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Abstract

In a two-stage procurement model, we compare two types of fixed-price contracting schemes, bundling and unbundling. The buyer's choice of scheme involves an intertemporal tradeoff: providing incentives for cost-reducing investment and sharing production-cost risk between the risk-neutral buyer and the risk-averse supplier. The main result shows that unbundling outperforms bundling when both the supplier and the entrant in *ex post* competitive bidding confront an aggregate risk, and the externality of the supplier's investment on the entrant's production cost is low.

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1 Introduction

There are two typical issues in procurement contracting: how to provide investment incentives with a contractor and how to share risk between contracting parties. In plant or building construction, a large company or a public official contracts with a contractor. The contractor's investment in design specifications at an early stage can reduce costs in the subsequent construction stages through innovative ideas. The exact amount of construction costs is determined only at a later stage, depending on various exogenous factors such as the availability of subcontractors or price fluctuations for raw materials, and thus is uncertain at the early stage. The performance of a contract can often be assessed by its effect on these two issues.

While the result in the moral-hazard literature demonstrates the effectiveness of cost-sharing contracts, simple fixed-price contracts are more pervasive in many industries and countries.[1] In public-sector procurement, the Federal Acquisition Rules (FARs) in the U.S. bind the public entities to award fixed-price contracts by competitive bidding. In private-sector procurement, the fixed-price contracts called "lump-sum" have historically been prevalent. There are many plant engineering firms which specialize in lump-sum project execution, such as CB&I in the U.S., JGC Corporation in Japan, and so on. The survey by the Royal Institution of Chartered Surveyors (RICS) reports that, in 2004, 87.1% of 2330 projects in the U.K. construction industry used lump-sum contracts, and only 0.2% used cost-plus contracts (RICS, 2006).[2]

If a fixed price for entire works is agreed at the outset of a long-term project, then it provides the contractor with strong incentives for cost-reducing investment, but imposes most of the risk on the contractor. The relevant contracting schemes are the ones called "lump-sum turnkey" or "design and build" in the construction industry.[3] The bankruptcy of a major U.S. engineering firm, Stone & Webster, in 2000 was attributed to the lump-sum turnkey projects (Engineering News-Record, 2000).

Alternatively, in a multi-stage project, tasks can be split into several contracts to be awarded sequentially as the project information and design develop, as

[1] Bajari and Tadelis (2001) argue that fixed-price contracts, which have no need to measure actual construction costs, will dominate a larger set of cost-sharing contracts as it becomes more expensive to measure costs. They, however, compare the performance of fixed-price contracts with that of cost-plus contracts, focusing on the tradeoff between cost-reducing incentives and renegotiation costs.

[2] Cost-sharing contracts (including cost-plus contracts) are less pervasive in European countries or Japan than in the U.S. Albano, Calzolari, Dini, Iossa, and Spagnolo (2006) argue that unreliability of accounting data may induce the procurer to choose a fixed-price contract that does not rely on information produced by the contractor.

[3] There are many design-build firms, which undertake the tasks of both design and construction. Engineering News-Record (ENR) annually reports the top 100 design-build firms (ENR, 2010).

suggested by Navarrete (1995). For example, a purchaser of a petrochemical plant initially awards the Front End Engineering Design (FEED) contract to a contractor at a fixed price, and then awards the Engineering, Procurement, and Construction (EPC) contract to the contractor selected via competitive bidding at a fixed price. A contractor who is awarded the FEED contract also frequently wins the EPC contract. The scheme "design-bid-build", which is traditionally used in the building construction industry, is the similar one. These alternative schemes can reallocate risk between the purchaser and the contractor, but may lessen the contractor's *ex ante* investment incentives because the schemes allow the purchaser to extract the benefit of cost reduction in the *ex post* awarding process.

The aim of this study is to compare two types of fixed-price contracting schemes, *bundling* and *unbundling*, and to derive conditions under which each scheme is chosen in equilibrium. We develop a model based on the *incomplete contract* setting. A risk-neutral buyer (principal) procures a product such as a plant from a risk-averse supplier (agent).[4] Under bundling, the fixed prices of design specifications and a product are prespecified, and then the supplier invests in cost reduction and produces the product. Under unbundling, the fixed price of only design specifications is prespecified; after the supplier invests and the uncertainty about production costs is resolved, the buyer awards a production contract via a first-price auction between the supplier and a potential entrant, with the delivered design specifications. At the time of auction, the production costs for the supplier and the entrant are common knowledge between them,[5] but the buyer cannot observe these costs. Note that the supplier's investment can potentially reduce the entrant's production cost. The buyer chooses the efficient contracting scheme in equilibrium because she can obtain total surplus from trade at the *ex ante* stage.

The main results are as follows. As one would expect, bundling dominates unbundling when the supplier is risk-neutral, for risk sharing does not matter. Once the supplier is risk-averse, unbundling generates higher total surplus than bundling when both the supplier and the entrant confront *aggregate risk* in production costs and the investment externality is low; aggregate risk is defined as the case where their production costs have a perfect positive correlation and the same variance. On the other hand, bundling generates higher total surplus than unbundling regardless of the supplier's risk aversion when each of the supplier and entrant confronts his own *firm-specific risk* in production costs; firm-specific risk is defined as the case

[4] In the petroleum industry, large oil companies (e.g., Exxon Mobil) procure new plants from specialized contractors. Olsen and Osmundsen (2005), who also assume that the supplier is risk-averse, argue that contractors are less able to carry risk because, for example, their portfolios of projects are less diversified.

[5] We will also analyze the case where the realized values of production costs are their private information with some assumptions.

where their production costs are independent of each other.

We now turn to a review of the related literature. The recent literature on Public-Private Partnerships (PPPs) has focused on a comparison between the analogous schemes (Hart, 2003, Bennett and Iossa, 2006, Maskin and Tirole, 2008, Martimort and Pouyet, 2008, Chen and Chiu, 2010, Hoppe and Schmitz, 2010). Contrary to the traditional scheme of public-sector procurement in which two sequential tasks of building infrastructures are unbundled and delegated to separate contractors, the scheme of PPPs has a feature that these tasks are bundled and assigned to a single contractor (or a consortium). For instance, in the case of a prison, it matters whether the two tasks of prison construction and operation should be bundled or not. The above articles compare the performance of bundling (PPPs) with that of unbundling (traditional procurement). The central issue is how each scheme affects the suppliers' incentives for various kinds of investment.[6] Martimort and Pouyet (2008), however, additionally examine a risk-sharing issue in a multitask model.[7] They consider the quality-enhancing investment in the first stage and the cost-reducing effort in the second stage. In an environment where asset quality is unverifiable but operation costs are verifiable so that cost-sharing contracts are feasible,[8] they investigate conditions under which each organizational form, which is a combination of the contracting scheme (bundling or unbundling) and the ownership structure, is desirable for the buyer. There are significant differences between the model of Martimort and Pouyet (2008) and ours. First, we examine the risk-sharing issue in a situation where only fixed-price schemes are feasible. Second we assume that unbundling allows the supplier to bid for a production contract. Under unbundling, the supplier wins for sure in equilibrium with his cost advantage, but the entrant's bid considerably affects not only investment incentives but also risk sharing.

