The Royal Veterinary and Agricultural University
Food and Resource Economic Institute

A UNIVERSITY OF LIFE SCIENCES

Unit of Economics Working Papers 2001/9

Incentive Problems and Investment Timing Options.

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August 27, 2001

[1] We thank Anil Arya, Stan Baiman, John Fellingham, Hans Frimor, Will Goetzmann, David Green, Mike Maher, Steve Ross, Martin Walker, Mark Wolfson, Rick Young and workshop participants at Columbia University, the Copenhagen Business School, Glasgow University, the University of Manchester, Northwestern University, Ohio State University, Stanford Summer Research Camp, University of Waterloo, the Yale School of Management and two anonymous referees for helpful comments on earlier versions of this paper.

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Abstract

We characterize optimal investment and compensation strategies in a model of an investment opportunity with managerial incentive problems, caused by asymmetric information over investment costs and the manager's desire to consume slack, and flexibility over the timing of its acceptance. The flexibility over timing consists of the opportunity to invest immediately, delay investment for one period, or not invest at all. The timing option provides an opportunity to invest when circumstances are most favorable. However, the timing option also gives the manager an incentive to influence the timing of the investment to circumstances in which he gets more slack.

Under the assumption that investment costs are distributed independently over time, the optimal investment policy consists of a sequence of target costs, below which investment takes place and above which it does not.

The timing option reduces optimal cost targets, relative to the case when no timing option is present. The first cost target is lowered because the compensation function calls for the payment of an amount equal to the manager's option to generate future slack, should investment take place. This increases the cost of

investing at the first opportunity, thus reducing its attractiveness. In order to ease the incentive problem at the initial investment opportunity, the second target cost is also lowered, even though no further timing options remain.

Making the additional assumption that costs are uniformly distributed, we generate additional insights. We find circumstances in which the probability of investing initially exceeds the probability of investing at the second opportunity, a result that is impossible in the first-best context. Second, we identify circumstances under which the initial target cost is increased by incentive effects. Third, we identify the conditions under which the option to wait is effectively shut down when incentive problems exist.

The implications of relaxing several key assumptions, such as investment cost independence, the owner's commitment to the manager and not to renegotiate, are explored.

0.1. Introduction

The purpose of this paper is to explore the effects of incentive problems, dispersed information and opportunities to time investment. Many modern theories of investment decision-making stress the flexibility embedded in investment opportunities. Embedded opportunities for flexibility are called *real options*. Real options include the opportunity to time the acceptance of an investment, to temporarily or permanently shut down a project subsequent to its acceptance, or to make adjustments to key operating parameters such as production levels. [1]

Amongst real options, perhaps the one that has attracted the most attention has been the opportunity to time the acceptance of an investment. Ross [1995, 101] states that '... when evaluating investments, optionality is ubiquitous and unavoidable.' Dixit and Pindyck [1994, 6] argue that '... irreversibility *and the possibility of delay* are very important characteristics of most investments in reality.' (emphasis added) The owner of the opportunity to time the acceptance of an investment opportunity is said to possess a *timing option*. For example, a shopping mall can be built on a parcel of real estate now or later, but not both. Investment in production facilities to exploit new technologies can be made now or later, but not both. These examples stress the mutual exclusivity of investing now or later.

The literature on decision-making about investments that include a timing option ignores incentives and information issues. This may not be so important for passive investments undertaken in market contexts. However, for investments undertaken within firms, where information may be dispersed among managers who also play a role in implementation, ignoring incentives and dispersed information does not seem wise. A lot of research on investment decision-making emphasizes the effects of incentive and information problems on both social welfare and optimal investment policies.[2] For example, in a single period model, Antle and Eppen [1985] show that limiting the information rents paid to a manager who possesses private information about an investment's profitability involves limiting investment by setting hurdle rates higher than the cost of capital.[3] Antle and Fellingham [1990] show how incentive problems can render optimal linking otherwise separate investment decisions that occur at two points in time.[4] Antle, Bogetoft and Stark [1999] and Arya and Glover [2000] are the analyses closest to ours. They focus on the advantages of combining investments into pools, which implicitly includes delaying investments. We know of no analyses, however, that directly address the interaction between incentive problems and the timing of the acceptance of investment opportunities. The purpose of this paper is to begin to fill this void.[5]

The effects of timing options on investment decisions are not clear when there are management control problems. In the presence of incentive problems, a timing option might benefit a manager intent on pursuing his or her self-interest at the expense of the interests of the owner, especially if the manager possesses private information relevant to the exercise of the timing option. Investigating how to control the managerial use of timing option flexibility then becomes of interest.

To investigate these effects, we analyze an investment opportunity that can be accepted at two possible points in time, if it is to be accepted at all. The owner of the project employs a manager to, if necessary, implement the project. We assume that the interests of the owner and manager are inextricably linked over the period covering the availability of the project and, hence, they are committed to each other. The manager possesses informational advantages over the owner of the project in terms of knowing precisely, at each point in time at which the investment opportunity can be accepted, the cost of implementing the project. The owner never has such precise knowledge. An incentive problem is present because (i) the manager has a preference for slack consumption; (ii) slack consumption represents a wasteful use of resources from the point of view of the owner; but (iii) the owner is unable to monitor the manager's slack consumption. Slack is acquired by the manager as a result of being given more resources by the owner than are necessary to implement the project. Given the set-up sketched above, our analysis can examine the impact of incentive problems on the timing of investment opportunities.

The remainder of the paper is organized as follows. Section 2 presents the model. Section 3 analyzes the model's solution. Section 4 presents benchmarks against which the investment strategies identified in Section 3 can be evaluated. Section 5 provides comparisons that display the economic effects of incentives and the timing option. Section 6 analyzes the effect of relaxing some of the key assumptions of our model. Section 7 provides further results based upon the assumption that costs are uniformly distributed. Section 8 provides concluding remarks and directions for additional research.

0.2. Model

A risk neutral owner can invest now or one period from now. The investment project has a present value of $1 when undertaken. There is only one project, so the opportunities to invest now or later are mutually exclusive. The abandonment value of the project is assumed to be so low that abandonment is never optimal after an investment has been made.[6]

The investment must be implemented by a manager.[7] The manager knows the investment required if the project is started immediately, and he will learn the investment required if the project is delayed one period.[8] The owner knows the joint distribution governing the investment costs in both periods. We assume that the cost if the project is implemented now is independent of the cost if implemented one period from now. Also, the owner and the manager agree on the distribution of future costs.

To formalize these ideas, let the two points in time at which an investment can take place be denoted by t_0 and t_1, where t_0 is 'now'. Let c_0 and c_1 be the costs required to produce the project if the investment occurs at t_0 or t_1, respectively. If implemented, the project has a present value of \$1 at the time of implementation.

At t_0, the manager knows c_0. The owner believes c_0 is drawn from a probability distribution on $[c_0^L, c_0^U]$. Let $F_0(c_0)$ and $f_0(c_0)$ denote the cumulative distribution and density functions, respectively, of the probability measure. At t_0, both the owner and manager believe c_1 is distributed on $[c_1^L, c_1^U]$, with cumulative distribution $F_1(c_1)$ and density $f_1(c_1)$, independent of c_0. We assume that costs at t_1 are independent of those at t_0 in order to achieve tractability.[9] At t_1, the manager observes c_1. We assume that $\frac{F_0(c_0)}{f_0(c_0)}$ and $\frac{F_1(c_1)}{f_1(c_1)}$ are increasing in c_0 and c_1 over their respective supports. For simplicity, we omit subsequently the subscripts on the probabilities, and let their argument identify the distribution. Thus, from now on, $F_0(c_0) = F(c_0)$ and $F_1(c_1) = F(c_1)$.

The owner must transfer to the manager the funds required to carry out the investment. Let y denote the total amount the owner turns over to the manager. To create an incentive issue in the model, we first assume the manager can consume any funds transferred from the owner in excess of those required to carry out the investment. For example, if the investment is to be made at t_0 with attendant cost c_0 and the owner provides resources of y_0, the manager consumes the excess, $y_0 - c_0$. This excess is 'slack'. Second, we assume the owner cannot monitor the manager's slack consumption. Further, slack must always be non-negative, implying that the manager is not allowed to fund investment from his or her own resources.

It will be useful for us to break up the resources the owner provides to the manager into the cost of the investment at time t, c_t, and the manager's slack, $s_t = y_t - c_t$, at time t. Therefore, we model the owner as paying the cost of the investment, c_t, and the manager's slack, s_t. Slack plays the role of compensation in our model, and we refer to slack as compensation from now on.[10]

At t_0, the owner asks the manager to report the cost that would be incurred if the investment were to be undertaken now. If the option to invest is kept open at t_0, the owner asks the manager to report the cost of the investment at t_1, after he learns it. We assume the owner can commit to contracts, so he can carry out the resource allocation decision by constructing a menu of contracts from which the manager must choose.[11] The menu gives the resources allocated and whether the investment is to be undertaken at each point in time as a function of the manager's communication about cost.[12] Without loss of generality, the menu is designed to induce the manager to communicate truthfully the cost.[13]

The owner's objective is to maximize the expected net present value of the opportunity. His cost of capital is $\rho \geq 0$, with corresponding discount factor $k = 1/(1+\rho) \leq 1$. The choice variables are the functions describing the manager's compensation and whether the investment is undertaken depending on the manager's cost report. Let s_0 be a function mapping the set of possible costs at t_0, $[c_0^L, c_0^U]$, into the non-negative reals; i.e., s_0: $[c_0^L, c_0^U] \rightarrow \Re^+$. s_0 gives the manager's t_0 compensation as a function of his cost message. Let s_1 be a function mapping the set of possible pairs of costs, $[c_0^L, c_0^U] \times [c_1^L, c_1^U]$, into the non-negative reals; i.e., s_1: $[c_0^L, c_0^U] \times [c_1^L, c_1^U] \rightarrow \Re^+$. s_1 gives the manager's time t_1 compensation as a function of his t_0 and t_1 cost reports.

