Capital Budgeting, the Hold-up Problem, and Information System Design

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In this article, we explore the connection between information system design and incentives for project search. The choice of an information system affects the level of managerial slack that is generated during project implementation. Whether slack is beneficial or costly to an organization has been the subject of debate. In our model of the hold-up problem in capital budgeting, there are both costs and benefits to having managerial slack. The cost of slack is the consumption of perquisites by the manager. The benefit of slack is that it can serve as a motivational tool. The possibility of increasing his slack may encourage a self-interested manager to conduct a more diligent search for a profitable project. To trade off the costs and benefits of slack in our model, an optimal information system sometimes incorporates coarse information, late information, and a mix of monitored and self-reported information. These features are familiar to accountants. Accounting incorporates both verified (monitored) and unverified (self-reported) information and provides information that is aggregated (coarse) and historical (late).

(*Capital Budgeting; Hold-up Problem; Slack*)

1. Introduction

Capital budgeting is the process by which firms make long-term investment decisions. For many long-term investments, the same manager is likely to be involved in the development of the project proposal and, if approved, in the project's implementation. The approval (ratification) and monitoring of the project is typically the responsibility of a budget center. In addition to the information provided by project proposers, the budget center may receive other information about the projects. For example, it might be possible to obtain audited information about the project's past cash flows. The information system in place influences managers' expectations of how the budget center will evaluate projects, which in turn affects the managers' behavior in project search. This connection between information system design and incentives for project search is the focus of this article.

The choice of an information system affects the level of managerial slack that is generated during project implementation. Whether slack is beneficial or costly to an organization has been the subject of debate. On the one hand, it is argued that slack plays a crucial role in encouraging innovations in organizations (Cyert and March 1963, pp. 278–279). Slack provides a source of funds for long-term innovations (slack innovation); funds to experiment may not be approved under tighter resource constraints. A much-cited example of slack innovation is the chance discovery of Post-it Notes at 3M (Mokyr 1990).[1]

On the other hand, slack can be viewed as gains that accrue to self-interested managers at the expense of

[1] Cyert and March also discuss a second type of innovation. Organizations with less slack may come up with short-term innovations by necessity (problem-oriented innovation).

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the firm (Jensen 1986, Leibenstein 1969, Williamson 1963). Standard resource allocation (agency) models are consistent with this line of thinking (Antle and Eppen 1985). In these models, the cost of slack manifests itself in an interesting manner: To limit managerial slack (the manager's informational rents), it is sometimes optimal for the principal to reject a positive net present value project.

In this article, we extend the standard resource allocation model to incorporate both costs and benefits of slack. The cost of slack is the consumption of perquisites by the manager. The benefit of slack is that it can serve as a motivational tool: The possibility of increasing his own slack may encourage a self-interested manager to conduct a more thorough project search.[2] The importance of perquisites as an incentive device is often discussed in textbooks (e.g., Kaplan and Atkinson 1989). However, this role does not show up in the standard resource allocation models because the manager's effort in project search is unmodeled.

To highlight (and isolate) both the motivational benefit and the consumption cost of perquisites, we assume the manager receives a fixed salary as compensation.[3] Our focus is not on the compensation contract but instead on the resource allocation contract (a contract governing project approval and funding). In our model, a complete resource allocation contract would require the budget center to commit to the precise way in which it will make future resource allocation decisions. We think such contracts are not descriptive of the budgeting process in many firms. In practice, contracts are often situation-specific (delayed). For example, a manager involved in developing project proposals and subsequently implementing projects may be aware that resources will be rationed when project proposals are evaluated. However, at the time the manager is hired, it seems unlikely the budget center would specify how resources will be rationed at all future dates.[4] Delayed contracting can also arise as an optimal response to mutually observable but unverifiable information. (See the discussion at the end of the introduction and the extension section of the article.)

In this article, the resource allocation contract is offered by the budget center to the manager after the manager identifies a project. This timing of resource allocation decisions leads to a hold-up problem. A hold-up problem arises when one party incurs a cost in undertaking a productive activity that will be ignored in subsequent negotiations with other parties because the cost is sunk when the negotiations occur (Tirole 1986, Williamson 1975). As a result, the productive activity may not be undertaken.

The delay (incompleteness) in contracting highlights the motivational role of slack and its implications for information system design. In particular, the choice of an information system can be used to mitigate the hold-up problem. This is because the information system is installed before the manager chooses his search effort in our model. As Demski (1994, p. 431) writes, "being able to evaluate presumes we took care to lay in the requisite information in the first place." We study information system choice in terms of the timing of information (when the system produces information) and the fineness of monitoring (how much public information is produced).

In our model, information (both monitored information and the manager's report of his private information) is generated either before production (early) or after production (late). We provide conditions under which an information system that produces late information and coarse monitoring is preferred by the budget center to an information system that produces early information and fine monitoring. In contrast, if a complete contract could be written on the date the manager is hired, it would be optimal to choose early information over late information and finer monitoring over coarser monitoring.

[2] In our model, the level of slack does not motivate project search; the change in slack (incremental slack) motivates project search. In contrast, the traditional discussion of the benefits and costs of slack focuses on the level of slack.

[3] We are not suggesting that managerial compensation contracts are devoid of incentive clauses. However, employees sometimes prefer a combination of perquisites and compensation to receiving either just compensation or just perquisites (for example, because of tax considerations). On this point, see Chapter 11 in Brickley et al. (1997). In such a world, it is reasonable to expect some incentives to be provided through slack instead of through compensation. The fixed salary assumption allows us to concentrate on the incentive effect of slack.

