

# A Decision Support Contract for Cost-Quality Trade-Off in Projects under Information Asymmetry

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## Abstract

The three key drivers of a project success include cost, completion time, and scope, the interplay of which have a significant impact on the decision making in project management. In this study, we propose a theoretical framework to be used as a Project Management Decision Support System for understanding and balancing the interplay between the project cost and quality, which is a key component of the project scope. To this end, we develop a Decision Support Contract (DSC) for a project manager when outsourcing to a contractor whose delivery outcome is subject to quality risk. On the one hand, to reduce the risk of project failure, the contractor can invest in a quality improvement effort, the cost of which is the contractor's private information. On the other hand, the contractor's decision on quality improvement is unobservable to the project manager. In designing the DSC, we consider both problems resulting in information asymmetry between the project manager and the contractor. We first obtain the first-best solution assuming that the cost efficiency of the contractor is publicly known, and then solve for the second-best optimal cost plus incentive fee (CPIF) contract under information asymmetry. Our comparative study between the first- and second-best contracts reveals that the project manager may prefer to incur efficiency loss due to underinvestment decision by the high-cost contractor to reduce the information rent demanded by the low-cost contractor. Finally, we compare the effectiveness of CPIF contract to that of fixed-price contract, which enables us to characterize the value of incentive fee term for the project manager. This latter analysis reveals that incentive-fee term is more valuable when the improvement effort is more likely to reduce the quality failure risk.

**Keywords:** project management, cost-quality trade-off, incentive contracts, information asymmetry

## 1. Introduction

It is well-known that the properties of a project can be described along three dimensions: the costs associated with the project, the completion time of the project, and the scope of the project (Marques et al., 2011). Trade-off between these three conflicting aspects of projects is crucial in today's competitive market, specifically because these components do not move in the same direction; improving one component worsens another. This leads researchers in developing two-pair trade-off models. For example, depending on the firm's competitive strategy, a firm may find it worthwhile (i) to improve the quality aspects of a product at the cost of investing in a process improvement effort, or (ii) to sacrifice the quality aspects of an R&D project to hasten the time of product launch and be the first-mover in the market. Accordingly, an optimal balancing of the trade-off between these three components becomes critical in any project management decision-making. What makes such a decision-making more complicated is that the whole project, or some components of it, are outsourced to contractors. The inability of the project manager in observing the efficiency aspects of contractors (such as cost efficiency or technological and quality aspects) may result in an inefficient trade-off analysis.

More than half of businesses experience project failure because of inefficient management of the outsourcing. Specifically, in the information technology (IT) projects, according to Computerworld report (Skaistis, 2007), a low percentage of outsourcing relationships is considered successful, and at least 50% of outsourcing relationships are terminated early (Qi & Chau, 2012). Despite the continuous increase in the IT outsourcing activities, it has been reported that a significant percentage of outsourcing deals are either considered a failure or suffered from serious problems such as lack of trust and commitment. This is mainly due to the risks associated with the uncertain environment where outsourcing is performed, the decentralized decision-making mechanism

among parties involved, as well as the lack of proper contractual decision-support system. Noting that these problems occur at the implementation stage of IT outsourcing, researchers suggest that the focus of studies on IT outsourcing should be shifted to the design of contract-based mechanisms (Lee et al., 2003; Qi & Chau, 2012). Without a proper contractual decision-support, each side of the project (e.g., project owner and contractor) cares only about their own benefits to secure a premium for their own risk. This, in turn, may result in a suboptimal solution for all stakeholders. Therefore, an efficient outsourcing practice may require coordination among multiple vendors, contractors, or agencies who handle different deliverables. If not managed properly, it may result in conflicts between parties and jeopardize the success of projects. One example is the incompatibilities and expensive delays due to lack of coordination in the Airbus A380 manufacturing project in which the parts manufactured by different vendors who were using different CAD software (Clark, 2006). For the similar reason, the general contractor for the construction of a building, that could be the Austin's largest hotel, has filed a lawsuit seeking at least 27 million in damages against a subcontractor that allegedly caused the project to fall behind schedule (Dinges, 2013).

Due to its unique features, in any project (one can think about an R&D project, specifically), it is quite likely that the contractor is offered a contract to perform a work that has not been done before, namely, a *new design with unique features*. The uncertainty in managing technology and innovation on the supply side, along with the uncertainty due to competition and consumer taste on the demand side complicates the contractual relationship between the project manager and the contractor. The problem faced by the project manager is whether the contractor is honest and does his best to complete the work according to the contract. Specifically, the project manager wonders: May the contractor neglect investing in any potential process improvement that could result in a better quality of the project outcome?

What if the contractor underinvests in process improvement but asks for high reimbursement amount? Failing to answer these questions may ruin the trust in the outsourcing relationship resulting in less efficient cost-quality trade-off analysis. The main concern for the project manager, therefore, is how to design a contract to (i) induce the appropriate level of investment in quality improvement on the contractor (e.g., through quality-cost trade-off), and (ii) incentivize the contractor to reveal his true level of investment cost to get reimbursed fairly.

The above discussions shed light on the importance of designing an effective outsourcing contractual strategy to support project manager's decision-making process when outsourcing to a contractor who is privileged with private information about his cost-efficiency and quality improvement decisions. In this situation, the project manager may lose visibility over two critical pieces of information. The first one is the unobservability over the process improvement effort that the contractor may exert in order to increase the likelihood that project outcomes are aligned with the quality specifications set by the project manager. The second one is the cost efficiency of the contractor in performing such a quality improvement effort. The following figure 1 conceptualizes the underlying cost-quality trade-off, which is the focus of this paper. Namely, this paper aims to develop an effective Decision Support Contract (DSC) model for project management problems to help the project manager increase its control and visibility over the contractor's quality improvement effort. Specifically, we aim to answer the following research questions:

- Which types of inefficiencies does the project manager face with when outsourcing to a contractor whose cost efficiency and the level of process improvement is not observable?
- What are the characteristics of an efficient DSC for the project manager to balance the trade-off between a costly investment and quality improvement under information asymmetry?

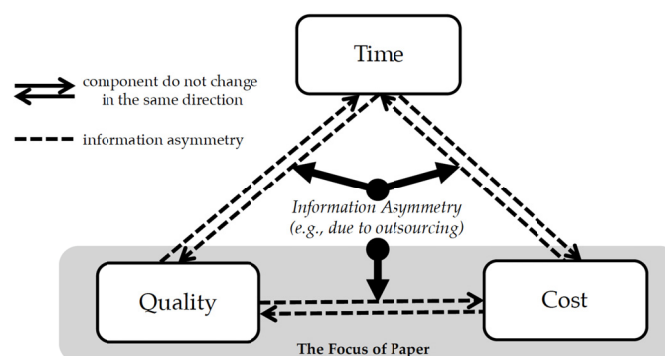


Figure 1. Project management triangle and underlying trade-offs

To answer the above questions, we develop a model with two parties; a *project manager* who outsources a project, or a component of it, with some quality specifications to a *contractor*. The contractor's delivery outcome is stochastic and may or may not comply with the specifications given by the project manager. However, the contractor may invest in a costly process improvement effort in adopting the specifications and to reduce the likelihood of project failure. We assume that the cost of such a process improvement effort is known only to the contractor. Moreover, the level of the process improvement chosen by the contractor is not observable to the project manager. The former dimension of information asymmetry results in *adverse selection* problem whereas the latter results in *moral hazard* according to economics literature (Laffont & Tirole, 1993). Using this model, we aim to characterize an optimal contract that the project manager can offer to the contractor to maximize its profit. Specifically, we need to identify the potential costs, namely, *agency costs* in the theory of incentives (Laffont & Martimort, 2009), that the project manager may incur under information asymmetry when outsourcing to a risky contractor.

