Impacts of Organizational Learning and Knowledge Transfer on Investment Decisions under Uncertainty

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Abstract

Investments in innovative technologies face uncertainties and are often made in stages. We develop a multi-period game-theoretical model where the potential of a new technology is uncertain, and players involved can only learn about its true potential over time. Players involved include a decision maker and a project manager (or manager in short). The manager gains knowledge through direct access to the project and updates his beliefs about the potential of the new technology accordingly, while the decision maker learns about the new technology from knowledge transferred from the manager. We show that the manager with misaligned incentives may transfer his knowledge untruthfully and distort the learning process of the decision maker. As a result, the decision maker will discount the manager’s report due to expectations of possible misreporting, leading to inefficient investment decisions. We also propose solutions to this problem.

1. Introduction

Investments in research and developments (R&D) of a new technology are often made when the potential value of the technology is still uncertain. Firms face the tradeoffs between strategic advantages of early investments and the option to wait until some uncertainty is resolved (see, among others, [9, 15, 19]). In response, firms often make investments in multiple stages, so that at each stage they can decide whether to continue to invest based on information gained from earlier stages [18, 21].

What has largely been ignored is that the process in which uncertainty around a new technology resolves is also the process in which the investing organizations learn about the potential of the technology. Previous studies usually assume that once some uncertainty is resolved, it becomes common knowledge to parties involved; in other words, the details of organizational learning – how participants learn about a new technology and how the knowledge is transferred from one participant to another – are not considered.

This paper focuses on how organizations gain knowledge about new technologies while investing in these technologies, and how the learning process may influence investment decisions. We posit that learning about the potential of an unproven technology and transferring this knowledge effectively within an organization present new challenges to investment decisions under uncertainty. We develop a multi-period game-theoretical model to describe and explore the impacts of learning and knowledge transfer processes on investment decisions.

Individual and organizational knowledge often takes the form of beliefs about reality [22]. In our model, a participant’s knowledge about a new, unproven technology involves a belief in the potential value of the technology. Some new technologies are superior to others, and an intrinsically superior technology is more likely to be more profitable. A player forms beliefs about the type to which a technology belongs, based on all the information available to him/her. Furthermore, as more information is revealed over time, a player updates his/her beliefs. One key feature of our model is that players learn about the potential of a technology through different conduits, and thus update their beliefs in different patterns. Specifically, all players hold the same initial belief about a new technology’s potential value before an investment is made. Once a firm invests in the R&D of this technology, players in the firm can either observe or get reports about the progress of the project, and revise their beliefs about the potential of the technology.

In large organizations, major investment decisions are often made at the highest corporate level based on reports from lower-level managers. Lower-level managers usually have access to first-hand information regarding the progress of projects. Decision makers rely on these managers who provide updated information about the projects. Such information asymmetry between decision makers and lower-level managers may not be a serious concern when the projects are routine and reported outcomes
can be easily verified. When a firm is investing in a novel technology and there is uncertainty around the potential of the technology, managers with direct access to the project may understand the technology much better than decision makers, and the decision makers may not be able to fully observe or correctly interpret the progress of the project. This has been widely observed and documented in the product development processes of many industries, including software [8], aerospace [5], automotive [23, 31], and electronics [30]. In such situations, it is critical for managers to truthfully report the progress of a new technology project so that decision makers can make well-informed decisions.

Managers who gain first-hand knowledge may untruthfully report their knowledge. When a new technology is not as promising as expected or the project progress is less than satisfactory, managers may not want to report the true status of the project for a sundry of reasons. For example, they may fear that such reports will be interpreted as their failure as managers rather than the technology’s lack of potential; or, they may want to entrench their positions in the organization by continuing working on the project but a negative report is likely to result in a halt of the project. Research has shown that concealment of problems is quite common in R&D efforts [11, 24, 27]. Ford and Sterman [12] observed that at a defense contractor the project team leaders who met weekly were known as a "liar’s club" because everyone withheld knowledge about the problems and delays in their subsystems.

Our game-theoretic model describes the interactions between two parties: a decision maker, and a project manager. At one stage of the game, the two parties engage in a knowledge transfer process: the project manager is a knowledge sender who may interfere with the learning processes of the decision maker, who is a knowledge receiver. When it is possible for managers to untruthfully report the progress of a new technology project, it can result in inefficient investment decisions. If decision makers are unaware of untruthful reporting, they will make misguided decisions, usually resulting in over-investment. If decision makers are fully aware of such problems, however, they tend to discount reports from managers and may not invest even when they should, which leads to underinvestment.

