of the potential signals for innovation are not tied directly to managerial or employee compensation.

Lastly, the limitation of contracting also highlights the importance of alternative devices and solutions in implementing innovation: In the presence of moderate or high
ambiguity, hiring the right kind of CEO with less aversion to ambiguity may be the only way to implement innovation. Thus, examining firms’ practice of screening and hiring of managers and employees may provide better explanations for innovation than incentives and compensations alone. Likewise, managerial preferences and style would be predicted to have greater explanatory power to explain innovative outputs than other factors related to compensation (Bertrand and Schoar 2003).

5.2 Organizational Forms

While pointing out the the limits of extrinsic incentives to solve agency conflicts in the presence of ambiguity seem discouraging, it gives new predictions on what type of environment and organizations on best suited for implement more ambiguous innovations (Gompers, Lerner, and Scharfstein, 2005; Robinson, 2008; Seru, 2014). From the Corollary 2, we can infer that incentivizing innovation is more likely in a situations where the agent is facing a single objective to innovate, rather than having multiple options to invest in other technologies. Likewise, the existence of alternative investment choices that are highly profitable may also hinder incentivizing innovation. If we suppose that conglomerates and mature firms are more likely to have established practices and tasks, then our model predicts that these firms are less likely to implement innovation under ambiguity; innovative tasks are therefore more likely to be carried out by stand-alone firms. Similarly, mature firms and conglomerates are more likely to implement incremental innovations with low ambiguity while stand-alone firms and young firms are more likely to implement radical and novel innovations.

Thus, the results give a different perspective into what types of investments are to be expected from conglomerates and diversified firms (Lang and Stulz, 1994; Stein, 1997; Rajan, Servaes, and Zingales, 2000; Scharstein and Stern, 2000; Schoar, 2002; Ozhus and Scharfstein, 2010). Seru (2014), for example, finds that conglomerates are less likely to make novel and radical innovation on their own, and are more likely to obtain novel innovations outside firm’s boundaries through joint ventures and partnerships. The assumption in Seru (2014) is that novel innovations are associated with higher information
asymmetry between the principal and the agent. This paper predicts an similar outcome even in environments where the principal and the agent share the exact same information but differ in how much they are averse to dealing with uncertainty.

6 Conclusion

The Ellsberg (1961) experiment and the subsequent body of research have shown that people in general behave differently in situations where they are uncertain about the exact risk associated with their decisions. Such environments typify the process of innovation, which requires people to explore unfamiliar territories of knowledge. In this paper, we study the problem of incentivizing managers to innovate in such environments.

We show that the presence of ambiguity and the agent’s aversion to ambiguity limit the use of high-powered incentives in motivating innovation. This is in contrast to the expected utility paradigm in which the existence of observable and contractible measures of innovation guarantees the use of high-powered incentives (Holmstrom, 1989; Holmstrom and Milgrom, 1991; Manso, 2011). Under ambiguity, however, the use of low-powered incentives such as high tolerance for failures, non-pecuniary compensations, and the managers’ and employees’ intrinsic motivations, play a significant role in motivating innovation. The framework for innovation presented in this paper generates various testable predictions regarding incentives, governance, and organizations forms, among others, in promoting innovation and creativity, some of which are consistent with the existing empirical findings and others that are yet to be tested. We leave these remaining ambiguities for future research.
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1653.
A Incentivizing Convention

First, we solve for the optimal wage scheme that motivates the agent to choose convention with high effort. To do so, the principal has to induce the agent to choose convention over innovation and low effort. The principal’s utility is the expected payoff from implementing convention minus the expected wage cost.