The remainder of the paper is structured as follows: first, we review the existing relevant literature in Section 2. The modeling approach and assumptions will be discussed in Section 3. In Section 4, we characterize the optimal contract under full information scenario. Section 5 characterizes the optimal cost-plus-incentive-fee contract under information asymmetry. In Section 6, we identify the value of incentive-fee term for the project manager when balancing the cost-quality trade-off under information asymmetry. Finally, Section 7 concludes the paper.

## 2. Literature Review

This article is related to three main streams of research (i) decision supports for project management, (ii) cost-scope trade-off, and (iii) incentive contracts under information asymmetry. In what follows, we discuss and relate our paper to each stream.

### 2.1 Decision Supports in Project Management

Developing effective decision supports for project management activities has always been an important area of research from both methodology and application perspectives. Various decision support systems have been proposed to examine project portfolio selection (Ghasemzadeh & Archer, 2000), software project management (García et al., 2004), R&D project management (Marmier et al., 2013; Tian et al., 2005), project management efficiency (Dweiri & Kablan, 2006), project risk assessment (Du et al., 2007; Fang & Marle, 2012; Kumar, 2002), project work-breakdown structure (Golpayegani & Emamizadeh, 2007), project performance analysis (Plaza & Turetken, 2009), and project schedule control (Marmier et al., 2013). Our study also provides with a decision-support system for the project manager but with its three unique features: (i) inclusion of the interplay between cost and quality in project, (ii) considering information asymmetry in project management, and (iii) using contract theory to characterize the decision support, hence, we refer to our proposed model as the decision support contract.

### 2.2 Project Cost-Scope Trade-Off

Contrary to the extensive literature on the cost-time trade-off in project management, the literature on the cost-scope (specifically, cost-quality) in project management is relatively sparse. That said, the concept of project scope is used in a broad way in the literature; it encompasses various performance characteristics, from the amount of work performed in a project, to its quality, and to any other performance indicator valued by the project owner (Bower et al., 2002; Rose & Manley, 2011).

A trade-off between the construction duration and its safety, as a feature of project scope, has been studied in (Gangwar & Goodrum, 2005). Through a questionnaire survey, (Meng & Gallagher, 2012) analyzed the relationship between the use of incentives and the performance of a project. (Tang et al., 2008) reports the findings of an empirical survey of the Chinese construction industry to measure the effectiveness of incentives in obtaining satisfactory project outcomes. (Lauras et al., 2010) developed a general framework which allows the project manager to better control the performance of their projects in the presence of various dimensions of project performance, including cost, time, quality, and risk. For a detailed review of this stream of research, readers can refer to (Kerkhove & Vanhoucke, 2016). We contribute to this stream of literature by developing a contractual incentive strategy where the quality of the project outcome (as a key component of project scope) can be improved through a costly process improvement, hence this paper provides a project manager with a cost-quality trade-off tool.

### 2.3 Incentive Contracts under Information Asymmetry

As mentioned earlier, our paper draws mainly on the body of literature related to the project scope (since the contractor's process improvement decision affects the quality of the outcome) and project cost (since inducing

the process improvement on the contractor affects the project cost).

A recent research (Chen et al., 2019) studied the effectiveness of deadline-based contracts for a project manager who works with a contractor whose cost information is private and may exert effort to reduce the completion time of the project. Different from our study, where the contractor's effort has a probabilistic impact on the project outcome quality, (Chen et al., 2019) assumes that the contractor's effort has deterministic impact on reducing the time of the project. Therefore, the problem in (Chen et al., 2019) boils down to the false moral hazard problem (refer to (Perrigne & Vuong, 2011) and the citations therein). Similarly, (Fu et al., 2018) considers an agency problem where a firm employs a manager who has private information about his risk aversion magnitude and puts unobservable efforts to implement an R&D project through a menu of incentive contracts. Using the framework of principal-agent theory, they investigate the impacts of information asymmetry on the optimal compensation contracts and the firm's profit. (K. Yang et al., 2016) investigates the impacts of uncertain project duration and asymmetric risk sensitivity information on the structure of the incentive contracts in a project with a risk-neutral project manager and a risk-averse contractor. In their problem, the project manager can offer a duration-based incentive contract to the contractor to ensure that he invests his best effort to shorten the project duration and reveals his risk sensitivity information truthfully. Different from (K. Yang et al., 2016), which studies contracting for the completion time of the project, our paper aims to develop a model to address the risks associated with the quality (i.e., scope) of the project. Furthermore, in fulfilling our contributions to the literature, in this paper, we compare the effectiveness of two contracts when dealing with the cost-quality trade-off under information asymmetry; firm fixed-price contract to cost plus incentive-fee contract. The problem of designing a contract mechanism to allocate the component sub-projects of a large project to a pool of contractors has been studied by (Gutierrez & Paul, 2000). Using an analytical modeling, they address issues concerning the project owner's risk diversification by partitioning the project and assigning the sub-projects to multiple contractors whose performance characteristics are imperfectly known. (Gangwar & Goodrum, 2005) developed a parsimonious stochastic model to compare fixed-price, cost plus percentage, and a menu of contracts from the project owner's perspective. (Bayiz & Corbett, 2005) study a problem where the project manager who deals with managing two sub-projects that are outsourced to different subcontractors where the project manager cannot observe how hard the subcontractors work. Given the fact that the project manager earns more revenue if it is completed faster, they derive a set of optimal incentive contracts to be offered to the subcontractors when the tasks are conducted in series or in parallel. The effectiveness of delayed payment contracts is studied by (Kwon et al., 2010) in which the manufacturer imposes delayed payments under which each contractor is paid only when all contractors have completed their tasks. (Kwon et al., 2010) presented a class of project contracting problems in which the completion time of each task is exponentially distributed. They explored which types of project contracts can coordinate the channel optimally. Different from the above studies, in our problem, we assume that, in addition to the regular work to complete the project, the contractor can improve its performance characteristics (specifically, the quality of deliver outcome) by investing in a costly process improvement effort. For instance, he can invest in a new technology to improve the quality measures of the project outcome or reduce the time/cost of the work.

### 3. Model Framework

Consider a project manager (hereafter denoted by "she") who wants to delegate the production of a project module to a contractor (hereafter denoted by "he"). The contractor's cost to build the module is  $\$c$ , and if the contractor can build the project module based on the given specifications, then the project manager enjoys a revenue of  $\$U$ . The quality of the module built by the contractor is stochastic and may or may not follow the specifications given by the project manager. To model this, we assume that the quality of the outcome depends on the contractor's investment in a costly process improvement effort denoted by  $e_\theta \in \{0,1\}$ , where  $\theta$  indicates the type of the contractor in terms of the cost of process improvement. Specifically, if the contractor invests in process improvement (i.e.,  $e_\theta = 1$ ), then he incurs a cost of  $Z_\theta$ . For analytical tractability, we consider two types of contractors;  $h$ - and  $l$ -type indicating high- and low-cost, respectively, where we have  $Z_h \geq Z_l$ . Moreover, the project manager has only a-priori belief about the distribution of the contractors. Namely, from the project manager's perspective, the probability that the contractor is of  $l$ - and  $h$ -type is  $\nu$  and  $1 - \nu$ , respectively. We also define  $p(e_\theta)$  to show the survival probability of producing an acceptable outcome by the contractor, i.e., an outcome in compliance with the project manager's specifications. We assume that if the contractor invests in process improvement, then it is less likely that the project outcome fails to be aligned with project specifications. In mathematically term it means that  $p(e_\theta = 1) \geq p(e_\theta = 0)$ .