Our research contributes to several strands of literature. It has been recognized that aligning participants’ incentives with organizational objectives is an important dimension for the design of information and knowledge management systems [2]. Building on the sender-receiver framework for knowledge transfer proposed by Lin, Geng and Whinston [20], we study how information asymmetry and misaligned incentives between parties may challenge effective knowledge transfer in the setting of investment decisions.

March [22] describes how organizations may learn from individuals’ knowledge and notes that it is possible that in equilibrium all individuals and the organization may share the same but inaccurate beliefs. We use game theory to explicitly model the behavior of parties and show how such undesirable knowledge transfer outcomes may happen.

Our research also contributes to the literature on investment under uncertainty. We highlight the importance of parties’ learning behavior when organizations make investments under uncertainty, which has only been vaguely alluded to in the real options theory or strategic investment literature.

Our model has features of both signaling games and signal-jamming games. A manager’s report serves as a signal to the decision maker, but the signal can be jammed. Our research is related to the “signal-jamming” model presented in Stein’s 1989 paper [26]. In Stein’s paper, the process of natural earnings is common knowledge; in our model, there is an additional layer of uncertainty in the investment opportunity.

2. The Model

2.1 Model Setup

A firm endowed with one unit of asset considers whether to invest in the R&D of a new technology. There are three dates: 0, 1, and 2, and the time intervals between two adjacent dates are called Period 1 and Period 2 respectively. At date 0, the firm faces two investment strategies. If the firm invests in a traditional technology, the unit asset invested will have a deterministic value \( a \) at date 1.\footnote{A deterministic return simplifies the analysis. We can also introduce risk to this investment opportunity without affecting the results.} We normalize the value \( a \) to 1. The other strategy is to invest in a new technology. If the R&D efforts make good progress in Period 1, the value of the invested asset becomes \( g \) at date 1; and if the project progress is discouraging (i.e. bad), however, the value at date 1 is \( b \). Compared with the traditional strategy, investing in a new technology leads to a higher value if it goes smoothly but a much lower value otherwise, reflecting the risky nature of technology investments.

\textbf{Assumption 1:} \( g > a = 1 > b > 0 \).
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The opportunity to start investing in the new technology only occurs at date 0. Therefore, if the firm chose the traditional investment strategy at date 0, at date 1 it no longer has the option to invest in the new technology, and thus can only continue with the traditional investment, which means that the value of the asset will remain the same. If the firm chose to invest in the new technology R&D at date 0, however, it can choose one of these two strategies at date 1: to continue with the new technology investment, or to switch to the traditional strategy. Switching to the traditional strategy means that the asset will retain its value at date 2 (= g if the Period-1 progress was good, and = b if bad). Continuing with the R&D efforts will result in either a good or bad outcome at date 2. Therefore, if Period-1 progress was good, the asset will be worth g^2 if Date-2 outcome is again good, and gb if Date-2 outcome is bad; similarly, if Period-1 progress was bad, the asset will be worth gb if Date-2 outcome turns out to be good, and b^2 if Date-2 outcome is also bad. We assume that there is no discounting between periods, and that switching investment strategies at date 1 incurs no cost.2

The true probability that the new technology will yield a good outcome in each period is \( \beta \), and the probability of getting a bad outcome is \( 1 - \beta \). \( \beta \) represents the type of a technology, with a higher \( \beta \) indicating a superior technology. The uncertain nature of the technology investment lies in that the true probability for a technology to succeed (i.e., the true value of \( \beta \)) is unknown to all players involved at date 0 and date 1. We assume that the new technology can be either a superior type (\( \beta_s \)) or an inferior type (\( \beta_i \)), where \( \beta_s > \beta_i > 0 \). If a new technology is a superior or high type, the probability of getting \( g \) in each period is \( \beta_s \), and the probability of getting \( b \) is \( 1 - \beta_s \). For an inferior technology (a low type), the probability of getting \( g \) in each period is \( \beta_i \). It must be noted that the progress observed at date 1 does not reveal the type of a technology to a player: an inferior technology can make good progress in period 1 (\( g \) observed) while a superior technology may not (\( b \) observed).

There are two players in our model: the project manager and the decision maker. The decision maker (D) chooses which investment strategy to pursue, while the project manager (M) implements the selected strategy, observes and reports the outcome. Both players are risk-neutral. At Dates 0 and 1, D chooses the investment strategy that maximizes the expected value of the asset at date 2. M’s payoff will be discussed later.

