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Auctions versus negotiations: the effects of inefficient renegotiation

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For the procurement of complex goods, the early exchange of information is important to avoid costly renegotiation. If the buyer can specify the main characteristics of possible design improvements in a complete contingent contract, scoring auctions implement the efficient allocation. If this is not feasible, the buyer must choose between a price-only auction (discouraging early information exchange) and bilateral negotiations with a preselected seller (reducing competition). Bilateral negotiations are superior if potential design improvements are important, if renegotiation is very costly, and if the buyer's bargaining position is strong. Moreover, negotiations provide stronger incentives for sellers to investigate design improvements.

1. Introduction

■ A company or a government agency that wants to procure a complex project has to decide which procurement mechanism to use. For complex projects, such as a customized component in production, a tailor-made software, or an original building, it is often the case that potential contractors have superior information about possible design options and know better than the buyer what the optimal design is. In these situations, the early exchange of information is of crucial importance for using the knowledge and expertise of a contractor before the designs are complete and production begins.

Two procurement procedures frequently applied in practice are (i) price-only auctions and (ii) bilateral negotiations. The advantages of auctions are well understood. An auction achieves low prices by inducing strong competition between bidders, and it safeguards against corruption and favoritism. For these reasons, the law in most industrialized countries requires that public

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procurement orders have to be awarded by auction if certain thresholds are exceeded.[1] Private companies, on the other hand, are more reluctant to use competitive procedures to award procurement contracts. For instance, Bajari, McMillan, and Tadelis (2009) report in their data of private construction contracts in Northern California that 43% have been awarded via negotiations with a sole supplier and only 18% via open competitive tendering.[2] They find that auctions perform poorly and are rarely applied when projects are complex.

In this article, we show that negotiations may outperform auctions because they give better incentives to sellers to reveal private information about possible design improvements early. Our model formalizes a trade-off between competition and information exchange. It is built on two crucial ingredients. First, potential contractors may be aware of a more efficient design than the buyer. Second, adjusting the design *ex post* via contract renegotiation is costly and inefficient. Note that if renegotiation is costless and yields an efficient outcome, there is no problem: the buyer and the contractor always renegotiate to the efficient design, no matter what the initial contract specifies. Furthermore, the seller with the best idea for a design improvement is likely to win the auction. He would gain most from renegotiation, and therefore bid most aggressively. However, there is substantial evidence that contract renegotiation is often costly and inefficient. In an empirical analysis of highway procurement contracts in California, Bajari, Houghton, and Tadelis (2014) estimate that the costs of renegotiation "range from 55 cents to around two dollars for every dollar in change." Thus, with costly renegotiation, the early exchange of information is important.

First, as a benchmark, we show that if the buyer can fully specify all characteristics of possible design improvements in a complete contingent contract, then she can use a scoring auction to achieve early information revelation and strong competition at the same time. However, if the buyer does not know how possible design improvements look like and if she cannot describe their characteristics *ex ante*, she has to award an incomplete contract that may have to be renegotiated *ex post*. In this case, the buyer has to choose between a price-only auction (for a given design) and contract negotiations with one seller.

In either case, we allow for a communication stage before the buyer fixes the design she wants to procure. We show that with a price-only auction, suppliers have no incentives to inform the buyer about superior designs before the contract is signed. An informed supplier maximizes his profits by hiding his information, bidding more aggressively, and recouping profits after winning the contract by revealing a superior design *ex post* and engaging in contract renegotiation.[3] In contrast, if the buyer commits to negotiate with one seller, the selected seller has a strict incentive to reveal design improvements early.[4] The intuition is that with negotiations, the parties are in a bilateral monopoly during their entire relationship. Thus, revealing design improvements early benefits both parties. In contrast, with an auction, there is a highly competitive environment

[1] The Agreement on Government Procurement (GPA), which came into effect in 1996 under the auspices of the World Trade Organization, requires transparent, nondiscriminatory, and open competitive tendering for the award of public procurement orders that exceed certain thresholds. The GPA is a multilateral agreement signed by most industrialized countries, including the United States and the European Union (Audet, 2002). In the United States, public procurement is regulated by the Federal Acquisition Regulation in accordance with the GPA. In the European Union, three directives prescribe the rules for public procurement orders, which are often stricter than the GPA rules (Drijber and Stergiou, 2009).

[2] The remaining contracts have been assigned mostly via an auction among a restricted group of suppliers. Leffler, Rucker, and Munn (2003) investigate private company sales of timber in North Carolina. They report that roughly 50% of the contracts are awarded via bilateral negotiation.