Another strand is the literature on "second sourcing" (Anton and Yao, 1987, Demski, Sappington, and Spiller, 1987, Laffont and Tirole, 1988, Riordan and Sappington, 1989). In the context of the public procurement of defense systems or the regulation of a natural monopoly, these studies examine a form of competition in which an incumbent supplier's technology is transferred to an alternative entrant (second source), competing for a production contract with the incumbent supplier. Riordan and Sappington (1989) show that the buyer's option to switch suppliers affects the supplier's investment incentives. Unlike this paper, production is shifted to the inefficient entrant with positive probability in equilibrium so that the buyer can limit the supplier's informational rents. The prospect of lower returns at the

[6]The effect of an ownership structure of a facility on investment incentives is also an issue (Bennett and Iossa, 2006, Martimort and Pouyet, 2008, Chen and Chiu, 2010).

[7]In the context of PPPs, risk sharing is also an important practical issue. See OECD (2008).

[8]They also consider an environment where both quality and operation costs are verifiable.

production stage in turn reduces the supplier's incentives in the investment stage. Laffont and Tirole (1988) analyze the regulator's switching (or breakout) policy and its interaction with incentive schemes. They consider an environment where the supplier's cost-reducing investment may or may not be transferable to the entrant, and their results depend on this condition. With transferable investment, the supplier underinvests because he has no incentives to internalize the externality. The regulator then mitigates this inefficiency by awarding a production contract to the supplier with higher probability than the first-best (complete information) case. In this paper, we also show that the existence of the potential entrant causes underinvestment due to the investment externality. Moreover, the potential entrant in the same industry as the supplier behaves as if the entrant reported a production cost index through competitive bidding. In the case of aggregate risk, particularly, the winning price which is equal to the index is positively correlated with the supplier's production cost. This risk sharing benefit of second sourcing has not been pointed out in the literature.

Finally, the literature on incomplete contract has also emphasized investment incentives (Williamson, 1975, 1985, Grossman and Hart, 1986, Hart and Moore, 1990, Hart, 1995). One of the insights is that long-term contracts can enhance efficiency by fostering relation-specific investment (Miceli, 2008). In our setting, while bundling (long-term fixed-price contracting) can prevent opportunistic behavior by the buyer and resolve the underinvestment problem due to "holdup", its rigidity imposes most of the risk on the supplier. Aghion, Dewatripont, and Rey (1994) show that a long-term contract with a complex revelation mechanism achieves *ex ante* efficiency in a general environment where the supplier make cost-reducing investment and the buyer make value-enhancing investment, and both parties are risk-averse. Their mechanism, however, must be committed in an initial contract.[9] Assuming that under unbundling the buyer only commits to a first-price auction to award a production contract, we focus on more practical contracting schemes in procurement.

The remainder of the paper is organized as follows. Section 2 presents the model. Section 3 characterizes the equilibrium outcome and provides the sufficient conditions under which each scheme generates higher surplus than the other. Section 4 discusses the implications. Section 5 concludes. All proofs are in the Appendix.

[9] Although their mechanism relies on the assumption that the good to be traded is perfectly divisible, more complex mechanism may be able to achieve *ex ante* efficiency in our environment. However, the analysis is beyond the scope of this paper. Remark 2 will discuss the related topic.

2 The model

A risk-neutral buyer (principal) B procures one unit of product such as a plant. A risk-averse supplier (agent) S has a CARA utility function $u(\pi) = 1 - \exp(-r\pi)$, where $\pi \in \mathbb{R}$ and $r > 0$ is his coefficient of absolute risk aversion.[10]

Valuation $v > 0$ for the product by B is common knowledge. S invests in design specifications before production of the product. With the design specifications developed by S, either S or a potential entrant E can produce the product. Investment $a \in \mathbb{R}_+$ by S, which has a positive externality on E, reduces the production costs for both S and E (c_S and c_E, respectively). Each $c_i(a, \theta_i)$ for $i = S, E$ is a function of both an investment level a and a random variable $\theta_i \in [\underline{\theta}, \overline{\theta}]$ representing exogenous factors in the cost. If S chooses an investment level a with investment cost $\psi(a)$ and θ_S is realized, then his total cost is $\psi(a) + c_S(a, \theta_S)$. We make the following assumptions.

Assumption 1. $v > c_E(a, \theta_E) > c_S(a, \theta_S)$ for all a and all θ_S, θ_E.

Assumption 2. $-\frac{\partial c_S(a,\theta_S)}{\partial a} > -\frac{\partial c_E(a,\theta_E)}{\partial a}$ for all a and all θ_S, θ_E.

Assumption 3. The investment cost function $\psi : \mathbb{R}_+ \to \mathbb{R}_+$ is twice continuously differentiable, $\psi'(a) > 0$, $\psi''(a) > 0$, $\lim_{a \to 0} \psi'(a) = 0$, and $\lim_{a \to \infty} \psi'(a) = \infty$.

Assumption 4. The production cost function $c_i : \mathbb{R}_+ \times [\underline{\theta}, \overline{\theta}] \to \mathbb{R}_+$ is twice continuously differentiable in a, $\frac{\partial c_i(a,\theta_i)}{\partial a} < 0$, and $\frac{\partial^2 c_S(a,\theta_S)}{\partial a^2} \geq \frac{\partial^2 c_E(a,\theta_E)}{\partial a^2} \geq 0$, for all a, all θ_i, and all $i = S, E$.

Assumption 5. c_i is strictly increasing in θ_i for all $i = S, E$.

Assumptions 1 and 2 imply that S has an advantage in production over E.[11] Assumption 1 also ensures that trade of the product between B and either supplier (S or E) generates positive gains. Assumptions 3 and 4 ensure a unique interior solution for the optimal investment levels. Assumption 5 is almost without loss of generality.

The procurement game proceeds as follows. At date 0, B chooses between two contracting schemes: bundling and unbundling. If B selects bundling, then the game proceeds as follows. At date 1, B offers two fixed prices $(p_1, p_2) \in \mathbb{R}^2$ in exchange for both the design specifications and the product.[12] S then either accepts

[10] Even if B is also risk-averse, almost all results remain qualitatively unchanged when B has a CARA utility function and less risk-averse than S.

[11] The assumption that the entrant's production cost is always higher than the supplier's cost may be justified by certain learning costs, as suggested by Riordan and Sappington (1989).