[4] A complete resource allocation contract in conjunction with a fixed salary brings us back to square one—there is no difference between this setup and allowing for compensation contracts.

By installing an information system that produces late information, the budget center effectively commits to letting the manager earn slack from the implementation of the project.[5] Under early information, slack can be reduced by lowering production when the manager reports that production is more costly than in other states. This is not possible under late information, since production is undertaken before any information is realized. The cost of late information is the additional slack the manager obtains. The benefit of late information is that the manager is motivated to be more diligent in project search.

A familiar game-theoretic idea is that there are games in which a player can gain by limiting his own information if the opponents know he has done so, because this can induce the opponents to play in a desirable fashion. In agency models that study this problem, information is usually reduced by coarsening it. The usefulness of coarse monitoring as a commitment device in models of the hold-up problem has been studied in Sappington (1986) and Riordan (1990).[6,7] Relative to their papers, our article adds a timing perspective. Delaying information revelation may help alleviate the hold-up problem. Accounting information, which is sometimes criticized for being late, may prove to be valuable in such circumstances.

Turning now to the fineness dimension of information system design, the standard explanations for less-than-perfect monitoring are that perfect monitoring would be prohibitively costly and would make those being monitored feel distrusted to the point of reducing motivation.[8] We provide an additional explanation. Coarser monitoring enables the budget center to commit to letting the manager earn enough slack that he is motivated to conduct a more thorough project search.

Under the parameters established in our proposition and its corollary, either coarsening information or delaying information does not mitigate the hold-up problem but both coarsening and delaying information does. Moreover, the slack provided by simultaneously coarsening and delaying information is not simply the sum of the slack provided under coarsened information alone and delayed information alone—there is an interaction effect between the fineness and timing of information.

In an extension section, we make two points about the design of the reporting system made available to the manager for conveying his private information. First, it is sometimes optimal to use a mix of imperfectly monitored and self-reported information rather than relying on perfectly monitored information alone or on self-reported information alone. Second, the center sometimes prefers coarse (self-reported) budgets to detailed budgets.

As far as we are aware, the design of the manager's reporting system has received relatively little attention in models in which the principal's ability to commit is limited.[9] Our modeling of the information system design problem is intended to present a view of accounting as a way of capturing, manipulating, processing, and formatting both verified (monitored) and unverified (self-reported) financial messages that are passed around in organizations. Having to fit financial

[5] Information timing is also studied in Demski and Sappington (1986). In their paper, the principal can sometimes reduce the cost of motivating an agent to acquire information by delaying the release of other information.

[6] Papers that study the hold-up problem's implications for accounting include Baiman and Rajan (1995), Edlin and Reichelstein (1995), and Sahay (1997). The broader theme of information system design as a commitment device has been studied in, for example, Baiman (1975), Cremer (1995), Aghion and Tirole (1997), and Arya et al. (1997b).

[7] In Sappington (1986), Riordan (1990), and our paper, information system design is a costly substitute for commitment. In contrast, in an oligopoly setting with capacity investment, Krishnan and Röller (1993) show that limited commitment can make an incumbent better off. While most papers assume irreversible investment in capacity (strong commitment by the incumbent), Krishnan and Röller assume that capacity can be sold to an entrant in the same industry (an intermediate level of commitment). Resalable capacity gives the incumbent an additional source of power—the price at which to resell capacity.

[8] As Ijiri (1983, p. 80) writes: "[T]he most serious danger involves the impact of overaccountability on the motivation of the accountor. Requiring a minute-by-minute recording of one's activities, to take an extreme case, is the surest way of converting motivated managers to robots. This is because the feeling of being trusted is often essential to motivation, and requirements of recording and reporting stem, more or less, from the lack of complete mutual trust."

[9] A paper in which the design of both the monitoring system and the manager's reporting system is studied is Arya et al. (1997a). In Arya et al. (1997a), there is no hold-up problem; the role of coarsened information is to eliminate slack, whereas in this paper it is to create slack.

messages into the accounting system can be a way of restricting communication from managers.

In a third extension, we take a closer look at the delayed contracting assumption. We present an example in which information about the productive environment is generated during the project search phase. This information is mutually observed by the budget center and the manager but cannot be verified by a court and, hence, cannot be contracted on. For example, this may be information that only the manager and the budget center can properly interpret because of their relation-specific expertise.[10] In our example, delayed contracting is optimal. Delayed contracting allows the parties to condition the contract on the realization of the unverifiable information.

The remainder of the paper is organized into four sections. Section 2 presents the model. Section 3 presents our results on the optimal timing of information and the optimal amount of monitoring. Section 4 studies extensions, and §5 provides concluding remarks.

2. Model

We model a firm whose participants are a risk-neutral budget center (principal) and a risk-neutral manager (agent). The manager receives as compensation a fixed salary, s, $s \geq 0$. One of the activities the manager performs is to search for and identify the best possible project. The effectiveness of the search depends on a personally costly action, a, the manager privately undertakes, $a \in \{a_L, a_H\}$, $a_L < a_H$. For simplicity, set $a_L = 0$. The search stage is followed by ratification and implementation stages.

During the ratification stage, the budget center decides on the project's scale (production level), x, $x \in [0, X]$. The revenue generated by x units of production is \$$x$. The cost function is linear, and there is no fixed cost: The cost of producing x units is cx, $c \in \{c_1, c_2, c_3\}$, $c_1 < c_2 < c_3$. For any level of production, the project is profitable: $c_3 < 1$.