[3] This is in line with the informal argument made by Bajari and Tadelis (2006) in their handbook chapter: "A supplier has no incentive to offer the procurer advice on how to improve the plans [. . .] a supplier would have the incentive to keep any findings [. . .] to himself as they offer him a competitive advantage over his rivals in a competitive tendering process."

[4] In fact, if a buyer negotiates the contract with a selected seller, the two parties typically spend a lot of time discussing the optimal design of the project before the contract is signed, see Bajari and Tadelis (2006). Thus, there is less need for costly renegotiation *ex post*.

ex ante that is turned into a bilateral monopoly after the contract is signed.[5] The seller benefits from his ideas only if he reveals them *ex post*.

Hence, there is a trade-off between competition and early exchange of information. If renegotiation is efficient, early information exchange is not important, and a price-only auction outperforms bilateral negotiation. However, if renegotiation is costly, bilateral negotiations may outperform price-only auctions, in particular if complex projects are to be procured. Arguably, the more complex a project is, the more likely it is that sellers have superior knowledge about design options that the buyer did not see, the higher are the gains from possible design improvements, and the more costly are *ex post* design modifications. This may explain why practitioners and handbooks of procurement often recommend using negotiations for the procurement of complex projects.[6]

In a next step, we consider the incentives of sellers to invest into finding design improvements. This gives rise to a second trade-off. On the one hand, a seller who negotiates with a buyer always has a stronger incentive to invest than any seller participating in the auction. This is due to the fact that the return of this investment is diminished in the auction. On the other hand, there is a sampling effect that favors the use of auctions: the more bidders there are, the more likely it is that at least one of them finds the design improvement. The analysis of this section confirms our earlier results. It shows that if the inefficiencies caused by contract renegotiation are substantial, the probability of implementing design improvements is higher with bilateral negotiation than with an auction.

The tension between competition and efficient information exchange is also acknowledged by the lawmaker. In 2004, the European Union introduced a new procurement procedure called "Competitive Dialogue" that is specifically intended for the procurement of complex projects (European Commission, 2006). The Competitive Dialogue can be described as a two-stage procedure where the buyer first communicates with all potential suppliers secretly and bilaterally. Thereafter, the buyer collects (possibly multidimensional) tenders and awards the contract to the supplier who placed the best offer according to prespecified objective criteria. We show under what conditions the Competitive Dialogue encourages early information exchange, and under what conditions it boils down to a price-only auction with no early revelation of possible design improvements in equilibrium.

This article contributes to several strands of the literature. First, there is a large literature on optimal procurement contracts (McAfee and McMillan, 1986; Laffont and Tirole, 1993). This literature assumes that the performance of a contract is independent of the procedure by which the contract is awarded. In contrast, the contribution of our article is to point out that the way how the contract is allocated (by auction or by negotiation) affects the incentives for information exchange and thereby contract performance.

Second, there is a literature comparing auctions and negotiations. Starting with Bulow and Klemperer (1996), most of this literature finds that auctions outperform negotiations.[7] However, Manelli and Vincent (1995) show that negotiations may be preferable if quality is not contractible and costs and quality are positively correlated. In our setup, noncontractible quality is not an issue, so this problem does not arise.

Our approach is most closely related to Goldberg (1977) and Bajari and Tadelis (2001). Goldberg (1977) points out that the procurement mechanism does not only affect the price at which a good is procured but also the exchange of information between the buyer and potential contractors, and thereby the design of the good. This observation is also at the heart of our

[5] Williamson (1985) calls this the "fundamental transformation."

[6] In the *Handbook of Procurement*, Bajari and Tadelis (2006) offer "Practical conclusion 7: For complex projects for which the expertise and input of an experienced supplier is essential at the design stage, favor a cost-plus contract to be awarded using a negotiation with a reputable supplier."

[7] Bulow and Klemperer (2009) directly compare a simple simultaneous auction to sequential negotiations when participation is costly. The auction generates higher expected revenues but is less desirable from a welfare point of view. A similar finding is obtained by Pagnozzi and Rosato (2016) in the context of firm takeovers.

article. However, Goldberg is mainly concerned with the problem of who should bear the cost of information production. Contract renegotiation and the withholding of seller information do not play a role in his article, nor does he compare auctions to negotiations.