The values of the parameters \( g, b, \beta_s, \) and \( \beta_i \) are common knowledge to both players. However, neither knows the actual type of the new technology in which the firm invests. Both players initially share the belief that the investment has a probability of \( \gamma_0 \) to be a high type, i.e. \( P(\beta = \beta_s) = \gamma_0 \). For notational convenience, we define: \( \eta_0 = \beta_s \gamma_0 + \beta_i (1- \gamma_0) \), which is the initially believed probability of a good period-1 result.

The high risk in new technology investment largely comes from the lack of understanding of the business potential of new technologies, and their possible impact on industrial organization structures. Nevertheless a company can better learn its position after it stays in the business for a while for reasons including the maturing of the technology, a better understanding of market demand, and the stabilization of competition.

In our model, the learning process is reflected by the fact that the progress in period 1 can help players obtain a better estimate of the type of the technology.3 As discussed in the next subsection, if the outcome after period 1 is good and this information is fully observed by both parties, then they will gain confidence in the new technology; if, on the other hand, the progress is not as good, people will realize that the initial belief, \( \gamma_0 \), is too optimistic.

2.2 The First-Best Case

As a benchmark, we first discuss what investment strategy D will choose if he has the same knowledge as M. Therefore, in this subsection, we assume that D can observe period 1 outcome. In this first-best case, D simply makes the investment decisions by solving a maximization problem. The sequence of events is as follows. At date 0, D decides to invest in new or traditional technology based on the expected value using all available information. At date 1, D observes the Period-1 outcome and updates his belief on the type of the technology, and then chooses the investment strategy for period 2 based on

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2 A low switching cost will not change the results.

3 It may take years for a company to fully understand its investment’s potential, and thus the learning process may take many periods. However to model the misreporting issue related to technology investments, a two-period model is enough to reveal all the intuition.
the updated beliefs. At date 2, the period 2 outcome is realized.

If D chooses to invest in the new technology at date 0, and consequently observes period 1 result, he can update his date 1 belief about this investment being a high type using Bayes’ rule as follows:

- if period 1 outcome is good, D updates his belief to
  \[ \gamma_{ig} = P(\beta_h | g) = \frac{\beta_h \gamma_0}{\beta_h \gamma_0 + \beta_i (1 - \gamma_0)}; \]
- if period 1 outcome is bad, D updates his belief to
  \[ \gamma_{ib} = P(\beta_h | b) = \frac{(1 - \beta_i) \gamma_0}{(1 - \beta_i)\gamma_0 + (1 - \beta_i)(1 - \gamma_0)}. \]

For notational convenience, we also define:

\[ \eta_{ig} = \gamma_{ig} \beta_h + (1 - \gamma_{ig}) \beta_i, \]
which is the updated probability of getting a good result at date 2 after observing a good period-1 result; and

\[ \eta_{ib} = \gamma_{ib} \beta_h + (1 - \gamma_{ib}) \beta_i, \]
which is the updated probability of getting a good result at date 2 after observing a bad period-1 result.

If \( \eta_{ig} g + (1 - \eta_{ib}) b > 1 \), D will continue his new technology investment even if the period 1 outcome is bad. Consequently, D will choose the new technology investment in date 0 and continue this investment choice in date 1 regardless of period 1 outcome. For the rest of the paper, we focus on the more interesting case where a bad result in period 1 is sufficient to let D discontinue the new technology investment.

**Assumption 2 (Risky new technology investment):**

\[ \eta_{ib} g + (1 - \eta_{ib}) b < 1 . \]

We can now characterize D’s optimal choice at date 0 in the first-best case:

**Proposition 1.** Suppose D can observe the result of period 1 at date 1. D chooses the new technology investment at date 0 if and only if the following condition is met:

\[ \eta_{ig} g + (1 - \eta_{ib}) b > 1 . \]

If the condition in Proposition 1 does not hold, D will never choose the new technology investment even in this first best case. This is also an analytically uninteresting case and we rule it out using the following assumption:

**Assumption 3 (Promising new technology investment):**

\[ \eta_{ib} g + (1 - \eta_{ib}) b > 1 . \]

### 2.3 Asymmetric Learning and Conflicting Interests between Players

Now we examine the case where the decision maker cannot observe the period 1 outcome directly and has to rely on a report from the project manager. Problems may arise when the manager has a personal interest that conflicts with that of the decision maker.

**Assumption 4:** The result in period 1 is observable only to M, but not to D.

M realizes a payoff at date 2, which may consist of three components based on the outcomes. First, M’s compensation (which can be understood as bonus) is related to the Date-2 value of the project. This part of M’s payoff is \( \alpha \) fraction of the value of asset at date 2.

