Incentives for Innovation and Delegated versus Centralized Capital Budgeting*

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Abstract

This paper investigates how the allocation of investment decision authority affects managers' incentives for innovation to develop investment opportunities. We study a capital budgeting setting in which a divisional manager can exert personally costly effort to improve the expected quality of the investment project available to the division, and subsequently gains private knowledge about the investment payoff. Our analysis examines how centralized and delegated capital budgeting systems perform along the two dimensions: (i) the induced level of innovation effort, and (ii) the firm's expected payoff. We find that delegation of investment authority always induces higher level of innovation than centralization. We also predict that investment decision authority will be delegated to divisions that are relatively large and operate in innovation intensive environments.

Key Words: capital budgeting; centralization; delegation; innovation

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1 Introduction

A key decision variable in designing an effective organizational structure is the assignment of capital investment decision rights. In practice, investment decisions are either centralized at the corporate level or delegated to divisional managers. An extensive literature based on agency theory has examined the optimal choice of centralized capital budgeting mechanisms when managers have better information about investment opportunities than is available to corporate headquarters.[1] Other papers have examined conditions under which delegated investment decision-making can replicate the performance attained by centralized capital budgeting. Specifically, a number of papers have shown that under certain circumstances, a decentralized organizational form, in which divisional managers are given autonomy over their investment decisions and are compensated on the basis of residual income, can replicate the performance of centralized capital budgeting.[2]

A limitation of this stream of work is that firms' investment opportunities are assumed to be entirely exogenous. In most contexts, however, managers must undertake extensive innovation efforts to identify, develop, and improve investment opportunities available to their firms. For example, entering new markets, or launching new products, requires extensive efforts to develop ideas and processes for new products, and identify potential customers. The rapid pace of technological progress has increased the importance of innovation activities in modern business organizations. There is a need to understand how the allocation of investment authority impacts on managers' incentives for innovation to develop investment opportunities for the future, and, in turn, how that affects firms' preferences for centralized control versus delegated decision-making.[3]

[1]See, for instance, Antle and Eppen (1985), Harris, Kriebel and Raviv (1982), and Bernardo, Cai, and Luo (2001). Rajan and Reichelstein (2004) provide a review of this literature.

[2]See, among others, Baldenius (2003), Dutta (2003), and Dutta and Reichelstein (2002). There has also been a surge of interest in residual income as a managerial performance measure in the real world. Management consulting firms have successfully marketed residual income under various names such as Economic Value Added (EVA) and Economic Profit.

[3]Based on the "conventional wisdom" that more autonomy provides managers with stronger incentives to

In this paper, we undertake a theoretical investigation to address these questions. We model a firm consisting of headquarters, which represents the interests of the firm's shareholders, and a single division, which is managed by a self-interested manager. The division has a potentially profitable investment opportunity. To examine the relationship between the allocation of investment decision rights and incentives for innovation, we follow the modeling framework in Dutta and Fan (2009) and assume that the project's expected profitability depends on the manager's innovation effort undertaken earlier in developing the project. Since headquarters cannot directly monitor the manager's innovation effort, it must take into account how the capital budgeting process impacts on not only the *ex post* efficiency of the investment decision, but also *ex ante* innovation incentives. Our main objective is to examine how centralized and delegated capital budgeting systems fare along the two dimensions: (i) the induced level of innovation effort, and (ii) the firm's expected profit.

We show that delegation of investment authority always induces higher level of innovation than centralization. Our analysis also identifies conditions under which it is optimal to centralize the firm's capital investment decisions or to delegate them to the divisional manager. We relate these conditions to the manager's innovation incentives and other observable characteristics such as the size of division, relative importance of innovation, and the degree of informational asymmetry between headquarters and the manager.

To understand our results, it is useful to consider the key differences between the two forms of investment decision-making. Under delegation, the division is structured as an investment center and given complete autonomy over its capital investment choices. To ensure that the self-interested manager makes the desirable investment decision and has appropriate incentives to exert innovation effort, headquarters pre-commits to compensate the manager on the basis of divisional residual income. Though headquarters does not directly control the investment decision, it can influence this decision through its choice of rate at which the manager is charged for the use of capital in the residual income performance

innovate, it has been argued that the widespread shift towards decentralized organizational forms reflect the increased importance of innovation in modern business organizations. For empirical evidence on the shift towards delegation, see Rajan and Wulf (2005).

measure.

In contrast, under centralization, headquarters takes a "hands on" approach and retains the investment decision authority. To make the investment decision, headquarters relies on the investment proposal submitted by the division as well as the information it gathers from its own independent investigation. Specifically, we assume that headquarters' investigation reveals the project's true rate of return with a positive probability. In this case of symmetric information, headquarters simply dictates the investment choice; i.e, the division is asked to take the project if and only if it is positive NPV. Headquarters extracts all the surplus and the manager does not earn any "returns" from his earlier investment in innovation effort. When headquarters' investigation does not reveal the project's rate of return, the investment decision has to be based on the manager's report. As is typical in models with asymmetric information, the manager must be provided with informational rents in order to elicit his private information.[4] To curtail the manager's informational rents, headquarters optimally foregoes some marginally positive NPV projects; that is, the investment *hurdle rate* is set above the firm's cost of capital.

While informational rents are often viewed as private benefits that accrue to self-interested managers at the expense of the firm, they serve a useful incentive role in our model: they provide the manager with incentives to exert innovation effort. Since the manager earns informational rents only when headquarters does not have the relevant information *and* the project is undertaken, a lower hurdle rate increases the likelihood that the manager enjoys the benefits of project approval. The manager's incentives to contribute innovation effort are therefore decreasing in the hurdle rate chosen by headquarters. Under centralization, however, headquarters treats the manager's innovation effort as sunk, and chooses the hurdle rate to maximize its *ex post* payoffs. Put differently, since headquarters does not commit to an investment decision rule before conducting its investigation, it acts opportunistically in

[4] Specifically, in our model, the manager has an incentive to understate the project's profitability. Doing so allows him to consume perks at the job and ascribe the resulting poor financial performance to low investment returns. To deter the manager from engaging in such misreporting, he must be provided with informational rents.

making the investment decision. This creates a holdup problem with respect to the manager's earlier choice of innovation effort.

In contrast, under delegation, headquarters contractually assigns the investment decision rights to the manager and commits to ignore any new information that it may subsequently receive.[5] Headquarters can pre-commit to any investment policy, and hence any level of managerial rents, through its choice of the rate at which the division is charged for the use of capital. In particular, in order to induce the level of innovation effort that is optimal from an *ex ante* perspective, headquarters sets a capital charge rate that is lower than what would be optimal *ex post*. This is why the induced level of innovation effort is always higher under delegation than under centralization.

Centralized control allows headquarters to use its information in curtailing managerial rents and thus improving the *ex post* efficiency of the investment decision. However, this comes at the expense of dampening the manager's incentives to undertake costly innovation effort. On the other hand, the advantage of organizing the division as a decentralized investment center is that headquarters can effectively commit to an investment decision rule that may be suboptimal *ex post*. This allows headquarters to set the innovation incentive intensity at the level that is optimal form ex ante point of view, but at the expense of *ex post* investment efficiency. Our analysis therefore finds that the firm would prefer to exercise centralized control over capital investment decisions when innovation is a relatively less crucial determinant of investment payoffs. In contrast, when the manager's innovation effort is relatively more effective in shifting the distribution of investment returns, the firm finds it optimal to delegate the investment decision rights to the manager. It is worth noting that this preference for delegation holds even if headquarters and the manager are symmetrically informed about the division's investment payoffs (e.g., headquarters has access to a perfect monitoring technology). This contrasts with the usual textbook argument that information

[5]Conducting an independent investigation of the division's investment projects would presumably require setting up some monitoring system in advance. Therefore, by not acquiring such monitoring technology at the outset, headquarters can credibly commit to not interfere in the division's investment decisions.

asymmetry drives the need for, and desirability of, decentralization.[6]

Since the marginal benefit of managerial innovation effort increases with the scale of investment, it becomes relatively easy as well as productive to motivate innovation. Our analysis thus finds that divisions with relatively large investment opportunities will be organized as decentralized units with autonomy over their capital investments. This result contrasts with the findings of Harris and Raviv (1996) who show that larger projects are more likely to be centrally controlled than smaller projects. In our setting, delegation generates stronger incentives for innovation than centralization. Since the marginal effect of innovation increases in the project size, our analysis predicts that firms are more likely to delegate investment decision rights for larger projects than for smaller projects. In contrast, Harris and Raviv (1996) consider a setting in which the manager derives private benefits from empire building; i.e., more capital investments. To curtail the manager's incentives for overinvestment, the firm prefers to exercise centralized control over large projects.

Taken together, our results predict that (i) delegation of investment authority improves managers' innovation incentives, and (ii) investment decision-making authority will be delegated to divisions that are relatively large and/or operate in environments in which innovation plays a critical role in determining future performance. To the extent one can find a suitable proxy for the relative importance of innovation in determining performance, these predictions are empirically testable. The empirical results of Kust, Martimot, and Piccolo (2008) support our finding that delegation improves incentives for innovation. Using internal management data from Italian manufacturing companies, the authors document evidence for a positive and causal relationship between delegation of decisions and incentives for innovation as measured by "soft" R&D investments.[7]

Our paper relates to the extensive literature on centralized control versus delegation in accounting, economics, and corporate finance. Baiman and Rajan (1995) investigate the choice between centralization and delegation in a capital investment setting. The modeling approaches and predictions of their analysis are, however, quite different from ours. They

[6] See, for instance, Kaplan and Atkinson (1982).