The transfer from the budget center to the manager is denoted by t. All funds for investment are provided by the budget center: $t - cx \geq 0$.[11] The contract governing project implementation, i.e., the firm's resource allocation contract, is denoted by $\{x, t\}$.

The manager's utility over wealth and effort is $s + t - cx - a$. That is, the manager likes salary and slack $(t - cx)$ and is effort averse. The budget center's utility is $x - s - t$.

If the manager chooses a_H, denote the (common knowledge prior) probability of c_i by p_i; if the manager chooses a_L, the probability is denoted by p'_i, $i = 1, 2, 3$. The distribution under a_H first-order stochastically dominates the distribution under a_L: $p_1 \geq p'_1$ and $p_1 + p_2 \geq p'_1 + p'_2$, with at least one of the two inequalities being strict. Hence, a_H can be interpreted as a more productive act than a_L.

Before the project search stage begins, the budget center publicly installs an information system. There are two key characteristics of the information system: the timing of information and the extent (fineness) of monitoring. The information system provides either early or late information. If an early information system is chosen, information (both monitored information and the manager's report of his private information) is generated between the project search and ratification stages. The information is regarding the cost of production that is yet to be undertaken—early information refers to pre-production information. If a late information system is chosen, information is generated at the end of the implementation stage. The information is regarding the cost of production that has already occurred—late information refers to post-production information.

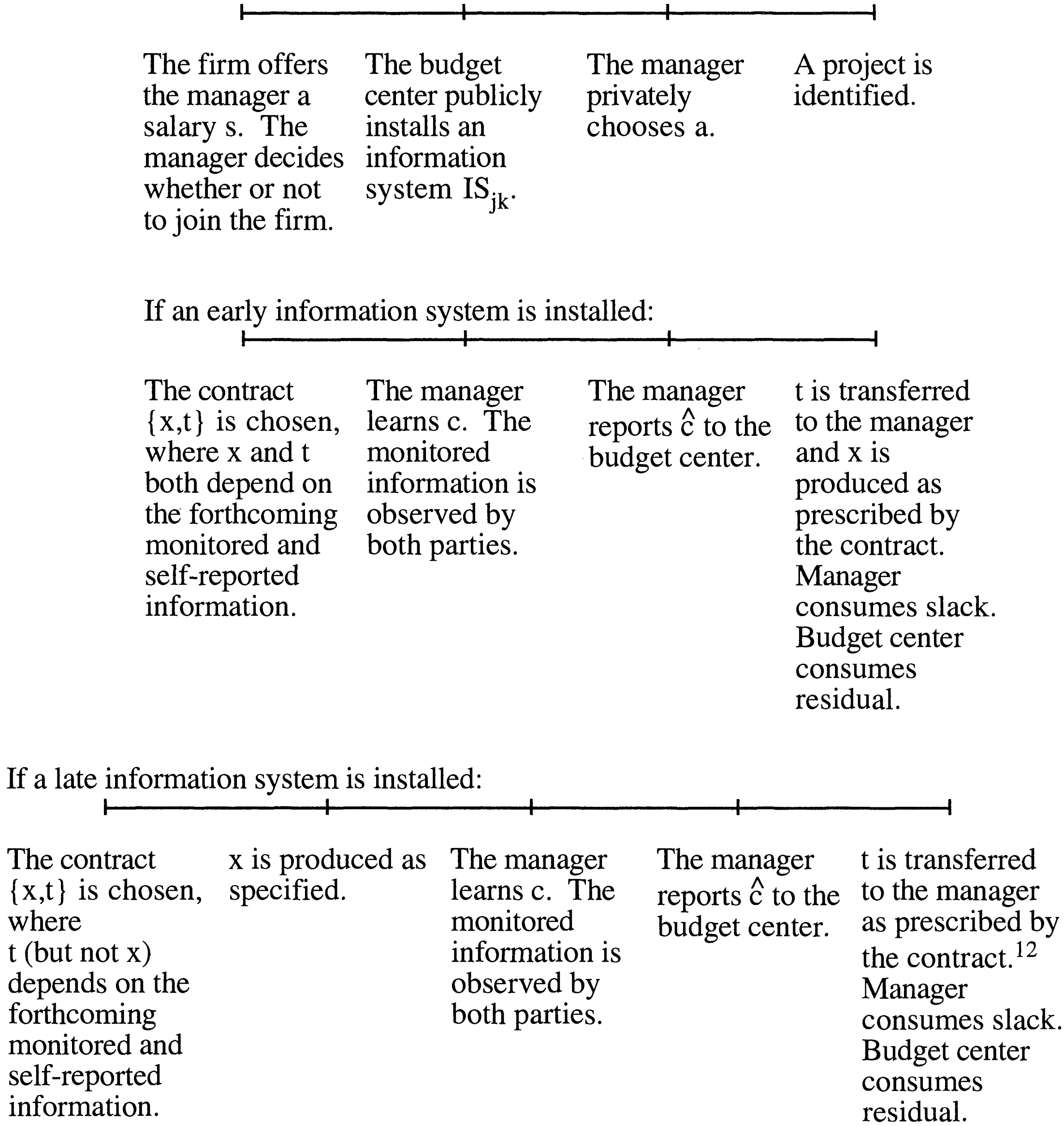
We consider three levels of monitoring. Denote $\{c_1, c_2\}$ by π_L and $\{c_3\}$ by π_H. The information system provides either no monitoring, imperfect monitoring (whether the cost is an element of π_L or π_H), or perfect monitoring (c). Under all information systems, the manager learns c and is asked to submit a cost report $\hat{c}$ to the budget center.