We model the decision to undertake the investment with an indicator function. Let d_0 be a function mapping $[c_0^L, c_0^U]$ into $\{0, 1\}$, with $d_0(c_0) = 0$ representing no investment at t_0 and $d_0(c_0) = 1$ representing investment at t_0. Let d_1 be a function mapping $[c_0^L, c_0^U] \times [c_1^L, c_1^U]$ into $\{0, 1\}$, with $d_1(c_0, c_1) = 0$ representing no investment at t_0 and $d_1(c_0, c_1) = 1$ representing investment at t_1. The mutually exclusive nature of the investment implies the decision rules must satisfy the constraint $d_0(c_0) + d_1(c_0, c_1) \leq 1 \; \forall c_0, c_1$.

Using this notation, the owner's problem is to choose $d_0(\cdot)$, $d_1(\cdot,\cdot)$, $s_0(\cdot)$, and $s_1(\cdot,\cdot)$ to maximize his objective function:

$$\int_{c_0^L}^{c_0^U} \int_{c_1^L}^{c_1^U} [d_0(c_0)(1 - c_0) - s_0(c_0) + k(d_1(c_0, c_1)(1 - c_1) - s_1(c_0, c_1))] f(c_0) f(c_1) dc_0 dc_1$$

subject to constraints guaranteeing:

1. The manager's compensation is non-negative:[14]

$$s_0(c_0) \geq 0 \; \forall c_0 \tag{1}$$

and

$$s_1(c_0, c_1) \geq 0 \; \forall c_0, c_1. \tag{2}$$

We assume that the manager requires the present value of slack received across the two periods to be non-negative (i.e., the manager's two-period reservation utility is zero). Constraints (1) and (2) assure that this is the case and, hence, no separate constraint is required to ensure that the manager is willing to initially accept employment from the owner.[15]

2. The manager has incentives to report truthfully the cost at each point he may be required to report:[16]

$$s_1(c_0, c_1) \geq s_1(c_0, \hat{c}_1) + d_1(c_0, \hat{c}_1)(\hat{c}_1 - c_1) \ \forall c_0, c_1, \hat{c}_1 \tag{3}$$

and

$$s_0(c_0) + k \int_{c_1^L}^{c_1^U} s_1(c_0, c_1) f(c_1) dc_1$$
$$\geq s_0(\hat{c}_0) + d_0(\hat{c}_0)(\hat{c}_0 - c_0) + k \int_{c_1^L}^{c_1^U} s_1(\hat{c}_0, c_1) f(c_1) dc_1 \ \forall c_0, \hat{c}_0. \tag{4}$$

3. The decision function respects the invest/do not invest nature of the problem:

$$d_0(c_0) \in \{0, 1\} \ \forall c_0 \tag{5}$$

and

$$d_1(c_0, c_1) \in \{0, 1\} \ \forall c_0, c_1. \tag{6}$$

4. The decision function respects the mutual exclusion of investing at t_0 or t_1:

$$d_0(c_0) + d_1(c_0, c_1) \leq 1 \; \forall c_0, c_1. \tag{7}$$

We now characterize the solution to this model.

0.3. Analysis

The optimal solution to the owner's problem, in terms of investment strategy, takes the form of target costs, below which the project is undertaken and above which it is not. Further, the target cost at t_1 is independent of the cost outcome at t_0. We have the following proposition which characterises this investment strategy, together with the associated compensation strategy.

Proposition 1. *The optimal investment strategy, should it exist, has target costs at t_0 and t_1, c_0^* and c_1^* respectively, such that:*

$$d_0^*(c_0) = 0 \; \forall c_0 > c_0^*; = 1 \; \forall c_0 \leq c_0^*,$$

$$d_1^*(c_0, c_1) = 0 \; \forall c_0 \leq c_0^*$$

and

$$d_1^*(c_0, c_1) = 0 \ \forall c_0 > c_0^* \text{ and } c_1 > c_1^*; = 1 \ \forall c_0 > c_0^* \text{ and } c_1 \leq c_1^*.$$

Further, an optimal compensation schedule for the optimal pair of target costs (c_0^*, c_1^*) *is:*

$$s_0^*(c_0) = (c_0^* - c_0) + k \int_{c_1^+}^{c_1^*} (c_1^* - c_1) f(c_1) dc_1 \text{ if } c_0 \leq c_0^*; = 0 \text{ otherwise}$$

and

$$s_1^*(c_0, c_1) = (c_1^* - c_1) \text{ if } c_0 > c_0^* \text{ and } c_1 \leq c_1^*; = 0 \text{ otherwise.}$$

Thus, the optimal decision rules involve two target costs, one for each period. The first period project is funded if and only if the reported cost is below the first period target. The second period project is funded if and only if the reported cost is below the second period target and no investment was undertaken in the first period.

The optimal managerial compensation at t_1 for a target-cost decision rule takes a simple form. If the manager reports any cost above the target, his compensation is zero. If the manager reports any cost below the target at t_1, assuming no investment has been undertaken at t_0, his compensation is the difference between the target cost, c_1^*, and the reported cost, c_1. That is, if c_0 is such that no investment has taken place at t_0 and c_1 is such that investment will take place at t_1, $s_1(c_0, c_1) = c_1^* - c_1$.

The manager's compensation at t_0 is more complex. If the reported cost is such that investment takes place, the manager's compensation reflects two effects. One is the value of the manager's observation of cost. This effect is no different than that which gives rise to non-zero t_1 compensation when no investment has taken place at t_0. The second effect is the manager's value of the opportunity to invest at t_1. If investment is made at t_0, it cannot be made at t_1. This deprives the manager of his option on future information rents, and he must be compensated for this loss if he is to report truthfully.[17]

Put another way, the flexibility afforded to the owner over the timing of investment also affords the manager flexibility over the timing of compensation payments. The manager possesses a timing option too. This complicates the design of an incentive system designed to align, as much as is possible, the preferences of the owner and manager over the timing of investment.

The results in Proposition 1 allow us to reduce the owner's problem to one of choosing the target costs, c_0^* and c_1^*, to maximize:

$$F(c_0^*)(1 - c_0^*) + k(1 - F(c_0^*))F(c_1^*)(1 - c_1^*) - kF(c_0^*) \int_{c_1^+}^{c_1^*} (c_1^* - c_1) f(c_1) dc_1. \quad \text{(OF)}$$

After some manipulation and rearrangement, the first-order conditions for optimal (interior) solutions are:

1. The partial derivative with respect to c_0^* equals 0, which produces:

$$c_0^* = 1 - \left(\frac{F(c_0^*)}{f(c_0^*)}\right) - k \int_{c_1^+}^{c_1^*} (1 - c_1) f(c_1)\, dc_1. \tag{8}$$

2. The partial derivative with respect to c_1^* equals 0, which produces:

$$(1 - F(c_0^*))\,(1 - c_1^*) - \left(\frac{F(c_1^*)}{f(c_1^*)}\right) = 0. \tag{9}$$

We examine these first-order conditions to gain insight into the effects of the timing option and the incentive problem on the target costs. By comparing the conditions with appropriate benchmarks, we can display the economic effects of these two aspects of the investment problem.

0.4. Benchmarks

In understanding the properties of the target costs derived above, we need to understand the separate contributions to each cost target of incentive and timing option issues. First, we compare c_0^* and c_1^* with the target costs at t_0 and t_1 that would hold if there were no incentive issues but a timing option exists. Second, we compare the target costs to the target costs if there are incentive issues but there is no timing option and the investment opportunity is a one-shot deal at either t_0 or t_1.

0.4.1. The First-Best Solution in the Presence of a Timing Option

The first-best version of the owner's problem is obtained by first observing that, when the manager's two-period reservation utility is zero, the optimal compensation to the manager is identically zero. Second, it is clear that the appropriate first-best target cost at t_1 is 1, or is c_1^U if $c_1^U < 1$. Denoting the optimal first-best (No Incentives - NI) target costs at times t_0 and t_1 by c_0^{NI} and c_1^{NI}, respectively, then

$$c_1^{NI} = Min[c_1^U, 1], \tag{10}$$

The optimal c_0^{NI} is given by the first-order condition given in equation (11):

$$1 - c_0^{NI} = k \int_{c_1^L}^{Min[c_1^U,1]} (1 - c_1) f(c_1) dc_1. \tag{11}$$

unless such a cost target exceeds c_0^U or is exceeded by c_0^L. Thus, generally, the optimal t_0 target cost is the *maximum* of c_0^L and the *minimum* of the cost target given by equation (11) and c_0^U.

The first-order condition given in equation (11) weighs the net present value produced by investing at t_0, $1 - c_0$, against the discounted value of the expected net present value from keeping open the investment option until t_1,

$$k \int_{c_1^L}^{Min[c_1^U,1]} (1 - c_1) f(c_1) dc_1.$$

This discounted value of expected net present value is non-negative. Therefore, the timing option reduces the first-best target cost at t_0 below 1, even if $c_0^U > 1$. Intuitively, the target cost is reduced to take account of an additional cost of investing at t_0: the opportunity cost of foregoing investment at t_1. The reduction in the target cost is only affected by the distribution of costs at t_1 - the distribution of costs at t_0 is irrelevant to the target cost at t_0 in the first-best situation.

0.4.2. The Second-Best Case in the Absence of a Timing Option

In the one period case where there are incentive but no timing issues (No Option - NO), it is straightforward to demonstrate that the optimal target cost, c^{NO}, is generally determined by the following first-order condition:[18]

$$c^{NO} = 1 - \left(\frac{F(c^{NO})}{f(c^{NO})}\right). \tag{12}$$

In our case, we have benchmarks from the static case which can be applied at t_0 and t_1. We refer to these benchmarks as c_0^{NO} and c_1^{NO}.

0.5. Comparisons

Given the benchmark target costs established above, we are in a position to initially analyse the properties of c_0^* and c_1^*. We consider the effects at t_1 first.

0.5.1. Effects at t_1

We express the effects at t_1 in the form of a proposition.