[7] Acemoglu et al. (2007) also provide evidence of a positive correlation between delegation and innovation.

examine a setting in which the successful implementation of a *given* project requires personally costly investment from the manager. In their model, delegation eliminates managerial perks derived from private information, whereas in our model, delegation increases managerial perks and motivates innovation effort. Furthermore, as common in most of the literature, they assume that the project's rate of return is exogenous.

Harris and Raviv (1996) also consider the question of delegation versus centralization in a capital budgeting setting in which the investment opportunity set is exogenous. As noted earlier, they restrict their analysis to a scenario in which the manager is motivated only by the desire for empire building, and does not respond to monetary incentives. Aghion and Tirole (1997) also rule out performance-based incentive contracts in their analysis of the relationship between allocation of authority and managerial incentives. In contrast, we explicitly model a performance measurement and control system, which allows us to generate a richer set of tradeoffs and testable predictions.

Arya et. al. (2000) consider an information system design problem in a centralized capital budgeting setting. Their analysis shows that an optimal information system may rely on coarse information because it provides the agent with stronger incentives to improve *ex ante* productivity. Unlike the focus of our paper, however, they do not consider the trade off between delegation and centralization. In our model, the agent's private information is endogenous in that the manager's choice of innovation effort affects the project's expected profitability. Arya et. al. (2000), Baiman and Rajan (1998), Dutta and Fan (2009), Laffont and Tirole (1993), and Laux and Mittendorf (2009) also consider settings in which the agent's type is endoegenously determined through his choice of costly action. While our analysis and these studies share this modeling feature, our paper is quite different from these studies in terms of its research focus and other modeling choices.

The remainder of the paper proceeds as follows. Section 2 describes the model. Sections 3 and 4 characterize the investment decision and the innovation effort induced under centralization and delegation, respectively. Section 5 compares the performances of centralized and delegated capital budgeting and identify sufficient conditions under which each of these organizational structures emerges as the optimal choice. Section 6 concludes the paper.

2 Basic Model

We consider a one-period model of a firm consisting of headquarters and a single division. Headquarters, or the center, represents the interests of the firm's shareholders and has access to capital. The division manager has no capital of his own. Headquarters and the division manager are both risk-neutral. The period begins at date 0 and ends at date 1. At the beginning of the period, the division has access to a potentially profitable project. Undertaking this project requires an initial cash outlay of k dollars at date 0, and generates gross cash earnings of $(1 + r) \cdot k$ dollars at date 1. Therefore, r denotes the project's rate of return. Without loss of generality, we normalize the firm's cost of capital to zero, and hence the project's NPV is simply equal to $k \cdot (1 + r) - k = k \cdot r$.

The division's earnings (or, net cash flows) are given by:

$$c = k \cdot r \cdot I + x - b, \tag{1}$$

where $I \in \{0, 1\}$ is an indicator variable that denotes whether the project is undertaken, x denotes the earnings from existing assets. While x is a commonly known parameter, the project's rate of return r is the manager's private information. To introduce a divergence of preferences between headquarters and the manager, we assume that the manager can consume divisional resources in perquisites. In equation (1), $b \geq 0$ denotes the amount of divisional resources that the manager uses for personal consumption of perquisites at the job. We assume that when the project is undertaken (i.e., $I = 1$) and r is the manager's private information, managerial consumption of perquisites cannot be verifiably separated from regular expenditures that are necessary for operating the division. In contrast, since the earnings from the division's existing assets, x, are commonly known, the manager's perquisite consumption can be directly detected when the project is not undertaken; i.e., $I = 0$.

Headquarters observes the aggregate earnings in expression (1), but not its individual components. Inability to distinguish between regular operating expenditures and managerial perquisite consumption, combined with the manager's private information regarding the project's rate of return r, creates an agency problem that prevents headquarters from achieving the first-best outcome. Specifically, in our model, the manager has a natural incentive to consume perks and then ascribe the resulting poor performance to low investment returns.[8]

A key feature of our model is that the manager can undertake personally costly project development or innovation efforts to improve the project's expected profitability. Many investment projects, such as launching new products or entering new markets, require extensive innovation and development efforts at the outset. The expected payoffs from these projects depend on the level of innovation effort undertaken prior to the project's implementation. To model this, we follow Dutta and Fan (2009) and assume that the rate of return r is increasing in the level of innovation effort undertaken by the manager. In particular, the project's rate of return r is given by:

$$r = m \cdot e + \varepsilon, \tag{2}$$

where e denotes the level of innovation effort chosen by the manager, $m > 0$ denotes the marginal productivity of innovation, and ε is the realization of a normally distributed random variable with mean zero and variance σ^2. Let $F(\varepsilon)$ and $f(\varepsilon)$ denote the corresponding distribution and density functions, respectively. We note that normal distribution satisfies the usual monotone inverse hazard rate condition; i.e.,

$$H(\varepsilon) \equiv \frac{1 - F(\varepsilon)}{f(\varepsilon)}$$

is decreasing in ε.

Headquarters seeks to maximize divisional earnings net of compensation payment to the manager, s:

$$k \cdot r \cdot I + x - b - s.$$

Letting $v(e) = \frac{1}{2} \cdot e^2$ denote the manager's disutility of effort e, his net utility is given by:

$$V = s + w \cdot b - v(e), \tag{3}$$

[8] Alternatively, we could assume that the manager contributes a personally costly and unobservable effort a to enhance divisional earnings; e.g., $c = k \cdot r \cdot I + x + a$. See, for instance, Dutta and Fan (2009).

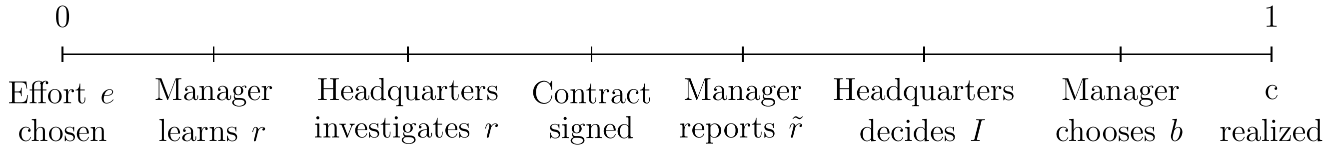
where $w \in (0, 1)$ denotes the compensation that the manager will accept in exchange for giving up a dollar of perk consumption. The assumption $w < 1$ reflects the notion that the manager would prefer to receive $1 of additional compensation, which allows him unrestricted consumption choices, to an alternative of using the same amount of cash to consume perquisites at his job. Without loss of generality, we normalize the manager's reservation utility to zero. We also assume that the manger cannot be prevented from quitting after observing r, and therefore the manager's participation constraints must be satisfied not only on *ex ante* basis (i.e., in expectation over r), but also on interim basis for each realized value of r.

3 Centralized Capital Budgeting

We first examine a centralized capital budgeting process in which headquarters retains the investment decision rights, and hence the division is effectively organized as a profit center. As a part of the centralized capital budgeting system, headquarters sets up a monitoring system to independently assess the profitability of the investment project. This investigation generates a signal about the project's rate of return r. The signal is perfectly revealing about the project's rate of return r with probability q, and is uninformative with the complementary probability of $1 - q$.[9] We assume that r is inherently "soft" information and cannot be directly used for contracting purposes.

A key feature of the centralized capital budgeting process is that headquarters cannot commit to an investment decision rule prior to conducting its own investigation of the project's profitability. The sequence of events in the centralized capital budgeting scenario is depicted in the time line below.

[9] We note that it would be costly to set up monitoring systems to assess divisional investment opportunities. However, we ignore this exogenous cost of information collection and focus on the endogenous cost of opportunism on the part of headquarters. Our analysis shows that the firm may prefer delegation and hence choose *not* to install any monitoring system even when it is costless to do so. When monitoring costs are taken into account, the case for delegation becomes even more compelling.



Sequence of Events under Centralization

At the beginning of the period, the manager undertakes his innovation effort e anticipating headquarters' subsequent choices of compensation scheme and investment decision rule. Subsequently, the manager privately observes the project's rate of return r. Headquarter then conducts its investigation of the project's profitability. At this stage, in choosing the investment decision rule and the managerial compensation contract, headquarters acts in a sequentially rational manner taking the manager's innovation effort choice as sunk and given. If investigation reveals the value of r, headquarters implements the first-best investment decision; that is, the project is undertaken if and only if its rate of return r is greater than the firm's cost of capital (i.e., $I(r) = 1$ if and only if $r \geq 0$). In this case, headquarters offers a simple forcing contract to the manager under which he receives a fixed payment equal to his reservation utility provided that the earnings are $k \cdot r \cdot I(r) + x$. Thus, in this symmetric information case, the manager earns his reservation utility of zero for all values of r.

When headquarters' investigation is unsuccessful, the manager is asked to submit a report $\tilde{r}$ about the project's rate of return after headquarters has committed to an incentive plan for the manager. A managerial incentive plan specifies the manager's compensation $s(\tilde{r})$, the required performance $c(\tilde{r})$, and the investment decision rule $I(\tilde{r})$, all as functions of the manager's report $\tilde{r}$. When the project's true rate of return is r but the manager reports $\tilde{r}$, let $b(\tilde{r}, r)$ denote the maximum amount of perquisites that the manager can consume, and yet generate performance consistent with his report $\tilde{r}$. That is:

$$b(\tilde{r}, r) \equiv \max\{b | k \cdot r \cdot I(\tilde{r}) + x - b \geq c(\tilde{r})\} = k \cdot r \cdot I(\tilde{r}) + x - c(\tilde{r}) \quad (4)$$

Contingent on the reported return of $\tilde{r}$ and the true return of r, the manager's *interim* utility, before taking into account the cost of innovation efforts, becomes:

$$U(\tilde{r}, r) = s(\tilde{r}) + w \cdot b(\tilde{r}, r).$$

Let $U(r)$ denote the manager's utility when he reports his private information truthfully; that is,

$$U(r) \equiv U(r, r).$$

Similarly, define $b\,(r) \equiv b(r, r)$. Given the definition in (4), a managerial incentive plan can be equivalently represented by the triplet $\{I(\tilde{r}), b\,(\tilde{r})\,, s\,(\tilde{r})\}$. It follows from the Revelation Principle that we can restrict our focus to contracts that induce the manager to reveal his private information truthfully.