[12] B pays a total price $p_1 + p_2$ after both the design specifications and the product are delivered. We can assume instead that B pays each price just after S delivers the corresponding object.

or rejects the offer. If S rejects the offer, the game ends and B and S obtain their reservation utilities 0. If S accepts the offer, the game continues. At date 2, S chooses an investment level a. At date 3, random variables (θ_S, θ_E) are realized and the game ends. If B selects unbundling at date 0, then the game proceeds as follows. At date 1, B offers a fixed price $p_1 \in \mathbb{R}$ in exchange only for the design specifications. The game continues in the same way as for bundling until date 3. At date 4, in a first-price auction, S and E simultaneously submit a bid $p_2 \in \mathbb{R}$ competing for a production contract. The supplier who submits the lowest bid wins; when both S and E submit the same bid, S wins with his cost advantage. The game then ends. Figure 1 summarizes the time line.

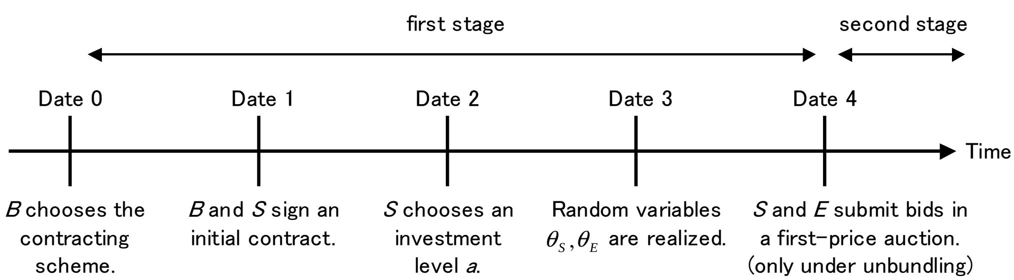


Figure 1: Timeline

The information structure at date 4 is as follows. The investment level a is known only by S. The realized value of θ_i is known only by $i = S, E$. The production costs $c_S(a, \theta_S)$ and $c_E(a, \theta_E)$ are common knowledge between S and E.[13] B does not know these variables at all.[14]

As will be explained in the next section, under either scheme, S produces and delivers the product in the equilibrium outcome. Given prices (p_1, p_2), investment a, and the realized values of (θ_S, θ_E), the payoff for B is $U_B = v - (p_1 + p_2)$ and that for S is $U_S = 1 - \exp\{-r[(p_1 + p_2) - \psi(a) - c_S(a, \theta_S)]\}$.

We assume that investment a, realization of (θ_S, θ_E), and production costs $c_S(a, \theta_S)$, $c_E(a, \theta_E)$ are unverifiable. When B can offer an initial contract in which prices are contingent on both the investment a and the realized value of θ_S (or both the investment a and the production cost $c_S(a, \theta_S)$), the *ex ante* efficient outcome is realized, in which (i) B induces S to choose the *efficient investment level* $\tilde{a}$ that

[13]This assumption may be justified when each contractor can precisely estimate his competitor's production cost from the design specifications included in bidding documents.

[14]Tirole (1986), who considers the case of military procurement, also assumes that in the incomplete contract setting the buyer does not know the supplier's production cost.

minimizes expected total cost $\psi(a) + E[c_S(a, \theta_S)]$,[15] and (ii) B pays the realized total cost $\psi(\tilde{a}) + c_S(\tilde{a}, \theta_S)$ for all θ_S to S. B then obtains the *first-best (expected) payoff* $v - \{\psi(\tilde{a}) + E[c_S(\tilde{a}, \theta_S)]\}$.

3 Bundling versus unbundling

In this section, we explore the subgame perfect equilibrium of the procurement game. We focus on the following two cases concerning the degree of correlation between production costs. Case (i): θ_S and θ_E are statistically independent, so that production costs $c_S(a, \theta_S)$ and $c_E(a, \theta_E)$ are independent. Case (ii): For any investment level a, production costs $c_S(a, \theta_S)$ and $c_E(a, \theta_E)$ have a perfect positive correlation and the same variance.

The first case may be plausible when each of the supplier and entrant confronts his own firm-specific risk, such as the availability of his associated subcontractors. The second case may be plausible when both S and E confront aggregate risk, such as price fluctuations for raw materials for the plant or uncertain buyer requirements which are only established in the design specifications.

Note that in any case the equilibrium outcome of a first-price auction at date 4 under unbundling is the same as that of Bertrand competition; in a unique equilibrium both S and E submit $p_2 = c_E(a, \theta_E)$ and S wins. Competitive bidding determines the price p_2 as if the production cost for E were verifiable. This result, however, depends on the assumption that both S and E know each other's production costs. Some remarks are given at the end of the next subsections.

3.1 The case of firm-specific risk

In this subsection, we consider case (i). Before examining the equilibrium investment level, we characterize the *risk premium* for S. After S delivers the product, he obtains profit $\pi = (p_1 + p_2) - \psi(a) - c_S(a, \theta_S)$ under bundling with prices (p_1, p_2) and profit $\pi' = (p_1' + p_2') - \psi(a) - c_S(a, \theta_S)$ under unbundling with prices $(p_1', p_2' = c_E(a, \theta_E))$. These profits are random variables. S's risk premium $\rho > 0$ for π is such that his expected utility $E[u(\pi)]$ is equal to $u(E[\pi] - \rho)$. His risk premium $\rho' > 0$ for π' is defined in the same way.

Lemma 1. Let ρ be S's risk premium for $\pi = (p_1 + p_2) - \psi(a) - c_S(a, \theta_S)$, and ρ' be that for $\pi' = (p_1' + c_E(a, \theta_E)) - \psi(a) - c_S(a, \theta_S)$. Then, in the case of firm-specific risk, $\rho' > \rho > 0$ when the same investment level a is chosen under both schemes.

[15] In this paper, $E[\cdot]$ and $\mathrm{Cov}(\cdot, \cdot)$ represent the expectation operator and the covariance operator of random variables, respectively.

Lemma 1 shows that S bears even more risk under unbundling than under bundling if the investment level a is the same under both schemes. This result is trivial. Since production costs $c_S(a,\theta_S)$ and $c_E(a,\theta_E)$ are statistically independent in case (i), S must bear an additional risk for the product price $p_2 = c_E(a,\theta_E)$ under unbundling.

We next characterize the equilibrium investment level under each scheme. Let a^* denote the equilibrium investment level in the subgame after B chooses bundling at date 0, and a^{**} denote that for unbundling.

Lemma 2. In the case of firm-specific risk, $a^* > a^{**}$.

This result is a version of the "holdup problem". The investment by S is "relation-specific" because the investment is made to produce the product customized for B. Under bundling, S can capture the full benefit from the relation-specific investment, with assurance of the product price and no room for renegotiation.[16] However, under unbundling, an increase in investment induces aggressive bidding by E because of the positive externality for the production cost of E. Owing to the reduction in price $\frac{\partial c_E(a,\theta_E)}{\partial a} < 0$, S has an incentive to lower the investment level compared to bundling. If B can commit to give all the bargaining power to S and not to switch suppliers, this underinvestment does not occur.

However, we cannot generally say whether each equilibrium investment level is lower or higher than the efficient level $\tilde{a}$ because investment by S affects the riskiness of the production costs. Lemma 4 will provide further details.