An information system is denoted by IS_{jk}. The first

[10] For examples of papers in which information is mutually observable but not contractible, see Hermalin and Katz (1991) and Lewis and Sappington (1991).

[11] Our linear model combines a moral hazard story with respect to project search and a perquisites consumption story with respect to project implementation. The former builds on the work of Lambert (1986), while the latter (and the linear formulation) builds on the work of Antle and Eppen (1985), Antle and Fellingham (1990, 1995), Fellingham and Young (1990), and Harris et al. (1982).

Figure 1 **Time-Line**



Note. The "12" in the last cell in Figure 1 refers to Footnote 12 that is presented below.

subscript denotes the timing of information: $j = E, L$, where E denotes early information and L denotes late information. The second subscript denotes the amount of monitoring: $k = N, I, P$, where N denotes no monitoring, I denotes imperfect monitoring, and P denotes perfect monitoring.

While the information system must be installed

[12] We require only that the transfer to the manager cover the cost of production, whether the transfer occurs before or after production. If instead the center had to provide for the cost of production before production takes place, this constraint would lead to the same conclusions we obtain, but the presentation of the results would be more cumbersome. Under this alternative constraint, the center would provide an initial transfer to the manager to cover the cost of production and the allocation contract would specify the amount the manager has to return to the center subsequent to production as a function of all gathered information.

before the project search stage, the resource allocation contract is not decided on until the ratification stage. The form of the contract depends on the information system installed. If an early system is installed, $\{x, t\}$ specifies production levels and transfers from the budget center to the manager as a function of all information provided. If a late information system is installed, only the transfer can be conditioned on the information provided. Figure 1 is intended to clarify the sequence of events.

We assume the budget center and manager will play as follows. The budget center chooses a salary level and an information system (prior to the manager's search activity) and a resource allocation contract (subsequent to the manager's search activity) to maximize her expected utility, correctly anticipating the manager's response. Given the information system chosen by the budget center, the manager chooses a level of search activity that maximizes his expected utility, correctly anticipating the allocation contract the budget center will subsequently specify. Given the information system, his own act, and the resource allocation contract, the manager chooses a reporting strategy that maximizes his expected utility.

The equilibrium played by the budget center and manager is required to be individually rational in the following sense. The manager must find it worthwhile to accept employment with the firm instead of joining another firm. To focus on the role of slack, we assume the manager's reservation utility (what he could earn in the employment of another firm) is zero. This implies the manager's salary is also zero.[13] The manager can join the firm and choose a_L $(=0)$ and receive a utility of $s + t - cx - a_L = t - cx \geq 0$. (Recall the resource allocation contract is required to satisfy $t - cx \geq 0$.) Of course, the manager may wish to choose a_H instead, and the budget center may design the information system to motivate a_H. Given that the manager's compensation is a fixed salary and the resource allocation contract is not decided upon until after the project search is complete, the information system is the only potential means available to motivate a_H.

[13] If the reservation utility (or a_L) were sufficiently large, a nonzero salary would be needed to satisfy individual rationality.

3. Information System Choice

The information system design problem is influenced by the dual role for slack in our model. On one hand, by not installing the perfect monitoring technology, the budget center may be forced to provide slack to the manager during the project implementation stage. On the other hand, the budget center may actually benefit from slack if it motivates the manager to conduct a more diligent project search. In this section, we explore how this tradeoff affects the budget center's choice of an information system.

We begin the process of identifying an optimal information system with the following lemma, which effectively reduces from six to two the number of information systems we need to consider.

LEMMA.
(i) IS_{LP} *and* IS_{EP} *are equivalent in terms of payoffs.*
(ii) *Neither* IS_{LN} *nor* IS_{EN} *is optimal.*
(iii) *If* IS_{EI} *is optimal, then so is* IS_{LI}.

PROOF.
(i) Under both IS_{LP} and IS_{EP}, the budget center learns c and there is no use for self-reports. Further, since production is always profitable ($c_3 < 1$), the budget center optimally sets $x = X$ and $t = cX$ under both systems. This limits the manager's slack to 0. Once the manager observes that the budget center has installed the perfect monitoring technology, he knows all benefits to his search activity in identifying a desirable project will be expropriated by the budget center. Hence, the manager chooses a_L under either information system. The manager's expected utility is 0, and the budget center's expected profit is $X(1 - \Sigma_i p_i' c_i)$. The two systems are equivalent in terms of the payoffs they provide to the budget center and the manager. (Since IS_{LP} and IS_{EP} result in identical production levels and transfers, we will refer to them as IS_P throughout the remainder of the paper.)

(ii) IS_{LN} can never be optimal because the budget center prefers IS_P to IS_{LN}. The optimal contract under IS_{LN} is to set $x = X$ and $t = c_3X$. The budget center's expected profit is $X(1 - c_3)$, which is less than $X(1 - \Sigma_i p_i' c_i)$, her expected profit under IS_P.