Proposition 2. *Assuming that c_0^*, c_1^* and c_1^{NO} are arrived at by solving the appropriate first-order conditions, the target cost at t_1 in the presence of incentive problems and timing issues, c_1^*, is less than or equal to the target cost, c_1^{NO}, if* *the opportunity at t_1 is a one-shot opportunity to invest with incentive problems, which is, in turn, less than or equal to the target cost, c_1^{NI}, if the opportunity at t_1 has no incentive problems but a timing option exists at t_0. In symbols, we have:*

$$c_1^* \leq c_1^{NO} \leq c_1^{NI} = Min[c_1^U, 1].$$

The normal motivation for (weakly) reducing the target cost when a one-shot investment opportunity is under consideration in the presence of an incentive problem is to reduce the manager's information rents. Therefore, $c_1^{NO} \leq c_1^{NI} = Min[c_1^U, 1]$. Now, note that if t_1 is reached without investment having taken place, the investment opportunity there appears to be a one-shot deal. The key result here, however, is that $c_1^* \leq c_1^{NO}$. In other words, the *presence* of the timing option at t_0 has an impact on the optimal target cost at t_1 (inspection of equation (9) suggests that the inequality will hold strictly unless $c_0^* = c_0^L$, that is, unless the investment option is never exercised at t_0).

The reason for this result is that the manager possesses a timing option at t_0 on compensation to be received at t_1, the size of which is determined by the target cost at t_1. Lowering the t_1 target decreases the expected value of the manager's compensation at t_1. Other things being equal, the manager is less tempted to report a high cost at t_0, forego investment at t_0, and preserve the option on his compensation at t_1. Therefore, lowering the target cost at t_1 is helpful in maintaining incentives for truthful reporting at t_0. Thus, the t_1 target cost is only disturbed because of the incentive problem, but the amount by which it is disturbed is affected by the presence of the timing option. The total effect is the joint product of timing and incentive effects.

0.5.2. Effects at t_0

Again, we state these effects in the form of a proposition.

Proposition 3. *Assuming that c_1^*, c_0^* and c_0^{NO} are arrived at by solving the appropriate first-order conditions, c_0^*, is less than or equal to the target cost, c_0^{NO}, that would obtain if the investment opportunity is a one-shot deal in the presence of an incentive problem at t_0. In symbols, we have:*

$$c_0^* \leq c_0^{NO}$$

The intuition here is that a timing option at t_0 introduces benefits from waiting which are available to both owner and manager. As a consequence, the target cost is weakly reduced below what it would have been in the absence of a timing option. This is reflected in the third term on the right hand side of equation (8) which represents the social value of the timing option, given a target cost of c_1^*, as opposed to the value of the timing option to either the owner or the manager separately.[19] Indeed, the reduction in the target cost is strictly positive unless $c_1^* = c_1^L$, that is, unless the option to wait is effectively shut off. We analyze circumstances in which this is the case below.

0.6. Changing Key Assumptions of the Analysis: Independent Costs and Renegotiation

The propositions above have established many of the effects of a timing option on target costs in the presence of an incentive problem. Our formulation and results have employed at least three assumptions that merit further examination:

1. the costs at t_0 and t_1 are independent;
2. the owner and manager are tied together inextricably across the two periods - the owner is unwilling or unable to fire the manager after one period if investment does not take place at t_0;
3. the owner and manager both resist the temptation to renegogiate before the investment decision is taken at t_1 if investment has not taken place at t_0.

We now examine the impact of relaxing these assumptions. Initially, we relax the assumption that costs are independent. Then, we consider the possibility that the owner may want to fire the manager if investment does not occur at t_0. Finally, we analyze the effects of allowing renegotiation. We relax these assumptions one at a time, not in combination.

0.6.1. Correlated Costs

In prior sections, we have restricted our attention to the case where investment costs are independently distributed at t_0 and t_1. Now we briefly consider the case where these costs are not necessarily independent. As a consequence, we represent the cost distribution at t_1 by $f(c_1 \mid c_0)$. In this case, the objective function and constraints must be modified to acknowledge the dependence of the distribution of c_1 on c_0. The objective function becomes:

$$\int_{c_0^L}^{c_0^U} \int_{c_1^L}^{c_1^U} [d_0(c_0)(1-c_0)-s_0(c_0)+k(d_1(c_0,c_1)(1-c_1)-s_1(c_0,c_1))] f(c_1 \mid c_0) f(c_0) dc_1 dc_0$$

Constraint (4) becomes:

$$s_0(c_0) + k \int_{c_1^L}^{c_1^U} s_1(c_0,c_1) f(c_1 \mid c_0) dc_1$$

$$\geq s_0(\hat{c}_0) + d_0(\hat{c}_0)(\hat{c}_0 - c_0) + k\int_{c_1^L}^{c_1^U} s_1(\hat{c}_0, c_1) f(c_1 \mid c_0) dc_1 \; \forall c_0, \hat{c}_0. \qquad (13)$$

In describing the solution to this problem, it is useful to interpret our solution to the original problem in a different way. A different way of looking at our solution in the case of uncorrelated costs is that the owner announces to the manager that, if investment takes place at t_0, an amount, y_0, given by:

$$y_0^* = c_0^* + k\int_{c_1^L}^{c_1^*} (c_1^* - c_1) f(c_1) dc_1$$

is transferred to the manager out of which the cost of investment must be funded and, if investment takes place at t_1, an amount, y_1, given by:

$$y_1^* = c_1^*$$

is transferred. The investment decision is then delegated to the manager and any excess over the amount transferred and that required to fund investment is kept by the manager for personal consumption. It is easy to demonstrate that the manager will only invest if $c_0 \leq c_0^*$ at t_0 and, if investment has not taken place at t_0, will only invest at t_1 if $c_1 \leq c_1^*$. In other words, the hurdle rate characteristic is reproduced. Further, the payoffs to the manager, in terms of excess resources, are identical to those specified in Proposition 1.

In the case of non-independent costs, some of this structure is carried over to the solution. In particular, the owner still chooses resource transfers, y_0^* and y_1^*, that are handed to the manager if investment takes place at t_0 and t_1, respectively.[20] The manager must then fund the investment cost out of these transfers but, again, may keep any excess. It can be shown that, if investment has not taken place at t_0, investment will only take place at t_1 if $c_1 \leq y_1^*$. In other words, a hurdle rate strategy is maintained at t_1 and y_1^* plays the same role as c_1^*. Put another way:

$$d_1^*(c_0, c_1) = 0 \; \forall c_0 \text{ such that } d_0^*(c_0) = 1$$

and

$$\begin{aligned} d_1^*(c_0, c_1) &= 0 \; \{\forall c_0 \text{ such that } d_0^*(c_0) = 0 \text{ and } c_1 > y_1^*\}; \\ &= 1 \; \{\forall c_0 \text{ such that } d_0^*(c_0) = 0 \text{ and } c_1 \leq y_1^*\}. \end{aligned}$$

At t_0, however, the investment strategy followed by the manager may be complex. Investment will only take place at t_0 if:

$$y_0^* \geq c_0 + k \int_{c_1^L}^{y_1^*} (y_1^* - c_1) f(c_1 \mid c_0) dc_1$$

or, re-expressed:

$$d_0^*(c_0) = 1 \text{ if } y_0^* \geq c_0 + k \int_{c_1^L}^{y_1^*} (y_1^* - c_1) f(c_1 \mid c_0) dc_1 \ ; = 0; \text{ otherwise}$$

What is changed here relative to the case of independent costs is that the investment strategy at t_0 *no longer automatically takes the hurdle rate form.* That is, the optimal investment region at time t_0 may not be an interval of (small) cost values. For some small cost values, investment may be deferred, and for some high cost levels, investment may be undertaken. The reason is that the value of the slack option available to the manager by delaying investment may vary with the observed investment cost at t_0, c_0, in a way that disrupts the neat tie between optimal investments and c_0.[21]

To summarize, with non-independent investment costs, the owner's problem *remains* that of identifying two optimal resource transfers associated with investment at t_0 and t_1. The transfers then imply an investment strategy that takes a hurdle rate form at t_1 but does not necessarily take such a form at t_0. The transfers at t_0 implicitly must compensate the manager for the lost slack option if any investment is to take place at t_0, as in the case of independently distributed costs. As a consequence, little of principle is changed in the solution by introducing non-independent costs but, without making specific assumptions about the nature of the dependence, closed form solutions characterising y_0^* and y_1^* cannot be obtained.

0.6.2. Cross-period Links between Owner and Manager

Now we relax the assumption that the owner and manager are tied together over the two periods. Suppose the owner dismisses the incumbent manager at t_0 if the cost report leads to the deferral of the investment decision to t_1. He then hires another manager to provide a cost report at t_1. In this case, a target cost strategy is still optimal. However, there is no need to provide the incumbent manager at t_0 with a slack option to induce truth-telling - a key part of the incentive mechanism identified in Section 3. The owner's objective then is to maximize:

$$F(c_0^*)(1 - c_0^*) + k(1 - F(c_0^*))F(c_1^*)(1 - c_1^*)$$

Letting the target cost solutions to this problem be denoted by c_0^{NC} and c_1^{NC} (NC - no commitment to the manager), the first-order conditions for optimal (interior) solutions reduce to:

$$c_0^{NC} = 1 - \left(\frac{F(c_0^{NC})}{f(c_0^{NC})}\right) - kF(c_1^{NC})(1 - c_1^{NC})$$

and

$$c_1^{NC} = 1 - \left(\frac{F(c_1^{NC})}{f(c_1^{NC})}\right)$$

We can note two aspects of the solution. First, $c_1^{NC} = c_1^{NO}$ - the target cost at t_1 is identical to that which would hold if the investment were a one-shot deal.[22] Second, the target cost at t_0 is reduced by the value of the owner's option to wait - $kF(c_1^{NC})(1 - c_1^{NC})$. Here, the reduction is less than in equation (8) by the amount of the slack option that has to paid when the same manager is employed over both periods. Assuming all relevant cost targets are determined by the appropriate first-order conditions, and using the same methods used to prove the results in Proposition 3, we can show that:

$$c_0^{*} \leq c_0^{NC} \leq c_0^{NO}$$

Note that, in this case, the owner commits *not* to rehire the manager with any positive probability. This, of course, is a commitment strategy of another type, the rationality of which relies heavily upon the existence of a rich and frictionless market in ready-made replacements for the incumbent manager. If the incumbent can only be replaced at a cost or, alternatively, has a skill advantage over competing managers, it is difficult to sustain a commitment *not* to rehire the incumbent. Such a commitment would not automatically be economically rational.