The equilibrium expected payoffs for B for bundling and unbundling are given by

$$EU_B^* = v - \left\{ \psi(a^*) + \frac{1}{r}\ln\{E[\exp(rc_S(a^*,\theta_S))]\} \right\},$$

$$EU_B^{**} = v - \left\{ \psi(a^{**}) + \frac{1}{r}\ln\{E[\exp(-r(c_E(a^{**},\theta_E) - c_S(a^{**},\theta_S)))]\} + E[c_E(a^{**},\theta_E)] \right\},$$

respectively. The big bracket terms are total payments to S. B can obtain total expected surplus from trade at the *ex ante* stage, so that she optimally chooses the scheme which generates higher surplus than the other. The following proposition shows that B always prefers bundling to unbundling.

[16] Assumption 1 ensures that it is common knowledge that cancellation of production or switching suppliers just after date 3 does not increase surplus. Even though renewing the initial fixed-price contract to a cost-plus contract between date 2 and 3 increases surplus, this renegotiation is impossible because the production cost is unverifiable; see Fudenberg and Tirole (1990), Hermalin and Katz (1991), and Edlin and Hermalin (2001).

Proposition 1. In the case of firm-specific risk, for any coefficient of absolute risk aversion r, B optimally chooses bundling, which generates higher surplus than unbundling.

Figure 2 illustrates this result. Under unbundling, which imposes more risk on S than bundling does, B must make a higher total payment. Therefore, in the case of firm-specific risk, the superiority of bundling over unbundling holds even if S is risk-averse.

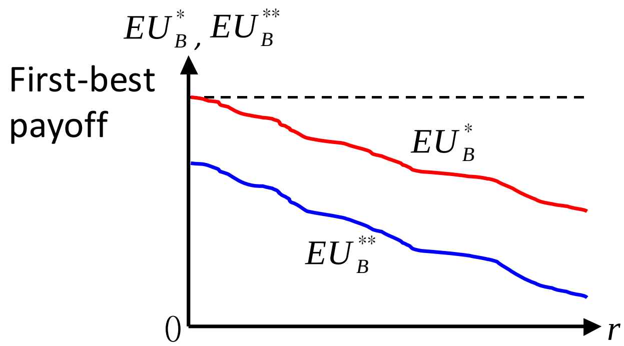


Figure 2: Illustration of Proposition 1.

Remark 1. If the production cost for each of S and E is his private information, which may be plausible in the case of firm-specific risk, then the equilibrium outcome of a first-price auction under unbundling changes. In this situation, S has no incentive to make a lower bid than the minimum of E's production cost $c_E(a, \underline{\theta})$; S can win with probability one by bidding this minimum cost provided that E never makes a lower bid than his own production cost. S may, however, have an incentive to make a higher bid than the minimum cost $c_E(a, \underline{\theta})$ in order to raise a winning price at the expense of winning for sure.

Nevertheless, if S has a sufficient advantage in production over $\underline{E}$, so that given the investment level a the maximum of S's production cost $c_S(a, \overline{\theta})$ is sufficiently lower than the minimum of E's production cost $c_E(a, \underline{\theta})$, we can obtain the same result as Proposition 1 with some assumptions. With these assumptions, S optimally makes a bid equal to $c_E(a, \underline{\theta})$ regardless of his own production cost $c_S(a, \theta_S)$. The winning price $c_E(a, \underline{\theta})$ then depends only on a, not on θ_E, so that under unbundling S bears no additional risk for the product price but he still has an incentive to underinvest. The Appendix provides formal statements and proofs.

3.2 The case of aggregate risk

In this subsection, we consider case (ii). In the same way as for case (i), we characterize the risk premium for S and the equilibrium investment levels a^* and a^{**} in the following lemmas.[17]

Lemma 3. Let ρ be S's risk premium for $\pi = (p_1 + p_2) - \psi(a) - c_S(a, \theta_S)$, and ρ' be that for $\pi' = (p_1' + c_E(a', \theta_E)) - \psi(a') - c_S(a', \theta_S)$. Then, in the case of aggregate risk, $\rho > \rho' = 0$.

Under bundling, in which prices are fixed in advance, S must bear all production cost risks. On the other hand, the assumption for the case of aggregate risk ensures that under unbundling the contract price $p_2 = c_E(a, \theta_E)$ is determined to eliminate the risk that S must bear; when his production cost is high (low), the cost for his competitor E is also high (low), so that S can (must) submit a high (low) bid.

Lemma 4. In the case of aggregate risk, $a^{**} < \tilde{a}$. Regardless of the cases,

$$a^* > \tilde{a} \text{ if } -\frac{\partial c_S(a, \theta_S)}{\partial a} \text{ is increasing in } \theta_S, \tag{1}$$

$$a^* = \tilde{a} \text{ if } -\frac{\partial c_S(a, \theta_S)}{\partial a} \text{ is independent of } \theta_S, \tag{2}$$

$$a^* < \tilde{a} \text{ if } -\frac{\partial c_S(a, \theta_S)}{\partial a} \text{ is decreasing in } \theta_S. \tag{3}$$

Under bundling, S has an incentive to decrease risk in production cost. If condition (1) (condition (3)) is satisfied, then an increase in investment changes the distribution of his production cost to a less (more) risky one, so that S has an incentive to overinvest (underinvest) compared to the efficient level. If condition (2) is satisfied, so that an increase in investment only changes the expectation for the production cost of S, then there are no such distortions because of a CARA utility function. On the other hand, under unbundling, S bears no risk, as explained in Lemma 3; once again, underinvestment occurs owing to the holdup problem.

The following proposition presents the main result. To specify the supremum of the total payment under bundling, let $\overline{a}^*$ denote the optimal investment level for the infinitely risk-averse S under that scheme; the Appendix shows that $\overline{a}^* = \arg\min_a [\psi(a) + c_S(a, \overline{\theta})]$ and the supremum of the total payment is $\psi(\overline{a}^*) + c_S(\overline{a}^*, \overline{\theta})$.

Proposition 2. Consider the case of aggregate risk. If $\psi(\overline{a}^*) + c_S(\overline{a}^*, \overline{\theta}) \leq \psi(a^{**}) + E[c_S(a^{**}, \theta_S)]$, then B optimally chooses bundling. Otherwise, there exists a threshold $\hat{r} > 0$ such that B optimally chooses bundling for all $r < \hat{r}$, and unbundling for

[17] With an abuse of notation, we denote the risk premium, the equilibrium investment level, and the equilibrium payoff for B by the same notations as case (i).

all $r > \hat{r}$. B optimally chooses the scheme which generates higher surplus than the other scheme.