In Bajari and Tadelis (2001), the procurement contract is incomplete and renegotiation is costly, as in our model. They do not consider different award procedures but compare the performance of two types of contracts, fixed-price and cost-plus contracts. For standardized goods, the buyer should use a fixed-price contract that gives strong cost-saving incentives to the seller. If the good is complex, however, the procurement contract is likely to be renegotiated under asymmetric information. Thus, with a fixed-price contract, renegotiation fails with positive probability, giving rise to an inefficient outcome. With a cost-plus contract, on the other hand, renegotiation is always efficient, but it does not give any cost saving incentives to the seller. If the cost of renegotiation is sufficiently large, a cost-plus contract outperforms a fixed-price contract. Our model differs in three important respects from Bajari and Tadelis (2001). First, we investigate how the procurement contract should be awarded. Second, Bajari and Tadelis (2001) focus on *ex post* asymmetries of information whereas we are interested in the efficient design of the project *ex ante*. Finally, we endogenize the incentives of the sellers to find project improvements.

At a conceptual level, our article is also related to the literature on contracts as reference points (Hart and Moore, 2008; Herweg and Schmidt, 2015) that offers a behavioral explanation for why contract renegotiation is often costly and inefficient, and to the literature on endogenously incomplete contracts (Tirole, 2009), where contracting parties have to invest effort *ex ante* in order to figure out how the contract should deal with possible contingencies.

The remainder of the article is organized as follows. In Section 2, we briefly discuss the inefficiencies of renegotiation. The model is introduced in Section 3. We analyze the model by backward induction for the different procurement mechanisms in Section 4. In Section 5 we compare these mechanisms and derive our main results. We augment our model by an investment stage that endogenizes the probability that a supplier learns about design improvements in Section 6. In Section 7 we discuss the relation of our results to the "Competitive Dialogue" procurement procedure introduced in the European Union. Section 8 concludes. All proofs are relegated to Appendix A.

2. Costly renegotiation

■ Contract renegotiation with substantial design changes are frequently observed in the procurement of complex projects but they are often plagued by high adjustment costs. Several empirical studies emphasize that renegotiation is costly and inefficient, including Crocker and Reynolds (1993), Chakravarty and MacLeod (2009), and Bajari, Houghton, and Tadelis (2014). Bajari, Houghton, and Tadelis (2014) consider highway procurement contracts in California and report that renegotiation costs are substantial. They distinguish between "direct" and "indirect adaptation costs."

1. **Direct (physical) adjustment costs** are due to disruption of the originally planned work. The initial contract is embedded in a nexus of other contracts with suppliers, subcontractors, and customers. All of these other contracts are based on the assumption that the initial contract is implemented. Some of the involved parties have made relationship-specific investments. If the contract is renegotiated, this affects the timetable of the project and the value of the investments that have been sunk already. All of these contracts and investments need to be adjusted to the new design.[8]

[8] For example, if a new airport is built, contracts with airlines, airport hotels, airport shops, and public transport companies have to be written. These contracting partners engage in substantial relationship-specific investments that are contingent on the specification of the airport and the timetable of its completion. The new airport in Berlin offers a vivid example of how costly it can be to adjust these contracts. For further details, see Fiedler and Wendler (2015).

2. **Indirect (psychological) adjustment costs** are due to disputes and conflict resolution: "Each side may try to blame the other for any needed changes, and they may disagree over the best way to change the plans and specifications. Disputes over changes may generate a breakdown in cooperation on the project site and possible lawsuits" (Bajari, Houghton, and Tadelis, 2014). Tversky and Kahneman (1991) argue that these adjustment costs are due to loss aversion. Renegotiating the initial contract to a new contract requires both parties to make concessions. Suppose that the seller proposes a superior design that is more expensive to produce but also more valuable to the buyer. The buyer has to pay a higher price than planned initially. She may be unwilling to pay for all of the higher cost, in particular, if some of the additional physical adjustment cost could have been avoided if the seller had informed her early enough. The seller has to incur higher production costs. He feels that he should be compensated for his increase in production cost and for any additional physical adjustment costs that he has to incur. Furthermore, sellers often feel that the initial price was unfairly low, in particular if this price was determined by a competitive process, and that renegotiation is an opportunity to correct the too-low price. These feelings of losses and entitlements often lead to haggling and disputes that result in costly delays, inefficient adjustments, and expensive conflict resolution.[9]

3. The model

□ **Costs, benefits, and designs.** A buyer (female), denoted by B, wants to procure a complex project that is tailored to her specific needs, such as an original building, a tailor-made software program, or a custom-made component needed in production. The project can be executed by $n \geq 2$ potential sellers (male), denoted by $i = 1, \ldots, n$. We assume that sellers are symmetric and have the same cost function $c(\cdot)$, which depends on the implemented design of the project.[10] The seller who is selected to carry out the project is called the "contractor" (C). The buyer's gross benefit $v(\cdot)$ also depends on the design of the project. Without receiving additional information, the buyer believes that design y_0 maximizes social surplus. Design y_0 gives rise to gross benefit $v(y_0) = v_0$, cost $c(y_0) = c_0$, and social surplus $S_0 = v_0 - c_0 > 0$. The outside option utilities of all parties are normalized to zero.