IS_{EN} can never be optimal because the budget center prefers installing either IS_P or IS_{LI}. The optimal contract under IS_{EN} involves a hurdle rate: If $\hat{c} \leq k$, production is X and the transfer to the manager is kX. If $\hat{c} > k$, production is 0, and the transfer to the manager is 0. Suppose $k = c_1$. Under this contract, the manager earns no rents and, hence, chooses a_L. Installing IS_P leads to the manager choosing the same act but has the added advantage of allowing profitable production to occur when the cost is c_2 or c_3. Suppose $k = c_2$. Installing IS_{LI} is now preferred. The optimal contract under IS_{LI} is to set $x = X$ and $t = c_2X$ when π_L is observed and $t = c_3X$ when π_H is observed. The manager gets exactly the same rents under IS_{LI} and IS_{EN} (when $k = c_2$) and so chooses the same act. The only difference is that under IS_{LI} the budget center also obtains profitable production when $c = c_3$. Suppose $k = c_3$. In this case, IS_{EN} and IS_{LN} provide the same profits to the budget center. As we argued earlier, the budget center prefers IS_P to IS_{LN}, and, hence, IS_P is also preferred to IS_{EN}.

(iii) Under IS_{EI}, the optimal contract is $x = X$ and $t = c_3X$ if π_H is observed and a hurdle rate contract (k is c_1 or c_2) if π_L is observed. If $k = c_1$, then IS_{EI} cannot be optimal. The budget center is better off installing IS_P. This is because under both IS_{EI} (with $k = c_1$) and IS_P, the manager earns zero slack and, hence, chooses a_L. Under IS_P, the budget center obtains profitable production when c_2 occurs that is forgone under IS_{EI}. If $k = c_2$, the same production and transfer occur in each state under both IS_{EI} and IS_{LI}. IS_{EI} (with $k = c_2$) and IS_{LI} are equivalent. □

Having narrowed our search for an optimal information system to either IS_P or IS_{LI}, the following proposition provides conditions under which IS_{LI} is (at least weakly) preferred to IS_P. If the manager chooses a_L under IS_{LI}, the budget center will strictly prefer IS_P because of reduced slack when c_1 is realized—under IS_P the transfer to the manager is c_1X, while under IS_{LI} the transfer to the manager is c_2X. It is optimal to install IS_{LI} instead of IS_P if and only if (1) it is incentive compatible for the manager to choose a_H when IS_{LI} is installed and (2) the budget center's expected profit under a_H and IS_{LI} is greater than under a_L and IS_P. These conditions correspond to (C.1) and (C.2) in the proposition.

Proposition. *IS_{LI} is optimal if and only if the following conditions are satisfied*:

(C.1) $p_1(c_2 - c_1)X - a_H \geq p'_1(c_2 - c_1)X - a_L$.

(C.2) $(p_1 + p_2)(1 - c_2) + p_3(1 - c_3) \geq p'_1(1 - c_1) + p'_2(1 - c_2) + p'_3(1 - c_3)$.

Proof. The optimal contract under IS_{LI} is $x = X$ and to set $t = c_2X$ when π_L is observed and to set $t = c_3X$ when π_H is observed. Under this contract, the manager earns rents only when $c = c_1$. The manager chooses a_H instead of a_L if and only if

$$p_1(c_2 - c_1)X - a_H \geq p'_1(c_2 - c_1)X - a_L. \quad (1)$$

This is (C.1). Given the manager chooses a_H, the budget center's expected profit under IS_{LI} is:

$$(p_1 + p_2)(1 - c_2)X + p_3(1 - c_3)X. \quad (2)$$

The optimal contract under IS_P is $x = X$ and $t = cX$. The manager chooses a_L, and the budget center's expected profit is:

$$p'_1(1 - c_1)X + p'_2(1 - c_2)X + p'_3(1 - c_3)X. \quad (3)$$

The budget center prefers IS_{LI} to IS_P if and only if her expected profit is greater under the former, i.e., (2) > (3). This is (C.2). □

The reason we did not consider IS_{EI} in the proof of the proposition is part (iii) of the lemma: If IS_{EI} is optimal, then so is IS_{LI}. IS_{LI} is uniquely optimal if and only if IS_{LI} is strictly preferred to both IS_P and IS_{EI}. This is true if and only if (C.1) holds, (C.2) holds as a strict inequality, and the manager choosing a_H and the budget center setting $k = c_2$ are not best responses to each other under IS_{EI}. The last condition corresponds to (C.3) in the following corollary.

Corollary. *IS_{LI} is uniquely optimal if and only if* (C.1) *holds,* (C.2) *holds as a strict inequality, and the following condition holds*: (C.3) $p_1(1 - c_1) > (p_1 + p_2)(1 - c_2)$.

Proof. From the proof of the proposition, it is clear that (C.1) and strict (C.2) are both necessary and sufficient for IS_{LI} to be strictly preferred to IS_P. To see that (C.3) is necessary for IS_{LI} to be uniquely optimal, assume (C.3) is not satisfied. There are two cases to consider. If IS_{LI} motivates a_H, then IS_{EI} also motivates a_H since a violation of (C.3) implies that the same contract is offered under both information systems. Under both IS_{LI} and IS_{EI}, the center would always accept the project and transfer c_2X to the manager when π_L is realized and c_3X when π_H is realized—IS_{LI} is not uniquely optimal. If IS_{LI} motivates a_L, then IS_{LI} is not uniquely optimal since IS_P is strictly preferred. Hence, (C.3) is necessary for IS_{LI} to be uniquely optimal.