Using the above modeling framework, we aim to study the effect of project manager's un-observability over (i) contractor's type (i.e., cost of process improvement  $Z_\theta$ ) and (ii) contractor's process improvement effort

$e_\theta \in \{0,1\}$ . In the next section, we first analyze a first-best scenario where both contract's type  $\theta \in \{h, l\}$  and process improvement  $e_\theta \in \{0,1\}$  are observable by the project manager. We then analyze the problem under information asymmetry, i.e., when project manager suffers from both unobservability over contractor's type (which is called "adverse selection" in economics), and contractor's decision on process improvement (which is called "moral hazard" in economics). Our goal is to develop an optimal menu of contracts that helps the project manager screen each contractor and reduce the adverse effect of agency costs when delegating the project to a contractor. We develop a two-part tariff contract through which the project manager can induce the optimal level of process improvement to the contractor. The first term is an upfront *fixed transfer payment*, denoted by  $w$ , which is payable to the contractor if he accepts the terms of the contract. The second term is contingent payment, denoted by  $s$ , which is an *incentive-fee* to the contractor only if the project delivery is aligned with the specifications. Note that cost incentives are the most researched incentive category in practice (Kerkhove & Vanhoucke, 2016). According to (Weitzman, 1980), the cost incentives contracts can be categorized as one of six basic contract types: firm fixed-price (FFP), guaranteed maximum price (GMP), fixed-price incentive (FPI) (or target cost contract (TCC)), cost plus incentive-fee (CPIF), cost plus fixed fee (CPFF), and cost plus percentage fee (CPPF) contracts. Clearly, the contract applied in our study is of *cost plus incentive-fee* type. There are various ways in which incentive-fees are introduced in the literature. For example, similar to the second term in our contract, (Babich & Tang, 2012) used *contingent payment* in a quality uncertainty setting to reward the contractor for the items that are successfully delivered to the customer. Such a fee can be modeled as an incentive-fee in the case of the agent's default risk. Specifically, (Baiman et al., 2000; Gurmani & Shi, 2006; Nikoofal & Gümüř, 2018, 2019; Reyniers & Tapiero, 1995; Z. Yang et al., 2009) embedded *penalty* terms into their contracts to recover damages for non-delivery or defective deliveries. We refer to (Demski & Sappington, 1984; Kwon et al., 2010; Wang & Gerchak, 2003) and the citations within for a review of the incentive contracts applied in project management in practice.

### 3.1 First-Best Solution

To examine the impact of the project manager's inability to observe the contractor's type  $\theta$  and process improvement  $e_\theta$ , first, we develop and analyze a benchmark under full information scenario. Specifically, we assume that the contractor's type  $\theta$  is publicly known and his choice of process improvement effort  $e_\theta$  is observable by the project manager. This readily means that the contractor's process improvement is enforceable (Note 1) by the project manager. The project manager's optimization problem has two levels. In the upper level, she needs to find the optimal process improvement effort  $e_\theta^*$  to be induced on the  $\theta$ -type contractor. In the inner level, she needs to solve for the optimal contract terms  $(w_\theta, s_\theta)$ , given that the contractor exerts the optimal process improvement  $e_\theta^*$  dictated in the upper level. Given a contract  $(w_\theta, s_\theta)$  offered by the project manager and the process improvement effort  $e_\theta$  exerted by the  $\theta$ -type contractor, we define  $\pi_C^\theta(w_\theta, s_\theta | e_\theta)$  and  $\pi_P^\theta(w_\theta, s_\theta | e_\theta)$  to indicate the  $\theta$ -type contractor's and project manager's expected profit, respectively. The project manager's optimization problem can be cast succinctly as follows:

$$\max_{e_\theta \in \{0,1\}} \max_{w_\theta, s_\theta} \pi_P^\theta(w_\theta, s_\theta | e_\theta) = -w_\theta + p(e_\theta)U - p(e_\theta)s_\theta \tag{1}$$

Subject to

$$\pi_C^\theta(w_\theta, s_\theta | e_\theta) = w_\theta - c + p(e_\theta)s_\theta - e_\theta Z_\theta \geq 0 \tag{2}$$

Under full information scenario, because both contractor's type and his choice of improvement effort are observable by the project manager, the project manager can directly induce the  $\theta$ -type contractor to exert the intended level of improvement. Note that the project manager also needs to satisfy the contractor's participation constraint (4.1) via the contract terms. Proposition 1 characterizes the optimal level of process improvement effort to be induced on the  $\theta$ -type contractor, as well as the optimal contract parameters associated with the optimal level of improvement (All the proofs for all propositions are presented in the Appendix).

**Proposition 1.** *Under full information scenario:*

- *Inducing process improvement ( $e_\theta^* = 1$ ) on contractor- $\theta$  is optimal if  $Z_\theta \leq [p(e_\theta = 1) - p(e_\theta = 0)]U$ .*
- *the fixed-price term  $w_\theta$  is enough to induce the optimal level of improvement;  $w_\theta = c + Z_\theta$  if  $e_\theta^* = 1$  and  $w_\theta = c$  if  $e_\theta^* = 0$ .*

From the first part of proposition 1, one can verify that the project manager internalizes the cost and benefits of inducing process improvement. The cost of exerting process improvement by the contractor is  $Z_\theta$ . The benefit comes from the decrease in the likelihood of producing non-compliance item (i.e.,  $[p(e_\theta = 1) - p(e_\theta = 0)]$ ) multiplied by the revenue  $U$ . Therefore, the project manager induces process improvement on the contractor as long as the expected benefit exceeds its cost, i.e.,  $Z_\theta \leq [p(e_\theta = 1) - p(e_\theta = 0)]U$ . The second part of

proposition 1 indicates that a fixed-term contract  $w_\theta$  suffices for the project manager to induce the optimal level of process improvement on its contractor. This is because, under full information, the contractor's choice of process improvement is observable, hence it is enforceable. This is aligned with the contract design literature that the fixed-term contracts are theoretically the best contract in terms of achieving the overall system efficiency (Laffont & Tirole, 1993). As we show in the next section, the fixed-price contract is not enough to coordinate the project manager and contractor objectives under information asymmetry.