Second, M personally prefers the new technology investment (if chosen by D at date 0) to switching to the traditional technology at date 1. This is a private benefit to M that cannot be captured by the firm, which may come from several sources. For example, M can gain personal experience with the new technology (even if it fails); or can further entrench his position in the firm; or has psychological attachment to the project. M has an additional payoff of \( p \) at date 2 if at D chooses to continue with the new technology investment at date 1.

The third component of M’s payoff depends on M’s behavior and the outcome of the project. From previous analysis, we know that if D could observe the outcome at date 1, he would update his belief accordingly; as a result, if the period-1 result were bad, he would choose to switch to the traditional technology. Since D cannot observe the outcome at date 1, it is possible for M to untruthfully report the outcome to D. Due to his private benefit from continuing with the technology investment, M has an incentive to report a good outcome to D when the actual outcome is bad. However, there is a potential cost for M to do so. Suppose M reports a good outcome at date 1 when the actual is bad. Let \( \hat{g} \) be the outcome that the manager reports to the decision maker, which we call the “reported outcome”, as to be distinguished from the true outcome. If the project realizes a value of \( gb \) at Date-2, we assume that M’s misreporting will not be detected. If, however, the value at date 2 turns out to be \( b' \), it clearly indicates that M misreported and M will suffer a loss of \( d \). \( d \) can be regarded as reputation loss or the cost of being fired. Managers differ in their concerns for reputation or losing a job. Suppose that \( d \in [0, \infty) \) with a continuous and
strictly increasing distribution function $F()$. Since $d$ differentiates managers, for convenience we call $d$ the “type” of the manager. We make the stylized assumption that $F()$ is common knowledge while only the manager observes his own type.

3. The Results

3.1. Signal-jamming

Since this is a multi-period model with incomplete information, the equilibrium concept we use is Perfect Bayesian Equilibrium (PBE). Our model falls into the broad range of sender-receiver games [7, 14]. This model has the signaling component [see 1, 25], as the manager’s type is his private information that will be partially revealed when he chooses his action (to report truthfully or not) in a semi-separating equilibrium as we later show. This model also has the signal-jamming component [see 13, 16], as the purpose of the manager’s action is to “jam” the transmission of nature’s signal on the type of new investment (high or low) to the decision maker.

The signal-jamming component in our model is more important as D only cares about whether or not M jams nature’s signal: once the new technology investment is chosen at date 0 and if the reported outcome in period 1 is good, it could be a false result that is forged by a cheating manager in a bad period 1, or it could be a true outcome in a good period 1. Consequently, even if equilibrium exists and a reported good period 1 result is observed, D is not sure about the true period 1 outcome (nature’s signal) or whether the manager cheated (manager’s signal).

We use notation “*γ*i” to distinguish the updating rules in this section from ones in the benchmark case in Section 2. For example, we keep the notation “*γ*i” for the benchmark case, and use “*γ*i” for this section. Note that $\hat{\gamma}_{ib} = \gamma_{ib}$ since the manager will never report “bad” when period 1 outcome is good.

The next lemma shows that, although the signal from nature is jammed by M’s action, D may still uncover partial information.

**Lemma 1.** *In any equilibrium, $\hat{\gamma}_{ib} \in [\gamma_{ib}, \gamma_{ib}]$.***

From Lemma 1 we know that, at date 1, if the reported result is good, D should expect the technology investment to be no worse than expected at date 0. Intuitively, the worst possible equilibrium is that a manager of any type will always cheat when period 1 outcome is bad, and consequently D should ignore any reported good result since it does not transfer any useful knowledge to D (i.e., $\hat{\gamma}_{ib} = \gamma_{ib}$).

All other possible equilibria can transfer at least a little useful knowledge since some types of managers will honestly report a bad period 1 result, which implies that $\hat{\gamma}_{ib} \geq \gamma_{ib}$.

Since $\hat{\gamma}_{ib}$ may be smaller than $\gamma_{ib}$, Assumption 3 is not enough to ensure that D will continue the new technology investment in date 1. We solve for $\hat{\gamma}_{ib}$ and study M’s misreporting problem and D’s decision problem in the next subsections.

3.2. Misreporting Problem in the New Technology Sub-Game

Based on D’s choice at date 0, there are two distinguishable sub-games: the one where D chooses the new technology investment at date 0, which we call the new technology sub-game, and the one where D chooses the traditional investment at date 0, which we call the alternative sub-game. It is straightforward to see that the misreporting issue does not exist in the alternative sub-game as it provides the manager no chance to gain from cheating. In this subsection, as well as in subsections 3.3 and 3.4, we focus on the new technology sub-game.