Figure 3 illustrates this result. Under unbundling, while S is free from risk and thus B only pays the expected total cost $\psi(a^{**}) + E[c_S(a^{**}, \theta_S)]$, the investment level a^{**} is lower than the efficient level. Under bundling, as S is more risk-averse, B must pay a higher risk premium to induce S to participate in this trade. In particular, if S is infinitely risk-averse, then B must compensate the highest production cost $c_S(\overline{a}^*, \overline{\theta})$ as if B faced a limited liability constraint. Therefore, in the case of aggregate risk, if the externality on the production cost for E is sufficiently low that under unbundling S optimally chooses an investment level close to the efficient level, then B optimally chooses unbundling for sufficiently large r. As the degree of externality decreases, the threshold $\hat{r}$ monotonically decreases. Clearly, when there is no externality ($\frac{\partial c_E(a,\theta_E)}{\partial a} = 0$), S optimally chooses the efficient investment level under unbundling, so that unbundling dominates bundling.

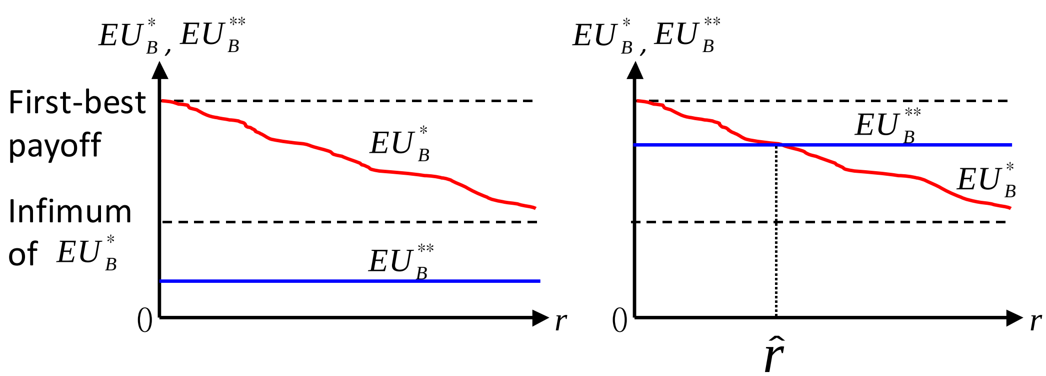


Figure 3: Illustration of Proposition 2.

Remark 2. In the case of aggregate risk, even if the production cost for each of S and E is his private information, the equilibrium outcome of a first-price auction under unbundling does not change. Since their production costs have a perfect positive correlation in this case, each of S and E can correctly infer his competitor's production cost from his own cost; thus, their production costs are essentially common knowledge between S and E.

Although B does not know their production costs, she may then be able to obtain the information by using some mechanisms. For instance, B can require E to report his production cost in order to know S's production cost, and then award a production contract to S without any information rent.[18] E then plays a role in

[18] In this mechanism, E is indifferent among all reports, so that there are multiple equilibria. More complex mechanisms may be able to resolve this problem.

"auditing".[19] Moreover, E can correctly infer the investment level from both his production cost $c_E(a,\theta_E)$ and the realization of θ_E because his production cost is monotonic in θ_E. Under unbundling, B can then obtain the first-best payoff with some mechanisms because the investment level and the production cost can be indirectly verifiable using messages reported by S and E.

Even if these mechanisms are feasible at date 4 under unbundling, when B cannot commit to use them in an initial contract, we can obtain the qualitatively similar result to Proposition 2. Under these mechanisms, B pays only the realized production cost $c_S(a,\theta_S)$ to S; S then becomes free from risk, but has no incentive for investment. We can interpret these mechanisms as the most severe opportunistic behavior by B. Thus, comparing the expected payment $\psi(0)+E[c_S(0,\theta_S)]$ under unbundling with the supremum payment $\psi(\bar{a}^*)+c_S(\bar{a}^*,\theta)$ under bundling, we obtain the similar statement to Proposition 2.

4 Discussion

Our findings shed light on when each scheme should be chosen in private-sector or public-sector procurement. From Propositions 1 and 2, we can expect that buyers are more likely to rely on unbundling than bundling in periods of aggregate shocks. Thus, there should be a positive correlation between the choice of unbundling and the volatility of material prices or wages.

To discuss the possibility, we focus on the construction of petrochemical plants.[20] In Japan, there are three large engineering companies, JGC Corporation, Chiyoda Corporation, and Toyo Engineering Corporation. These companies has carried out many projects in Asia, Africa, South America, Eastern Europe, the Middle East, and so on. The scheme of turnkey, which had been prevalent since 1930s in the U.S., was introduced to Japan in the 1950s. In their projects, lump-sum turnkey (bundling) contracts have been prevalent.

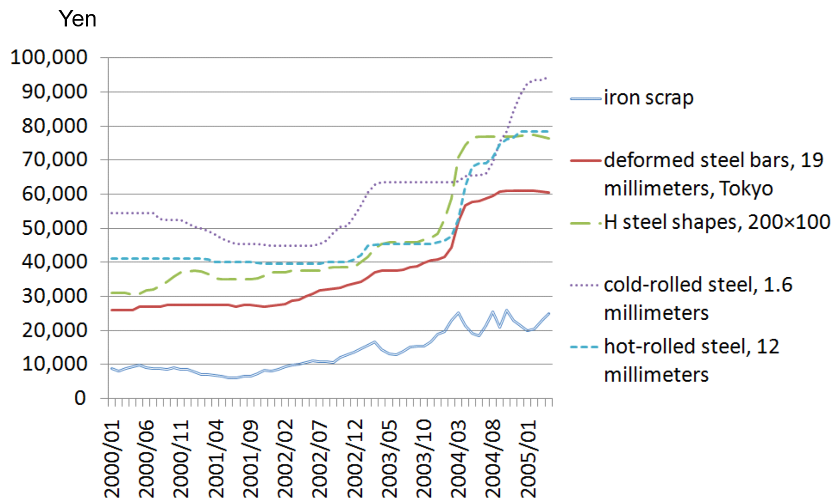
Their businesses, however, tremendously suffered due to the oil crisis in the 1970s. Since they had been already awarded some lump-sum turnkey projects, they inevitably experienced large cost overruns because of a substantial rise in material prices. Although it is useful for sharing these market risks to use "fixed-price with escalation" contracts, many procurers were reluctant to use the contracts.[21]

[19] Demski et al. (1987) show the similar auditing role of second sourcing.

[20] See Olsen and Osmundsen (2005) for the Norwegian petroleum industry.

[21] FARs also prescribe "fixed-price with economic price adjustment". Crocker and Reynolds (1993) argue that the flexibility of such a contract is constrained by the requirement that the contingencies and the compensation formulas must be explicitly prespecified.

Thirty years after, this industry was again hit by a steep rise in global material prices and workers' wages. Figure 4 provides the price chart of steel materials. The main reason behind the rise from 2003 is that there was a construction boom in oil-producing countries and China. We can expect that during the periods when material prices were uncertain the above Japanese companies charged high risk premia for risky lump-sum turnkey projects. Actually, Chiyoda Corporation undertook more FEED projects from 2003 to 2004 (Chiyoda, 2009). We can guess that procurers preferred unbundling to bundling in order to save risk premia.