### 3.2 Optimal Contract under Information Asymmetry

In this section, we analyze the problem under information asymmetry. Specifically, we assume that both the contractor's type  $\theta \in \{h, l\}$  and his process improvement decision  $e_\theta \in \{0,1\}$  are not observable by the project manager. This is called *mixed model of adverse selection followed by moral hazard* in economics literature. Note that, in our model, the contractor's type  $\theta$  is defined on process improvement cost, therefore, the project manager who may want to induce process improvement on the contractor does not know whether the contractor is of *h-* or *l-*type. This is called adverse selection, which constitutes the first component of information asymmetry in our model. Moreover, even if the project manager decides to induce process improvement on the  $\theta$ -type contractor, i.e.,  $e_\theta = 1$ , it is not perfectly known to the project manager whether the contractor exerts the effort or not. This is called moral hazard, which constitutes the second component of information asymmetry in our model. Note that, because the cost of quality improvement is private information for the contractor, the project manager has to design a menu of contracts from which each type of contractor self-selects the one that is intended for himself. Invoking the extended revelation principle for mixed adverse selection and moral hazard problems (Laffont & Martimort, 2009), without loss of generality, we can restrict our attention to direct-revelation mechanisms in which contractors truthfully reveal their types. Thus, the project manager offers two contracts, one for each type, i.e.,  $(w_l, s_l)$  and  $(w_h, s_h)$  and the  $\theta$ -type contractor self-selects the one that suits them better.

To study this scenario, we use backward induction to find the optimal solutions and examine the contractor's process improvement decision. The  $\theta$ -type contractor solves the following optimization problem to decide on whether to exert process improvement:

$$\pi_C^\theta(w_\theta, s_\theta | e_\theta) = \max_{e_\theta \in \{0,1\}} \{w_\theta - c + p(e_\theta)s_\theta - e_\theta Z_\theta\} \tag{3}$$

Note that, by exerting the process improvement, the contractor can stochastically decrease the failure probability, and for this, he should incur the cost of process improvement,  $Z_\theta$ . Therefore, his equilibrium decision depends on the contract terms offered to him:

**Proposition 2.** *Given a contract  $(w_\theta, s_\theta)$  offered by the project manager, the  $\theta$ -type contractor exerts process improvement if and only if  $Z_\theta \leq [p(e_\theta = 1) - p(e_\theta = 0)]s_\theta$ .*

Under information asymmetry, the  $\theta$ -type contractor chooses to exert process improvement effort as long as its cost (which is  $Z_\theta$ ) is less than its benefit. Note that the benefit of process improvement comes from the expected revenue if the project outcome is aligned with the specifications, which translates to the decrease in the likelihood of failure multiplied by the contingent payment, i.e.,  $[p(e_\theta = 1) - p(e_\theta = 0)]s_\theta$ .

Let us now develop the project manager's contract design problem. Note that the project manager's optimization problem has two levels: in the outer level, we need to determine the optimal process improvement effort to be induced on each contractor's type, i.e.,  $e_l^*, e_h^*$ ; and, in the inner level, we determine the optimal menu of contracts  $((w_l, s_l), (w_h, s_h))$  that best implements the process improvement effort dictated by the outer-level optimization. By combining the outer- and inner-level problems, we can formulate the project manager's optimal contract design problem as follows:

$$\max_{e_l^*, e_h^*} \max_{(w_l, s_l), (w_h, s_h)} \nu \pi_P^l(w_l, s_l | e_l^*) + (1 - \nu) \pi_P^h(w_h, s_h | e_h^*) \tag{4}$$

Subject to  $\pi_C^l(w_l, s_l | e_l^*) \geq 0$  I. R. L (5)

$\pi_C^h(w_h, s_h | e_h^*) \geq 0$  I. R. H (6)

$\pi_C^l(w_l, s_l | e_l^*) \geq \max_{e_l} \pi_C^l(w_h, s_h | e_l)$  I. C. L (7)

$\pi_C^h(w_h, s_h | e_h^*) \geq \max_{e_h} \pi_C^h(w_l, s_l | e_h)$  I. C. H (8)

$$\pi_C^l(w_l, s_l | e_l^*) \geq \pi_C^l(w_l, s_l | e_l \neq e_l^*) \tag{9}$$

$$\pi_C^h(w_h, s_h | e_h^*) \geq \pi_C^h(w_h, s_h | e_h \neq e_h^*) \tag{10}$$

$$w_l, w_h, s_l, s_h \geq 0 \tag{11}$$

where  $\pi_P^\theta(w_\theta, s_\theta | e_\theta^*) = -w_\theta + p(e_\theta)(U - s_\theta)$  denotes the project manager’s expected profit generated, provided that the  $\theta$ -type contractor accepts the contract  $(w_\theta, s_\theta)$  and subsequently exerts process improvement  $e_\theta^*$  as characterized in proposition 2. We take the weighted average of the ex-post profits with respect to a-priori beliefs for the  $l$ - and  $h$ -type contractors to develop the objective function (4). Constraints (5) and (6) assure participation of the  $l$ - and  $h$ -type contractors (which are called individual rationality (IR) constraints). Through the incentive compatibility (IC) constraints (7) and (8), one can ensure that  $l$ - and  $h$ -type contractors self-select the contracts designed for them, and that they cannot be better off by mimicking the other type. Finally, we need moral hazard incentive constraints (M.H.I.C), through which the project manager assures that the  $\theta$ -type contractor will never be better off if he does not choose the level of process improvement dictated in the outer problem  $e_\theta^*$ .

From the theory of incentives (Laffont & Martimort, 2009), we know that the project manager cannot induce the same first-best level of process improvement characterized in proposition 1 under asymmetric information. This is because of the existence of the adverse selection problem in our model. More specifically, the  $l$ -type contractor, for whom  $Z_l \leq Z_h$ , has incentives to mimic the  $h$ -type contractor by choosing the contract designed for the  $h$ -type contractor. The rationale behind this observation is as follows. Suppose that the project manager wants to induce process improvement on both types;  $e_h = e_l = 1$ . To do so, according to proposition 2, the contingent payment should satisfy  $s_\theta \geq \frac{Z_\theta}{p(1)-p(0)}, \theta = l, h$ . However, because we have  $Z_h \geq Z_l$ , the  $l$ -type contractor can be better off by mimicking the  $h$ -type and choosing  $(w_h, s_h)$  rather than  $(w_l, s_l)$ . In order to avoid the  $l$ -type contractor not to mimic the  $h$ -type, the project manager should offer him an extra payment, which is called *information rent*, via his contract terms  $(w_l, s_l)$ . Unfortunately, the amount of information rent increases when the cost gap between types (i.e.,  $Z_h - Z_l$ ) increases. Consequently, to stop paying the information rent, the project manager may decide to stop inducing process improvement on the  $h$ -type contractor, which results in efficiency loss due to lower expected quality of the outcome produced by the  $h$ -type contractor. The following figure 2 summarizes the above discussion and shows the decision tree for the project manager based on his a-priori belief distribution about contractor’s type  $v$  as well as  $l$ -type contractor strategic behavior to mimic the  $h$ -type.

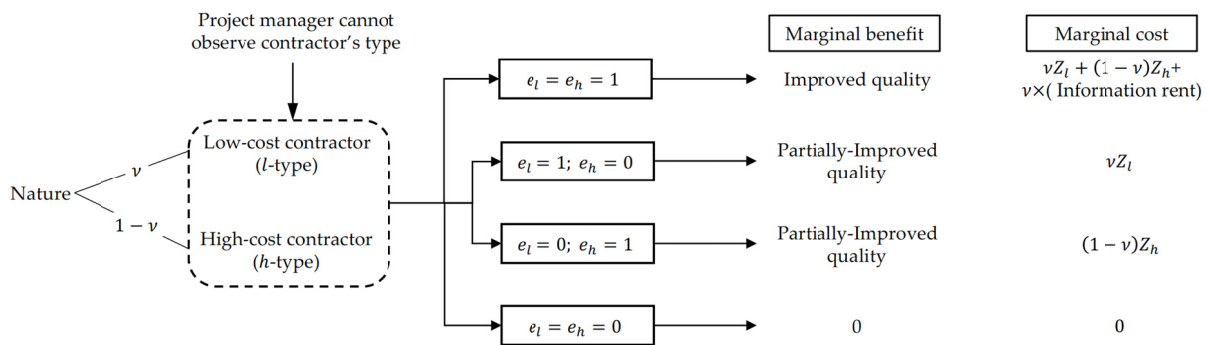


Figure 2. Project management triangle and underlying trade-offs

Notes. The dotted lines indicate that the contractor’s type is unknown, hence both types (i.e.,  $h$  and  $l$ ) are pooled.