Generally, we assume that there exists a PBE for the new technology sub-game where, if $d \in C$, the manager misreports (or cheats) when period 1 result is bad. So C is the set of cheating types (and we denote the set of honest types as N). In any PBE, M knows D’s belief updating process. As a result, after observing the true period 1 outcome and before deciding on cheating or not, M is well aware of the consequences of each alternative. He cheats if and only if his expected gain from continuing with the investment outweighs his expected loss. Define $d_n = [p - \alpha \beta (1 - \eta_{ib} g - (1 - \eta_{ib}) b)] / (1 - \eta_{ib})$. For ease of exposition, let $p$ be large enough so that $d_n$ is always positive.

**Lemma 2.** *Consider any PBE in which D continues the new technology investment upon a good reported outcome. If M observes a bad outcome in date 1, he will truthfully report if $d \geq d_n$, and cheat if $d < d_n$.***

Therefore, following a date 0 new technology investment, if in a PBE D’s optimal date 1 strategy upon a good reported outcome is to continue this
investment, we have $C=[0,d_n)$ and $N=[d_n,\infty)$. Whenever applicable, we refer to $d_n$ as the marginal type of $M$, who is indifferent between truthfully reporting and cheating. Given a continuous and monotonically increasing $F(\cdot)$, the probability of a manager being the marginal type is only infinitesimal. So hereafter we often ignore the discussion of the choice of the marginal type, and have $C=[0,d_n)$ and $N=(d_n,\infty)$. 

Now consider $C=[0,d_n)$ and $N=[d_n,\infty)$, and that $D$ will continue the new technology investment upon a good reported period 1 outcome (we will shortly verify this statement’s validity in equilibrium). Let $\phi$ denote the probability that the manager will cheat in a bad period 1, then $\phi=F(d_n)$. The following equations show how investors will update their beliefs about the new technology investment on receiving a reported period 1 result:

- if reported result is good, $\hat{\gamma}_{gb}=P(\beta=\beta_b|\hat{g})=(1-\phi)\beta_b+\phi\gamma_b/(1-\phi)\beta_b+\phi\gamma_b+(1-\phi)\beta_b\gamma_b/(1-\phi)\beta_b+\phi\gamma_b$;
- if reported result is bad, $\hat{\gamma}_{bb}=P(\beta=\beta_b|\hat{b})=\gamma_b(1-\beta_b)/(1-\beta_b)\gamma_b+(1-\beta_b)(1-\gamma_b)$.

We then have $\hat{\gamma}_b=\hat{\gamma}_{gb}\beta_b+(1-\hat{\gamma}_{gb})\beta_b$ and $\hat{\gamma}_b=\hat{\gamma}_{gb}\beta_b+(1-\hat{\gamma}_{gb})\beta_b$. Given the updated beliefs, $D$ will re-evaluate the new technology investment. Since $\hat{\gamma}_b=\gamma_b$, $D$ will choose to switch to the traditional technology investment upon receiving a bad reported period 1 result; when a good reported result is received, nevertheless, $D$ does not necessarily continue with the new technology investment, as shown in the next proposition.

**Proposition 2.** Suppose $D$ chooses the new technology investment at date 0. At date 1:

- If $\hat{\eta}_{gb}+(1-\hat{\eta}_{gb})b\leq 1$, $D$ will switch to the traditional technology investment regardless of $M$’s reported outcome.
- If $\hat{\eta}_{gb}+(1-\hat{\eta}_{gb})b> 1$, $M$ will cheat if and only if period 1 outcome is good and $d<d_n$. $D$ will continue with the new technology investment upon receiving a good reported outcome, and switch otherwise.

Proposition 2 is a strong result in the sense that it holds for all possible functional forms of $F(\cdot)$, i.e. the distribution of the loss to the manager when his cheating behavior is detected, as long as $F(\cdot)$ is continuous and monotonically increasing. Proposition 2 is also surprising since, unlike most signaling games, multiple equilibria do not emerge. Intuitively, on the one hand, since $P(g|\hat{g})$ is a decreasing function of $d_n$, the manager’s gain from cheating is a decreasing function of $d_n$, which is also fixed in the equilibrium. On the other hand, the manager’s expected loss from cheating is an increasing function of his type. Therefore, there exists a unique cutting type that, below this cutting level the manager finds cheating profitable while above this cutting level he finds the opposite.

**Corollary 1.** The existence of the misreporting problem may lead to inefficient investment decisions at date 1, and thus harms the expected value of the new technology investment.