At the time when headquarters chooses the incentive plan for the manager, the manager's innovation effort e is already sunk. Therefore, the optimal incentive scheme maximizes the expected profit given headquarters' conjecture about the manager's innovation effort e. Headquarters' problem when it does not observe r becomes:[10]

$$\mathbf{P}^c : \max_{\{I(\cdot), b(\cdot), s(\cdot)\}} \int_{-\infty}^{\infty} [k \cdot r \cdot I(r) - b(r) - s(r)]\, dF(r - m \cdot e)$$

subject to:

$$U(r) \geq U\,(\tilde{r}, r) \text{ for all } r \text{ and } \tilde{r}, \tag{i}$$

$$U(r) \geq 0 \text{ for all } r. \tag{ii}$$

For a given conjecture e, the above optimization program is a standard adverse selection problem. Its objective function reflects the expected value of the the firm's net payoff. The incentive compatibility constraints in (i) ensure that the manager finds it in his self interest to report his private information truthfully. The participation constraints in (ii) guarantee that the manager will earn at least his reservation utility.

[10]Since both parties are risk-neutral, all of our results would continue to hold if the terminal cash flows were subject to an additional random noise term; i.e, $c = k \cdot r \cdot I + x - b + \eta$ with $E(\eta) = 0$. See Laffont and Tirole (1986).

We note that the manager has a natural incentive to understate the project's rate of return. By understating the project's profitability, the manager can consume perks and yet deliver the required level of performance. To counteract the manager's incentives to understate the project's rate of return, he must be provided with informational rents. Since the manager puts a higher value on an unrestricted compensation payment than on the equal amount of cash consumed through perks (i.e., $w < 1$), it can never be optimal to induce $b > 0$.

Applying the standard arguments from the adverse selection literature based on "local" incentive compatibility constraints, it can be shown that the manager's informational rent takes the form:[11]

$$U\left(r\right) = k \cdot w \cdot \int_{-\infty}^{r} I\left(u\right) du. \tag{5}$$

This local first-order condition combined with the monotonicity requirement that $I(r)$ is non-decreasing (i.e., the investment policy is upper-tailed) ensures that the mechanism is globally incentive compatible. Equation (5) shows that if the project is approved, the manager will earn more than his reservation utility of zero; i.e., the manager will earn informational rent.

Using integration by parts, the expected informational rent becomes:

$$\mathrm{E}[U\left(r\right)] = k \cdot w \cdot \int_{-\infty}^{\infty} [1 - F\left(r - m \cdot \ e\right)] \cdot I\left(r\right) dr. \tag{6}$$

Headquarters' maximization problem thus simplifies to:

$$\max_{I(\cdot)} \int_{-\infty}^{\infty} k \cdot I\left(r\right) \cdot [r - w \cdot H(r - m \cdot e)] \cdot dF(r - m \cdot e).$$

Since the above optimization problem must be solved subject to the monotonicity constraint that $I(r)$ is non-decreasing, the choice of investment decision rule $I(\cdot)$ simply amounts to choosing a hurdle rate $h^*(e)$ such that the project is approved if and only if $r > h^*(e)$, where

$$h^*(e) = w \cdot H(h - m \cdot e). \tag{7}$$

[11]See the proof of Proposition 1 in the Appendix for details

To gain some intuition for expression (7), it is instructive to evaluate how headquarters' choice of hurdle rate affects its expected payoff. First, if the hurdle rate is increased by a small amount of ε, the expected profit decreases by the amount of $k \cdot h \cdot f(h - m \cdot e) \cdot \varepsilon$ because of the net present value forgone. At the same time, the increase in hurdle rate reduces the manager's informational rent by $k \cdot w \cdot \varepsilon$ for each type above h. Therefore, the expected compensation cost decreases by $k \cdot w \cdot \varepsilon[1 - F(h - m \cdot e)]$. At the optimum, headquarters sets the marginal cost of underinvestment, $k \cdot h \cdot f(h - m \cdot e)$, equal to its marginal benefit $k \cdot w \cdot [1 - F(h - m \cdot e)]$.

Since the inverse hazard rate $H(\cdot)$ is decreasing, it can be readily verified that headquarters' response function $h^*(e)$ is upward slopping; that is, the hurdle rate is increasing in e. To understand this, note that an exogenous increase in the project's expected profitability, $m \cdot e$, increases the probability of investment (i.e., $[1 - F(h - m \cdot e)]$), and hence the manager's information rents. Headquarters thus optimally adjusts the hurdle rate upward.

The manager chooses his innovation effort e to maximize his *ex ante* expected utility, $E[U(r)] - v(e)$. When headquarters finds out the project's true rate of return, which happens with probability q, the manager's interim utility $U(r)$ is equal to zero for each r. When monitoring is unsuccessful, the expected utility is given by equation (6). If the manager's conjecture on headquarters' choice of hurdle rate is h, he will choose his innovation effort to maximize:

$$(1 - q) \cdot k \cdot w \cdot \int_h^\infty [1 - F(r - m \cdot e)] dr - v(e). \tag{8}$$

The first term of the manager's objective function represents the expected value of managerial informational rents for a given hurdle rate h, whereas the second term is the manager's disutility of effort.[12] To characterize the manager's optimal innovation effort choice,

[12]We note that the interim participation constraints (ii) in program $\mathbf{P}^c$ ensure that $U(r)$ is non-negative for each realization of r, and hence the manager can always earn an *ex ante* expected utility of greater than zero by undertaking zero level of innovation effort. As a consequence, the manager will always be willing to participate in the game even without any explicit contract at the outset.

we impose the following technical assumption:[13]

Assumption A1 : $\max f(\cdot) < \frac{1}{2 \cdot k \cdot w \cdot m^2}$.

This assumption ensures that the manager's objective function is concave in e, and therefore the optimal choice of e can be replaced with its first-order condition:

$$e^*(h) = (1-q) \cdot k \cdot w \cdot m \cdot [1 - F(h - m \cdot e^*(h))]. \tag{9}$$

In choosing the level of innovation effort e, the manager equates the marginal return from increasing e to its marginal cost e. To understand the expression for the marginal return from increasing the innovation effort e, the manager's information rent in equation (5) can be written as:

$$U(r) = k \cdot w \cdot \max\{0, r - h\}. \tag{10}$$

This can be interpreted as the manager receiving $k \cdot w$ "options" each with a strike price of h. For each of these options, the manager's marginal return from increasing e is equal to the marginal increase in the value of the option when it is in-the-money (i.e., m) times the probability that the option ends up in-the-money (i.e., $[1 - F(h - m \cdot e)]$). Since the manager earns information rents in (10) with probability $(1-q)$, the marginal return from increasing the innovation effort is equal to $(1-q) \cdot k \cdot w \cdot m[1 - F(h - m \cdot e)]$.

It can be readily verified that the manager's best response, $e^*(h)$, is decreasing in h. The manager's incentives for innovation are driven by his expectation of informational rents. Since the manager can earns rents only if the project is undertaken, his marginal return from innovation effort is decreasing in the hurdle rate h. [14]

[13] It requires that the variance of ε, σ^2, is not too small, which ensures that the marginal return of innovation effort increases at a sufficiently low rate so that the manager's objective function is globally concave in e.

[14] Under the option interpretation, an increase in the hurdle rate amounts to increasing the strike price, which decreases the probability that the options end in-the-money (i.e., $[1 - F(h - m \cdot e)]$ decreases in h). Therefore, the manager's marginal return from e is decreasing in h.

A pure strategy Nash Equilibrium is defined as the pair (h^c, e^c) such that h^c and e^c are mutual best responses; that is, $h^c = h^*(e^c)$ and $e^c = e^*(h^c)$.

Proposition 1 *Under centralized capital budgeting, the unique pure strategy equilibrium is characterized by:*

$$e^c = (1 - q) \cdot k \cdot w \cdot m \cdot [1 - F(h^c - m \cdot e^c)] \tag{11}$$

$$h^c = w \cdot H(h^c - m \cdot e^c) \tag{12}$$

Proof: All proof are in the Appendix.

Taking the manager's innovation effort e^c as given, headquarters chooses the hurdle rate to balance its objectives of maximizing investment payoffs and minimizing managerial rents. Consistent with the findings of Antle and Eppen (1985) and others, equation (12) shows that the optimal hurdle rate h^c is greater than the firm's cost of capital (normalized to zero); that is, it is optimal to forgo some marginally profitable projects in order to curtail managerial rents.

Corollary 1 *The innovation effort e^c and the hurdle rate h^c are:*

(i) decreasing in the informativeness of the monitoring technology, q,

(ii) increasing in the marginal productivity of innovation effort, m, and

(iii) increasing in the scale of investment, k.