Given that the principal implements convention, the principal’s contract design problem is equivalent to minimizing her expected wage cost by setting the wage contract subject to the agent’s incentive compatibility constraints.

\[
\min_{w_S, w_F} p_c w_S + (1 - p_c) w_F \quad \text{s.t.}
\]

\[
(I C_i) \quad p_c w_S + (1 - p_c) w_F - C_c \geq \min_{\tilde{p}_i \in \mathcal{P}_i} \{ \tilde{p}_i w_S + (1 - \tilde{p}_i) w_F - C_i \}
\]

\[
(I C_{c|l}) \quad p_c w_S + (1 - p_c) w_F - C_c \geq p_{c|l} w_S + (1 - p_{c|l}) w_F
\]

\[
(I C_{l|c}) \quad p_c w_S + (1 - p_c) w_F - C_c \geq \min_{\tilde{p}_{c|l} \in \mathcal{P}_{c|l}} \{ \tilde{p}_{c|l} w_S + (1 - \tilde{p}_{c|l}) w_F \}.
\]

The first constraint states that the payoff to the agent for implementing convention is higher than implementing innovation. The second and third constraints set the payoff of implementing convention higher than shirking.

Because the optimal contract requires \(w_S \geq w_F\), we end up with \(p_{c|l} = p_{c|l}^L\). If \(p_{c|l}^L < p_{c|l}\), then \(p_l = \max(p_{c|l}, p_{c|l}^L) = p_{c|l}\), and \(IC_{c|l}\) automatically implies \(IC_{c|l}\). On the other hand, if \(p_{c|l}^L > p_{c|l}\), then \(p_l = p_{c|l}^L\), and \(IC_{c|l}\) is redundant. Thus, only one of the two shirking constraints is binding, and the only relevant constraints are \(IC_i\) and one of the binding \(IC_{c|l}\)’s. In solving for the optimal contract for implementing convention, we solve for the optimal contract in terms of \(p_l\), which corresponds to the maximum of \(p_{c|l}\) and \(p_{c|l}^L\).

Without the loss of generality, we assume that \(p_c > p_{c|l}\), which implies \(p_l = p_{c|l}\). Before we proceed further, we define the following terms for the ease of exposition:

\[
\beta = \frac{p_{c|l}^L}{p_c} - \frac{p_l}{p_c - p_l} \quad \text{and} \quad I = \max(x, 0).
\]

\(\beta\) captures the relative profitability of innovation to convention. The numerator is the marginal increase in the probability of success when implementing innovation, and the denominator captures the marginal increase in the probability for implementing convention. The following proposition characterizes the optimal contract for implementing convention.

**Proposition.** The optimal wage contract for implementing convention with high effort contains the following terms:

\[
\begin{align*}
    w_F &= 0, \\
    w_S &= \frac{C_c}{p_c - p_l} + \frac{C_c}{p_c - p_{c|l}^L} \left( \beta - \frac{C_{c|l}}{C_c} \right) +
\end{align*}
\]

**Proof.** See Appendix B

The optimal contract that motivates convention resembles a standard “pay for perfor-
mance” contract. The agent is paid in case of success, and the amount of wage conditional on success compensates the agent for the cost of high effort. The reward for success has a second term, which captures the additional compensation required to induce the manager to forgo innovation. Note that this second term is zero if the cost of effort for innovation is high compared to that of convention. Thus, the principal must pay a higher premium for convention when convention is harder for the agent to implement than innovation. Note that the second term exists even if ambiguity is not present. As long as the principal must satisfy two incentive compatibility constraints, the wage scheme will depend on two separate premiums, one for each constraint.

The degree of ambiguity, however, is inversely related to the compensation for success since \( p_L^i = \bar{p}_i - \epsilon \). The ambiguity-averse agent discounts the utility from innovation since the expected payoff associated with innovation is ambiguous. Thus, compensating the agent to take on convention becomes cheaper to the principal. In other words, the presence of ambiguity alleviates the agency problem in incentivizing convention. Therefore, the presence of ambiguity narrows the possible set of alternative actions that the principal must consider in compensating the agent to implement a desired action. One implication from this result is that the existence of ambiguity is more likely to lead to situations in which explicit incentives do not play any role in motivating innovation.

B Proof of Proposition in Appendix A

Proof. First, we show that \( p_c = p_L^c \).

To start, \((IC_1)\) can be re-expressed as

\[
(p_c - p_l)(w_S - w_F) \geq C_c.
\]

Then it must be that \( w_S - w_F \geq \frac{C_c}{p_c - p_l} > 0 \).