Data source : NEEDS-Financial QUEST
(http://www.nikkei.co.jp/needs/services/fq.html)

Figure 4: Price chart of steel materials in Japan

In the model, the entrant's identity is exogenously given. If, however, the buyer can endogenously search an appropriate entrant in advance and credibly commit to award a production contract via a first-price auction, then the *ex ante* efficient outcome is realized. That is, the buyer needs to find the entrant (or the second source) who confronts aggregate risk but obtains no benefit from the supplier's investment. With this credible commitment, the supplier requires no risk premium and invests efficiently. Thus, this commitment by the buyer should be allowed in order to improve efficiency although the activity seems anticompetitive.

5 Concluding remarks

In the situation where only fixed-price contracting schemes are feasible, we have examined the issues of investment incentives and risk sharing. We compared two schemes, bundling and unbundling, and established sufficient conditions under which each scheme generates higher surplus than the other and is chosen in equilibrium.

We have assumed that the supplier has a cost advantage over the entrant so that the supplier can win a production contract for sure. In practice, however, there may be more competition between them. Under the assumption that the entrant's production cost can be lower than the supplier (i.e., removing Assumption 1), some new effects will emerge. If the buyer cannot switch suppliers under bundling, then unbundling has an advantage because the buyer can switch from the inefficient supplier to the efficient entrant. This switching effect, however, may in turn reduce the supplier's investment incentives and impose an additional risk on the supplier; the supplier cannot obtain his investment benefit at all with positive probability, and he must bear the risk of losing a production contract. Although the results may be robust to switching with a small probability, the above effects are more likely to matter as the probability is higher. A more careful analysis will be needed.

Appendix

Proof of Lemma 1. In case (i), $c_S(a,\theta_S)$ and $c_E(a,\theta_E)$ are statistically independent. Thus,

$$\rho' - \rho = E[c_E(a,\theta_E)] + \frac{1}{r}\ln\{E[\exp(-rc_E(a,\theta_E))]\} > 0.$$

This follows from a simple calculation and Jensen's inequality. □

Proof of Lemma 2. The expected utility for S on choosing a at date 1 is $E[1 - \exp\{-r[(p_1+p_2) - \psi(a) - c_S(a,\theta_S)]\}]$ under bundling, and $E[1-\exp\{-r[p_1 - \psi(a) + c_E(a,\theta_E) - c_S(a,\theta_S)]\}]$ under unbundling. The necessary and sufficient first-order conditions for a^* and a^{**} are given by

$$-\frac{E\left[\frac{\partial c_S(a^*,\theta_S)}{\partial a}\cdot\exp(rc_S(a^*,\theta_S))\right]}{E[\exp(rc_S(a^*,\theta_S))]} = \psi'(a^*), \tag{4}$$

$$-\frac{E\left[\left(\frac{\partial c_S(a^{**},\theta_S)}{\partial a} - \frac{\partial c_E(a^{**},\theta_E)}{\partial a}\right)\cdot\exp(-r(c_E(a^{**},\theta_E) - c_S(a^{**},\theta_S)))\right]}{E[\exp(-r(c_E(a^{**},\theta_E) - c_S(a^{**},\theta_S)))]} = \psi'(a^{**}). \tag{5}$$

Since $c_S(a,\theta_S)$ and $c_E(a,\theta_E)$ are statistically independent in case (i), condition (5) is

$$-\frac{E\left[\frac{\partial c_S(a^{**},\theta_S)}{\partial a}\cdot\exp(rc_S(a^{**},\theta_S)\right]}{E[\exp(rc_S(a^{**},\theta_S)]}=\psi'(a^{**})-\frac{E\left[\frac{\partial c_E(a^{**},\theta_E)}{\partial a}\cdot\exp(rc_E(a^{**},\theta_E)\right]}{E[\exp(rc_E(a^{**},\theta_E)]}. \tag{6}$$

The second term on the right-hand side of (6) is strictly positive, so we have $a^* > a^{**}$ by comparing (4) with (6). $\square$

Proof of Proposition 1. Since $c_S(a,\theta_S)$ and $c_E(a,\theta_E)$ are statistically independent,

$$E[\exp(-r(c_E(a,\theta_E)-c_S(a,\theta_S)))]=E[\exp(-rc_E(a,\theta_E))]E[\exp(rc_S(a,\theta_S))].$$

Thus,

$$\begin{aligned}EU_B^{**}=v-\Big\{\psi(a^{**})+\frac{1}{r}\ln\{E[\exp(rc_S(a^{**},\theta_S))]\}\\ +\frac{1}{r}\ln\{E[\exp(-rc_E(a^{**},\theta_E))]\}+E[c_E(a^{**},\theta_E)]\Big\}.\end{aligned}$$

By Jensen's inequality, $\frac{1}{r}\ln\{E[\exp(-rc_E(a^{**},\theta_E))]\}+E[c_E(a^{**},\theta_E)]>0$. In addition, $a^*=\arg\min\{\psi(a)+\frac{1}{r}\ln\{E[\exp(rc_S(a,\theta_S))]\}\}$. Therefore, $EU_B^{**}<v-\{\psi(a^*)+\frac{1}{r}\ln\{E[\exp(rc_S(a^*,\theta_S))]\}\}=EU_B^*$ for all r. $\square$

Proof of Lemma 3. Under bundling, the distribution of $\pi=(p_1+p_2)-\psi(a)-c_S(a,\theta_S)$ is nondegenerate, so that the risk premium ρ for π is positive. Under unbundling, in case (ii), because there exists a function $c(a)$ such that $c_E(a',\theta_E)=c_S(a',\theta_S)+c(a')$, the risk premium ρ' for $\pi'=p_1'-\psi(a')+c(a')$ is zero. $\square$

Proof of Lemma 4. The necessary and sufficient first-order condition for $\tilde{a}=\arg\min[\psi(a)+E[c_S(a,\theta_S)]]$ is given by

$$-E\left[\frac{\partial c_S(\tilde{a},\theta_S)}{\partial a}\right]=\psi'(\tilde{a}). \tag{7}$$

Since $c_E(a,\theta_E)-c_S(a,\theta_S)$ is independent of the realized values of (θ_S,θ_E) in case (ii), condition (5) is

$$-E\left[\frac{\partial c_S(a^{**},\theta_S)}{\partial a}\right]=\psi'(a^{**})-E\left[\frac{\partial c_E(a^{**},\theta_E)}{\partial a}\right]. \tag{8}$$

The second term on the right-hand side of (8) is strictly positive, so we have $\tilde{a} > a^{**}$ by comparing (7) with (8). We can rewrite condition (4) as

$$-E\left[\frac{\partial c_S(a^*, \theta_S)}{\partial a}\right] = \psi'(a^*) - \frac{\mathrm{Cov}\left(-\frac{\partial c_S(a^*,\theta_S)}{\partial a}, \exp(rc_S(a^*, \theta_S))\right)}{E[\exp(rc_S(a^*, \theta_S)]}. \tag{9}$$