This corollary directly follows Proposition 2. When $\hat{\eta}_{gb}+(1-\hat{\eta}_{gb})b\leq 1$, period 1 outcome does not benefit $D$ at all since he completely ignores $M$’s reported outcome. When $\hat{\eta}_{gb}+(1-\hat{\eta}_{gb})b> 1$, period 1 outcome is (imperfectly) transmitted to $D$, yet if $d<d_n$ $D$ will still be mislead to inefficiently continue the new technology investment. As a result, the investment can never lead to an expected value as the one in the first-best case.

### 3.3. Risky Technology Investment Worsens the Misreporting Problem

In the preceding subsection we established the relationship between unobservability of interim outcome and the misreporting issue for risky technology investments. In this subsection we address a further question: does the misreporting issue worsen when the technology investment is riskier? In other words, are highly innovative technologies more likely to be plagued by misreporting issues?

We model risk as a mean-preserving spread of the expected value of the investment. Formally, given the same expected value of the new technology investment at date 0, we consider the impacts of the variance of the expected value on managerial behavior and investment decisions. Let $\Delta=[g,b\mid \eta_g+(1-\eta_b)b=R]$, which is the set of $(g,b)$ that has a constant expected value of $R$. In this subsection we only consider values such that $(g,b)\in \Delta$. Within $\Delta$, a higher $g$ implies a lower $b$ and means a riskier technology.
In the first-best case discussed in Section 2, risk comes from a possible bad period 1 outcome, which is more likely when the technology investment is of a low type. Nevertheless, D has the option at date 1 to switch to the traditional investment once he discovers that period 1 outcome is bad. The following lemma shows that in the first-best case D prefers a higher g for any \((g, b) \in \Delta\), a.k.a. a riskier technology investment.

**Lemma 3.** In the first-best case where D can observe period 1 outcome, the date 0 expected value of the new technology investment is an increasing function of \(g\) for \((g, b) \in \Delta\).

Intuitively, when the technology becomes riskier, it makes a good outcome better and a bad outcome worse. If period 1 outcome is bad, there is always the option to switch to the traditional technology at date 1 to protect the company from further loss; if period 1 outcome is good, however, the company can continue with the investment and reap even higher value in the next period. Overall, the benefit from the upside of a riskier project outweighs the cost of the downside, making D prefer riskier technology investments in the first-best case. This is a typical result for growth options documented in the real options literature [9].

Nevertheless, once we consider the misreporting issue, the opposite could happen, as shown in the next proposition.

**Proposition 3.** Suppose at date 0 D chooses the new technology investment. Given \((g, b) \in \Delta\). If

\[
\frac{g}{R} > \frac{1 + 1/\eta_0 + (1-\eta_0)(1-1/R)}{2} = \frac{\eta_0 - \eta_b}{2}
\]

the possibility that the manager cheats upon a bad period 1 outcome is an increasing function of \(g\).

Proposition 3 shows that, given equation (1), more innovative technologies worsen the misreporting issue. In other words, the riskier the technology investment is, the more likely the manager reports a bad period 1 outcome untruthfully.

When will equation (1) hold? One specific example, as justified by the following corollary, is the case of investment in innovative technologies, which is often characterized by large risk (small \(\beta_1\)) and huge gain upon success (large \(g\)).

**Corollary 2.** Suppose at date 0 D chooses the new technology investment. Given \((g, b) \in \Delta\), if \(\beta_1\) is small enough and \(g\) is large enough, the possibility that the manager cheats upon a bad period 1 outcome is an increasing function of \(g\).

### 3.4. Inefficient Investment Decisions

In previous subsections, we have considered the sub-game where date-0 choice is the new technology investment. In this subsection we analyze D's investment decision at date 0.

If D chooses the new technology investment in date 0, the expected value of the investment is

\[
v = \eta_0 g [\hat{h}_d g + (1 - \hat{h}_d) b] + (1 - \eta_0) b.
\]

Given \(g, b, \beta_1, \beta_h\) and \(F(\bullet)\), this value is a function of \(d_m\), i.e.,

\[
v = v(d_m).
\]

It is also straightforward to show that

\[
v(d_m) = \lim_{d_m \to \infty} v(d_m),
\]

which is the value of the new technology investment if M always cheats. Let \(d_m\) be the solution to \(v(d_m) = 1\) when \(v_m < 1\).