Given that \( w_S > w_F \), the agent’s utility under implementing innovation, \( \tilde{p}_i w_S + (1 - \tilde{p}_i) w_F - C_i \), is minimized when \( \tilde{p}_i \) is minimized. Thus, the \( p_L^i \), which is the lowest \( \tilde{p}_i \in \tilde{p}_i = [p_L^i, p_H^i] \), is the solution to the agent’s minimization problem.

Secondly, we prove that \( w_F = 0 \).

The \((IC_i)\) can be expressed as

\[
(p_c - p_L^i)(w_S - w_F) \geq C_c - C_i.
\]

Assume (for proof by contradiction) that the optimal contract \( \vec{w} \) contains \( w_F > 0 \). Let \( \vec{w}' \) be an alternative contract with \( w_S' = w_S - w_F \) and \( w_F' = 0 \). Then we have \( w_S' - w_F = w_S - w_F \). Thus, this contract is less costly to the principal and satisfies both IC constraints, which is a contradiction.

With \( w_F = 0 \), the IC constraints become

\[
(IC_i) \quad w_S \geq \frac{C_c - C_i}{p_c - p_L^i},
\]

\[
(II_i) \quad w_S \geq \frac{C_c}{p_c - p_l}.
\]

Now, we are ready to derive the optimal contract for implementing convention.

Case 1: \( p_c \geq p_L^c \). The optimal \( w_S \) will be binding at the IC constraints. In this case, the
$w_S$ simply becomes

$$w_S = \max \left( \frac{C_c - C_i}{p_c - p^L}, \frac{C_c}{p_c - p_l} \right).$$

The point at which the two expressions are equal is when $\frac{C_c - C_i}{p_c - p^L} = \frac{C_c}{p_c - p_l}$. It can also be expressed as $\frac{C_c}{C_i} = \frac{p_c^L - p_l}{p_c - p_l}$. If $\frac{C_c}{C_i} > \frac{p_c^L - p_l}{p_c - p_l}$, then $w_S = \frac{C_c}{p_c - p_l}$, and $w_S = \frac{C_c - C_i}{p_c - p^L}$ if otherwise.

The we can see that the solution can also be expressed as

$$w_S = \frac{C_c}{p_c - p_l} + \frac{C_c}{p_c - p^L} \left( \beta - \frac{C_i}{C_c} \right)^+, \quad$$

where $\beta = \frac{p_c^L - p_l}{p_c - p_l}$.

**Case 2:** $p_c < p^L_i$. In this case, the IC constraints become

$$(IC_i) \quad w_S \leq \frac{C_i - C_c}{p^L_i - p_c}$$

$$(IC_c) \quad w_S \geq \frac{C_c}{p_c - p_l}.$$

The $(IC_i)$ is now an upper boundary condition, rather than a lower boundary constraint. Therefore, if $\frac{C_i - C_c}{p^L_i - p_c} > \frac{C_c}{p_c - p_l}$, we obtain $w_S = \frac{C_c}{p_c - p_l}$. This condition can also be written as $\frac{C_i}{C_c} > \beta$.

But if $\frac{C_i - C_c}{p^L_i - p_c} > \frac{C_c}{p_c - p_l}$, then there does not exist $w_S$ that can satisfy the IC constraints, and therefore, incentivizing convention becomes infeasible.

The principal may alternatively implement convention by implementing the action $c | l$, which is the agent implementing convention while shirking. The principal can implement this by providing zero incentive, $w_S = w_F = 0$ and invoke the agent to implement the action $c | l$ through intrinsic motivation. But notice that when $p_c < p^L_i$, we have $w_c < p_l$, where the right hand side probability is the principal’s prior on innovation’s expected probability of success. Therefore, the principal will never implement conventional strategy when $p_c < p^L_i$ and $\frac{C_i}{C_c} < \beta$.