0.6.3. Renegotiation

We now turn to the case where renegotiation is allowed prior to the investment decision being made at t_1 if investment has not taken place at t_0. We assume after the manager has acquired information about the cost of investing at t_1 before any renegotation. If renegotiation is allowed, the optimal renegotiation-proof[23] target cost at t_1, which we denote by c_1^{RP} (RP - renegotiation proof), equals c_1^{NO} - the target cost that would hold if the project were a one-shot deal at t_1. As a consequence, the owner picks the optimal renegotiation-proof t_0 target cost, c_0^{RP}, to maximize:

$$F(c_0^*)(1-c_0^*)+k(1-F(c_0^*))F(c_1^{NO})(1-c_1^{NO})-kF(c_0^*)\int_{c_1^*}^{c_1^{NO}}(c_1^{NO}-c_1)f(c_1)dc_1$$

resulting in the following first-order condition for c_0^{RP}:

$$c_0^{RP}=1-\left(\frac{F(c_0^{RP})}{f(c_0^{RP})}\right)-k\int_{c_1^*}^{c_1^{NO}}(1-c_1)f(c_1)\,dc_1$$

Again using similar methods to those used to prove Proposition 3, and assuming all relevant cost targets are determined by the appropriate first-order conditions, note that $c_0^{RP}\leq c_0^*$ because $c_1^*\leq c_1^{NO}$. As a consequence, we have:

$$c_0^{RP}\leq c_0^*\leq c_0^{NO}$$

There are some commonalities involved in the effects of relaxing the two assumptions identified above. First, the t_0 target cost is still reduced relative to that that would hold if there were no option to delay investment, as in the analysis above. Bringing together the relationships for the various target costs at t_0 suggests that:

$$c_0^{RP}\leq c_0^*\leq c_0^{NC}\leq c_0^{NO}$$

Second, the target cost at t_1 is that which would obtain for a one-shot investment opportunity at that time. Therefore:

$$c_1^* \leq c_1^{NC} = c_1^{RP} = c_1^{NO}$$

Having analysed the effects of relaxing three key assumptions of our analysis, we revert to assuming that the costs are independent and that the owner wishes to commit to employing the manager over both periods and not to renegotiate after t_0 if investment has not taken place. We rationalize maintaining these assumptions on the following grounds. First, we believe further analysis of the independent cost case is likely to be instructive. Second, we assume that, although undoubtedly a replacement for the incumbent can be found, replacement is at such prohibitive cost (as a consequence of, for example, the need for training in (unmodelled) firm-specific skills necessary to fulfill job responsibilities) as to effectively rule out such a course of action. Third, we assume that the owner can contract, at sufficiently low cost, with a third party such that, should renegotiation take place after t_0, the terms of the contract require the third-party to 'fine' the owner an amount large enough to discourage such renegotiations. Note that, given the results of Propositions 2 and 3, this is a rational course of action to take at t_0.

0.7. Further Analysis Under the Assumption That Costs Are Distributed Uniformly

Previous analysis left us unable to describe generally the effect of changing cost distributions at either t_0 or t_1 on target costs. Further, it left open how the presence or absence of an incentive problem affects target costs at t_0 when a timing option exists (i.e., the relationship between c_0^* and c_0^{NI}). Additionally, we were not in a position to identify general circumstances under which the timing option is valueless in the presence of an incentives problem and make comparisons between these circumstances and those under which the timing option is valueless in the absence of incentive problems. To gain insight into these issues, we now make some specific distributional assumptions. In particular, we assume that costs are independent and uniformly distributed in both periods.[24]

0.7.1. Some Comparative Statics of the Effects of Changing Cost Distributions

We begin by examining the effects of changing cost distributions on the optimal target costs at t_0 and t_1. We compare these effects with those that occur in the absence of incentive problems. By so doing, we are able to identify the important economic forces that incentive problems add to investment decision-making in the presence of a timing option.

We analyze the case where $c_0 \sim U[0, \hat{c}_0]$ and $c_1 \sim U[0, \hat{c}_1]$, with $\hat{c}_0 > 1 - \frac{k}{2\hat{c}_1}$ and $\hat{c}_1 \geq 1$. The lower bounds on $\hat{c}_0$ and $\hat{c}_1$ ensure that c_0^{NO}, c_1^{NO} and c_0^{NI} are all determined by the appropriate first-order conditions and, hence, so are c_0^* and c_1^*. Under these circumstances, the first-order conditions identified above for c_0^* and c_1^* reduce to:

$$2\hat{c}_1(1 - 2c_0^*) - kc_1^*(2 - c_1^*) = 0 \tag{14}$$

and

$$\hat{c}_0(1 - 2c_1^*) - c_0^*(1 - c_1^*) = 0 \tag{15}$$

respectively.

We wish to identify the effects of varying $\hat{c}_0$, $\hat{c}_1$ and k on the target costs. Let z represent an arbitrarily chosen parameter from the previously mentioned three. Let the left hand sides of equations (14) and (15) be represented by the functions $A(c_0^*(z), c_1^*(z), z)$ and $B(c_0^*(z), c_1^*(z), z)$ respectively. Then, matrix equation (16) provides the basis for identifying the effects of varying $\hat{c}_0$, $\hat{c}_1$ and k on the target costs:

$$\begin{bmatrix} \frac{dc_0^*}{dz} \\ \frac{dc_1^*}{dz} \end{bmatrix} = \frac{1}{|J|} \begin{bmatrix} B_2 & -A_2 \\ -B_1 & A_1 \end{bmatrix} \begin{bmatrix} -A_3 \\ -B_3 \end{bmatrix} \tag{16}$$

where

$$J = \begin{bmatrix} A_1 & A_2 \\ B_1 & B_2 \end{bmatrix}$$

and A_i (B_i) is the partial derivative of A (B) with respect to the i'th argument of the function. From this matrix equation, we can derive the following proposition.

Proposition 4. *(i) c_0^* decreases and c_1^* increases as $\hat{c}_0$ increases; (ii) c_0^* increases and c_1^* decreases as $\hat{c}_1$ increases; and (iii) c_0^* decreases and c_1^* increases as k increases.*

We can compare these results with those that hold when incentive problems do not exist. Specifically,

$$c_0^{NI} = 1 - \frac{k}{2\hat{c}_1}$$

and $c_1^{NI} = 1$. Most interestingly for our purposes, we note that:

1. the target cost at t_0 is unaffected by varying $\hat{c}_0$ in the absence of incentive problems whereas, in the presence of incentive problems, it is affected; and

2. the target cost at t_1 is unaffected by varying any of $\hat{c}_0$, $\hat{c}_1$ and k in the absence of incentive problems whereas, in the presence of incentive problems, it is affected by these factors.

We provide intuition for these outcomes in the following way. First, the fact that increasing $\hat{c}_0$ decreases c_0^* but leaves c_0^{NI} unaffected is a consequence of the incentive problem being increased at t_0 because of the increase in $\hat{c}_0$. Increasing $\hat{c}_0$ increases the spread of the uniform distribution from which the t_0 cost is drawn, thereby increasing the cost of ensuring truth-telling at that time.[25] As a consequence, investment at t_0 is rendered less attractive relative to investment at t_1, resulting in a reduction in c_0^*. Obviously, these effects do not exist when considering an optimal c_0^{NI}. Whereas the first-best t_0 target cost only reflects the cost distribution at t_1, the second-best t_0 target cost will, additionally, reflect the *relative* strength of the incentive problems at t_0 and t_1 induced by the cost distributions of c_0 and c_1.

Second, for similar reasons to those in the previous paragraph, the second-best t_1 target cost will also reflect the *relative* strength of the incentive problems at t_0 and t_1. Hence, c_1^* is positively associated with $\hat{c}_0$, because an increase in $\hat{c}_0$ increases the cost of ensuring truth-telling at t_0, whereas the first-best t_1 target cost hurdle is unaffected by the cost distribution at t_0. Further, increases in $\hat{c}_1$

increase the costs of truth-telling at t_1, leading to a decrease in the attractiveness of investment at t_1. This results in a decrease in c_1^*. It is only incentive problems to which these influences on c_1^* can be attributed.

Third, the effect of k on the target cost at t_1 can be explained in the following way. Increases in the discount factor, *ceteris paribus*, increase the present value of the slack option paid to the manager at t_0 should investment take place then. This decreases the attractiveness of investment at time t_0 and results in a decrease in c_0^* and the attendant probability of investment at t_0. Nonetheless, because of this decrease in c_0^* and associated probability of investment at t_0, an increase in c_1^* occurs - again, an effect that cannot happen in the absence of an incentives problem.

We now use the analysis above to illustrate a set of conditions involving the upper bounds of the cost supports at t_0 and t_1 under which $c_0^* > c_1^*$. This result is of interest because it is not possible for the t_0 cost target to be higher than that at t_1 under first-best conditions if $\hat{c}_1 \geq 1$. The following Proposition illustrates these conditions.

Proposition 5. *If $c_0 \sim U[0, \hat{c}_0]$ and $c_1 \sim U[0, \hat{c}_1]$, with $\hat{c}_0$ and $\hat{c}_1 \geq 1$, and*

$$\hat{c}_0 = \frac{c^*(1 - c^*)}{(1 - 2c^*)} \tag{17}$$

$$\hat{c}_1 = \frac{kc^*(2 - c^*)}{2(1 - 2c^*)}, \tag{18}$$

and $2 - \sqrt{3} < c^* < .5$, *then* $c_0^* = c_1^* = c^*$ *and* c_0^{NI} *is interior. By Proposition 4, an increase in the upper bound of the cost support at* t_1, *or a decrease in the lower bound of the cost support at* t_0 *relative to those indicated in equations (17) and (18) will produce circumstances under which* $c_0^* > c_1^*$.