Sellers often have additional skills and knowledge and may be able to come up with a more efficient design than y_0. The buyer lacks these skills and knowledge and therefore is unaware of the superior design, which might also be a reason for why the project is procured from an outside firm and not produced in-house. We model this as follows: there exists a superior design y^* which yields a higher social surplus than y_0. To avoid uninteresting case distinctions, we assume that design y^* yields a higher benefit for the buyer but is also more costly to produce for the sellers than design y_0, that is,[11]

$$v^* = v(y^*) > v_0, \quad c^* = c(y^*) > c_0, \quad \text{and} \quad S^* = v^* - c^* > S_0 .$$

The additional surplus that is generated by the superior design y^* is denoted by

$$\Delta S^* = S^* - S_0. \tag{1}$$

Each seller is aware of the superior design y^* with some exogenous probability $q \in (0, 1)$, which is drawn independently for each seller and the realization of which is private information. The new project design y^* is an innovative idea how the project could be specified differently from y_0. Once this idea is explained to any seller—even a seller who did not come up with this

[9] A formal model of inefficient renegotiation based on loss aversion is provided by Herweg and Schmidt (2015).

[10] The assumption that all sellers are symmetric is made for simplicity only. It strengthens the case for auctions because in this case, an auction gives all the surplus to the buyer. We discuss the case of asymmetric sellers in Section 5.

[11] It is straightforward to extend the analysis to the case where y^* reduces the buyer's benefit but reduces the seller's cost even more, or where y^* increases the buyer's benefit and decreases the seller's cost. See Herweg and Schmidt (2015) for a formal analysis of costly renegotiation in these cases.

idea himself—he is able to implement this idea at cost c^*; that is, an initially uninformed seller can implement the superior design at the same cost as initially informed sellers.

□ **Procurement mechanisms.** We consider three different procurement mechanisms: scoring auctions, price-only auctions, and bilateral negotiations. Which procurement mechanism can be used depends on the prior knowledge of the buyer. A scoring auction invites sellers to propose designs and prices, and it specifies a complete contingent scoring function that maps these bids into a single score. A scoring auction is a powerful procurement mechanism, but it is informationally very demanding. It requires that the buyer knows the main characteristics of alternative designs and that she is able to objectively describe and quantify them in a complete contingent contract. If a complex project is to be procured, this is often not feasible because the buyer is unaware of potential design improvements, she does not know how such improvements may look like, and she is unable to describe *ex ante* and verify *ex post* the effects of different designs on the costs and benefits of the project. Therefore, she cannot specify a complete, contingent scoring rule. Instead, she may either use a price-only auction or negotiate with one preselected seller. In either case, she can communicate with the seller(s) about potential design improvements before the contract is auctioned or negotiated.

The three procurement mechanisms are described in more detail below.

1. **Scoring auction.** We consider a so-called second-score auction that is very similar to a second-price auction. The buyer specifies a scoring function G that maps bids on design and price (y, p) into a single score. The seller who places the bid that leads to the highest score wins the auction. This seller can freely select any design-price pair that matches the second highest score offered. This pair $(\bar{y}, \bar{p})$ is specified in the initial contract signed between the buyer and the winning seller. If the highest score is offered by two or more sellers, one of these sellers is selected at random as the winner, who then has to select a design-price pair that matches the highest score.
2. **Price-only auction.** If nonprice criteria cannot be described and quantified in a scoring rule *ex ante*, the contract has to be awarded solely on the basis of price. This, however, does not preclude the buyer from communicating with potential sellers about design improvements before she collects tenders. Thereafter, the buyer runs a second-price sealed-bid auction for the best design she is aware of. If none of the sellers revealed y^*, she awards a procurement contract for design y_0, whereas if she is informed about y^*, she collects bids for design y^*. The seller who offers the lowest price is awarded the contract and receives the price offered by the second lowest bidder. If several bidders make the same lowest bid, one of them is selected at random.[12]
3. **Bilateral negotiations.** When the buyer decides to award the procurement contract via bilateral negotiation, she preselects one seller. In our model, all sellers are symmetric, so each seller is selected with probability $1/n$. Before negotiating the price, the buyer can again communicate with the preselected seller about possible design improvements, and the seller can reveal y^* to the buyer if he has observed it. The outcome of the negotiation game is given by the Generalized Nash Bargaining Solution (GNBS), with $\alpha \in (0, 1)$ being the buyer's relative bargaining power. Thus, if the contractor informs the buyer about y^*, the parties split the surplus S^* in proportion α and $1-\alpha$. If the contractor does not observe y^* or decides not to disclose this information, the parties split S_0 in the same proportions.[13]