It remains to be shown that the corollary's conditions are sufficient for IS_{LI} to be strictly preferred to IS_{EI}. Consider the manager's action choice under IS_{EI}. The manager must be choosing a_H with probability less than 1. If the manager were to choose a_H with probability 1, then from (C.3) the center's best response would be to offer the rationing contract (set $k = c_1$) when π_L is realized, which provides the manager with no slack and, hence, no incentive to choose a_H. If the manager were to choose a_L with probability 1, then from (C.1) and strict (C.2), IS_{LI} is strictly preferred to IS_P, which is strictly preferred to IS_{EI}. If the manager is randomizing between a_L and a_H, then the center's best response is to offer either the slack contract (set $k = c_2$) with probability 1 when π_L is realized or to randomize between the slack contract and the rationing contract when π_L is realized. In the former case, the allocation is the same under IS_{EI} as under IS_{LI}, but the manager is choosing a_H less often than under IS_{LI}. Hence, the center strictly prefers IS_{LI} to IS_{EI}. In the latter case, the center is indifferent between the slack and the rationing contracts. Again, since the manager is choosing a_H less often under IS_{EI} than under IS_{LI}, the center strictly prefers IS_{LI} to IS_{EI}. □

We now present an example to illustrate our result.

Example 1. $X = 100$, $a_L = 0$, $a_H = 10$, $c_1 = 0.3$, $c_2 = 0.5$, $c_3 = 0.9$, $p_1 = 0.8$, $p_2 = 0.1$, $p_3 = 0.1$, $p_1' = 0.1$, $p_2' = 0.1$, and $p_3' = 0.8$.

These parameters satisfy the conditions of the corollary, and, hence, IS_{LI} is uniquely optimal. Nevertheless, it may be useful to consider each of the six information systems separately.

IS_{LP} and $IS_{EP}(IS_P)$. Under perfect monitoring, the optimal contract is: $x = 100$ and $t = 100c$. This contract drives slack to zero. Anticipating the contract that will be offered, the manager's best response is to choose a_L. Any benefits of choosing higher effort accrue only to the budget center. The budget center's expected profit is $0.1(100 - 30) + 0.1(100 - 50) + 0.8(100 - 90) = 20$; the manager's expected utility is 0.

IS_{LI}. Under late information and imperfect monitoring, the optimal contract is: $x = 100$, $t(\pi_L, \hat{c}) = 50$, and $t(\pi_H, \hat{c}) = 90$. The manager chooses his search effort to maximize his expected slack less disutility of effort. If he chooses a_L, he obtains $0.1(50 - 30) - 0 = 2$; if he chooses a_H, he obtains $0.8(50 - 30) - 10 = 6$. The manager's best response is to choose a_H. The budget center's expected profit is $0.8(100 - 50) + 0.1(100 - 50) + 0.1(100 - 90) = 46$; the manager's expected utility is 6.

IS_{EI}. Under early information and imperfect monitoring, the equilibrium is in mixed strategies. The mixed strategy equilibrium is calculated as follows. Assume the manager adopts a strategy that has him choosing a_L with probability q and a_H with probability $(1 - q)$. Assume the budget center adopts a strategy as follows. Given π_H, the budget center offers the contract $x(\pi_H, \hat{c}) = 100$ and $t(\pi_H, \hat{c}) = 90$. Given π_L, the budget center offers the rationing contract (sets $k = c_1$) with probability r and the slack contract (sets $k = c_2$) with probability $(1 - r)$. (Recall, k denotes the hurdle rate above which projects are not funded.) Given the common prior and the manager's strategy, the probability of c_1, c_2, and c_3 is $0.1q + 0.8(1 - q)$, 0.1, and $0.8q + 0.1(1 - q)$, respectively.

Given π_L, the center must be indifferent between offering the rationing and the slack contracts. Given π_L, the center's expected profit under the rationing contract is $[0.1q + 0.8(1 - q)]/[0.1q + 0.8(1 - q) + .1](100 - 30)$ and under the slack contract is 50. Equating the two expected profits yields $q = 11/14$.

The manager must be indifferent between choosing a_L and a_H. If the manager chooses a_L, his expected utility is $0.1(1 - r)(20)$. If the manager chooses a_H, his expected utility is $0.8(1 - r)(20) - 10$. Equating the two expected utilities yields $r = 2/7$.

Under the mixed strategy, the center's expected profit is $(11/14)[0.2(50) + 0.8(10)] + (3/14)[0.9(50) + 0.1(10)] = 24$. The manager's expected utility is $(11/14)[0.1(5/7)(20)] + (3/14)[0.8(5/7)(20) - 10] = 1\frac{3}{7}$.

IS_{LN}. Under late information and no monitoring, the optimal contract is: $x = 100$ and $t(\hat{c}) = 90$. The manager's best response is to choose a_H. The budget

center's expected profit is $(100 - 90) = 10$; the manager's expected utility is 42.

IS_{EN}. Under early information and no monitoring, the equilibrium is in mixed strategies. With probability 16/21, the budget center offers the contract $x(\hat{c} = c_1) = 100$, $t(\hat{c} = c_1) = 30$, and $x = t = 0$ otherwise. With probability 5/21, the budget center offers the contract $x(\hat{c}) = 100$ and $t(\hat{c}) = 90$. With probability 46/49, the manager chooses a_L. With probability 3/49, the manager chooses a_H. The budget center's expected profit is 10; the manager's expected utility is $2\frac{8}{21}$.

We summarize below the outcome under the alternative information systems.