This proposition specifically illustrates the potential for the incentives problem to shift the *relative* balance of investment from one point in time to the other, as captured by the relationship between cost targets at the two points in time. In the first-best case, it is not possible for c_0^{NI} to equal or exceed c_1^{NI}. In the second-best case, the *relative* balance shifts in favour of earlier rather than later investment, in the sense that the probability of investment at t_0 is higher, relative to the *conditional* probability of investment at t_1, in the second-best than in the first-best case.[26]

Indeed, under certain circumstances, the ratio of these two probabilities in the second-best case can exceed 1 when both $\hat{c}_0$ and $\hat{c}_1$ are equal and exceed 1. This, again, is something that cannot happen in the absence of incentive problems. Let the discount factor be given by:

$$k = \frac{2(1 - c^*)}{(2 - c^*)}$$

with $\frac{3-\sqrt{3}}{2} < c^* < .5$. Then, using Proposition 5, both $\hat{c}_0$ and $\hat{c}_1$ exceed 1 and the probability of investment at t_0 equals the conditional probability of investment at t_1. By Proposition 4, a small decrease in k will produce an outcome where the probability of investment at t_0 strictly exceeds the conditional probability of investment at t_1.

0.7.2. Identifying a Class of Circumstances Where $c_0^* \geq c_0^{NI}$

As indicated above, the relationship between the second-best and first-best target costs is ambiguous in the presence of a timing option. The analysis above suggests that incentive problems can produce a shift in the relative likelihood of investment towards t_0. This raises the possibility that the balance of incentive problems between t_0 and t_1, when combined with the balance between expected costs at the two points in time, might combine to raise the second-best target cost at t_0 above that which holds in the absence of incentive problems. This is a possibility that does not exist for one-shot investment decisions.

We assume that $c_0 \sim U[c_0^L, c_0^U]$, $c_0^L < 1 - \frac{k}{2\bar{c}_1} < c_0^U$, and $c_1 \sim U[0, \bar{c}_1]$. Let $r = \frac{k}{2\bar{c}_1}$. Define $f(r)$ by:

$$f(r) = \frac{(c_0^U - 1 + r)(3c_0^U - 1 + r - 2c_0^L)}{(2c_0^U - 1 + r - c_0^L)^2}$$

Now consider only those $\{c_0^L, c_0^U\}$ pairs that satisfy

$$1 - c_0^L = r(2 - f(r)) \tag{19}$$

Then we can provide the following proposition.

Proposition 6. *For a fixed $r = \frac{k}{2\bar{c}_1}$, $c_0^* > c_0^{NI}$ if (i) c_0^*, c_1^* and c_0^{NI} are determined by the appropriate first-order conditions; (ii) $c_1 \sim U[0, \bar{c}_1]$, $\bar{c}_1 \geq 1$; and (iii) $c_0 \sim U[c_0^L, b]$, where $[c_0^L, b] \subset [c_0^L, c_0^U]$ for some $\{c_0^L, c_0^U\}$ pair that satisfy equation (19) and $b \geq c_0^* > c_0^{NI} \geq c_0^L$.*

This proposition thus defines conditions under which the existence of incentive problems increases the probability of investing at t_0. Essentially, it defines the trade-offs that are possible between the upper and lower bounds of the support of c_0 which allow for the equality of c_0^* and c_0^{NI} via equation (19). Hence, equation (19) defines a curve in (c_0^L, c_0^U) space, for a given distribution of c_1, such that points below the curve define lower and upper bounds of the uniform support of c_0 that, as long as c_0^* and c_1^* are identified as a result of the first-order conditions, produce the outcome: $c_0^* > c_0^{NI}$.

We illustrate $\{c_0^L, c_0^U\}$ pairs which satisfy equation (19) for a particular value of r for which $k = .9$ and $\bar{c}_1 = 1$. Thus, $r = .45$. Here, $c_0^{NI} = 1 - .45 = .55$. Table 1 illustrates a number of such pairs.

Table 1

Upper and Lower Bounds on the Support of First Period Costs That Allow $c_0^* > c_0^{NI}$

c_0^L	c_0^U
.404	1
.399	.95
.393	.9
.384	.85
.371	.8
.35	.75
.318	.7
.268	.65
.194	.6

Table 1 illustrates that situations in which $c_0^* = c_0^{NI}$ for $k = .9$ and $\hat{c}_1 = 1$ are characterised by lower uncertainty at t_0 relative to t_1, as characterized by the relative spread of costs. Nonetheless, the mean expected cost at t_0 can be lower or higher than the mean expected cost at t_1 without the result becoming impossible. As a consequence, it is difficult to say much about the likelihood of the types of situations illustrated by Proposition 6 occurring in empirical situations. All that can be said is that such situations are not impossible *a priori*.

0.7.3. When is the Timing Option Valueless in the Presence of Incentives Problems?

We now turn to the issue of when the value of the timing option is zero in the presence of incentives problems. We confine ourselves initially to the consideration of cases where c_0^* and c_1^* are arrived at by solving the appropriate first-order conditions and $c_1^* = c_1^L$. If $c_1^* = c_1^L$, investment never takes place at t_1 and, hence, the timing option is valueless. We present the following proposition which illustrates a class of circumstances in which such is the case.

Proposition 7. *Assuming that (i) $c_0 \sim U[c_0^L, c_0^U]$ and $c_1 \sim U[c_1^L, c_1^U]$; and (ii) c_0^* and c_1^* are arrived at by solving the appropriate first-order conditions, then $c_1^* = c_1^L$ if*

$$c_0^U = \frac{(1 + c_0^L)}{2}$$

and the uniform cost distributions at t_0 and t_1 are related in the following way:

$$c_0^L < 1 - \frac{k(1 - c_1^L)^2}{(c_1^U - c_1^L)}$$

Further, under these conditions, c_0^{NI} is not interior and equals c_0^U.

It is worth briefly discussing the results of Proposition 7. The first order condition given by equation (9) makes it clear that if t_1 costs are uniformly distributed and $c_1^* = c_1^L$ then $F(c_0^*) = 1$ and, hence, $c_0^* = c_0^U$. Therefore, if the timing option is valueless, the problem reduces to a one-shot deal with investment always taking place.[27] When costs are uniformly distributed at t_0, if c_0^{NO} is interior then it equals $\frac{(1+c_1^L)}{2}$. Therefore, c_0^U must also equal $\frac{(1+c_1^L)}{2} < 1$. Nonetheless, if t_0 costs are distributed in this way, the solution $c_0^* = c_0^U$ and $c_1^* = c_1^L$ *always* satisfies the first-order conditions for the owner's problem given by equations (8) and (9). As a consequence, the second condition in the Proposition comes from the appropriate second-order condition for this particular solution to be a maximum.

We provide some examples of the relationship between the cost distributions implied by the Proposition. Let $c_0 \sim U[0, .5]$ and $k = .9$. Table 2 provides some possible combinations of c_1^L and c_1^U that lead to the *equality* of c_0^L and $1 - \frac{k(1-c_1^L)}{(c_1^U - c_1^L)}^2$. Increasing c_1^U above the value indicated in the table will certainly produce circumstances where the value of the timing option is zero, given the other characteristics of the situation.[28]

Table 2

Upper and Lower Bounds on the Support of Second Period Costs That Allow the Option to Wait to Be Shutoff in the Presence of Incentive Problems

c_1^L	c_1^U
0	.9
.1	.829
.2	.776
.3	.741
.4	.724
.5	.725
.6	.744
.7	.781
.8	.836
.9	.909

Table 2 illustrates nicely the trade-offs between the balance between expected costs and incentive problems. The spread of costs decreases as we move down Table 2, reducing incentive problems at t_1, and, hence, all other things being equal, increasing the value of the timing option. But, other things are not equal. Expected costs are increasing as we move down the table reducing the value of the timing option. The two effects cancel out, leaving the timing option consistently valueless. Obviously, increasing c_1^U above the figure indicated in the Table increases both expected costs and incentive problems at t_1, keeping the value of the timing option at zero.

A further conclusion to be drawn from the proposition is that if incentives problems cause the shutting-off of a timing option that is valuable in their absence, and costs are uniformly distributed at t_0 and t_1, it must arise from problems in which the first-order conditions do not determine the optimal second-best target costs. Examples of such problems can be easily constructed. Consider the following. Let $c_0 \sim U[.7, .8]$, $c_1 \sim U[0, 1\frac{2}{3}]$, and $k = 1$. Here, $c_0^{NI} = .7$ and $c_1^{NI} = 1$. In the presence of an incentive problem, $c_0^* = .8$.[29] This cost target is not the outcome of solving the first-order conditions for the problem. The incentive problem, however, effectively shuts off the timing option in a situation where, in the first-best world, the timing option is the *only* source of value for the opportunity. In the first-best world, the spread of costs at t_1 gives sufficient chance of low costs to make waiting attractive. In the second-best world, this sufficient chance of low costs has to be traded-off against the impact of the incentive problem caused by the large spread of costs at t_1 compared with that at t_0. Here, the incentive problems outweigh the possibility of low costs and waiting has no value. As a consequence, although in the first-best world flexibility to time the acceptance of the investment opportunity provides economic benefits, it does not do so in the second-best world.[30]

0.8. Conclusion

We characterize the optimal investment and compensation strategies in a model of an investment opportunity with managerial incentive problems and flexibility over the timing of its acceptance. Acceptance is possible at two points in time. In the first-best world, such flexibility is viewed as potentially providing real economic benefits. The investment opportunity has a real option embedded within it - the opportunity to wait to invest.

In the second-best world, as in the first-best world, the optimal investment policy consists of target costs, below which investment takes place and above which it does not. We show how timing and incentive effects interact to affect these target costs. The interaction of these effects is fairly intricate. The existence of the timing option reduces optimal cost targets at both points in time. The t_0 target is lowered because the compensation function at t_0 calls for the payment of an amount equal to the manager's option to generate slack at t_1, should investment take place. This increases the cost of investing at t_0, thus reducing its attractiveness. The target cost is also lowered at t_1 when no further timing options remain. Lowering the target cost in the final period reduces the value of the agent's option on slack, which eases the incentive problem at t_0.