[12] In general, a cost-minimizing auction involves setting a maximum bid. However, in our model, all sellers have the same cost function. Thus, if the surplus from good y_0 is sufficiently high, the optimal maximum bid for the procurement of good y_0 is simply $c(y_0) = c_0$, which never precludes a seller from participating in the auction. Therefore, focusing on second-price auctions without maximum bid does not impose additional restrictions on the buyer.

[13] Strictly speaking, if the seller knows y^* but does not inform the buyer about it, initial negotiation takes place with asymmetric information. The GNBS is a concept for bargaining under symmetric information. The seller does not reveal

□ **Renegotiation.** If the superior design y^* is revealed to the buyer *ex ante*, that is, before the procurement contract is written, the buyer will specify y^* in the contract and will procure the efficient project right from the start. However, it is possible that no seller informs the buyer about y^*, even though some sellers did observe it. Then, the buyer writes a contract with one of the sellers (the contractor C) on design y_0 initially. If the contractor knows the superior design, he may propose to renegotiate this contract to y^* *ex post*.

We model renegotiation as follows. If the parties renegotiate contract $(y_0, \bar{p})$ to contract (y^*, p^R) with $v^* > v_0$, $c^* > c_0$, and thus $p^R > \bar{p}$, the final utilities of the buyer and the contractor are given by

$$U^B(y^*, p^R) = v^* - p^R - \lambda^B[p^R - \bar{p}], \quad \text{and} \tag{2}$$

$$U^C(y^*, p^R) = p^R - c^* - \lambda^C[c^* - c_0], \tag{3}$$

respectively. The parameter $\lambda^j \geq 0$, with $j \in \{B, C\}$, measures how costly renegotiation is to party j, both in terms of physical and/or psychological adjustment costs. For simplicity, we assume that these costs are proportional to the adjustment. In fact, this model is very similar to the model of Bajari, Houghton, and Tadelis (2014), who use it to capture physical adjustment cost. It is identical to the model of Herweg and Schmidt (2015), who analyze psychological adjustment costs due to loss aversion.[14] We choose this specification of renegotiation costs because it allows for a unified treatment of physical and psychological adaptation costs. Furthermore, the simplicity of the model due to its linear structure allows us to fully characterize the renegotiation outcome. Our main findings do not rely on our specific modelling approach but hold (qualitatively) for any model of costly renegotiation.[15]

To avoid uninteresting case distinctions, we restrict attention to the case where the adjustment costs are not too high, so that there is scope for contract renegotiation if y_0 is implemented initially and y^* is revealed *ex post*, which is implied by the following assumption.

Assumption 1. The renegotiation cost parameters $\lambda^B, \lambda^C \geq 0$ satisfy[16]:

$$1 < (1 + \lambda^B)(1 + \lambda^C) < \frac{v^* - v_0}{c^* - c_0}. \tag{4}$$

The surplus generated by contract renegotiation is split between the two parties according to the GNBS with $\alpha \in (0, 1)$ denoting the buyer's relative bargaining power. In other words, the buyer obtains share α and the contractor share $1 - \alpha$ of the surplus that is generated due to design adjustments *ex post*. The buyer has the same bargaining power in the renegotiation game as in the bargaining game when she negotiates the initial contract with one preselected seller. Note that the initial contract is a specific performance contract that can be enforced by the courts and thus determines the parties' threat points.[17]

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his information, thus both parties behave as if they agree that trading specification y_0 is optimal. This is exactly what is characterized by the GNBS in this case. In refers to Appendix B, we show that the identical result can be obtained for a bargaining game where the asymmetric information is taken explicitly into account.

[14] See Herweg and Schmidt (2015) for a detailed discussion and analysis of loss aversion in contract renegotiation.