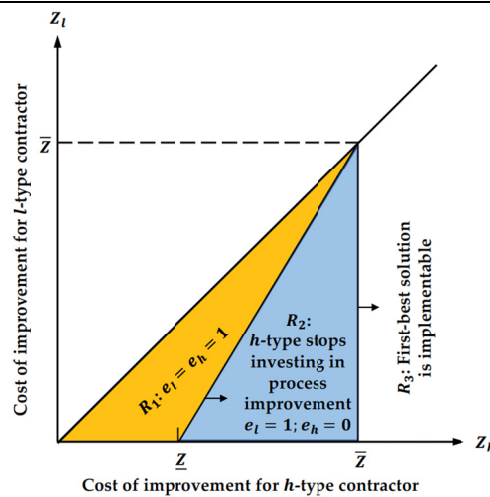
Now, we characterize the optimal menu of contracts, the optimal level of process improvement, the information

rent, and the improvement loss due to the second-best level of process improvement in proposition 3.

**Proposition 3.** Under information asymmetry, the optimal menu of contracts  $(w_\theta, s_\theta)$ , the second-best level of process improvement  $e_\theta$ , the information rent payable to the  $l$ -type contractor, and the efficiency loss are characterized in Table 1.

Table 1. Optimal menu of contract, contractor’s process improvement, information rent, and efficiency loss under information asymmetry

Region	Optimal Contract	Process improvement	Information rent	Efficiency loss
$R_1$	$w_l = c + Z_h - \frac{p(1)}{p(1)-p(0)}Z_l$ $s_l = \frac{Z_l}{p(1)-p(0)}$ $w_h = c - \frac{p(0)}{p(1)-p(0)}Z_h$ $s_h = \frac{Z_h}{p(1)-p(0)}$	$e_l = 1; e_h = 1$	$v(Z_h - Z_l)$	0
$R_2$	$w_l = c - \frac{p(1)}{p(1)-p(0)}Z_l$ $s_l = \frac{Z_l}{p(1)-p(0)}$ $w_h = c - \frac{p(0)}{p(1)-p(0)}Z_l$ $s_h = \frac{Z_l}{p(1)-p(0)}$	$e_l = 1; e_h = 0$	0	$(1 - v)[(p(1) - p(0))U - Z_h]$
$R_3$	$w_l = c$ $s_l = 0$ $w_h = c$ $s_h = 0$	$e_l = 0; e_h = 0$	0	



Notes.  $\underline{Z} = (1 - v)[p(1) - p(0)]U$ ;  $\bar{Z} = [p(1) - p(0)]U$ .

Let us discuss the main observations from proposition 3. First of all, when the cost of process improvement is sufficiently high, i.e., region  $R_3$ , then the first-best solution is implementable without any agency cost. This is because the process improvement effort is too costly, hence its cost dominates its expected benefits, therefore, the project manager does not need to induce process improvement on the contractor. However, when the process improvement is less costly, i.e.,  $Z_\theta \leq (1 - v)[p(1) - p(0)]U$ , then the first-best level of improvement effort (characterized in proposition 1) may or may not be implementable. This is because of the agency costs under the information asymmetry scenario, which are discussed below.

In general, there are two types of agency costs incurred by the project manager. The first one is the *information rent*, which is payable to the  $l$ -type contractor (with probability  $v$ ) due to his cost efficiency over the  $h$ -type. To be specific, suppose that the project manager wants to induce the action profile  $e_h = e_l = 1$ . According to



proposition 2, the incentive-fee should be enough to cover for the expected cost of process improvement effort for each type, i.e.,  $s_\theta \geq \frac{Z_\theta}{p(1)-p(0)}$ . Because  $Z_h \geq Z_l$ , the incentive-fee, that is designed for the  $h$ -type, is greater than that for the  $l$ -type. As a result, the  $l$ -type contractor has an incentive to mimic the  $h$ -type and receive a higher incentive-fee. To avoid such an opportunistic behavior and to incentivize the  $l$ -type contractor to reveal his type truthfully, the project manager has to give the right amount of incentive to the  $l$ -type contractor via upfront payment  $w_l$ . To summarize, in equilibrium, the  $l$ -type contractor makes a profit by receiving the total amount of  $c + Z_h$  whereas his total cost is only  $c + Z_l$ . The amount of information rent (i.e.,  $l$ -type contractor's profit) is therefore  $Z_h - Z_l$ . This corresponds to region  $R_1$  in proposition 3 (under Table 1). Note that the amount of information rent increases when the cost asymmetry between types ( $Z_h - Z_l$ ) increases. Recall that this is the case when the project manager induces the action profile  $e_h = e_l = 1$ . To reduce the information rent payable to the  $l$ -type contractor, the project manager may have to induce the second-best level of process improvement effort on the  $h$ -type contractor, i.e.,  $e_h = 0$ , and covering only for the production cost  $c$ . Consequently, the  $l$ -type contractor has no longer any incentive to mimic the  $h$ -type one, but, this results in an *efficiency loss* by the  $h$ -type contractor, the second element of agency cost. This corresponds to region  $R_2$  in proposition 3.

### 3.3 Value of the Incentive-Fee Term

So far, in section 4 and 5, we characterize the optimal contract under full information and asymmetric information, respectively. Specifically, our analysis in section 4 showed that the project manager could induce the optimal level of process improvement on its contractor using the fixed-price term  $w_\theta$ . However, under information asymmetry, because the choice of process improvement is not observable, the project manager should give extra incentives through incentive-fee  $s_\theta$ . In this section, we aim to characterize the value of the incentive-fee term (i.e.,  $s_\theta$ ) for the project manager under information asymmetry. Therefore, we first need to evaluate the power of fixed-price contract (in which the contract has only upfront payment  $w_\theta$  term) under information asymmetry. Comparing the agency costs with and without incentive-fee, we can then characterize the value of the incentive-fee term under information asymmetry.