### C Proof of Proposition 1

**Proof.** High ambiguity case has $p^L_i < p_l$. First, note that $p_{c|l} > p^L_{i|l}$, so we have $p_l = p_{c|l}$, meaning only shirking constraint that will be binding will be convention with low effort.

Consider the minimization problem in the IC constraints:

$$IC_c : \min_{\tilde{p}_i \in P_i} \{ \tilde{p}_i w_S + (1 - \tilde{p}_i) w_F - C_i \} \geq p_c w_S + (1 - p_c) w_F - C_c$$

$$IC_l : \min_{\tilde{p}_i \in P_i} \{ \tilde{p}_i w_S + (1 - \tilde{p}_i) w_F - C_i \} \geq p_l w_S + (1 - p_l) w_F$$

with $p_i'$ being the arg min of the minimization problem. If $w_S \geq w_F$, then the $\tilde{p}_i$ that minimizes the agent’s payoff is $p_i^L$, so $p_i' = p_i^L$. If $w_S < w_F$, then, $p_i' = p_i^{H}$. With this in
mind, we can rewrite $IC_2$ as the following: For any $\tilde{p}_i \in [p^l_i, p^H_i]$,

$$IC_i : \quad p'_i w_S + (1 - p'_i) w_F - C_i \geq p_i w_S + (1 - p_i) w_F$$

$$\Leftrightarrow \quad (p'_i - p_i)(w_S - w_F) \geq C_i$$

As we have established, when $w_S - w_F \geq 0$, then $p'_i = p^H_i$. Therefore, the term $(p'_i - p_i)(w_S - w_F)$ on the LHS of $IC_2$ will be negative since $(p^H_i - p_i) < 0$. With $C_i > 0$, the IC constraint will not be satisfied for any $p_i$. Now, consider the alternative case where $(w_S - w_F) < 0$. Then, $p'_i = p^l_i$, and thus we have a positive term for $(p'_i - p_i)$, but with $(w_S - w_F) < 0$, the LHS is once again negative and therefore, the IC constraint will not be satisfied. Therefore, under high ambiguity, it is infeasible to implement innovation $(m = i)$. Then only way to implement innovation is to implement through intrinsic motivation via $m = i | l$. Such would be the case when $p_{0.2} \geq p_{0.1} S$ and $p_{0.2} S \geq p_c S - W(c)$, where $W(c)$ is the principal’s expected wage cost in implementing convention.

D Proof of Proposition 2

*Proof.* Under moderate ambiguity, we have that $p_i$ is $p_{c|l}$ because $p^l_i - \tau < p_{c|l}$.

First, we can establish that $p'_i = p^H_i$.

We rewrite $IC_1$ as the following: For any $p_i \in [p^l_i, p^H_i]$,

$$IC_1 : \quad \tilde{p}_i w_S + (1 - \tilde{p}_i) w_F - C_i \geq p_i w_S + (1 - p_i) w_F$$

$$\Leftrightarrow \quad (\tilde{p}_i - p_i)(w_S - w_F) \geq C_i$$

Since $\tilde{p}_i > p_i$ in the case of moderate ambiguity, i.e., $p_c > p^l_i > p_i$, $IC_2$ implies that $w_S > w_F$. Otherwise, it is never satisfied. Then the solution to the agent’s minimization problem over $\mathcal{P}_i$ is the lowest possible value for $\tilde{p}_i$, which is $p^l_i$.

From this, we get

$$\min_{\tilde{p}_i \in \mathcal{P}_i} \tilde{p}_i w_S + (1 - \tilde{p}_i) w_F - C_i = \tilde{p}^l_i w_S + (1 - \tilde{p}^l_i) w_F - C_i.$$ 

The IC constraints are thus

$$IC_c : \quad p^l_i w_S + (1 - p^l_i) w_F - C_i \geq p_c w_S + (1 - p_c) w_F - C_c$$

$$IC_l : \quad p^l_i w_S + (1 - p^l_i) w_F - C_i \geq p_i w_S + (1 - p_i) w_F$$

They can be re-expressed as the following:

$$IC_c : \quad w_S - w_F \leq \frac{C_c - C_i}{p_c - p^l_i}$$

$$IC_l : \quad w_S - w_F \geq \frac{C_i}{p^l_i - p_i}$$

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Combining the two constraints, we get

\[ \frac{C_i}{p_i^L - p_i} \leq w_S - w_F \leq \frac{C_c - C_i}{p_c - p_i^L}. \]