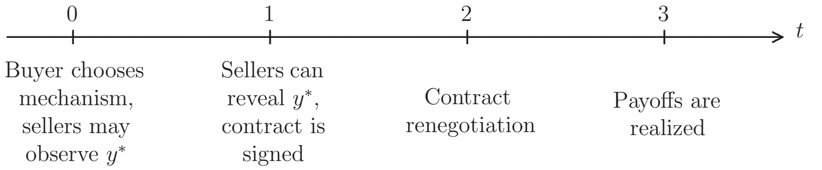
[15] Our main findings rely on the assumption that the surplus that can be generated by adjusting the design from y_0 to y^* *ex post*, that is, via renegotiation, is smaller than ΔS^*. For example, modelling renegotiation costs à la Anderlini and Felli (2006) would give rise to the same trade-off between competition and information revelation that we identify. Anderlini and Felli (2006) do not have linear adjustment costs, but assume that each party has to incur a fixed cost in order to reach the renegotiation stage.

[16] Recall that $v^* - v_0 > c^* - c_0$ implies $(v^* - v_0)/(c^* - c_0) > 1$.

[17] Binmore, Rubinstein, and Wolinsky (1986) discuss the relationship between the Nash Bargaining Solution and noncooperative models of bargaining. They argue that if the players want to reach an agreement early because they are impatient, then the threat point used in the Nash Bargaining Solution should correspond to the outcome obtained in the event of a breakdown of the bargaining process. In our model, if the parties do not come to an agreement, the initial contract will be carried out. Therefore, the initial contract $(y_0, \bar{p})$ is the appropriate threat point.

FIGURE 1

TIME STRUCTURE



□ **Time structure.** The time structure of the model is summarized as follows:

0. The buyer announces the mechanism to be used for awarding the procurement order. If she uses bilateral negotiations, she also (randomly) selects the seller. An independent draw of nature determines for each seller $i \in \{1, \ldots, n\}$ whether he observes the superior design y^*.
1. Each seller who observed y^* and participates in the mechanism can reveal this information to the buyer. This revelation can either be part of the mechanism or it takes place before the mechanism is executed. The procurement mechanism is executed. As a result of the mechanism, one seller receives a contract $(\bar{y}, \bar{p})$, specifying a design $\bar{y} \in \{y_0, y^*\}$ the seller has to deliver and a price $\bar{p}$ the buyer has to pay. Design y^* can be specified only if at least one seller revealed y^* to the buyer.
2. After the contract has been assigned, the contractor can reveal y^* to the buyer if he knows y^* and the buyer does not. In this case, the parties may adjust the design by renegotiating the initial contract to a renegotiated contract (y^*, p^R).
3. The (renegotiated) contract is executed and payoffs are made.

It is important to note that the procurement process of a complex project is a time-consuming process and that it often takes many months to run a proper auction or to negotiate a procurement contract. This process is intertwined with other decisions and contracts that the parties have to engage in. For example, the buyer has to contract with her investors who finance the project, with her customers who use the project, and with other suppliers who provide complementary goods and services. Similarly, the seller is engaged in other projects at the same time that compete for his resources, he has to employ subcontractors, and he has to secure financing. All of these additional contracts are based on the initial design specified at date 1. When the contract is renegotiated at date 2, these other contracts and decisions have to be adjusted, which makes renegotiation costly even if the parties anticipate that the initial contract may be renegotiated.

4. Analysis

■ The buyer chooses the procurement mechanism in order to maximize her expected utility

$$\mathbb{E}[v(y) - p - \lambda^B(p - \bar{p})],$$

and each seller maximizes his expected profits

$$\mathbb{E}[p - c(y) - \lambda^C(c(y) - c(\bar{y}))],$$

where (y, p) is the final contract (possibly after renegotiation) and $(\bar{y}, \bar{p})$ is the initial contract.

We analyze the model by backward induction and look for symmetric pure-strategy perfect Bayesian Nash equilibria. Thus, we first characterize the outcome of renegotiation for an initial contract $(y_0, \bar{p})$. Thereafter, we investigate sellers' optimal behaviors under the three mechanisms.

□ **The outcome of renegotiation.** Suppose the buyer and the contractor concluded a contract $(y_0, \bar{p})$ at stage 1. If the contractor is unaware of the superior specification, this initial contract is executed. If the contractor is aware of y^*, there is scope for renegotiation at stage 2—that is, the contractor reveals y^* to the buyer and the parties renegotiate the initial contract.