Since headquarters does not pre-commit to an investment decision rule, it acts opportunistically in making the investment decision. In particular, when headquarters has information about the project's rate of return, it extracts all the surplus and leaves the manager with no returns from his innovation effort undertaken earlier. This creates a holdup problem with respect to the manager's *ex ante* choice of innovation effort. The holdup problem becomes more severe as the monitoring technology becomes more informative (i.e., as q increases), and therefore the manager's response curve $e^*(h)$ shifts downward as q increases. This leads to a decline in both e^c and h^c, as illustrated in Figure 1. Put differently, an increase in the informativeness parameter q lowers the manager's innovation incentives, which in turn reduces the project's expected rate of return. Since the hurdle rate increases in the expected rate of return, h^c also decreases in q.

As the marginal productivity of managerial innovation effort increases, the manager's response function $e^*(h)$ shifts upward. Since the expected rate of return, $m \cdot e$, is increasing in m, headquarters' response curve $h^*(e)$ shifts to the right. Consequently, both e^c and h^c increase in the marginal productivity parameter m. The scale of investment k amplifies the marginal productivity of managerial innovation effort, and hence the manager's response curve $e^*(h)$ shifts upward as k increases. This is why both e^c and h^c increase in the project size.[15] To summarize, Corollary 1 predicts that hurdle rates will be higher for divisions with investment opportunities that are larger in scale and depend more crucially on innovation than for divisions with smaller and less innovation-intensive investment projects.

To conclude this section, we examine how the informativeness of monitoring technology (i.e., q) impacts on the firm's expected profit.

Proposition 2 *If the marginal productivity of innovation effort, m, is sufficiently small (large), the firm's expected payoff is increasing (decreasing) in the informativeness of monitoring technology, q.*

The investment decision becomes more efficient as monitoring becomes more effective (i.e., as q increases). However, an increase in q also reduces the manager's expected information rents, which weakens his *ex ante* incentives for innovation. If headquarters were not concerned about incentives for innovation (i.e., $m = 0$), it would prefer its monitoring technology to be as informative as possible. When m is relatively large, however, it becomes relatively productive to induce innovation. Since innovation incentives decline in q, the

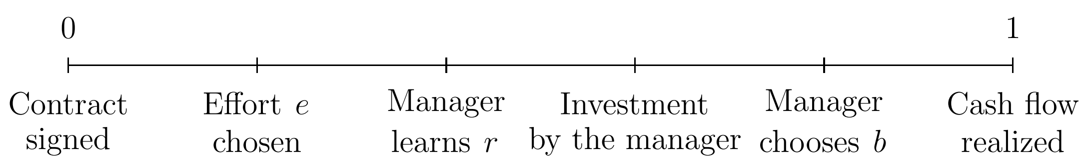
[15] In contrast, we note from equation (7) that the optimal hurdle rate would be independent of the level of investment if the division's investment opportunity were entirely exogenous (e.g., $m = 0$).

expected profit also declines in q when m is relatively large. This implies that when provision of innovation incentives is sufficiently crucial, headquarters would not like to improve its monitoring even if it could do so costlessly. Figure 2 depicts the relationship between expected profit and informativeness of monitoring for two different values of m.

4 Delegated Investment Setting

We now examine an alternative capital budgeting process in which headquarters adopts a "hands off" decentralized approach to investment decision-making. Specifically, the division is now structured as an investment center with complete autonomy over its capital investment decisions. The division is no longer required to communicate its information, and also headquarters does not engage in any investigation of its own. To ensure that the manager makes the desirable investment decision and has proper incentives for innovation, the manager's compensation is tied to residual income.

The time line below summarizes the sequence of events in the delegated investment setting.



Sequence of Events under Delegation

We will first derive the optimal investment decision rule for a (hypothetical) direct revelation game in which the manager is asked to communicate his private information and headquarters makes the investment decision. We then show that the performance of such a revelation game can be replicated by a delegated incentive scheme with linear compensation contracts based on residual income as the performance measure.

A key difference from the centralized capital budgeting system is that headquarters now commits to an investment decision rule *before* the manager chooses his innovation effort. Thus, headquarters acts as a Stackelberg leader and takes into account the impact of its investment decision rule on the manager's choice of innovation effort e. The objective function remains the same as in program $\mathbf{P}^c$ in the previous section. In addition to the truth-telling constraints in (i) and the interim participation constraints in (ii), an optimal revelation scheme must now also satisfy the incentive compatibility constraint with respect to the manager's innovation effort:[16]

$$e = \operatorname*{argmax}_{\tilde{e}} \int_{-\infty}^{\infty} U(r) dF(r - m \cdot \tilde{e}) - v(\tilde{e}) \tag{13}$$

As before, the manager's truth-telling and participation constraints require that his informational rents must satisfy equation (5). It will again be optimal for headquarters to choose a hurdle rate mechanism; i.e., the investment project is undertaken if and only if the project's rate of return r exceeds some hurdle rate h. Therefore, headquarters' optimization problem reduces to choosing (h, e) so as to maximize:

$$\pi(h, e) \equiv \int_{h}^{\infty} k \cdot [r - w \cdot H(r - m \cdot e)] dF(r - m \cdot e)$$

subject to the manager's incentive compatibility constraint:

$$e = \operatorname*{argmax}_{\tilde{e}} k \cdot w \cdot \int_{h}^{\infty} [1 - F(r - m \cdot \tilde{e})] dr - v(\tilde{e}).$$

Given Assumption A1, the innovation effort incentive constraint can be replaced with its first-order condition:

$$e(h) = k \cdot w \cdot m \cdot [1 - F(h - m \cdot e(h))]. \tag{14}$$

[16]We do not need to impose the *ex ante* participation constraint $\int_{-\infty}^{\infty} U(r) dF(r - m \cdot e) - v(e) \geq 0$, since it is implied by the interim participation constraints in (ii), which ensure that $U(r)$ is non-negative for each realization of r. Hence, even when $e = 0$, the manager's *ex ante* expected utility is greater than zero.

In the delegated investment setting, the optimal hurdle rate must balance headquarters' objectives of (i) maximizing expected investment payoffs *net* of managerial informational rents, and (ii) providing innovation incentives to the manager. In contrast, in the centralized capital budgeting process considered in the previous section, headquarters takes the manager's innovation effort as given and concerns itself only with objective (i) above.

For a given hurdle rate h, let $\Pi(h) \equiv \pi(h, e(h))$ denote the firm's expected profit evaluated at the manager's optimal response $e(h)$ given by (14). Differentiating with respect to h gives:

$$\frac{d\Pi}{dh} = \frac{\partial \pi}{\partial h} + \frac{de}{dh} \cdot \frac{\partial \pi}{\partial e}$$

The first term on the right-hand side of the above equation reflects the hurdle rate's "direct" effect on the expected profit and captures the familiar tension between curtailing information rents and maximizing investment efficiency for a given e.[17] The second term represents the hurdle rate's "indirect" effect on the expected profit through its impact on the manager's incentives to exert innovation effort. Since $\pi(h, e)$ is increasing in e and the manager's response curve $e(h)$ is downward slopping, this indirect effect of increasing the hurdle rate on the expected profit is always negative.

We show in the Appendix that $\Pi(\cdot)$ is a single-peaked function of h, and the optimal hurdle rate is given by the unique solution to the first-order condition $\frac{d\Pi}{dh} = 0$. At the optimum, the induced level of innovation effort is then given by $e^d = e(h^d)$.

Lemma 1 *The unique optimal solution* $\left(h^d, e^d\right)$ *is characterized by the following two equations:*

$$e^d = k \cdot w \cdot m \cdot \left[1 - F\left(h^d - m \cdot e^d\right)\right] \tag{15}$$

$$h^d = w \cdot H\left(h^d - m \cdot e^d\right) - m \cdot e^d \tag{16}$$

[17]If the innovation effort were exogenous, the optimal hurdle rate would be given by the solution of the equation $\frac{\partial \pi}{\partial h} = 0$

We now show that the performance of the revelation scheme in Lemma 1 can be replicated by a delegated incentive scheme in which the manager is compensated on the basis of divisional residual income. We consider linear compensation contracts of the form:

$$s = \alpha + \beta \cdot RI, \tag{17}$$

where α denotes the fixed salary, β is the bonus parameter, and RI is the residual income performance measure. Unlike operating income, which does not charge for the use of capital, residual income has the advantage that headquarters can tailor the capital charge rate so that the manager internalizes the firm's investment objective. In our one period model, operating income equals net cash flow $x + k \cdot r \cdot I(r) - b$. Therefore, residual income corresponding to the capital charge rate of $\hat{r}$ becomes:

$$RI = x + k \cdot (r - \hat{r}) \cdot I - b. \tag{18}$$

A compensation contract of the form in (17) is said to generate optimal incentives if there exists compensation coefficients (α, β) such that it satisfies the manager's participation constraints, and generates the same expected payoff for the firm as the optimal revelation scheme.

Proposition 3 *The linear compensation contract in (17) generates optimal incentives if the capital charge rate is set equal to the optimal hurdle rate* h^d.

Under the delegation scheme identified above, headquarters allocates the investment decision right to the manager and commits to the linear compensation contract in (17) at the outset. For a given level of innovation effort e, the manager will choose his investment decision I to maximize $\alpha + \beta \cdot [k \cdot (r - \hat{r}) \cdot I - b] + w \cdot b$, and thus implement the optimal investment policy provided the capital charge rate $\hat{r}$ is set equal to h^d. Furthermore, the manager will not engage in any perquisite consumption (i.e., he will choose $b = 0$) if the bonus coefficient β is set equal to w. An appropriate choice of fixed salary α then ensures that the linear contract in (17) will provide the manager with information rents in the amount of $k \cdot w \cdot \max\{0, r - h^d\}$, which is equal to his rents from the optimal revelation scheme.