Note that there are two possibilities. If \( \frac{C_i}{p_i^L - p_i} \geq \frac{C_c - C_i}{p_c - p_i^L} \) (which can be expressed as \( \frac{c_i}{c_c} \geq \beta \)), then the IC constraints cannot be satisfied. Therefore, the only possible way for the principal to implement innovation is by paying no monetary incentives and let the agent choose to implement the action \( i|l \), which is the implementation of innovation with minimum effort. But unlike in the case of convention where the principal will never prefer to implement \( c|l \) in the case where the incentives break down, the principal will wish to implement innovation with minimum effort if \( p_i S \geq p_c S - W(c) \) and \( p_{i|l} > p_{c|l} \). Therefore, implementing innovation through intrinsic motivation with \( w_S = w_F = 0 \) is the only way to implement innovation in the case of moderate ambiguity and \( \frac{C_i}{C_c} \geq \beta \).

Consider now the alternative case where \( \frac{C_i}{p_i^L - p_i} \leq \frac{C_c - C_i}{p_c - p_i^L} \) (or, in another form, \( \frac{C_i}{C_c} \leq \beta \)). Then, we have \( w_F = 0 \). To see this, assume (for proof by contradiction) that the optimal contract \( w \) has \( w_F > 0 \). Then let \( w' \) be an alternative contract with \( w'_F = 0 \) and \( w'_S = w_S - w_F \). Then this contract has a lower expected wage cost because \( w_F \) has been subtracted from the original contract. At the same time, the IC constraints are satisfied because \( w'_S + w'_F = w_S + w_F \). Therefore, \( w' \) is an improvement over the original contract, which is a contradiction.

Hence, the IC constraints results in

\[ \frac{C_i}{p_i^L - p_i} \leq w_S \leq \frac{C_c - C_i}{p_c - p_i^L}, \]

and therefore, the \( w_S \) will be binding at the lower boundary, which obtains our result.

### E Proof of Proposition 3

**Proof.** Under low ambiguity, \( p_i \) is \( p_{i|l} \) since \( p_{i|l} > p_{c|l} \).

We can use the exact same steps to obtain \( p_i' = p_i^L \), and obtain

\[
\begin{align*}
IC_c & \quad p_i^L w_S + (1 - p_i^L)w_F - C_i \geq p_c w_S + (1 - p_c)w_F - C_c \\
IC_l & \quad p_i^L w_S + (1 - p_i^L)w_F - C_i \geq p_l w_S + (1 - p_l)w_F
\end{align*}
\]

We now have \( p_i > p_c \) for any \( \bar{p}_i \in [p_i^L, p_i^H] \), so the IC constraints can be written as They can be re-expressed as the following:

\[
\begin{align*}
IC_c & \quad w_S - w_F \geq \frac{C_c - C_i}{p_c - p_i^L} \\
IC_l & \quad w_S - w_F \geq \frac{C_i}{p_i^L - p_l}
\end{align*}
\]

Then, we have \( w_F = 0 \). To see this, assume (for proof by contradiction) that the optimal contract \( w \) has \( w_F > 0 \). Then let \( w' \) be an alternative contract with \( w'_F = 0 \) and \( w'_S = w_S - w_F \). Then this contract has a lower expected wage cost because \( w_F \) has been
subtracted from the original contract. At the same time, the IC constraints are satisfied because \( w'_S + w'_F = w_S + w_F \). Therefore, \( w' \) is an improvement over the original contract, which is a contradiction.

Therefore, the solution is \( w_S = \max(C_i p_i - p_L, C_c - C_i p_c - p_L) \). The first term is greater when \( \frac{C_i}{C_c} \leq \beta \), and the second term is greater in the other case. Hence, we obtain our result.