Renegotiation is voluntary. Thus, both parties have to prefer the renegotiation outcome (y^*, p^R) to the initial contract. Individual rationality requires

$$v(y^R) - v_0 - (1+\lambda^B)(p^R - \bar{p}) \geq 0, \tag{IR^B}$$

$$p^R - \bar{p} - (1+\lambda^C)[c(y^R) - c_0] \geq 0. \tag{IR^C}$$

There are prices $p^R > \bar{p}$ so that both constraints, (IR^B) and (IR^C), are satisfied if and only if

$$(1+\lambda^C)(c^* - c_0) > \frac{v^* - v_0}{1+\lambda^B}, \tag{5}$$

which is always satisfied by Assumption 1. Hence, the parties will adjust y_0 to y^* *ex post* if the contractor knows y^*. The renegotiation price p^R is determined by the GNBS and thus solves

$$\max_p \ \left\{v^* - v_0 - (1+\lambda^B)(p - \bar{p})\right\}^\alpha \left\{p - \bar{p} - (1+\lambda^C)[c^* - c_0]\right\}^{1-\alpha}. \tag{6}$$

The solution to this problem is characterized by the following proposition.

Proposition 1 (outcome of renegotiation). Suppose that Assumption 1 holds and that the initial contract is $(y_0, \bar{p})$. If the contractor knows the superior design y^*, the initial contract will be renegotiated to contract (y^*, p^R), with

$$p^R = \bar{p} + \frac{1-\alpha}{1+\lambda^B}[v^* - v_0] + \alpha(1+\lambda^C)[c^* - c_0]. \tag{7}$$

Final payoffs are given by

$$U^B = v_0 - \bar{p} + \alpha\left\{v^* - v_0 - (1+\lambda^B)(1+\lambda^C)[c^* - c_0]\right\} \tag{8}$$

$$U^C = \bar{p} - c_0 + \frac{1-\alpha}{1+\lambda^B}\left\{v^* - v_0 - (1+\lambda^B)(1+\lambda^C)[c^* - c_0]\right\}. \tag{9}$$

Proof. All proofs are relegated to Appendix A. □

Note that the surplus from renegotiation not only depends on the adjustment cost parameters λ^B and λ^C, but also on α, the bargaining power of the buyer. If the buyer has all the bargaining power ($\alpha = 1$), the renegotiation surplus is given by

$$\Delta S^R \equiv v^* - v_0 - (1+\lambda^B)(1+\lambda^C)(c^* - c_0) > 0. \tag{10}$$

If the seller has some bargaining power ($\alpha < 1$), the surplus from renegotiation is reduced to $\frac{1+\alpha\lambda^B}{1+\lambda^B}\Delta S^R > 0$. The reason is that a higher bargaining power of the seller implies a higher renegotiated price for the buyer. Transfers, however, are costly, if $\lambda^B > 0$. A price increase by Δp reduces the buyer's utility by $(1+\lambda^B)\Delta p$ and thus gives rise to a further welfare loss of $\lambda^B \Delta p$.

□ **Benchmark: scoring auctions.** A scoring auction requires that the buyer knows the main characteristics of possible design improvements. In particular, she has to be able to specify a scoring function G that maps bids of designs and prices into a numerical score. We restrict attention to second-score auctions that use quasilinear scoring rules $G(y, p) = g(y) - p$.[18]

[18] See Che (1993) and Asker and Cantillon (2010) for a more detailed discussion of scoring auctions.

We presume that the buyer wants to induce informed sellers to reveal y^*.[19] This is also efficient from a welfare perspective, because contract renegotiation is costly. In order to ensure that informed sellers propose y^*, the buyer must leave an expected rent to informed sellers; that is, if an informed seller wins, this seller has to obtain a strictly positive expected payoff. A seller who observed y^* can mimic an uninformed seller by submitting design y_0. If this seller obtains the contract, he gets an additional payoff of $(1-\alpha)\Delta S^R/(1+\lambda^B)$ from contract renegotiation. If all other sellers are uninformed, an informed seller can win the auction for design y_0 at price $p = c_0$ by submitting a bid $(y_0, c_0 - \epsilon)$ with $\epsilon > 0$ but close to zero that slightly undercuts the optimal bids of his uninformed rivals. With probability $q(1-q)^{n-1}$, seller i is the only seller who observed y^*. Thus, in order to induce sellers to reveal their information early, a scoring auction must pay an expected information rent of at least $nq(1-q)^{n-1}(1-\alpha)\Delta S^R/(1+\lambda^B)$. The following scoring function induces sellers to reveal design improvements by giving an expected information rent to the sellers that is equal to the lower bound derived above:

$$G(y, p) = \begin{cases} v_0 - p & \text{if } y = y_0 \\ v_0 + \dfrac{1-\alpha}{1+\lambda^B}\Delta S^R + [c^* - c_0] - p & \text{if } y = y^* \end{cases}. \tag{11}$$