Consequently, the manager has incentives to exert the optimal amount of innovation effort e^d.

The result below characterizes how the optimal hurdle rate and the induced innovation effort vary with the exogenous parameters of the model.

Corollary 2 *(i) The optimal level of innovation effort e^d is increasing in both the marginal productivity of innovation effort m, and the scale of investment k.*

(ii) The optimal hurdle rate h^d decreases (increases) in m for small (large) m.

(iii) The optimal hurdle rate h^d decreases (increases) in k for small (large) k.

As the marginal productivity of managerial innovation effort increases, the manager responds with an increased level of innovation effort for a given hurdle rate h. In addition, managerial effort become more effective in improving the project's expected profitability. This is why the optimal innovation effort is increasing in m. Since the level of investment k amplifies the productivity of managerial effort, the optimal level of innovation effort is also increasing in k.

Under delegation, however, the optimal hurdle rate is non-monotonic in the parameter m. To understand the intuition behind this result, note that when m is zero, innovation effort has no effect on the investment's profitability, and headquarters will set the hurdle rate to curtail the manager's informational rents. Let h^0 denote the optimal hurdle rate when $m = 0$. Holding all else constant, an increase in m increases the manager's innovation effort and hence the profitability of the investment project. If the hurdle rate were to remain fixed at h^0, a large increase in m would induce a large amount of innovation effort which would shift the probability mass of the investment return distribution to extreme right. Consequently, the manager's innovation incentives would become largely insensitive to the hurdle rate. Headquarters would thus be mainly concerned with limiting the manager's informational rents and the optimal hurdle rate would increase above h^0. On the other hand, a small increase in m will induce a small amount of innovation effort so that the probability mass of the investment return distribution is more centered around h^0, in which case the manager's marginal informational rents (and hence his innovation incentive) remains quite sensitive to the choice of the hurdle rate. Headquarters thus optimally adjusts the hurdle rate below h^0 to encourage more innovation effort. A similar argument applies for the comparative statics result on k. Figure 3 depicts this non-monotonic relationship between h^d and m for a numerical example in which $w = 0.01$, $k = 1$, and $\sigma^2 = 1$.

5 Performance Comparison of Centralized and Delegated Capital Budgeting

This section compares centralized and delegated capital budgeting along two dimensions: (1) the induced level of innovation effort, and (2) headquarters' expected profit. The result below shows that organizing the division as an investment center generates more powerful incentives for innovation than those generated under the centralized organization form.

Proposition 4 *The optimal innovation effort under delegation is always higher than that under centralization. That is,* $e^d > e^c$ *for all* $q \in [0, 1]$, $m > 0$, *and* $k > 0$. *Furthermore, the difference* $e^d - e^c$ *is increasing in the quality of information* q.

Centralized control allows headquarters to utilize its information in improving the *ex post* efficiency of the investment decision and curtailing managerial rents. But it also dampens the manager's incentives for innovation. Put differently, the discretion to use *ex post* information in limiting informational rents also limits innovation incentives. Under delegation, the investment decision rights are contractually assigned to the manager and headquarters commits to an incentive scheme that is optimal from an *ex ante* perspective. Consequently, the delegated system always induces a higher level of innovation effort than the centralized system.[18]

[18] At first glance, it might seem surprising that the innovation effort under delegation is greater than that under centralization even when $q = 0$. We note, however, that headquarters has a first mover advantage

Since the manager's innovation incentives are decreasing in the hurdle rate and $e^d > e^c$, it might seem that the hurdle rate under delegation would be lower than its optimal value under centralization. This intuition is, however, incomplete because the hurdle rate also increases in the expected rate of return, which, in turn, depends on innovation effort. The numerical analysis in Figure 3 shows that the optimal hurdle rate under delegation exceeds that under centralization for sufficiently large values of m. However, it is interesting to note that even though the *average* quality of the available project is always higher under delegation because $e^d > e^c$, the *marginal* project undertaken can be of lower quality than that under centralization. To see this, we note from Figure 3 that the hurdle rate is lower under delegation than under centralization when m is small enough.

We now compare the relative performances of the two capital budgeting systems from the firm's point of view.

Proposition 5 *i For any given $q > 0$ and $k > 0$, delegation dominates (is dominated by) centralization for values of m sufficiently large (small).*

ii For any given $q > 0$ and $m > 0$, delegation dominates centralization for values of k sufficiently large.

The advantage of organizing the division as a decentralized investment center with investment decision rights is that headquarters can effectively commit to any investment rule through its choice of the rate at which the division is charged for the use of capital in the residual income performance measure. To maximize the expected profit, headquarters commits to a capital charge rate that is inefficient *ex post*, but induces the optimal amount of innovation effort *ex ante*.

On the other hand, centralized control allows headquarters to use its *ex post* information in curtailing managerial rents and improving the *ex post* efficiency of the investment decision.

under delegation and commits to a hurdle rate that is *ex post* suboptimal. In contrast, under centralization, since headquarter does not make any *ex ante* commitment, its choice of the hurdle rate is *ex post* best response to the manager's strategy.

For relatively small values of m, managerial innovation effort is not only relatively ineffective in improving the project's rate of return, but also relatively difficult to induce. Therefore, limiting managerial rents is more critical, and hence centralization outperforms delegation, for small values of m.

In contrast, when the marginal productivity of managerial innovation effort is relatively large, it is relatively easy as well as beneficial to provide the manager with innovation incentives. Therefore, for any $q \in [0,1]$ and any $k > 0$, there exists a $\hat{m}$ such that the firm's expected payoffs are greater under delegation than under centralization for all $m > \hat{m}$. To illustrate this result, Figure 4 plots the firm's expected payoff as a function of m. The solid and dotted curves depict the expected payoff under delegation and centralization, respectively. To generate data for this, we assume that $w = 0.01$, $q = 0.5$, $k = 1$, and $\sigma^2 = 1$.

We recall that the project's NPV is given by $k \cdot r$. The scale of investment, k, thus amplifies the marginal impact of managerial innovation effort on the project's net payoff. Holding all else constant, provision of innovation incentives becomes more crucial, and hence delegation becomes more compelling as the project size k increases. Our analysis thus predicts that divisions with relatively large investment opportunities will be organized as decentralized units with autonomy over their capital investments. In contrast, Harris and Raviv (1996) show that larger projects are more likely to be centrally controlled than smaller projects. The reasons for this difference are that Harris and Raviv (1996) consider a setting in which (i) the firm's investment opportunity set is exogenous, and (ii) the manager does not respond to monetary incentives and is motivated only by the desire for empire building; i.e., more capital investments. To curtail the manager's incentives for overinvestment, the firm prefers to exercise centralized control over large projects.

Taken together, the results in this section predict that (i) delegation of investment authority encourages innovation, and (ii) investment decision rights are likely to be delegated to divisions that are relatively large and operate in innovation intensive environments. The empirical results of Kust, Martimot, and Piccolo (2008) support our first prediction that delegation improves incentives for innovation. Using internal management data from a sample of Italian manufacturing companies, the authors document a positive and causal relationship between delegation of decisions and incentives for innovation as measured by “soft” R&D investments. To the extent one can find a suitable proxy for the relative importance of innovation in determining firm performance, our result that investment decision authority is more likely be delegated to divisions that operate in innovation intensive environment is also empirically testable.

6 Conclusion

To investigate how the allocation of investment decision rights impacts on managers' incentives for innovation to develop investment opportunities, we have considered a capital budgeting setting in which a divisional manager can exert personally costly effort to improve the expected quality of the investment project available to the division. Our analysis examines how centralized and delegated capital budgeting systems perform along the two dimensions: (i) the induced level of innovation effort, and (ii) the firm's expected payoff. Under centralized control, headquarters makes the investment decision on its own relying on the information submitted by the division as well as the information it gathers on its own. In contrast, under delegation, headquarters structures the division as an investment center and assigns it complete autonomy over its capital investment choices.

Our analysis highlights an essential tradeoff between *ex post* investment efficiency and *ex ante* innovation incentives. Centralized control allows headquarters to utilize its information in improving the *ex post* efficiency of the investment decision and curtailing managerial rents, but at the expense of the manager's *ex ante* incentives for innovation. In contrast, under delegation, headquarters can essentially pre-commit to compromise on the *ex post* investment efficiency in order to provide the manager with stronger innovation incentives. Consequently, we find that delegation of investment authority always induces higher level of innovation than centralization. We further show that the firm's preference for delegation versus centralization depends on the relative size of the project and the relative importance of innovation in determining its payoffs. In particular, our analysis predicts that investment decision authority will be delegated to divisions that are relatively large and operate in innovation intensive environments.

Our analysis suggests some new avenues for future research. For instance, it will be interesting to examine how the firm's preference for centralization versus delegation depends on the relative riskiness of the project. It might also be interesting to consider scenarios in which the manager's upfront innovation activities affect not only the expected value but also the variance of the project's returns.