By making the assumptions that costs are uniformly distributed, we are able to generate additional insights. First, circumstances are identified in which not only does the cost target at t_0 exceed that at t_1 but also the probability of investing at t_0 exceeds the conditional probability of investing at t_1, results impossible in the first-best context. Here, relatively speaking, incentive problems shift the probability of investment away from t_1 towards t_0. Second, incentive problems are generally thought to reduce target costs, relative to opportunities with no incentive problems, in order to limit the manager's slack on lower cost projects. Incentive problems, however, have more complex effects in the opportunity analyzed here. As a result, we are able to identify circumstances under which the target cost at t_0 may be increased by incentive effects, relative to the target cost that exists in the absence of incentive problems. Third, we are able to identify the conditions, derived from the first-order conditions for the problem, where the option to wait is effectively shut down when incentive problems exist. Under these conditions, the option to wait is also shut down in the first-best world. Nonetheless, an example is given, where cost targets are not identified from the first-order conditions, illustrating that it is possible for incentive problems to shut down a timing option that is valuable in the absence of such problems. As a consequence, we illustrate that incentive problems can render a timing option that is valuable in the absence of incentive problems valueless in their presence.

In generating the results indicated above, we make important assumptions concerning the opportunity sets of owner and manager. Essentially, we link the opportunity sets of the owner and manager across periods and, as a consequence, increase incentive costs by giving the manager an option on future information rents generated by linking with the owner. As a consequence, we examine how alternative assumptions about the relationship-specific capital, in particular how the owner's and manager's opportunity sets evolve over time, affect investment strategies.

The model presented in this paper can be used as the basis for many additional analyses. For example, information system design can be analyzed in a model with incentive and timing effects.[31] Further, we ignore the possible existence of either follow-up investment options (i.e., investment opportunities only accessible as a consequence of investing now) or abandonment options (i.e., the opportunity to dispose of an investment opportunity once acquired). Both these options are linked in with the original decision and give rise to potential further slack options for the manager. As a consequence, such linked opportunities will further complicate the manager's compensation scheme and, ultimately, investment decision-making.

0.9. Appendix

Proof of Proposition 1

First, we prove that if investment takes place at t_1 for a cost c_1 then it will also take place if the cost is $\hat{c}_1 < c_1$. Assume $\exists\, c_0, \hat{c}_1$, and c_1 with $\hat{c}_1 < c_1$ such that $d_1(c_0, \hat{c}_1) = 0$ while $d_1(c_0, c_1) = 1$.[32] Then the constraint in the second set under (2) that guarantees c_1 will be reported instead of $\hat{c}_1$ when the cost is $c_1 \Longrightarrow$

$$s_1(c_0, c_1) \geq s_1(c_0, \hat{c}_1).$$

But the constraint under (2) that guarantees $\hat{c}_1$ will be reported instead of c_1 when $\hat{c}_1$ is the true cost provides:

$$s_1(c_0, \hat{c}_1) \geq s_1(c_0, c_1) + (c_1 - \hat{c}_1).$$

Collecting these results and using that $\hat{c}_1 < c_1$ gives:

$$s_1(c_0, c_1) \geq s_1(c_0, \hat{c}_1) \geq s_1(c_0, c_1) + (c_1 - \hat{c}_1) > s_1(c_0, c_1),$$

- a contradiction.

Second, we prove that if investment takes place at t_0 for a cost c_0 then it will also take place if the cost is $\hat{c}_0 < c_0$. Assume $\exists$ c_0 and $\hat{c}_0$ with $\hat{c}_0 < c_0$ such that $d_0(\hat{c}_0) = 0$ while $d_0(c_0) = 1$. Then the constraint in the second set under (2) that guarantees $\hat{c}_0$ will be reported instead of c_0 when the true cost is $\hat{c}_0$ implies:

$$s_0(\hat{c}_0) + k\int_{c_1^L}^{c_1^U} s_1(\hat{c}_0, c_1)f(c_1)dc_1 > s_0(c_0) + (c_0 - \hat{c}_0) + k\int_{c_1^L}^{c_1^U} s_1(c_0, c_1)f(c_1)dc_1.$$

Because $\hat{c}_0 < c_0$, we have:

$$s_0(c_0) + (c_0 - \hat{c}_0) + k\int_{c_1^L}^{c_1^U} s_1(c_0, c_1)f(c_1)dc_1 > s_0(c_0) + k\int_{c_1^L}^{c_1^U} s_1(c_0, c_1)f(c_1)dc_1.$$

The constraint in (2) that guarantees c_0 will be reported instead of $\hat{c}_0$ when c_0 is the true cost gives:

$$s_0(c_0) + k\int_{c_1^L}^{c_1^U} s_1(c_0, c_1)f(c_1)dc_1 \geq s_0(\hat{c}_0) + k\int_{c_1^L}^{c_1^U} s_1(\hat{c}_0, c_1)f(c_1)dc_1.$$

Collecting the inequalities produces:

$$s_0(\hat{c}_0) + k\int_{c_1^L}^{c_1^U} s_1(\hat{c}_0, c_1)f(c_1)dc_1 > s_0(\hat{c}_0) + k\int_{c_1^L}^{c_1^U} s_1(\hat{c}_0, c_1)f(c_1)dc_1.$$

- a contradiction.[33]

The results above imply that there is a single cost target at t_0, c_0^T, and a possible range of cost targets at t_1 contingent on the cost reported at t_0. We denote this range by $c_1^T(c_0)$. We start by deriving some results about the properties of the compensation payments, $s_0(.)$ and $s_1(.,.)$. We begin the argument at t_1. Suppose $c_0 > c_0^T$ and c_1, $\hat{c}_1 \leq c_1^T(c_0)$. The truthtelling constraints at t_1 imply:

$$s(c_0, c_1) \geq s(c_0, \hat{c}_1) + (\hat{c}_1 - c_1);$$

and

$$s(c_0, \hat{c}_1) \geq s(c_0, c_1) + (c_1 - \hat{c}_1).$$

Taken together, these constraints imply:

$$s(c_0, c_1) - s(c_0, \hat{c}_1) = (\hat{c}_1 - c_1).$$

Therefore, the contract can be written as:

$$s(c_0, c_1) = a(c_0) + (c_1^T(c_0) - c_1) \; \forall c_0 > c_0^T \text{ and } c_1 \leq c_0^T(c_0).$$

Now suppose $c_0 > c_0^T$ and $c_1 > c_1^T(c_0)$. The truthtelling constraints for c_1 and $c_1^T(c_0)$ yield:

$$s(c_0, c_1) \geq a(c_0) + (c_1^T(c_0) - c_1);$$

and

$$a(c_0) \geq s(c_0, c_1).$$

This implies:

$$a(c_0) \geq s(c_0, c_1) \geq a(c_0) + (c_1^T(c_0) - c_1) \; \forall c_0 > c_0^T \text{ and } c_1 > c_1^T(c_0).$$

Taking the limit as c_1 approaches $c_1^T(c_0)$, we have:

$$s(c_0, c_1) = a(c_0) \; \forall c_0 > c_0^T \text{ and } c_1 > c_1^T(c_0).$$

Constraints (3), which require that all resources come from the owner, imply:

$$a(c_0) \geq 0 \; \forall c_0 > c_0^T.$$

Now consider the case when $c_0 \leq c_0^T$. By the similar use of truthtelling constraints, it can be shown that:

$$s(c_0, c_1) = b(c_0) \; \forall c_0 \leq c_0^T, \; c_1.$$

Now turn to the truthtelling constraints at t_0 for two costs, c_0, $\hat{c}_0 \leq c_0^T$. We have:

$$s(c_0) + kb(c_0) \geq s(\hat{c}_0) + (\hat{c}_0 - c_0) + kb(\hat{c}_0);$$

and

$$s(\hat{c}_0) + kb(\hat{c}_0) \geq s(c_0) + (c_0 - \hat{c}_0) + kb(c_0).$$

Taken together, these constraints imply:

$$s(c_0) + kb(c_0) - s(\hat{c}_0) - kb(\hat{c}_0) = (\hat{c}_0 - c_0).$$

Because this equation must hold for all pairs of costs no greater than the target, we have for some constant, e:

$$s(c_0) + kb(c_0) = e + (c_0^T - c_0).$$

The truthtelling constraints for a cost greater than the target, $c_0 > c_0^T$, and the target cost, c_0^T, itself give:

$$s(c_0) + k[a(c_0) + \int_{c_1^L}^{c_1^T(c_0)} (c_1^T(c_0) - c_1)f(c_1)dc_1] \geq e + (c_0^T - c_0);$$

and

$$e \geq s(c_0) + k[a(c_0) + \int_{c_1^L}^{c_1^T(c_0)} (c_1^T(c_0) - c_1)f(c_1)dc_1].$$

Taken together, these constraints imply:

$$e \geq s(c_0) + ka(c_0) + k\int_{c_1^L}^{c_1^T(c_0)} (c_1^T(c_0) - c_1)f(c_1)dc_1 \geq e + (c_0^T - c_0).$$

Taking the limit as the cost, c_0, approaches the target, c_0^T, from above, we have:[34]

$$e = s(c_0^T) + ka(c_0^T) + k\int_{c_1^L}^{c_1^T(c_0^T)} (c_1^T(c_0^T) - c_1)f(c_1)dc_1.$$

Using these results allows the objective function to be written as:

$$\begin{aligned}
&\int_{c_0^L}^{c_0^T} (1 - c_0^T)f(c_0)dc_0 \\
&-F(c_0^T)\left(s(c_0^T) + ka(c_0^T) + k\int_{c_1^L}^{c_1^T(c_0^T)} (c_1^T(c_0^T) - c_1)f(c_1)dc_1\right) \\
&+k\int_{c_0^T}^{c_0^H}\left(\int_{c_1^L}^{c_1^T(c_0)} (1 - c_1^T(c_0))f(c_1)dc_1\right)f(c_0)dc_0
\end{aligned}$$

$$-\int_{c_0^T}^{c_0^U} \left(s(c_0) + k(a(c_0))\right) f(c_0) dc_0.$$

The first two lines of this formulation of the objective function express the probability-weighted value of investing at t_0 whereas the second two lines represent the probability-weighted value of investing at t_1.