**Proposition 4.** If \(v_m \geq 1\), or if \(v_m < 1\) and \(d_m < d_m\), D chooses the new technology investment at date 0; at date 1, M cheats if and only if \(d < d_m\), and D continues the new technology investment if and only if receiving a good reported outcome.

If \(v_m < 1\) and \(d_m \geq d_m\), D chooses the traditional technology investment at date 0 and continues with this choice at date 1.

The condition \(v_m < 1\) is equivalent to \(\eta_0 g + (1 - \eta_0) b > 1\). Therefore, a necessary condition for D to shun away from the new technology investment is that, without any learning, the new technology is an inferior choice. Indeed, in this model the potential of the new technology lies in the possibility of learning from period 1 results and consequently adjusting the firm’s investment strategy.

Although in the first-best case the new technology has a higher expected return than the traditional one, in equilibrium the decision maker expects possible misreporting from the manager once the new technology investment is chosen. Consequently, D discounts the value of the new technology investment ex ante. In the worst case, D turns away from the new technology investment.

Note that if \(v_m < 1\) and \(d_m \geq d_m\), companies will avoid the new technology investment even if the manager is honest (i.e., with a large \(d\)). In other words, the existence of managers who are more likely to misreport (i.e., those with a small \(d\)) can make
companies shun away from new technology projects. It is worth noting, however, that this result is based on the assumption that the type of the manager of each firm is private information to the manager only; if a decision maker within the firms has private information about the exact types of his managers, such as through auditing or past experience, he will then be able to make efficient investment decisions.

3.5 Extension: Biased public beliefs

Up to now we assumed that the true distribution of M’s type, \( F(d) \), is common knowledge. Nevertheless, in reality this is not necessarily the case. The question we ask here is: how do biased beliefs on the manager’s types affect the manager’s cheating behavior?

Let \( \hat{F}(\cdot) \) be D’s belief on the distribution function of M’s type. If \( \hat{F}(\cdot) \) differs from \( F(\cdot) \), we say that D has biased belief. Since M will not have less information than D, M also knows \( \hat{F}(\cdot) \). Accordingly let \( \hat{d}_m \) be the marginal type in equilibrium under \( \hat{F}(\cdot) \). \( d_m \) still denotes the marginal type if D knew \( F(\cdot) \).

**Proposition 5**. Given \( \hat{d}_m \in (d, \tilde{d}) \),
if \( \hat{F}(\cdot) > F(\cdot) \) for any \( d \in [d, \tilde{d}] \), then \( \hat{d}_m < d_m \);
if \( \hat{F}(\cdot) < F(\cdot) \) for any \( d \in [d, \tilde{d}] \), then \( \hat{d}_m > d_m \).

Proposition 5 shows that if D is biased towards distrusting the manager the manager will be less likely to cheat. Intuitively, it is because D takes a reported good period 1 result less seriously and thus heavily discounts it, which makes cheating less attractive to the manager. In other words, Proposition 5 is somewhat surprising as it says that a biased belief (towards distrusting the management) will end up benefiting the decision maker by alleviating the misreporting problem.

On the other hand, Proposition 5 also suggests that when D is overconfident about the managers, believing that the reputation loss of being caught lying is high enough to deter lying in most managers, cheating is more likely to happen.

It is worth noting that whether or not the manager knows the truth distribution of the manager’s type, \( F(\cdot) \), the result in Proposition 5 remains the same.

4. Possible Remedies

Managers misreport the period-1 outcome when it is unobservable to the decision maker because of: a) conflicting interests, and b) private information about M’s own payoff. Therefore many remedies to this issue should focus on various ways to align the incentives of the managers and to make the managers incentives more transparent.

We first examine the effects of rewarding the managers based on the outcome of the project. In other words, we study how \( \alpha \) influences the manager’s behavior and the decision maker’s investment decision.

Another possible remedy is to **ex ante** explicitly announce the punishment to the manager if cheating is discovered later on.

The decision maker may also use auditing at date 1 to uncover any cheating behavior before the investment decision is made.

5. Concluding Remarks

Information technology (IT) investments face the challenge of committing irreversible investments when uncertainty abounds, and there has been a growing stream of research on IT investments using real options analysis (see, among others, [3, 4, 6, 10, 28, 29]). While real options analysis suggests that abandonment options can be as valuable as growth options, it is observed that firms escalate commitment to troubled IT projects [17].

This paper studies how an investment decision may be hampered by the learning and knowledge transfer processes within an organization. Uncertainty not only makes the overall evaluation difficult, but also makes the organizational learning process more complicated. The key message of this paper is that the novelty of a technology often leads to asymmetric learning processes of parties within an organization, which may lead to inefficient investment decisions.