APPENDIX

Proof of Proposition 1

The manager's utility payoff contingent on the true probability parameter r and the reported $\tilde{r}$ can be written as:

$$U(\tilde{r}, r) \equiv s(\tilde{r}) + w \cdot b(\tilde{r}, r), \tag{19}$$

where $b(\tilde{r}, r) = k \cdot r \cdot I(\tilde{r}) + x - c(\tilde{r})$ denotes the amount of perks that the manager can consume and yet generate cash flows consistent with his report $\tilde{r}$. It can be shown with standard techniques that any incentive compatible mechanism has to satisfy the following "local" condition:

$$\frac{d}{dr}U(r) = \frac{\partial}{\partial r}U(\tilde{r}, r)|_{\tilde{r}=r}.$$

Differentiating equation (19) with respect to r gives:

$$\frac{\partial}{\partial r}U(\tilde{r}, r)|_{\tilde{r}=r} = k \cdot w \cdot I(r).$$

Since the participation constraint $U(r) \geq 0$ will hold with equality for the lowest type (i.e., $U(-\infty) = 0$), the above equation implies that the manager will earn the following informational rents:

$$U(r) = k \cdot w \cdot \int_{-\infty}^{r} I(u)du. \tag{20}$$

Since $U(r) = s(r) + w \cdot b(r)$ by definition, it follows that $s(r) + b(r) = U(r) + (1 - w) \cdot b(r)$. Using the expression in (20) for $U(r)$ and integrating by parts yield:

$$\int_{-\infty}^{\infty} [s(r) + b(r)]dF(r - m \cdot e) = \int_{-\infty}^{\infty} [(1 - w) \cdot b(r) + H(r - m \cdot e) \cdot k \cdot w \cdot I(r)]\, dF(r - m \cdot e).$$

Since $w \in (0, 1)$, it is clearly optimal to set $b(r) = 0$ for all r. Consequently, the center's objective in $\mathbf{P}^c$ simplifies to the following optimization problem:

$$\max_{I(r)} \int_{-\infty}^{\infty} [r - w \cdot H(r - m \cdot e)] \cdot k \cdot I(r)]dF(r - m \cdot e),$$

By pointwise maximization, it follows that headquarters will choose $I(r) = 1$ if and only if $r \geq h^*$, where the hurdle rate h^* is given by:

$$h^*(e) = w \cdot H(h^*(e) - m \cdot e).$$

It remains to be shown that the above incentive scheme is globally incentive compatible. As shown by Mirrlees (1971), a mechanism is incentive compatible provided it is locally incentive compatible, and $\frac{\partial}{\partial r}U(\tilde{r}, r)$ is (weakly) increasing in $\tilde{r}$. For the above mechanism:

$$\frac{\partial}{\partial r}U(\tilde{r}, r) = w \cdot k \cdot I(\tilde{r}),$$

which is increasing in $\tilde{r}$ since the optimal $I(\cdot)$ is an upper-tail investment policy.

By the implicit function theorem,

$$\frac{dh^*}{de} = \frac{-w \cdot m \cdot H'(h^* - m \cdot e)}{1 - w \cdot m \cdot H'(h^* - m \cdot e)}.$$

Since $H'(\cdot) < 0$, we have $\frac{dh^*}{de} > 0$.

Let $\bar{V} = \mathrm{E}[U(r)|e] - \frac{e^2}{2}$ denote the manager's *ex ante* expected utility, i.e., expected informational rents net of innovation effort. The manager chooses his innovation effort to maximize $\bar{V}$. Given that

$$\mathrm{E}[U(r)|e] = (1-q)\int_h^\infty k \cdot w \cdot [1 - F(r - m \cdot e)]dr,$$

the first order condition for the manager's maximization problem in choosing e becomes:

$$\frac{d\bar{V}}{de} = k \cdot w \cdot m \cdot (1-q) \cdot [1 - F(h - m \cdot e)] - e = 0. \tag{21}$$

Notice that by (**A1**),

$$\frac{d^2\bar{V}}{de^2} = k \cdot w \cdot m^2 \cdot (1-q) \cdot f(h - m \cdot e) - 1 < 0.$$

Hence, $\bar{V}$ is globally concave in e and the second order condition is satisfied. Consequently, the manager's optimal response function is as given by (9).

By the implicit function theorem:

$$\frac{de^*}{dh} = \frac{(1-q)\cdot k\cdot w\cdot m\cdot f\left(h-m\cdot e^*(h)\right)}{(1-q)\cdot k\cdot w\cdot m^2\cdot f\left(h-m\cdot e^*(h)\right)-1} < 0. \tag{22}$$

Hence, (9) identifies the manager's best response function $e^*(h)$, which decreases in h. (7) identifies headquarters' best response function $h^*(e)$, which increases in e. The Nash Equilibrium is the pair $\{h^c,\ e^c\}$ identified by the unique point where the two best response functions intersect.

Proof of Corollary 1:

Let $z^c = h^c - m\cdot e^c$, then (12)$-m\cdot$(11) yields:

$$z^c = w\cdot H\left(z^c\right) - (1-q)\cdot w\cdot m^2\cdot k\cdot\left(1-F\left(z^c\right)\right). \tag{23}$$

Let $\Lambda^c = w\cdot H'\left(z^c\right) - 1 + (1-q)\cdot w\cdot m^2\cdot k\cdot f\left(z^c\right)$. Assumption (A1) ensures that Λ^c is strictly negative.

By the implicit function theorem,

$$\frac{dz^c}{dq} = \left[-w\cdot m^2\cdot k\cdot\left(1-F\left(z^c\right)\right)\right]\cdot\left(\Lambda^c\right)^{-1} \geq 0,$$
$$\frac{dz^c}{dm} = \left[2\cdot(1-q)\cdot w\cdot m\cdot k\cdot\left(1-F\left(z^c\right)\right)\right]\cdot\left(\Lambda^c\right)^{-1} \leq 0, \text{ and}$$
$$\frac{dz^c}{dk} = \left[(1-q)\cdot w\cdot m\cdot\left(1-F\left(z^c\right)\right)\right]\cdot\left(\Lambda^c\right)^{-1} \leq 0.$$

Now h^c and e^c can be written as

$$h^c = w\cdot H\left(z^c\right), \text{ and} \tag{24}$$

$$e^c = (1-q)\cdot k\cdot w\cdot m\cdot\left(1-F(z^c)\right). \tag{25}$$

Because $H(\cdot)$ and $1-F(\cdot)$ are decreasing functions, h^c and e^c must be increasing in m and k and decreasing in q.

Proof of Proposition 2:

Let $\Pi^c(e,h;q,k,m)$ denote the profit function and $\hat{\Pi}^c(q,k,m)$ denote the equilibrium value of Π^c as a function of exogenous parameters, i.e., $\hat{\Pi}^c(q,k,m) \equiv \Pi^c(e^c(q,k,m), h^c(q,k,m); q,k,m)$. Then

$$\frac{\partial \hat{\Pi}^c(q,k,m)}{\partial q} = \frac{\partial \Pi^c}{\partial q} + \frac{\partial \Pi^c}{\partial e^c} \cdot \frac{\partial e^c(q,k,m)}{\partial q} + \frac{\partial \Pi^c}{\partial h^c} \cdot \frac{\partial h^c(q,k,m)}{\partial q}.$$

Since h^c is chosen to maximize Π^c taking e^c as given, $\frac{\partial \Pi^c}{\partial h^c} = 0$. Hence,

$$\frac{\partial \hat{\Pi}^c(q,k,m)}{\partial q} = \frac{\partial \Pi^c}{\partial q} + \frac{\partial \Pi^c}{\partial e} \cdot \frac{\partial e^c(q,k,m)}{\partial q}.$$

For any $k > 0$, we have

$$\frac{\partial \Pi^c}{\partial q} = k \cdot \int_{-me^c}^{+\infty} (me^c + \epsilon)\, dF(\epsilon) - k \cdot \int_{h^c(m,q)-me^c}^{+\infty} (me^c + \epsilon - w \cdot H(\epsilon))\, dF(\epsilon) > 0,$$

$$\frac{\partial \Pi^c}{\partial e^c} = m \cdot k \cdot [q(1 - F(-me^c)) + (1-q)(1 - F(h^c - me^c))] \geq 0, \text{ and}$$

$$\frac{\partial e^c}{\partial q} = k \cdot \left[-w \cdot m \cdot (1 - F(z^c)) - (1-q) \cdot w \cdot m \cdot f(z^c) \cdot \frac{\partial z^c}{\partial q} \right] \leq 0.$$

When $k > 0$ and $m = 0$, both $\frac{\partial \Pi^c}{\partial e^c}$ and $\frac{\partial e^c}{\partial q}$ are equal to zero, so

$$\left.\frac{\partial \hat{\Pi}^c}{\partial q}\right|_{m=0} = \left.\frac{\partial \Pi^c}{\partial q}\right|_{m=0} > 0$$

Since $\hat{\Pi}^c$ is continuous in all of its arguments, it follows that $\frac{d\hat{\Pi}^c}{dq} > 0$ for small m.

Because $\frac{\partial z^c}{\partial q} \geq 0$ and $e^c = (1-q) \cdot k \cdot w \cdot m \cdot [1 - F(z^c))$,

$$\frac{\partial e^c}{\partial q} = k \cdot \left[-w \cdot m \cdot (1 - F(z^c)) - (1-q) \cdot w \cdot m \cdot f(z^c) \cdot \frac{\partial z^c}{\partial q} \right]$$
$$\leq -\frac{e^c}{(1-q)}.$$

Furthermore, because h^c is greater than zero, we have, for any positive k,

$$\frac{\partial \Pi^c}{\partial q} = k \cdot \int_{-me^c}^{+\infty} (me^c + \epsilon)\, dF(\epsilon) - k \cdot \int_{h^c(m,q)-me^c}^{+\infty} (me^c + \epsilon - w \cdot H(\epsilon))\, dF(\epsilon)$$
$$< k \cdot \int_{-me^c}^{+\infty} (me^c + \epsilon)\, dF(\epsilon) - k \cdot \int_{-me^c}^{+\infty} (me^c + \epsilon - w \cdot H(\epsilon))\, dF(\epsilon)$$
$$= w \cdot k \cdot \mathrm{E}[\max(me^c + \epsilon, 0)].$$

Therefore, when $k > 0$,

$$\frac{\partial \hat{\Pi}^c}{\partial q} < w \cdot k \cdot \mathrm{E}\left[\max\left(me^c, 0\right)\right] - m \cdot k \cdot \left[q\left(1 - F\left(-me^c\right)\right) + (1-q)\left(1 - F\left(z^c\right)\right)\right] \cdot \frac{e^c}{(1-q)}.$$

Notice that in order to satisfy (23) as m becomes arbitrarily large, z^c has to decrease without bound. Consequently, the first term above goes to $w \cdot m \cdot k \cdot e^c$, and the second term goes to $\frac{m \cdot k \cdot e^c}{1-q}$. Hence, $\frac{d\hat{\Pi}^c}{dq} < 0$ for sufficiently large values of m.