Now suppose we set

$$s(c_0) = a(c_0) = 0 \ \forall c_0 > c_0^T \text{ and } a(c_0^T) = 0.$$

To maintain incentives to tell the truth at t_0, we must have that $c_1^T(c_0)$ is a constant with respect to c_0 which we shall denote by c_1^T. Further, set $c_1^T(c_0^T) = c_1^T$. Is this optimal? Any increase in $s(c_0)$ or $a(c_0)$ must be associated with a reduction in $c_1^T(c_0)$ below c_1^T to maintain truth-telling constraints. But, as long as $c_1^T \leq 1$, reducing $c_1^T(c_0)$ below c_1^T is not in the interests of the owner because the owner values additional production. Hence, setting $s(c_0) = a(c_0) = 0 \ \forall c_0 > c_0^T$ and having a single cost target at t_1 is optimal from the owner's point of view. Further, it is clearly optimal to set $a(c_0^T) = 0$ as the economizing solution.

In addition, $b(c_0)$ does not appear in the objective function and, hence, can be arbitrarily set equal to 0. Given the above, we get:

$$s(c_0, c_1) = (c_1^T - c_1) \; \forall c_1 \leq c_1^T \text{ and } \forall c_0 > c_0^T;$$

and

$$s(c_0, c_1) = 0 \; \forall c_1 > c_1^T \text{ and } \forall c_0 > c_0^T;$$

and

$$s(c_0, c_1) = 0 \; \forall c_0 \leq c_0^T \text{ and } c_1;$$

and

$$s(c_0) = (c_0^T - c_0) + k \int_{c_1^L}^{c_1^T} (c_1^T - c_1) f(c_1) dc_1 \; \forall c_0 \leq c_0^T.$$

These are the forms of the optimal compensation functions given in the proposition.[35]

Given that these compensation functions must hold for arbitrary c_0^T and c_1^T, they must also hold for the optimal target costs, c_0^* and c_1^*.

Proof of Proposition 2

For interior c_0^* and c_1^*, c_1^* is determined by solving:

$$(1 - F(c_0^*))(1 - c_1^*) = \left(\frac{F(c_1^*)}{f(c_1^*)}\right).$$

An interior c_1^{NO} is determined by solving:

$$1 - c_1^{NO} = \left(\frac{F(c_1^{NO})}{f(c_1^{NO})}\right).$$

For an optimal c_0^* derived from the first-order conditions:

$$1 - F(c_0^*) \leq 1.$$

Given that $\frac{F(c_1)}{f(c_1)}$ is increasing in c_1 it must be the case that $c_1^* \leq c_1^{NO}$. Further, $c_1^{NO} \leq Min[c_1^U, 1] = c_1^{NI}$.

Proof of Proposition 3

For c_0^* and c_1^* derived from the appropriate first-order conditions, c_0^* is determined by solving:

$$c_0^* = 1 - \left(\frac{F(c_0^*)}{f(c_0^*)}\right) - k\int_{c_1^+}^{c_1^*}(1 - c_1)f(c_1)\,dc_1.$$

An optimal c_0^{NO} derived from first-order conditions is determined by solving:

$$c_0^{NO} = 1 - \left(\frac{F(c_0^{NO})}{f(c_0^{NO})}\right).$$

$c_1^* \geq c_1^t$, therefore:

$$k\int_{c_1^t}^{c_1^*}(1-c_1)f(c_1)dc_1 \geq 0.$$

Given that $\frac{F(c_0)}{f(c_0)}$ is increasing in c_0 it must be the case that $c_0^* \leq c_0^{NO}$. If the target cost in the absence of a timing option is determined by the first-order condition, $c_0^{NO} \leq Min\{c_0^U, 1\} = c_0^{NI}$.

Proof of Proposition 4

From the text, we have:

$$\frac{dc_0^*}{dz} = \frac{1}{\mid J \mid}(-B_2A_3 + A_2B_3)$$

and

$$\frac{dc_1^*}{dz} = \frac{1}{\mid J \mid}(B_1A_3 - A_1B_3)$$

where A_3 and B_3 are the partial derivatives of $A(c_0^*(z), c_1^*(z), z)$ and $B(c_0^*(z), c_1^*(z), z)$ with respect to the parameter of interest, z. We now prove that $\mid J \mid > 0$. From the first order conditions:

$$A_1 = -4\hat{c}_1$$

$$A_2 = -2k(1-c_1^*)$$

$$B_1 = -(1 - c_1^*)$$

$$B_2 = (c_0^* - 2\hat{c}_0)$$

Therefore, using the first-order conditions, we get:

$$| J | = 2\hat{c}_1(4\hat{c}_0 - 1) - k(2 - 6c_1^* + 3c_1^{*2})$$

Using differentiation, it can be shown that $| J |$ is increasing in c_1^* for $c_1^* < 1$. Evaluating $| J |$ at $c_1^* = 0$ suggests that $| J | > 0$ if:

$$\hat{c}_0 > \frac{1}{4} + \frac{k}{4\hat{c}_1}$$

Given that $k \leq 1$ and $\hat{c}_1 \geq 1$,

$$\hat{c}_0 > \frac{1}{2}$$

is sufficient to ensure that $| J |$ is positive. Note that the requirement in the proposition that:

$$\hat{c}_0 > 1 - \frac{k}{2\hat{c}_1}$$

ensures that this is the case.

Given that $|J| > 0$, we have:

$$Sgn[\frac{dc_0^*}{dz}] = Sgn[-B_2A_3 + A_2B_3]$$

and

$$Sgn[\frac{dc_1^*}{dz}] = Sgn[B_1A_3 - A_1B_3]$$

As a preliminary, note that for c_0^{NO} and c_1^{NO} derived from first-order conditions, $.5 = c_0^{NO} > c_0^*$ and $.5 = c_1^{NO} > c_1^*$. Now, the expressions for the signs of the various derivatives produces:

$$Sgn[\frac{dc_0^*}{d\hat{c}_0}] = Sgn[-2k(1 - c_1^*)(1 - 2c_1^*)] = -ve$$

$$Sgn[\frac{dc_1^*}{d\hat{c}_0}] = Sgn[4\hat{c}_1(1 - 2c_1^*)] = +ve$$

$$Sgn[\frac{dc_0^*}{d\hat{c}_1}] = Sgn[-2(-2\hat{c}_0 + c_0^*)(1 - 2c_0^*)] = +ve$$

$$Sgn[\frac{dc_1^*}{d\hat{c}_1}] = Sgn[-2(1 - c_1^*)(1 - 2c_0^*)] = -ve$$

$$Sgn[\frac{dc_0^*}{dk}] = Sgn[-c_1^*(2\hat{c}_0 - c_0^*)(2 - c_1^*)] = -ve$$

and

$$Sgn[\frac{dc_1^*}{dk}] = Sgn[c_1^*(1-c_1^*)(2-c_1^*)] = +ve$$

This establishes the results in the Proposition.

Proof of Proposition 5

Equations (17) and (18) straightforwardly arise from setting $c_0^* = c_1^* = c^*$ in equations (14) and (15) and solving. For an interior c_0^{NI}, we require that $c_0^{NI} = 1 - \frac{k}{2\hat{c}_1} < 1$, or $k > 2\hat{c}_1$. Using this inequality produces the condition that $0 > c^{*2} - 4c^* + 1$ or $(c^* - (2-\sqrt{3}))(c^* + (2-\sqrt{3})) < 0$. Thus, we require that $c^* > 2 - \sqrt{3}$.

Proof of Proposition 6

If $c_0 \sim U[c_0^L, c_0^U]$ and $c_1 \sim U[0, \hat{c}_1]$, $\hat{c}_1 \geq 1$, then the first-order condition for c_1^* suggests that:

$$c_1^* = \frac{(c_0^U - c_0^*)}{(2c_0^U - c_0^* - c_0^L)}$$

Using this expression in the first-order condition for c_0^* produces:

$$2c_0^* = 1 + c_0^L - \left[\frac{k}{2\hat{c}_1}\right]\left[\frac{(c_0^U - c_0^*)(3c_0^U - c_0^* - 2c_0^L)}{(2c_0^U - c_0^* - c_0^L)^2}\right]$$

Let

$$r = \frac{k}{2\hat{c}_1}$$

Then

$$c_0^{NI} = 1 - r$$

If we require

$$c_0^* = c_0^{NI}$$

then using $c_0^* = 1 - r$ on both sides of the equation for c_0^* above produces an equation relating values of r, c_0^L and c_0^U that result in the equality of c_0^* and c_0^{NI}. Letting

$$f(r) = \frac{(c_0^U - 1 + r)(3c_0^U - 1 + r - 2c_0^L)}{(2c_0^U - 1 + r - c_0^L)^2}$$

this equation is:

$$1 - c_0^L = r(2 - f(r))$$

Using the same methods as in Proposition 4, we can then demonstrate that reducing c_0^U will result in an increase in c_0^* but not c_0^{NI}, thus producing the result.

Proof of Proposition 7

First, if $c_1^* = c_1^L$, note that equation (9) implies that $c_0^* = c_0^U$. Second, note that equation (8) reduces to the equation for solving for the cost target for a one-shot deal. For a target cost solution to this equation,

$$c_0^* = \frac{(1 + c_0^L)}{2}$$

Therefore

$$c_0^U = \frac{(1 + c_0^L)}{2}$$

Now consider the general case where $c_0 \sim U[c_0^L, \frac{(1+c_0^L)}{2}]$ and $c_1 \sim U[c_1^L, c_1^U]$. The first-order conditions become:

$$2(c_1^U - c_1^L)(1 + c_0^L - 2c_0^*) - k(c_1^* - c_1^L)(2 - c_1^L - c_1^*) = 0$$

and

$$(1 + c_0^L - 2c_0^*)(1 + c_1^L - 2c_1^*) - 2(c_0^* - c_0^L)(c_1^* - c_1^L) = 0$$

Note that $c_1^* = c_1^L$ and $c_0^* = c_0^U$ are *always* solutions of the two first-order conditions. The condition:

$$c_0^L < 1 - \frac{k(1 - c_1^L)^2}{(c_1^U - c_1^L)}$$

is derived from applying the second-order condition for a maximum. It then can be proved formally by simple integration that c_0^{NI} is not interior and hence:

$$c_0^{NI} = c_0^{U} = \frac{(1 + c_0^{I})}{2}$$

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Notes

[1]For comprehensive and authoritative coverage of the real options approach to investment decision-making, see Dixit and Pindyck [1994] and Trigeorgis [1996].

[2]See Antle and Fellingham [1997] for a selective review of this literature.