Information System	Budget Center's Expected Profit	Manager's Expected Utility	Project Search Effort Level
IS_{LP} and IS_{EP}	20	0	a_L
IS_{LI}	46	6	a_H
IS_{EI}	24	$1\frac{3}{7}$	mixed strategy
IS_{LN}	10	42	a_H
IS_{EN}	10	$2\frac{8}{21}$	mixed strategy

By both delaying and coarsening information, the budget center is able to motivate the manager to conduct a diligent project search. There is an interaction between these two aspects of information system design: The slack provided to the manager by delaying information alone (IS_{LP}) is 0; the slack provided to the manager by coarsening information alone (IS_{EI}) is $3\frac{4}{7}$; the slack provided to the manager by delaying and coarsening information (IS_{LI}) is 16.[14]

4. Extensions

4.1. The Optimal Means of Eliciting Information

In Example 1, an information system (IS_{LI}) that provides late information and coarse monitoring is optimal. Under IS_{LI}, the owner makes no use of self-reported information from the manager. This is because we studied a one-period model—the manager's report is submitted too late to be of any use. In other settings, the optimal information system sometimes makes nontrivial use of a mix of self-reported and monitored information. That is, the budget center sometimes prefers a system under which some information is elicited through self-reports instead of monitoring (even when monitoring is costless).

To see this, reconsider Example 1. Assume only early information is available.[15] Recall that IS_{EP} tracks perfectly monitored information, IS_{EN} tracks only self-reported information, and IS_{EI} tracks a mix of imperfectly monitored information and self-reported information.

From the table at the end of §3, the budget center prefers installing the mixed system to installing a system that tracks only perfectly monitored information or only self-reported information. Moreover, the optimal contract offered under the mixed system makes nontrivial use of both the monitored and self-reported information. The use of the mixed system allows the budget center to motivate the manager to conduct a more diligent search: Under perfect monitoring, the manager never chooses a_H; under self-reported information and no monitoring, he chooses a_H with probability 3/49; and under the mixed system, he chooses a_H with probability 3/14.

4.2. Detailed Versus Coarse Budgets

In the previous sections of the article, we varied the coarseness of the monitoring system but not the reporting system the manager uses to report to the budget center. The reporting system provided fine information in the sense that the manager was asked to submit detailed (precise) cost budgets. We next show that it is sometimes optimal to coarsen the manager's reporting system.

We study an example in which all information is early and there is no monitoring. The budget center can install either a reporting system that allows the manager to submit a detailed budget $\hat{c} \in \{c_1, c_2, c_3\}$ or a reporting system that allows the manager to submit only a coarse budget $\hat{\pi} \in \{\pi_L, \pi_H\}$. (Recall $\pi_L = \{c_1, c_2\}$ and $\pi_H = \{c_3\}$.)

EXAMPLE 2. $X = 100$, $a_L = 0$, $a_H = 5$, $c_1 = 0.4$, c_2

[14] The slack numbers differ from the manager's expected utility numbers since the latter are calculated net of effort. For example, under IS_{EI}, slack is $3\frac{4}{7}$, and the disutility from effort is (11/14) (0) + (3/14) (10) = $2\frac{1}{7}$. The difference in these two numbers is the manager's expected utility.

[15] The same point can be made under late information in a two-period model.

$= 0.75$, $c_3 = 0.91$, $p_1 = \frac{1}{3}$, $p_2 = \frac{1}{3}$, $p_3 = \frac{1}{3}$, $p'_1 = \frac{1}{6}$, $p'_2 = \frac{1}{6}$, and $p'_3 = \frac{2}{3}$.

Suppose the detailed budgeting system is installed. If the manager is choosing a_L, the budget center's best response is to accept the project if and only if the reported cost is 0.4, since $(1/6)(100 - 40) > (1/6 + 1/6)(100 - 75)$ and $(1/6)(100 - 40) > (100 - 91)$. The manager's best response to this contract is to choose a_L, since under this contract he does not obtain any slack. Hence, the manager choosing a_L and the budget center funding the project if and only if the reported cost is 0.4 are best responses to each other. There are no other equilibria (in either pure or mixed strategies), since the budget center strictly prefers to set the cutoff cost at 0.4 whether the manager is choosing a_L or a_H. The budget center's expected profit under detailed budgeting is $(1/6)(100 - 40) = 10$.

Suppose instead the coarse budgeting system is installed. If the manager is choosing a_H, the budget center's best response is to accept the project if and only if the reported cost is π_L, since $(1/3 + 1/3)(100 - 75) > (100 - 91)$. The manager's best response to this contract is to choose a_H, since $(1/3)(75 - 40) - 5 = 6\frac{2}{3} > (1/6)(75 - 40) - 0 = 5\frac{5}{6}$. Hence, the manager choosing a_H and the budget center funding the project if and only if the reported cost is π_L are best responses to each other. There are no other equilibria, since the manager strictly prefers to choose a_H whether the budget center sets the cutoff at π_L or π_H. The budget center's expected profit under coarse budgeting is $(2/3)(100 - 75) = 16\frac{2}{3}$.

The intuition for why coarse budgeting is preferred to detailed budgeting is similar to why coarse monitoring is preferred to fine monitoring in that they are both means of alleviating the hold-up problem. Installing a coarse information system is a way of assuring the manager that he stands to profit if he conducts a diligent project search. The intuition is different in that, with monitored information, coarseness results in a direct increase in the manager's slack. Under self-reported information, coarseness makes the budget center less able to trade off the benefit of efficient production with the cost of slack, which can indirectly lead to increased slack.

In the theory of centralization/decentralization, an important idea is that information should be linked to decision rights (Hayek 1945, Jensen and Meckling 1992). If it is relatively easy to get information to a central manager with the decision rights and for the central manager to process the information, communication channels should be established for such communication—centralization is optimal. Otherwise, decentralization is optimal.[16] Budgeting is both a method of delegating decision rights (authorizing lower-level managers to spend money as they see fit as long as the budget is not exceeded) and a device for communicating information to superiors (see Jensen and Meckling 1992, p. 266, and Zimmerman 1997, ch. 6).