Proof of Lemma 1:

Let $\pi(h) \equiv \pi\left(h, e\left(h\right)\right)$ denote the firm's expected payoff as a function of the hurdle rate h. Differentiating with respect to h yields:

$$\frac{d\pi}{dh} = \frac{\partial \pi}{\partial h} + \frac{de}{dh}\frac{\partial \pi}{\partial e}$$

where

$$\frac{\partial \pi}{\partial h} = -[h - w \cdot H(h - m \cdot e(h))] \cdot f\left(h - m \cdot e(h)\right) \cdot k$$

and

$$\frac{\partial \pi}{\partial e} = \left[h + H\left(h - m \cdot e(h)\right) \cdot (1-w)\right] \cdot f\left(h - m \cdot e(h)\right) \cdot m \cdot k$$

So

$$\begin{aligned}
\frac{d\pi}{dh} &= \left\{-[h - w \cdot H(h - m \cdot e(h))] + \frac{de}{dh}\left[h + H\left(h - m \cdot e(h)\right)(1-w)m\right]\right\} f\left(h - m \cdot e(h)\right) k \\
&= \left\{-\left(1 - m \cdot \frac{de}{dh}\right) h + \left[w + \frac{de}{dh}(1-w)m\right] H(h - m \cdot e(h))\right\} f\left(h - m \cdot e(h)\right) k \\
&= \left\{-\left(1 - m \cdot \frac{de}{dh}\right) f\left(h - m \cdot e(h)\right) k\right\} \left\{h - \frac{w + \frac{de}{dh}(1-w)m}{\left(1 - m \cdot \frac{de}{dh}\right)} \cdot H(h - m \cdot e(h))\right\} \\
&= \underbrace{\left\{-\left(1 - m \cdot \frac{de}{dh}\right) f\left(h - m \cdot e(h)\right) k\right\}}_{A} \underbrace{\left\{h - \left[w + \frac{m \cdot \frac{de}{dh}}{1 - m \cdot \frac{de}{dh}}\right] \cdot H(h - m \cdot e(h))\right\}}_{B}
\end{aligned}$$

Since $\frac{de}{dh} < 0$ from Proposition 1, $A < 0$ for any h, so $\frac{d\pi}{dh}$ and B are of opposite sign. Further, at the optimal h, $\frac{d\pi}{dh} = B = 0$, i.e.,

$$h^d = \left[w + \frac{m \cdot \frac{de(h^d)}{dh}}{\left(1 - m \cdot \frac{de(h^d)}{dh}\right)}\right] H(h^d - m \cdot e(h^d)) \tag{26}$$

Using the facts that $\frac{m\cdot\frac{de}{dh}}{1-m\cdot\frac{de}{dh}} = -k\cdot w\cdot m^2\cdot f(h-m\cdot e(h))$ and $e(h) = k\cdot w\cdot m\cdot[1-F(h-m\cdot e(h))]$, the optimal hurdle rate can be expressed as:

$$h^d = w \cdot H(h^d - m \cdot e^d) - m \cdot e^d, \tag{27}$$

where $e^d \equiv e(h^d)$ denotes the induced choice of return-enhancing effort at $h = h^d$, as defined by equation (14).

To show that the hurdle rate identified in equation (27) is indeed a global maximum, we will show that the owner's expected payoff function $\pi(h, e(h))$ is single-peaked in h. Differentiating B with respect to h yields

$$\begin{aligned}
&\operatorname{sgn}\left[\frac{dB}{dh}\right] && (28)\\
&= \operatorname{sgn}\left[\frac{d\left(h - w \cdot H(\cdot) + k \cdot w \cdot m^2 \cdot (1 - F(\cdot))\right)}{dh}\right] \\
&= \operatorname{sgn}\left[1 - w \cdot H'(\cdot)\left(1 - m \cdot \frac{de}{dh}\right) - k \cdot w \cdot m^2 \cdot f(\cdot)\left(1 - m \cdot \frac{de}{dh}\right)\right] \\
&= \operatorname{sgn}\left[1 - w \cdot H'(\cdot)\left(1 - m \cdot \frac{de}{dh}\right) - k \cdot w \cdot m^2 \cdot f(\cdot)\left(\frac{-1}{k \cdot w \cdot m^2 \cdot f(\cdot) - 1}\right)\right] \\
&= \operatorname{sgn}\left[\frac{2 \cdot k \cdot w \cdot m^2 \cdot f(\cdot) - 1}{k \cdot w \cdot m^2 \cdot f(\cdot) - 1} - w \cdot H'(\cdot)(1 - m \cdot \frac{de}{dh})\right] > 0 && (29)
\end{aligned}$$

where the argument of $H(\cdot)$, $F(\cdot)$, and $f(\cdot)$ is $(h - m \cdot e(h))$ and has been suppressed for brevity. Given Assumption A1, it follows that $k \cdot w \cdot m^2 \cdot f(\cdot) < 2 \cdot k \cdot w \cdot m^2 \cdot f(\cdot) < 1$. As a consequence, $\frac{2\cdot k\cdot w\cdot m^2\cdot f(\cdot)-1}{k\cdot w\cdot m^2\cdot f(\cdot)-1} > 0$. Furthermore, since $\frac{de}{dh} < 0$ and $H'(\cdot) < 0$, it follows that $\frac{dB}{dh} > 0$. Given that $B = 0$ at h^* and $A < 0$ for any h, π is increasing in h for $h < h^d$ and decreasing in h for $h > h^d$. Therefore, $\pi(\cdot)$ is single-peaked and the solution identified in (27) combined with $e^d \equiv e(h^d)$ constitutes the unique solution to the headquarter's maximization problem.

Proof of Proposition 3:

Since the capital charge rate is equal to h^d, equation (18) shows that the manager will invest if and only if $r \geq h^d$. If the bonus coefficient β is set equal to w, the manager has no incentives to consume perks. The choice of the fixed salary α ensures that the manager's compensation is equal to $\max\{0, k \cdot w \cdot (r - h^d) \cdot I(r)\}$. As a consequence, for each value of r, this delegated scheme generates the same information rent for the manager as the optimal revelation mechanism. This implies that the manager's participation constraints are satisfied and the owner's expected payoffs are the same as under the optimal revelation scheme.

Proof of Corollary 2:

Let $z^d = h^d - m \cdot e^d$. $(16) - m \cdot (15)$ yields:

$$z^d = w \cdot H\left(z^d\right) - 2 \cdot w \cdot m^2 \cdot k \cdot \left(1 - F\left(z^d\right)\right). \tag{30}$$

Let $\Lambda^d = w \cdot H'\left(z^d\right) - 1 + 2 \cdot w \cdot m^2 \cdot k \cdot f\left(z^d\right)$. Assumption (A1) ensures that Λ^d is strictly negative.

By the implicit function theorem,

$$\begin{aligned}\frac{dz^d}{dm} &= \left[4 \cdot w \cdot m \cdot k \cdot \left(1 - F\left(z^d\right)\right)\right] \cdot \left(\Lambda^d\right)^{-1} \leq 0, \text{ and} \\ \frac{dz^d}{dk} &= \left[2 \cdot w \cdot m^2 \cdot \left(1 - F\left(z^d\right)\right)\right] \cdot \left(\Lambda^d\right)^{-1} \leq 0.\end{aligned}$$

Hence $e^d = k \cdot w \cdot m \cdot (1 - F(z^d))$ increases in m and k.

Notice that when $m = 0$, $e^d = 0$ and $z^d = w \cdot H\left(z^d\right)$ must be positive. Further, in order to satisfy (30) as m or k increase to infinity, z^d has to go to negative infinity. Hence, as m or k increase, z^d decreases from a positive number to $-\infty$.

With $e^d = w \cdot m \cdot k \cdot \left(1 - F\left(z^d\right)\right)$,

$$\frac{\partial e^d}{\partial m} = w \cdot k \cdot \left(1 - F\left(z^d\right)\right) - w \cdot m \cdot k \cdot f\left(z^d\right) \cdot \frac{dz^d}{dm}.$$

With $h^d = w \cdot H\left(z^d\right) - m \cdot e^d$,

$$\begin{aligned}\frac{\partial h^d}{\partial m} &= w \cdot H'\left(z^d\right)\frac{dz^d}{dm} - e^d - m \cdot \frac{de^d}{dm} \\ &= w \cdot H'\left(z^d\right)\frac{dz^d}{dm} - 2 \cdot w \cdot m \cdot k \cdot \left(1 - F\left(z^d\right)\right) - w \cdot m^2 \cdot k \cdot f\left(z^d\right) \cdot \frac{dz^d}{dm} \\ &= 2 \cdot w \cdot m \cdot k \cdot \left(1 - F\left(z^d\right)\right) \cdot \left(w \cdot H'\left(z^d\right) + 1\right) \cdot \left(\Lambda^d\right)^{-1}\end{aligned}$$

Since $\Lambda^d < 0$, $\text{sgn}\left[\frac{\partial h^d}{\partial m}\right] = -\text{sgn}\left[w \cdot H'(z^d) + 1)\right]$. With normal distribution, $H'\left(z^d\right) = -1 + z^d \cdot \frac{(1-F(z^d))}{f(z^d)}$ decreases to $-\infty$ as z^d decreases from a positive number to $-\infty$. Because $H'(0) = -1$ and $-w > -1$, h^d must be first decreasing and then increasing in m.