[3]Related results can be found in Harris and Raviv [1996], Holmstrom and Weiss [1985], Rees [1986], and Sappington [1983].

[4]Their model is also applicable to two, nonmutually exclusive investment opportunities available at the same point in time, provided that the manager only knows the rate of return on one at the time of contracting and will learn the rate of return of the other later.

[5]Multiperiod agency models are relevant to our work. For example, Lambert [1984] studies a model in which an agent takes an action in each of two periods, and shows how real income smoothing can arise in equilibrium. Datar and Rajan [1995] analyze a sequential problem in which a manager takes an action at each stage. The second stage action could lessen a bottleneck problem, which is akin to expanding production options.

[6]In other words, the investment opportunity is irreversible.

[7]Because there is only one manager, coordination problems do not arise. See Kanodia [1993] for an analysis of a model involving coordination.

[8]Implicitly, we assume that the manager has unique skill in implementing the project, and cannot be profitably replaced. See Section 6 below for a discussion of this issue. This assumption

precludes any meaningful analysis of the assignment of decision rights, as in Baiman and Rajan [1995].

We also assume that the manager knows the cost at the time of any communication instead of simply being better informed that the owner but still uncertain. For analyses where communication takes place without the manager being completely informed, see Christensen [1982] and Kirby *et al* [1991].

[9]We explore the effects of relaxing this assumption in Section 6.

[10]Although slack consumption is the source of the incentive problem in the model, similar results can be obtained by assuming the manager has direct preferences for more investment (as in Harris and Raviv [1996]) or has a preference for the use of specific technologies.

[11]The owner's ability to commit and the absence of a moral hazard problem on his part imply he cannot benefit by assigning the rights to decide on the project entirely to the manager. For an analysis of the problem of assigning decision rights, see Baiman and Rajan [1995].

[12]We assume the manager will always turn over to the owner the proceeds of the investment if it is undertaken.

[13]The owner's ability to commit allows the application of the Revelation Principle (see Harris and Townsend [1981] and Myerson [1979]).

[14]These constraints also can be interpreted as implying that limited liability holds at both t_0 and t_1. An alternative set of constraints is:

$$s_0(c_0) \geq 0; \text{ and}$$

$$s_0(c_0) + s_1(c_0, c_1) \geq 0.$$

We do not use this formulation for two reasons. First, we regard slack as only consumable at the time it is provided - it is not storable. Interpreting slack as a lack of effort is consistent with this view. Second, as indicated above, we require that at no point in time can the owner insist that the manager use personal resources to fund investment. Hence, the manager always needs the owner to fund investment.

[15]The general constraint that ensures that the manager's compensation is sufficient to overcome his opportunity cost of working for the owner is:

$$s_0(c_0) + k \int_{c_1^L}^{c_1^U} s_1(c_0, c_1) f(c_1) dc_1 \geq \bar{U} \; \forall c_0,$$

where we assume that $\bar{U}$ is the reservation utility of the manager for a two-period contract. If $\bar{U} = 0$ then, clearly, requiring that $s_0(c_0) \geq 0$ and $s_1(c_0, c_1) \geq 0$ is sufficient to ensure this is so.

We assume that the manager's reservation utility is zero because if, alternatively, the manager's opportunity cost is very high, just fulfilling it would require all the benefits from the investment be given to the manager. In such a case, the manager internalizes all the externalities associated with the effects of his cost message on investment, and there are no incentive issues. We concentrate on cases in which there is a costly incentive problem by restricting $\bar{U}$ to be equal to zero. The solution will then reflect a costly tradeoff between distribution and efficiency, i.e., a costly incentive problem.

The same is true for the resource allocation models in Antle and Eppen [1985] and Antle and Fellingham [1990, 1995]. For example, in Antle and Eppen's one investment model, there is no rationing or slack if the manager's opportunity cost is so high as to require he get all the rents. For an extensive discussion of the tradeoff between distribution and efficiency in a one period model, see Antle and Fellingham [1995].

We assume the manager's discount rate is the same as the owner's. This assumption implies neither party has a comparative advantage in storage, and helps isolate the effects of incentives and timing options.

[16]The first set of constraints ensures that the manager will report truthfully at t_1 regardless of his t_0 report. The second set of constraints ensures that the manager will report truthfully at t_0, assuming the manager reports truthfully at t_1. These two sets of constraints are equivalent to the full set of constraints guaranteeing that the truthful reporting strategy is optimal for the manager.

[17]It is here that the assumed independence of costs across the two periods is crucial to the relatively simple form taken by the compensation function. Because of independence, the value of the manager's option on future information rents does not depend on the cost reported at t_0. If there were some form of interdependence between costs across the two periods, the specification of the optimal compensation function becomes substantially more detailed,

as we see below.

[18]This condition follows from Antle and Eppen's [1985] analysis of a one period, discrete model. Using a target cost policy, the principal maximizes $F(c)(1-c)$ over c. Equation (12) is the first-order condition for this problem.

[19]Another comparison we could make is with the situation in Antle and Fellingham [1990] who analyze a two-period model in which an investment can be made each period. Their model is slightly different from ours with the mutual exclusivity of investment constraint removed. Whereas we have a continuous set of possible costs and a discrete, produce or do not produce, investment decision, Antle and Fellingham [1990] require the set of possible costs to be finite and they allow fractional investments. Nonetheless, the economic substance of their analysis in our model is clear. If the owner can make two investments, Antle and Fellingham [1990] show he can increase the expected net present value of profits by linking the two decisions together. In particular, the owner can roll the manager's t_0 compensation for low c_0's forward to t_1, preserve its expected value, and reduce the costs of the incentive problem at t_1 by loading the compensation only on low c_1's. This allows the owner to raise the t_1 target above what it would otherwise have to be.

Restricting the owner to invest only at t_0 or t_1 removes any ability to use t_0 compensation to enhance expected profits at t_1. Compensation is only generated at t_0 if investment is made at t_0. But making the investment at t_0 precludes making it at t_1. Therefore, in comparison to the two-investment case, imposing the timing option constraint exacerbates the incentive problem.

[20]Proofs available from the authors.

[21]A hurdle rate form occurs if:

$$c_0 + k\int_{c_1^L}^{y_1^*}(y_1^* - c_1)f(c_1 \mid c_0)dc_1$$

is weakly increasing in c_0. This will occur, for example, if:

$$\frac{df(c_1 \mid c_0)}{dc_0} \geq 0, \forall c_0 \text{ and } c_1 \in [c_0^L, y_1^*].$$

This condition implies, in particular, that $F(c_1 \mid c_0)$ is increasing in c_0 $\forall$ $c_1 \in [c_0^L, y_1^*]$, i.e., the higher are costs at t_0, the higher the probability that costs will be lower than any c_1 for any $c_1 \in [c_0^L, y_1^*]$. This is a form of negative correlation of costs. Nonetheless, this condition is stronger than is necessary to ensure a hurdle rate research. Identifying more specific conditions is hampered by the absence of easy solutions for y_0^* and y_1^*.

[22]Observe that it makes no difference whether or not it is assumed that the owner can commit to an investment strategy at t_1 at t_0.

[23]When renegotiation is possible, it can be shown that the optimal target costs would be those that would survive a renegotiation. That is, the optimal targets are those that would be re-affirmed, rather than revised, by renegotiation. This makes them "renegotiation-proof."

[24]The analysis in this section owes much to the suggestions of one of the anonymous referees.

[25]The use of uniform distributions makes it relatively easy to link the costs of truth-telling with the characteristics of the cost distributions.

[26]Note that, under the conditions of the proposition, when $c_0^* = c_1^* = c^*$ the ratio of the probability of investment at t_0 to the conditional probability of investment at t_1 is $\left(\left(1 - \frac{\ell}{2\ell_1}\right)\frac{\ell_1}{\ell_0}\right)$ in the first-best case, whereas it is merely $\left(\frac{\ell_1}{\ell_0}\right)$ in the second-best case. Naturally, the absolute size of the probabilities might be decreased in the second-best relative to the first-best case.

[27]$c_1^* = c_1^L$ not implying $F(c_0^*) = 1$ requires identifying a distribution for costs at t_1 such that $\lim_{c_1 \to c_1^L} \frac{F(c_1)}{f(c_1)} > 0$. This then requires that $\lim_{c_1 \to c_1^L} f(c_1) = 0$ but that $\lim_{c_1 \to c_1^L} \frac{f(c_1)}{f'(c_1)} > 0$.

[28]Arithmetic calculation also suggests that, subject to rounding errors, the intervals indicated by the table will also induce the shutting off of the option to wait.

[29]It is straightforward to demonstrate that if the cost target at t_0 is set equal to c_0^U, then the cost target at t_1 will be set equal to c_1^L. This action is taken because any cost target above that wastes value (see (OF)). As a consequence a necessary condition for the cost target to be set equal to c_0^U is that $\delta \text{OF}/\delta c_0^* > 0$ when evaluated at $c_0^* = c_0^U$. It can also be observed that $\delta \text{OF}/\delta c_0^*$ decreases as c_0^* increases. If $c_0 \sim U[c_0^L, c_0^U]$, with $c_0^U < 1$, this condition reduces to:

$$\frac{(1 - c_0^U)}{(c_0^U - c_0^L)} > 1$$

[30] We do not study when an incentives problem creates a valuable timing option (i.e., the timing option has zero value in the absence of an incentives problem but has strictly positive value in the presence of an incentives problem). Arya and Glover [2000] study this issue in a related but different setting.

[31] Antle and Fellingham [1995] address the value and effects of information in a one period model. Antle, Bogetoft and Stark [2000] take an initial look at this issue in a model with incentive and timing effects.

[32] The assumption that $d_0(c_0) = 0$, i.e., with c_0 the investment is not undertaken in the first period, is implicit in the assumption $d_1(c_0, c_1) = 1$.

[33] The independence assumption is implicit in the densities under the integrals. Independence is used for the last weak inequality in the proof.

[34] We define $a(c_0^T)$ as the limit of $a(c_0)$ as c_0 tends to c_0^T from above and $c_1^T(c_0^T)$ as the limit of $c_1^T(c_0)$ as c_0 tends to c_0^T from above.

[35] Because of the arbitrary choice of $b(c_0)$, they are not unique.