In our model, the manager is endowed with decision rights for project initiation and implementation, whereas the budget center is endowed with decision rights for project ratification and monitoring. Decision rights and information are linked, as in Jensen and Meckling (1992), in the sense that some but not all information is communicated to the budget center. Delayed resource allocation decisions make limited communication optimal even when there are no (exogenous) costs associated with communicating or processing information.

4.3. On the Optimality of Delayed Contracting

Up to this point, we have assumed that contracts governing resource allocation are written subsequent to the manager's project search. In this subsection, we present an example in which writing such a delayed contract is preferred to writing a contract prior to project search.[17]

In our example, we assume some information is generated during the project search phase that is mutually observed by the manager and the budget center but that is not verifiable by a court and, hence, cannot be contracted on. The courts may be unable to verify this information because it can be properly interpreted only with the relation-specific expertise of the manager and the budget center. We assume the information system in place provides only self-reported information and these reports are submitted

[16] Emphasizing bounded rationality as a behavioral principle, Herbert Simon argued that it can create a demand for decentralization (see, for example, March and Simon 1958 and Simon 1955).

[17] We thank the referees for encouraging us to think more carefully about the motivation for delayed contracting.

prior to production. The question is: Should the resource allocation contract be written prior to project search or subsequent to project search?

EXAMPLE 3. During the project search phase, both parties observe an unverifiable signal θ, $\theta \in \{\theta_B, \theta_G\}$. θ_B and θ_G are equally likely. To keep things simple, there are only two possible costs, $c \in \{0.8, 0.9\}$. If θ_B is realized, the probability distribution over costs depends on the manager's effort. If a_L is chosen, $c = 0.8$ with probability 0.1; if a_H is chosen, $c = 0.8$ with probability 0.4. If θ_G is realized, $c = 0.8$ with probability 1, irrespective of the manager's effort. (θ_G is the good state from the principal's perspective.) Assume $X = 100$, $a_L = 0$, and $a_H = 0.1$.

Contract Written Prior to Project Search. The optimal contract is: $x(\hat{c} = 0.8) = 100$, $t(\hat{c} = 0.8) = 80\frac{2}{3}$, and $x(\hat{c} = 0.9) = t(\hat{c} = 0.9) = 0$. Under this "adjusted rationing" contract the manager chooses a_H: $(0.5)(0.4)(80\frac{2}{3} - 80) + (0.5)(80\frac{2}{3} - 80) - 0.1 \geq (0.5)(0.1)(80\frac{2}{3} - 80) + (0.5)(80\frac{2}{3} - 80)$.[18] The manager's expected utility is 11/30. The principal's expected profit is $(0.5)(0.4)(100 - 80\frac{2}{3}) + (0.5)(100 - 80\frac{2}{3}) = 13\frac{8}{15}$.[19]

Contract Written After Project Search. Depending on the realization of θ, a different contract is offered to the agent. If $\theta = \theta_B$, the optimal contract is the slack contract: $x(\hat{c}) = 100$ and $t(\hat{c}) = 90$. If $\theta = \theta_G$, the optimal contract is the rationing contract: $x(\hat{c} = 0.8) = 100$, $t(\hat{c} = 0.8) = 80$, and $x(\hat{c} = 0.9) = t(\hat{c} = 0.9) = 0$. Anticipating these contracts, the manager chooses a_H: $(0.5)(0.4)(90 - 80) - 0.1 \geq (0.5)(0.1)(90 - 80)$. The manager's expected utility is 1.9. The principal's expected profit is $(0.5)(100 - 90) + (0.5)(100 - 80) = 15$.

Note that both the principal and the agent are better off under delayed contracting. Delayed contracting enables the parties to take advantage of unverifiable information. Delayed contracting can be reinterpreted as writing a contract prior to project search but allowing for the possibility of renegotiation. In our setting, the budget center would specify the rationing contract as the status quo. When $\theta = \theta_B$, this contract is renegotiated to the slack contract. See Hermalin and Katz (1991) for a paper in which renegotiation is used to take advantage of unverifiable information.

[18] This is the manager's incentive compatibility constraint; $t(\hat{c} = 0.8)$ is determined by solving the incentive compatibility constraint as an equality.

[19] Motivating a_L using a rationing contract or motivating a_H using a slack contract provides the principal with a lower payoff than she obtains under the adjusted rationing contract.

5. Concluding Remarks

This article combines many of the elements of the budget problem. These elements are motivation for managers to conduct searches for capital projects, information production by the budget center, the fineness of information produced, the timing of information produced, and budgeting systems that process a mix of management-generated and monitored information.

Accounting systems incorporate both verified and unverified information: A firm's cash balance is easily verified by comparing it to bank statements, sales forecasts are typically not verified, and accounting earnings have components that are verified to differing extents. Also, accounting provides information that is aggregated (coarse) and historical (late). In our model of the hold-up problem in capital budgeting, these features of information can turn out to be optimal.

In the principal-agent literature, two distinct approaches have been taken to studying informational boundaries within organizations. First, because of limited communication channels (blocked communication), decentralized decision making can be optimal (as in Melumad et al. 1995). Second, when the principal is limited in her ability to commit, restricting the information made available to her can be optimal (as in Aghion and Tirole 1997, Cremer 1995, Riordan 1990, Sappington 1986, and this article). The first approach has been used to develop insights about the use of responsibility centers (Melumad et al. 1992), transfer pricing (Vaysman 1996), and hierarchical budgeting (Mookherjee and Reichelstein 1997). The second approach could also be used to develop insights about such practices.[20]

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