Note that the fixed-price contract fails to screen different types of contractor (i.e.,  $\theta \in \{l, h\}$ ) because it contains only a single term. To explain this, suppose that the project manager offers a menu of fixed-price contracts  $(w_l, w_h)$  where  $w_l \neq w_h$ . Clearly, regardless of his true type, the  $\theta$ -type contractor always chooses the higher term from the menu, i.e.,  $\max\{w_l, w_h\}$ , hence in equilibrium  $w_l = w_h = w$ . Moreover, because the process improvement effort is not observable, the project manager cannot verify whether the contractor invests in process improvement or not even if she pays the cost of improvement through the fixed-price. To be specific, suppose that the project manager wants to induce improvement effort on the  $\theta$ -type contractor. The fixed-price term should cover both the cost of the regular production and process improvement;  $w = c + Z_\theta$ . Clearly, the contractor never invests in process improvement because by doing so, his profit decreases by  $Z_\theta$ . Note that, under the fixed-price contract, the  $\theta$ -type contractor's profit is  $w - c - e_\theta Z_\theta$ . Given  $w = c + Z_\theta$ , his profit if he invests (resp. does not invest) in process improvement is 0 (resp.  $Z_\theta$ ). Therefore, whether the project manager covers the cost of the process improvement or not, the contractor never exerts in process improvement. As a result, the project manager never pays the cost of process improvement effort, hence the fixed-price contract only contains the cost of production;  $w = c$ . Proposition 4 summarizes the above discussion:

**Proposition 4.** *The fixed-price contract fails to induce the process improvement on the contractor under information asymmetry. Furthermore, it results in the expected efficiency loss  $[p(e_\theta = 1) - p(e_\theta = 0)]U - \mathbb{E}_\theta[Z_\theta]$  when  $Z_\theta \leq [p(e_\theta = 1) - p(e_\theta = 0)]U$ .*

From the above discussion, one can verify that the fixed-price contract not only fails in screening different types of contractors (hence fails to address adverse selection problem) but also it fails to address the *moral hazard problem* (since the project manager can never induce process improvement on its contractor). This is different from cost-plus-incentive-fee contract where, thanks to contingent payment term  $s_\theta$ , the project manager can induce the right level of process improvement on the contractor, although at the cost of information rent. Therefore, the value of incentive-fee for the project manager depends on whether it helps rectify the efficiency loss or information rent. Specifically, from proposition 3, recall that the project manager prefers to incur

information rent when the cost asymmetry between types ( $Z_h - Z_l$ ) is relatively low. This occurs in region  $R_1$  in proposition 3, where the project manager induces the action profile  $e_h = e_l = 1$ . The information rent is payable only to the  $l$ -type contractor which is  $v(Z_h - Z_l)$ . When the cost asymmetry between types increases (region  $R_2$ ), then the project manager is better off by inducing the second-best level of process improvement effort on the  $h$ -type contractor, i.e.,  $e_h = 0$ . This cuts the  $l$ -type contractor's incentives (i.e., information rent) to mimic the  $h$ -type, but, it brings its own efficiency loss due to underinvestment in process improvement by the  $h$ -type contractor. By comparing the expected efficiency loss under fixed-price contract in proposition 4 to the agency costs under cost-plus-incentive-fee contract in proposition 3, one can verify that the value of incentive-fee term for the project manager is

Value of incentive – fee

$$= \frac{[p(1) - p(0)]U - \mathbb{E}_\theta[Z_\theta]}{\text{Efficiency loss with fixed-price contract}} - \frac{(1 - e_h) \times (1 - v)[(p(1) - p(0))U - Z_h]}{\text{Efficiency loss with CPIF contract}} - \frac{e_l \times e_h \times v(Z_h - Z_l)}{\text{Information rent with CPIF contract}} \quad (12)$$

Accordingly, Proposition 5 characterizes the value of incentive-fee for the project manager under information asymmetry.

**Proposition 5.** *In the presence of information asymmetry, the value of incentive-fee term  $s_\theta$  for the project manager is  $[p(1) - p(0)]U - Z_h$  when  $v \leq \bar{v}$  and  $v[(p(1) - p(0))U - Z_l]$  when  $v > \bar{v}$ , where  $\bar{v} =$*

$$\frac{[p(1) - p(0)]U - Z_h}{[p(1) - p(0)]U - Z_l}$$

The key observations from proposition 5 are as follows. First, the incentive-fee term brings no value to the project manager wherever the first-best improvement effort is implementable with the fixed-price contract. This corresponds to region  $R_3$  in proposition 3 where the process improvement is too costly, hence it is more likely that its cost exceeds its expected benefits. Under this condition, the project manager prefers not to induce improvement on its contractor, hence the fixed-price contract suffices to cover the cost of regular production. Second, the value of incentive-fee increases when the probability of having more efficient contractor (i.e.,  $l$ -type) increases, i.e., when  $v \uparrow$ . This can be verified from each panel of figure 3 when looking at the increasing direction of horizontal axis  $v$ . Third, the incentive-fee becomes more valuable when the degree of information asymmetry (i.e.,  $Z_h - Z_l$ ) increases; refer to figure 3(a). Note that, when the probability of having  $l$ -type contractor is low enough, i.e.,  $v \leq \bar{v}$ , then the value of incentive-fee does not depend on the degree of information asymmetry because the benefit of inducing process improvement cancel out the cost of information rent. This corresponds to region  $R_1$  in proposition 3. However, when the degree of information asymmetry increases, the project manager only induces process improvement on the  $l$ -type (corresponding to region  $R_2$  in proposition 3), hence the value of incentive-fee comes from rectifying efficiency loss only for the  $l$ -type, i.e.,  $v[(p(1) - p(0))U - Z_l]$ . Therefore, as one can verify in figure 3(a), the value of incentive-fee increases when  $Z_l$  decreases. Finally, the value of incentive-fee term increases when the expected benefit due to process improvement increases. This occurs when either the likelihood of producing high quality outcome due to process improvement increases, i.e.,  $p(e_\theta = 1) - p(e_\theta = 0) = \Delta p \uparrow$  (refer to figure 3(b)), or the revenue of delivering acceptable outcome  $U$  increases (refer to figure 3(c)).

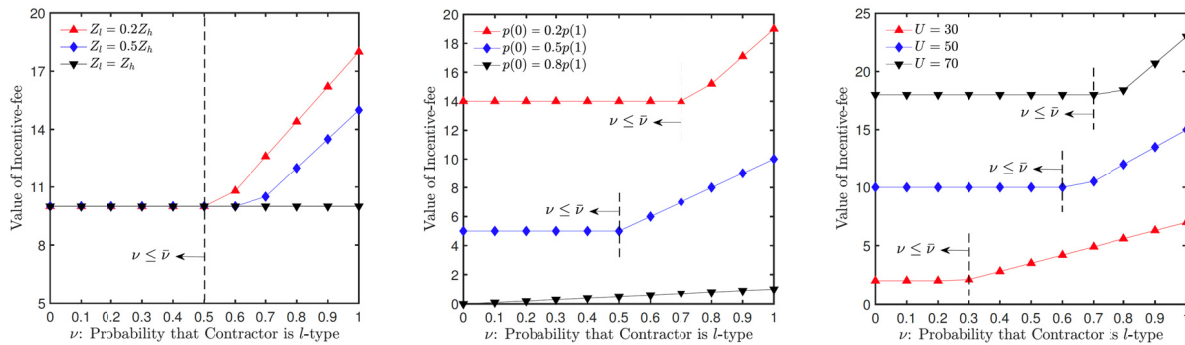


Figure 3. Value of Incentive-fee for the Project Manager under Information Asymmetry

Notes. Base parameters are  $U = 50$ ,  $p(1) = 0.6$ ,  $p(0) = 0.2$ ,  $Z_h = 10$ ,  $Z_l = 5$ .