If condition (1) (condition (3)) in Lemma 4 is satisfied, then the fact that the covariance between two positively (negatively) covarying variates is positive (negative) implies that the covariance term in (9) is positive (negative), so that $a^* > \tilde{a}$ ($a^* < \tilde{a}$) by comparing (7) with (9). If condition (2) is satisfied, then $a^* = \tilde{a}$ because the covariance term in (9) is zero. □

Proof of Proposition 2. As above, $c_E(a, \theta_E) - c_S(a, \theta_S)$ is independent of the realized values of (θ_S, θ_E) in case (ii). Thus,

$$\begin{aligned} EU_B^{**} &= v - \{\psi(a^{**}) + \frac{1}{r}\ln\{\exp(-rE[c_E(a^{**}, \theta_E) - c_S(a^{**}, \theta_S)])\} + E[c_E(a^{**}, \theta_E)]\} \\ &= v - \{\psi(a^{**}) + E[c_S(a^{**}, \theta_S)]\}. \end{aligned}$$

Now, a^{**} determined by (8) does not depend on r, so that EU_B^{**} does not depend on r as well.

We then show that (a) EU_B^* converges to the first-best payoff as $r \to 0$, (b) EU_B^* is decreasing in r, and (c) EU_B^* has an infimum.

(a) Since the optimal investment for S depends on his coefficient of absolute risk-aversion, we denote $a^* = a^*(r)$. Then,

$$EU_B^* = v - \psi(a^*(r)) - E[c_S(a^*(r), \theta_S)] - \rho(a^*(r), r),$$

where $\rho(a^*(r), r) = -E[c_S(a^*(r), \theta_S)] + \frac{1}{r}\ln\{E[\exp(rc_S(a^*(r), \theta_S))]\}$ is the risk premium. As $r \to 0$, $a^*(r) \to \tilde{a}$ because the covariance term in (9) converges to 0, and the risk premium $\rho(a^*(r), r)$ converges to 0. Therefore, as $r \to 0$, EU_B^* converges to the first-best payoff $v - \{\psi(\tilde{a}) + E[c_S(\tilde{a}, \theta_S)]\}$.

(b) Using the envelope theorem, $\frac{dEU_B^*}{dr} = -\frac{\partial \rho(a^*(r),r)}{\partial r}$. From Theorem 1 of Pratt (1964), as the coefficient of absolute risk-aversion is greater, the risk premium is greater. Thus, $\frac{\partial \rho(a^*(r),r)}{\partial r} > 0$, so that $\frac{dEU_B^*}{dr} < 0$.

(c) The certainty equivalent for S for $\pi = (p_1 + p_2) - \psi(a) - c_S(a, \theta_S)$, from which he obtains the same utility as $E[u(\pi)]$, is

$$(p_1 + p_2) - \psi(a) - \frac{1}{r}\ln\{E[\exp(rc_S(a, \theta_S))]\}.$$

Since c_S is increasing in θ_S, the highest production cost given a is $c_S(a, \overline{\theta})$. Thus, as $r \to \infty$, his certainty equivalent converges to $(p_1 + p_2) - \psi(a) - c_S(a, \overline{\theta})$. Then the infinitely risk-averse S optimally chooses $\bar{a}^*$ determined by $-\frac{\partial c_S(\bar{a}^*,\bar{\theta})}{\partial a} = \psi'(\bar{a}^*)$. Since $\lim_{a\to\infty}\psi'(a) = \infty$, $\bar{a}^*$ is finite. Therefore, as $r \to \infty$, EU_B^* converges to $v - \left\{\psi(\bar{a}^*) + c_S(\bar{a}^*, \bar{\theta})\right\} > 0$. This is the infimum of EU_B^*.

Comparing the infimum of EU_B^* with $EU_B^{**} = v - \{\psi(a^{**}) + E[c_S(a^{**}, \theta_S)]\} > 0$, which is less than the first-best payoff, completes the proof. $\square$

As noted in Remark 1, even if the production cost for each of S and E is his private information in the case of firm-specific risk, we can obtain the same result as Proposition 1 with some assumptions. We now prove this. The idea is based on the Example 1 of Maskin and Riley (2000). Given the investment level a and the realized values of (θ_S, θ_E), we use the notations $c_S = c_S(a, \theta_S)$, $c_E = c_E(a, \theta_E)$, $\bar{c}_S = c_S(a, \bar{\theta})$, and $\underline{c}_E = c_E(a, \underline{\theta})$.

Suppose first that E truthfully bids his production cost c_E. When S's production cost is c_S, his optimal bid is given by the solution to the following problem

$$\max_{p_2 \in [\underline{c}_E, \bar{c}_E]} 1 - F(p_2)\exp(-r(p_1 - \psi(a))) - (1 - F(p_2))\exp(-r(p_1 - \psi(a) + p_2 - c_S)), \tag{10}$$

where F is the distribution function of production cost for E. The first-order condition is given by

$$\begin{aligned} &\exp(-r(p_1 - \psi(a)))\times \\ &\{[\exp(-r(p_2 - c_S)) - 1]f(p_2) + \exp(-r(p_2 - c_S))(1 - F(p_2))r\} = 0, \end{aligned} \tag{11}$$

where f is the density function of production cost for E. By differentiating the left hand side of (11) with respect to p_2, we obtain

$$\begin{aligned} &\exp(-r(p_1 - \psi(a)))\times \\ &\{[\exp(-r(p_2 - c_S)) - 1]f'(p_2) - \exp(-r(p_2 - c_S))[(1 - F(p_2))r^2 + 2f(p_2)r]\}. \end{aligned} \tag{12}$$

If $f'(p_2)$ is always positive or $|f'(p_2)|$ is sufficiently small (e.g., uniform distribution), then the formula (12) is negative and thus the second-order condition is satisfied. We assume this to be the case.

Assumption 6. For all r, all $p_2 \in [\underline{c}_E, \bar{c}_E]$ and all c_S, the formula (11) is negative.

Now, $1 - F(\underline{c}_E) = 1$. Thus, if for all r, all a and all θ_S,

$$[\exp(-r(\underline{c}_E - c_S)) - 1] f(\underline{c}_E) + \exp(-r(\underline{c}_E - c_S))r \leq 0,$$

then the solution to the problem (10) is always a corner solution. Since c_S is increasing in θ_S, this condition is equivalent to the condition that for all r and all a,

$$[\exp(-r(\underline{c}_E - \bar{c}_S)) - 1] f(\underline{c}_E) + \exp(-r(\underline{c}_E - \bar{c}_S))r \leq 0. \tag{13}$$

If $f(\underline{c}_E)$ is positive and $\underline{c}_E$ is sufficiently higher than $\bar{c}_S$, then the condition (13) is satisfied; this yields a corner solution. We assume this to be the case.

Assumption 7. For all r and all a, the condition (13) is satisfied.

Lemma 5. If Assumptions 6 and 7 are satisfied, then in the subgame after unbundling is chosen and S invests there is an equilibrium in which S makes a bid equal to $c_E(a, \underline{\theta})$ regardless of his production cost and E truthfully bids his production cost $c_E(a, \theta_E)$.