In our model, managers learn about the potential of a new technology based on the intermediate outcome they observe. Decision makers, however, have to learn from the managers, who transfer knowledge to decision makers. Therefore, managers as knowledge senders have a chance to interfere with the learning process of the decision makers’. If they have such an incentive, managers can “jam” the decision makers’ learning process by misreporting the observed outcome.

When managers (knowledge senders) do not transfer their knowledge truthfully, the decision makers are unable to correctly update their beliefs, thus their knowledge is tainted. This is detrimental to firms because this leads to inefficient investment decisions. We find that understanding that such
interference may happen can deter untruthful reporting to some extent. But awareness alone does not lead to the best decisions.

This research also highlights the importance of the management of new technology investments. For example, developing proper incentive schemes for managers, building a corporate culture that encourages early detection of problems, etc. can be very important for companies to reap expected values from investments that are uncertain in nature.

Appendix

To save space, we only provide proof sketches for non-straightforward results.

**Proposition 1:** Since \( \eta_1 > \eta_0 \), from
\[
\eta_1 g[\eta_1 g + (1 - \eta_1) b] + (1 - \eta_0) b > 1
\]
we have
\[
\eta_1 g + (1 - \eta_1) b > 1.
\]
Therefore, if D’s optimal choice in date 0 is the new technology investment, he will continue this investment (switch to the traditional technology investment) if period 1 result is good (bad). The expected investment value is
\[
\eta_1 g[\eta_1 g + (1 - \eta_1) b] + (1 - \eta_1) b.
\]

If D’s optimal choice in date 0 is the traditional technology investment in date 0, he will continue this investment at date 1 since he receives no new information. The expected investment value is 1.

**Lemma 1:** Following the sub-game where date 0 choice is the new technology, suppose at date 0 D anticipates a good reported period 1 result with probability \( p \). Then \( p\hat{\gamma}_i + (1 - p)\hat{\gamma}_0 = \gamma_0 \). Since \( \hat{\gamma}_i = \gamma_0 \leq \gamma_i \), we have \( \hat{\gamma}_i \geq \gamma_0 \). \( p \) is minimized when M truthfully reports (i.e., first-best case), thus \( \hat{\gamma}_i \) has a maximum possible value of \( \gamma_i \).

**Lemma 2:** Suppose M observes a bad period 1 outcome. If he truthfully reports, D will switch to the traditional technology investment, thus M’s expected payoff is \( ab \). If he cheats, his payoff is \( ab(\eta_0 g + (1 - \eta_0) b) + p - d(1 - \eta_0) \). A comparison of these two values leads to this lemma.

**Proposition 2:** The proof under \( \hat{\gamma}_i g + (1 - \hat{\gamma}_i) b > 1 \) is straightforward: if M cheats if period 1 result is good and \( d < d_m \), the marginal value for continuing the new technology investment is \( \hat{\gamma}_i g + (1 - \hat{\gamma}_i) b \); if D continues the new technology investment upon a good reported result, \( d < d_m \) is the condition for M to cheat – not \( d_m \) does not depend on \( \phi \).

If \( \hat{\gamma}_i g + (1 - \hat{\gamma}_i) b \leq 1 \), we prove by contradiction. Suppose that D continues the new technology investment if M reports a good outcome. M then cheats if \( d < d_m \), and as a result the marginal value for continuing the new technology investment is \( \hat{\gamma}_i g + (1 - \hat{\gamma}_i) b \). This is not D’s optimal choice as he can get a marginal return of 1 by switching to the traditional investment strategy.

**Proposition 3:** We only need to show that \( d_m \) increases in \( g \).

Let \( \sigma = \eta_0 - \eta_1 = (\beta_0 - \beta_1)(\gamma_0 - \gamma_i) \), which is positive. \( d_m = \frac{p - ab(1 - \eta_0 g - (1 - \eta_1) b)}{(1 - \eta_1)} = \frac{p - ab(1 - R + \sigma(g - b))}{(1 - \eta_1)} \). Let \( y(g) = b(1 - R + \sigma(g - b)) = \frac{R - \eta_0 g}{1 - \eta_0} - \frac{g - R}{1 - \eta_0} \). We only need to show \( y'(g) < 0 \). \( y'(g) = \eta_0 R \sigma [1 + 1/\eta_0 + (1 - \eta_0)(1 - 1/\sigma)] ^2 / (1 - \eta_0) \), which is negative if \( g / R > [1 + 1/\eta_0 + (1 - \eta_0)(1 - 1/\sigma)] / 2 \).

References