#### 4. Conclusion

The major reason firms opt to outsource is because it does save time and money, although at the cost of losing visibility and control over the tasks which were originally performed in-house. This is particularly critical in project management since the quality outcome of the project delivery may significantly suffer due to outsourcing. Consequently, designing an efficient Decision Support Contract becomes a critical asset for many companies across various industries which allows the managers efficiently analyze the underlying cost-quality trade-off. This paper develops a DSC which proposes a set of contractual incentive strategies through which the quality of the project outcome can be balanced with the cost of process improvement in an optimal way. More specifically, our proposed DSC provides an optimal incentive contract for the project manager who outsources to a risky contractor whose delivery outcome is subject to quality risk. To reduce the likelihood of failure, the contractor can invest in a costly process improvement effort, while the cost of such effort is private information to the contractor. This situation results in an adverse selection problem. On the top of that, the contractor's decision on process improvement is unobservable to the project manager. This results in a moral hazard problem.

We show that a cost-plus-incentive-fee can help project manager to balance the cost-quality trade-off under information asymmetry. Specifically, the project manager may prefer to induce underinvestment decision (resulting in less expected quality) on high-cost contractor to reduce the information rent demanded by the low-cost contractor. Finally, we compare the effectiveness of CPIF contract to that of fixed-price contract, which enables us to characterize the value of incentive-fee term for the project manager. This latter analysis reveals that incentive-fee term is more valuable when either the improvement effort is more likely to reduce the quality failure risk, or the expected revenue due to successful project delivery increases.

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## Note

Note 1. In theory of incentives, an enforceable action means that the principal (here, the project manager) can impose the process improvement effort on agent (here, the contractor) so that the agent's action must be complied with the action written in the contract.

## Appendix

*Proof of proposition 1.* From the project manager's perspective, inducing process improvement on the  $\theta$ -type contractor is profitable when her expected profit by exerting improvement effort (i.e.,  $e_\theta = 1$ ) is more than that if she does not exert effort (i.e.,  $e_\theta = 0$ ). We need to solve the inner problem for two possibilities, i.e.,  $e_\theta = 0, 1$ , and then compare the project manager's profit under each scenario to find the optimal level of process improvement as well as the associated contract terms. Note that because project manager's profit is decreasing in both  $w_\theta$  and  $s_\theta$  (whereas the contractor's profit is increasing in both), therefore, the project manager can

maximize her profit when contractor’s profit function is binding. Therefore, any pair of  $w_\theta$  and  $s_\theta$  that satisfies  $w_\theta - c + p(e_\theta)s_\theta - e_\theta Z_\theta = 0$  is an optimal solution. Specifically, when inducing  $e_\theta = 1$  one can verify that  $w_\theta = c$  and  $s_\theta = \frac{Z_\theta}{p(e_\theta=1)}$  is an optimal solution, under which the project manager’s profit is  $-c + p(e_\theta = 1)U - Z_\theta$ . Similarly, if the project manager induces  $e_\theta = 0$ , then  $w_\theta = c$  and  $s_\theta = 0$  is an optimal solution, under which the project manager’s expected profit is  $-c + p(e_\theta = 0)U$ . Clearly, the project manager is better off by inducing process improvement on the  $\theta$ -type contractor when  $-c + p(e_\theta = 1)U - Z_\theta \geq -c + p(e_\theta = 0)U$ , or equivalently,  $Z_\theta \leq [p(e_\theta = 1) - p(e_\theta = 0)]U$ .

*Proof of proposition 2.* Given the contract  $(w_\theta, s_\theta)$  offered by the project manager, the contractor compares his expected profit with and without investing in process improvement. Specifically, from equation (5.1), if the contractor invests in process improvement, i.e.,  $e_\theta = 1$ , then his expected profit would be  $w_\theta - c + p(e_\theta = 1)s_\theta - Z_\theta$ . However, if he does not invest in process improvement, then his expected profit would be  $w_\theta - c + p(e_\theta = 0)s_\theta$ . Clearly, the contractor is better off by investing in process improvement if  $w_\theta - c + p(e_\theta = 1)s_\theta - Z_\theta \geq w_\theta - c + p(e_\theta = 0)s_\theta$ , or equivalently,  $Z_\theta \leq [p(e_\theta = 1) - p(e_\theta = 0)]s_\theta$ .

*Proof of proposition 3.* Note that there are four different action profiles that the project manager can induce on the contractor; (i) both types exert process improvement effort, i.e.,  $e_l = e_h = 1$ , (ii) only the  $l$ -type exerts effort, i.e.,  $e_l = 1; e_h = 0$ , (iii) only the  $h$ -type exerts process improvement effort, i.e.,  $e_l = 0; e_h = 1$ , and (iv) none of types exert effort, i.e.,  $e_l = e_h = 0$ . We need to solve for the optimal contract under each action profile and then by comparing the project manager’s expected profit under each profile, we can characterize the optimal contract under information asymmetry.

- $e_l = e_h = 1$ : The project manager’s contract design problem can be written as follows:

$$\max_{(w_l, s_l), (w_h, s_h)} \nu[-w_l + p(1)(U - s_l)] + (1 - \nu)[-w_h + p(1)(U - s_h)] \tag{12}$$

Subject to  $w_l - c + p(1)s_l - Z_l \geq 0$  (13)

$$w_h - c + p(1)s_h - Z_h \geq 0 \tag{14}$$

$$w_l - c + p(1)s_l - Z_l \geq w_h - c + p(\tilde{e}_l)s_h - \tilde{e}_l Z_l \tag{15}$$

$$w_h - c + p(1)s_h - Z_h \geq w_l - c + p(\tilde{e}_h)s_l - \tilde{e}_h Z_h \tag{16}$$

$$s_l \geq \frac{Z_l}{p(1)-p(0)} \tag{17}$$

$$s_h \geq \frac{Z_h}{p(1)-p(0)} \tag{18}$$

where  $\tilde{e}_\theta$  shows the optimal action under deviated contract, i.e., if the  $\theta$ -type mimics the other type. To solve for the optimal contract terms, we need to verify which constraints are binding. Note that, from theory of incentives it is easy to show that the participation constraint of the less efficient contractor (14) is binding at optimality, i.e.,  $w_h - c + p(1)s_h - Z_h = 0$ , or equivalently,  $w_h = c - p(1)s_h + Z_h$ . Furthermore, the  $l$ -type contractor has incentives to mimic the  $h$ -type contractor and picks a contract designed for the  $h$ -type. Therefore, to avoid the efficient contractor ( $l$ -type) not to mimic the less efficient one ( $h$ -type), the project manager should

give the right incentives to the *l*-type contractor, i.e., the *l*-type profit if he chooses its contract should at least be greater than that if he mimics the *h*-type. This means the incentive compatibility of the *l*-type contractor is binding at optimality. Furthermore, because  $s_h \geq \frac{Z_h}{p(1)-p(0)}$  (constraint (18)) and  $Z_h \geq Z_l$ , it means that if the *l*-type mimics the *h*-type, then he would exert process improvement effort, i.e.,  $\tilde{e}_l = 1$ . Therefore, from binding condition of constraint (15) we have  $w_l + p(1)s_l = w_h + p(1)s_h$ . Considering both binding constraints (14) and (18) we can get rid off  $w_h, s_h$  in the above optimization problem by rewriting  $w_h + p(1)s_h = c + Z_h$  in the objective function. So, the above optimization problem can be written as follows:

$$\max_{w_l, s_l} v[-w_l + p(1)(U - s_l)] + (1 - v)[p(1)U - c - Z_h] \tag{19}$$

Subject to  $w_l + p(1)s_l \geq c + Z_l$  (20)

$$w_l + p(1)s_l \geq c + Z_h \tag{21}$$

$$s_l \geq \frac{Z_l}{p(1)-p(0)} \tag{22}$$

Clearly, because  $Z_h \geq Z_l$ , the participation constraint (20) is redundant. Using the graphical approach, one can verify that the optimal solution is the intersection of two constraints (21) and (22), i.e.,  $w_l = c + Z_h - \frac{p(1)}{p(1)-p(0)}Z_l$ ;  $s_l = \frac{Z_l}{p(1)-p(0)}$  and  $w_h = c - \frac{p(0)}{p(1)-p(0)}Z_h$ ;  $s_h = \frac{Z_h}{p(1)-p(0)}$ . The information rent payable to the *l*-type contractor would be then  $Z_h - Z_l$  with probability  $v$ .