The proof for the comparative statics with respect to k follows from similar arguments as used above.

Proof of Proposition 4:

First, we use proof by contradiction to show that for any $m > 0$ and any $k > 0$, $e^d(m,k) > e^c(q=0,m,k)$.

When $q = 0$, $e^c(q = 0, m, k) = w \cdot m \cdot k \cdot (1 - F(h^c - m \cdot e^c))$ decreases in h^c, and $e^d(m,k) = w{\cdot}m{\cdot}k{\cdot}\left(1 - F\left(h^d - m \cdot e^d\right)\right)$ also decreases in h^d. Now suppose $e^c(q=0,m,k) \geq e^d(m,k)$, then we must have $h^c \leq h^d$ and $H(h^c - m \cdot e^c) > H\left(h^d - m \cdot e^d\right)$, which contradicts with $h^c = w \cdot H(h^c - m \cdot e^c)$ and $h^d = w \cdot H\left(h^d - m \cdot e^d\right) - m \cdot e^d$. Hence, $e^c(q=0,m,k) < e^d(m,k)$.

We have shown in the proof of Proposition 2 that

$$\frac{\partial e^c}{\partial q} = k \cdot \left[-w \cdot m \cdot (1 - F(z^c)) - (1-q) \cdot w \cdot m \cdot f(z^c) \cdot \frac{\partial z^c}{\partial q}\right] \leq 0.$$

Because $e^d(m,k)$ does not depend on q, $e^d(m,k) > e^c(q,m,k)$ for all $q \in [0,1]$ and the difference $e^d(m,k) - e^c(q,m,k)$ increases in q.

Proof of Proposition 5:

Let $\hat{\Pi}^d(m,k)$ denote the maximized value of expected profit, under delegation, as a function of m and k. Similarly, let $\hat{\Pi}^c(q,m,k)$ denote the value of the expected profit under centralization. It is obvious that $\hat{\Pi}^d(m=0,k) = \hat{\Pi}^c(q=0,m=0,k)$. Furthermore, for all $m, k > 0$, $\hat{\Pi}^d(m,k) > \hat{\Pi}^c(q=0,m,k)$ because $h^d(m,k)$ is chosen to maximize the firm's expected profit. We have shown in the proof of Proposition 2 that $\frac{\partial \hat{\Pi}^c}{\partial q} > (<) 0$ for sufficiently small (large) values of m. Therefore, by continuity, for any given $q > 0$ and $k > 0$, $\hat{\Pi}^c(q,m,k)$ is greater (less) than $\hat{\Pi}^d(m,k)$ for small (large) values of m.

To prove the result with respect to k, notice that

$$\frac{\partial\hat{\Pi}^c}{\partial q} < w \cdot k \cdot \mathrm{E}\left[\max\left(me^c, 0\right)\right] - m \cdot k \cdot \left[q\left(1 - F\left(-me^c\right)\right) + \left(1-q\right)\left(1 - F\left(z^c\right)\right)\right] \cdot \frac{e^c}{\left(1-q\right)}.$$

As k becomes arbitrarily large, the first term above goes to $w \cdot m \cdot k \cdot e^c$ and the second term converges to $\frac{m \cdot k \cdot e^c}{1-q}$. Hence, it has to be that for large enough k, $\frac{d\hat{\Pi}^c}{dq} < 0$. Since $\hat{\Pi}^d\left(m,k\right) > \hat{\Pi}^c\left(q=0,m,k\right)$ for all $m > 0$ and $k > 0$, it must be that $\hat{\Pi}^d\left(m,k\right) > \hat{\Pi}^c\left(q,m,k\right)$ for sufficiently large values of k .

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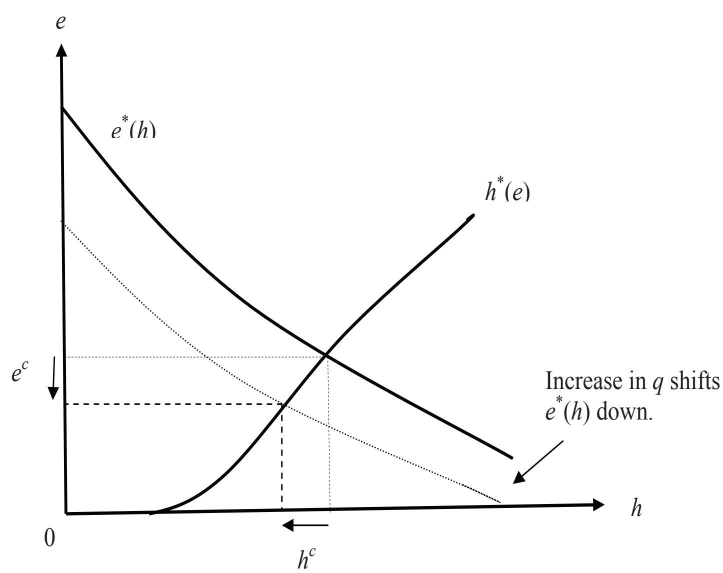

Figure 1: Response Curves under Centralization

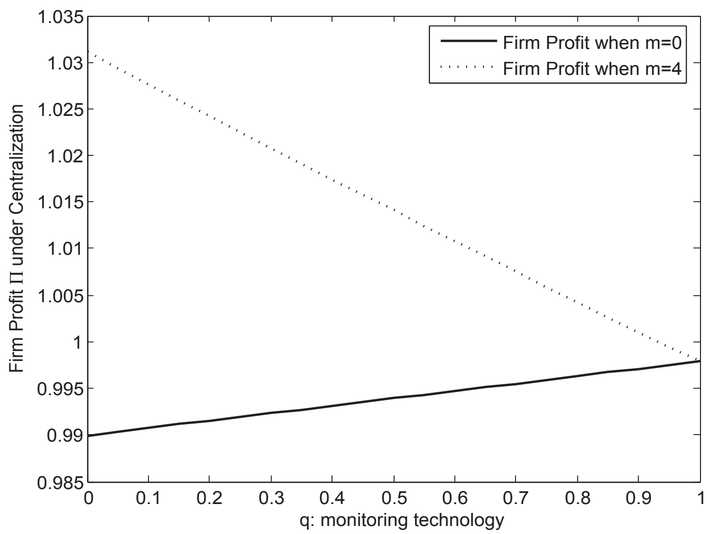

Figure 2: Expected Profit under Centralization

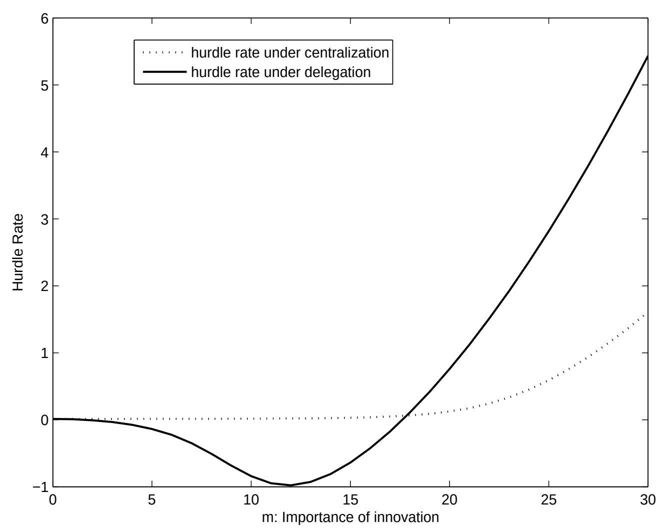

Figure 3: Hurdle Rate and Marginal Productivity of Innovation

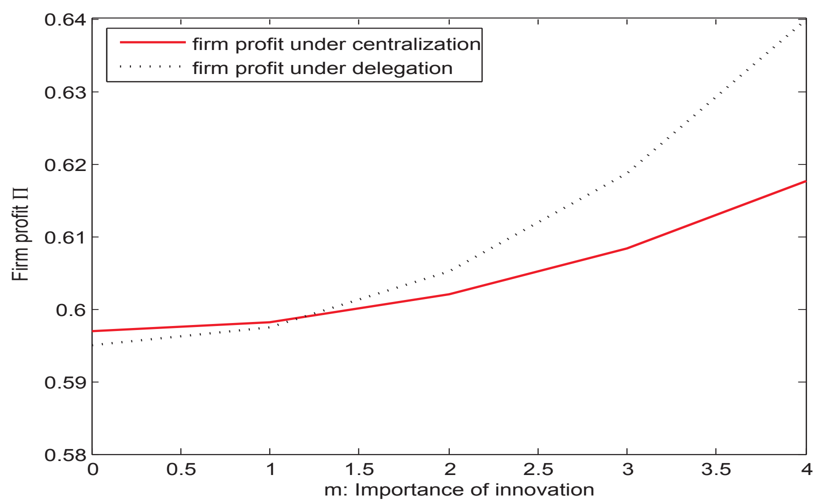

Figure 4: Firm Profit and Marginal Productivity of Innovation