Proof of Lemma 5. As explained above, given E's strategy to bid his production cost $c_E(a, \theta_E)$, S's best response is to bid $c_E(a, \underline{\theta})$ regardless of his production cost $c_S(a, \theta_S)$. Moreover, if S chooses this bidding strategy, then it is optimal for E to bid $c_E(a, \theta_E)$ because he cannot profitably win the auction. □

In the following we assume that in the subgame after unbundling is chosen and S invests the equilibrium in Lemma 5 occurs, so that S wins with probability one and the winning price is $p_2 = c_E(a, \underline{\theta})$.

Lemma 6. Let ρ be S's risk premium for $\pi = (p_1 + p_2) - \psi(a) - c_S(a, \theta_S)$, and ρ' be that for $\pi' = (p_1' + c_E(a, \underline{\theta})) - \psi(a) - c_S(a, \theta_S)$. Then, $\rho' = \rho > 0$ when the same investment level a is chosen under both schemes.

Proof of Lemma 6. By the assumption of a CARA utility function, both ρ and ρ' depend only on S's production cost $c_S(a, \theta_S)$, so that $\rho' = \rho > 0$. □

Lemma 7. $a^* > a^{**}$.

Proof of Lemma 7. The necessary and sufficient first-order condition for a^* is given by (4), and that for a^{**} is given by

$$-\frac{E\left[\left(\frac{\partial c_S(a^{**}, \theta_S)}{\partial a} - \frac{\partial c_E(a^{**}, \underline{\theta})}{\partial a}\right) \cdot \exp(r c_S(a^{**}, \theta_S))\right]}{E[\exp(r c_S(a^{**}, \theta_S))]} = \psi'(a^{**}). \tag{14}$$

We have $a^* > a^{**}$ by comparing (4) with (14). □

Proposition 3. For any coefficient of absolute risk aversion r, B optimally chooses bundling, which generates higher surplus than unbundling.

Proof of Proposition 3. Now, the equilibrium expected payoff for B for unbundling is given by

$$EU_B^{**} = v - \left\{ \psi(a^{**}) + \frac{1}{r} \ln\{E[\exp(rc_S(a^{**}, \theta_S))]\} \right\}.$$

Since $a^* = \arg\min\{\psi(a) + \frac{1}{r}\ln\{E[\exp(rc_S(a, \theta_S))]\}\}$, $EU_B^{**} < EU_B^{*}$ for all r. $\square$

References

Aghion, P., M. Dewatripont, and P. Rey (1994): "Renegotiation design with unverifiable information," *Econometrica*, 62, 257–282.

Albano, G., G. Calzolari, F. Dini, E. Iossa, and G. Spagnolo (2006): "Procurement contracting strategies," in *Handbook of procurement*, Cambridge University Press, chapter 4.

Anton, J. and D. Yao (1987): "Second sourcing and the experience curve: Price competition in defense procurement," *RAND Journal of Economics*, 18, 57–76.

Bajari, P. and S. Tadelis (2001): "Incentives versus transaction costs: A theory of procurement contracts," *RAND Journal of Economics*, 32, 387–407.

Bennett, J. and E. Iossa (2006): "Building and managing facilities for public services," *Journal of Public Economics*, 90, 2143–2160.

Chen, B. and Y. Chiu (2010): "Public-private partnerships: Task interdependence and contractibility," *International Journal of Industrial Organization*, 28, 591–603.

Chiyoda (2009): "Major projects," `http://www.chiyoda-corp.com/project/file/Major_Projects.pdf`.

Crocker, K. and K. Reynolds (1993): "The efficiency of incomplete contracts: An empirical analysis of air force engine procurement," *RAND Journal of Economics*, 24, 126–146.

Demski, J., D. Sappington, and P. Spiller (1987): "Managing supplier switching," *RAND Journal of Economics*, 18, 77–97.

Edlin, A. and B. Hermalin (2001): "Implementing the first best in an agency relationship with renegotiation: A corrigendum," *Econometrica*, 69, 1391–1395.

Engineering News-Record (2000): "Shaw wins Stone & Webster assets," , 12.

Fudenberg, D. and J. Tirole (1990): "Moral hazard and renegotiation in agency contracts," *Econometrica*, 58, 1279–1319.

Grossman, S. and O. Hart (1986): “The costs and benefits of ownership: A theory of vertical and lateral integration.” *Journal of Political Economy*, 94, 691–719.

Hart, O. (1995): *Firms, contracts, and financial structure.*, Oxford University Press, USA.

Hart, O. (2003): “Incomplete contracts and public ownership: Remarks, and an application to public-private partnerships,” *Economic Journal*, 69–76.

Hart, O. and J. Moore (1990): “Property rights and the nature of the firm.” *Journal of political economy*, 98, 1119–1158.

Hermalin, B. and M. Katz (1991): “Moral hazard and verifiability: The effects of renegotiation in agency,” *Econometrica*, 59, 1735–1753.

Hoppe, E. and P. Schmitz (2010): “Public-private partnerships versus traditional procurement: Innovation incentives and information gathering,” .

Laffont, J. and J. Tirole (1988): “Repeated auctions of incentive contracts, investment, and bidding parity with an application to takeovers,” *RAND Journal of Economics*, 19, 516–537.

Martimort, D. and J. Pouyet (2008): “To build or not to build: Normative and positive theories of public-private partnerships,” *International Journal of Industrial Organization*, 26, 393–411.

Maskin, E. and J. Riley (2000): “Asymmetric Auctions,” *Review of Economic Studies*, 67, 413–438.

Maskin, E. and J. Tirole (2008): “Public-private partnerships and government spending limits,” *International Journal of Industrial Organization*, 26, 412–420.

Miceli, T. (2008): *The economic approach to law*, Stanford Economics and Finance.

Navarrete, P. (1995): *Planning, estimating, and control of chemical construction projects*, Marcel Dekker.

OECD (2008): “Public-private partnerships – In pursuit of risk sharing and value for money,” .

Olsen, T. and P. Osmundsen (2005): “Sharing of endogenous risk in construction,” *Journal of Economic Behavior & Organization*, 58, 511–526.

Pratt, J. (1964): “Risk aversion in the small and in the large,” *Econometrica*, 32, 122–136.

RICS (2006): “A survey of building contracts in use during 2004,” `http://www.rics.org/site/scripts/download_info.aspx?fileID=4688`.

Riordan, M. and D. Sappington (1989): “Second sourcing,” *RAND Journal of Economics*, 20, 41–58.

Tirole, J. (1986): “Procurement and renegotiation,” *Journal of Political Economy*, 94, 235–259.

Williamson, O. (1975): *Markets and hierarchies, analysis and antitrust implications: A study in the economics of internal organization*, Free Press.

Williamson, O. (1985): *The economic institutions of capitalism: Firms, markets, relational contracting*, Free Press.