- $e_l = 1; e_h = 0$ : Note that to incentivize the *l*-type contractor to invest in the process improvement we need to satisfy  $s_l \geq \frac{Z_l}{p(1)-p(0)}$ . Furthermore, to avoid *h*-type contractor not to invest in the process improvement we need to satisfy  $s_h < \frac{Z_h}{p(1)-p(0)}$ . The project manager’s contract design problem can be written as follows:

$$\max_{(w_l, s_l), (w_h, s_h)} v[-w_l + p(1)(U - s_l)] + (1 - v)[-w_h + p(0)(U - s_h)] \tag{23}$$

Subject to  $w_l - c + p(1)s_l - Z_l \geq 0$  (24)

$$w_h - c + p(0)s_h \geq 0 \tag{25}$$

$$w_l - c + p(1)s_l - Z_l \geq w_h - c + p(\tilde{e}_l)s_h - \tilde{e}_l Z_l \tag{26}$$

$$w_h - c + p(0)s_h \geq w_l - c + p(\tilde{e}_h)s_l - \tilde{e}_h Z_h \tag{27}$$

$$s_l \geq \frac{Z_l}{p(1)-p(0)} \tag{28}$$

$$s_h < \frac{Z_h}{p(1)-p(0)} \tag{29}$$

where  $\tilde{e}_\theta$  shows the optimal action under deviated contract, i.e., if the  $\theta$ -type mimics the other type. First of all, the participation constraint of the *h*-type contractor is binding at optimality, hence  $w_h = c - p(0)s_h$ . Now, to

avoid mimicking behaviour of the  $l$ -type contractor, the  $l$ -type contractor should be indifferent between self-selecting his own contract and choosing the  $h$ -type contract, i.e., the incentive compatibility constraint (26) is binding in equilibrium. Therefore, to make the constraint (26) feasible, we need to induce  $\tilde{e}_l = 1$ , and the least costly way to do so is to set  $s_h = \frac{Z_l}{p(1)-p(0)}$ , which results in  $w_h = c - \frac{p(0)}{p(1)-p(0)}Z_l$ . It is then straightforward to verify that the project manager can satisfy the  $l$ -type participation by offering a break-even contract;  $w_l = c - \frac{p(0)}{p(1)-p(0)}Z_l$  and  $s_l = \frac{Z_l}{p(1)-p(0)}$ . Clearly, the contract is of pooling type and the information rent is zero.

- $e_l = 0; e_h = 1$ : Note that to incentivize the  $h$ -type contractor to invest in the process improvement we need to satisfy  $s_h \geq \frac{Z_h}{p(1)-p(0)}$ . Furthermore, to avoid the  $l$ -type contractor not to invest in the process improvement we need to satisfy  $s_l < \frac{Z_l}{p(1)-p(0)}$ . Moreover, because we have  $Z_l \leq Z_h$ , the  $l$ -type contractor invests in the process improvement under the deviated contract, i.e.,  $\tilde{e}_l = 1$ . The project manager's contract design problem can be written as follows:

$$\max_{(w_l, s_l), (w_h, s_h)} v[-w_l + p(0)(U - s_l)] + (1 - v)[-w_h + p(1)(U - s_h)] \tag{30}$$

Subject to  $w_l - c + p(0)s_l \geq 0$  (31)

$$w_h - c + p(1)s_h - Z_h \geq 0 \tag{32}$$

$$w_l - c + p(0)s_l \geq w_h - c + p(1)s_h - Z_l \tag{33}$$

$$w_h - c + p(1)s_h - Z_h \geq w_l - c + p(\tilde{e}_h)s_l - \tilde{e}_h Z_h \tag{34}$$

$$s_l < \frac{Z_l}{p(1)-p(0)} \tag{35}$$

$$s_h \geq \frac{Z_h}{p(1)-p(0)} \tag{36}$$

First of all, the participation constraint of the  $h$ -type contractor is binding, and the least costly way to induce improvement effort on him is to set  $s_h = \frac{Z_h}{p(1)-p(0)}$ , which results in  $w_h = c - \frac{p(0)}{p(1)-p(0)}Z_h$ . The project manager can satisfy the incentive compatibility constraint of the  $l$ -type contractor by  $w_l = c + Z_h - Z_l$  and  $s_l = 0$ . The  $l$ -type contractor can enjoy the information rent  $Z_h - Z_l$  due to his less costly process improvement.



- $e_l = 0; e_h = 0$ : The project manager can simply satisfy the participation constraints by only covering the production cost;  $w_l = w_h = c$  and  $s_l = s_h = 0$ .

We can now characterize the optimal contract by comparing the project manager's profit under all four action profiles. Table 1 in proposition 3 summarizes this comparison.

*Proof of Proposition 4.* First, under information asymmetry the fixed-price contract is  $w_l = w_h = w$ , and the contractor never invests in process improvement. But, from full information scenario (proposition 1) the project manager can benefit from contractor's process improvement when the cost of effort is less than the expected benefit, i.e.,  $Z_\theta \leq [p(e_\theta = 1) - p(e_\theta = 0)]U$ . Therefore, the expected efficiency loss is  $\mathbb{E}_\theta[[p(e_\theta = 1) - p(e_\theta = 0)]U - Z_\theta] = \nu[p(e_l = 1) - p(e_l = 0)]U - Z_l + (1 - \nu)[p(e_h = 1) - p(e_h = 0)]U - Z_h$  or, equivalently,  $[p(e_\theta = 1) - p(e_\theta = 0)]U - \mathbb{E}_\theta[Z_\theta]$ .

*Proof of Proposition 5.* Recall from proposition 3 that in region+3.3

32139847/////9845n  $R_1$  the project manager induces action profile  $e_h = e_l = 1$ , hence, from equation (12), the value of incentive fee is  $[p(1) - p(0)]U - Z_h$ . Similarly, in region  $R_2$  the project manager induces process improvement only on the  $l$ -type contractor, i.e.,  $e_h = 0; e_l = 1$ , under which the value of incentive fee is  $\nu \leq \bar{\nu}$  and  $\nu[(p(1) - p(0))U - Z_l]$ . Finally, per proposition 3, region  $R_1$  is in equilibrium when the information rent is less than efficiency loss, i.e.,  $\nu(Z_h - Z_l) \leq (1 - \nu)[(p(1) - p(0))U - z_h]$ , or equivalently  $\nu \leq \frac{[p(1)-p(0)]U-z_h}{[p(1)-p(0)]U-z_l} = \bar{\nu}$ .

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