Proposition 2. The second-score auction with scoring function (11) has a dominant strategy equilibrium, where each uninformed seller bids $(y, p) = (y_0, c_0)$ and each informed seller bids $(y, p) = (y^*, c^*)$. The expected payoff of the buyer from using this scoring auction (SA) is

$$EU^B_{SA} = S_0 + [1 - (1-q)^n]\Delta S^* - nq(1-q)^{n-1}\frac{1-\alpha}{1+\lambda^B}\Delta S^R. \tag{12}$$

This scoring auction is optimal for the buyer among all auctions with quasilinear scoring rules (i) if the buyer always wants to procure the project, and (ii) if she always wants to implement y^* *ex ante* if y^* has been observed by at least one seller.

In a second-score auction, as in a second-price auction, the bid of each seller determines whether he wins the contract, but it does not affect the terms of the contract. Thus, each seller has an incentive to offer the best contract—that is, the highest score, that just allows him to break-even. Bidding a lower score reduces the probability of winning without affecting the terms of the contract in case this seller wins. Bidding a higher score increases the probability of winning but only in cases in which the seller makes a loss when he has to match the second highest score. Note that the optimal bid is a (weakly) dominant strategy because it is independent of the bids of his competitors. Thus, the optimal bid for an uninformed seller is to bid (y_0, c_0) whereas the optimal bid for an informed seller is (y^*, c^*). Thus, in equilibrium, each informed seller reveals the design improvement y^*.[20] Moreover, if at least one seller is informed, an informed seller wins the auction because $G(y^*, c^*) > G(y_0, c_0)$.

This scoring auction is optimal for the buyer, because it implements y^* if y^* has been observed by at least one seller at the lowest possible cost. If none of the sellers is informed, the buyer obtains the full surplus generated by design y_0. If two or more sellers are informed, the buyer receives the full surplus generated by design y^*. Only if exactly one seller is informed, the buyer has to pay an information rent. The information rent is minimal because it equals the profit that the informed seller would have obtained from contract renegotiation if he had not revealed

[19] The case where she does not want to induce them to reveal y^* is equivalent to the case of a price-only auction analyzed in the next subsection.

[20] An informed seller is indifferent between bidding (y^*, c^*) and $(y_0, c_0 - (1-\alpha)\Delta S^R(1+\lambda^B)^{-1})$. If the score for offering design y^* is slightly higher, then an informed seller strictly prefers to bid (y^*, c^*). In this case, there is a unique symmetric equilibrium in (weakly) dominant strategies.

y^*. We will show below that this scoring auction strictly outperforms the two other mechanisms we consider, price-only auctions and bilateral negotiations.

Scoring auctions can be used if there are just a few important characteristics of potential designs that can be easily measured and compared, such as the time of completion of a highway project or the fuel efficiency of an engine. However, for complex projects, some characteristics are often difficult to measure objectively (e.g., aesthetic appeal), or there are many important characteristics that interact in a way that is impossible to foresee *ex ante* without knowing how exactly the designs look like. In these cases, the buyer has to award an incomplete procurement contract that may have to be renegotiated *ex post*.

□ **Price-only auction.** Consider now the case where the buyer lacks the prior knowledge necessary to formulate a scoring rule. In this case, she can award the procurement contract for a given design by a price-only auction. Before running the auction, the buyer may communicate with the sellers about the optimal design. We model this by splitting up stage 1 into two substages. (i) Each seller i who observed y^* decides whether or not to reveal this information to the buyer. (ii) The buyer runs the auction to award the procurement order for the best design she is aware of. If the buyer knows only y_0, this design is fixed in the initial contract. If at least one seller informed the buyer about the superior design y^*, the more efficient design y^* is procured and this is also optimal. We restrict attention to second-price auctions.

A crucial question is whether informed sellers have an incentive to reveal this information to the buyer early.

Proposition 3 (price-only auction). Suppose the buyer uses a price-only auction. Then, each informed seller strictly prefers not to reveal the possible project improvement to the buyer before the auction takes place. At the auction, uninformed sellers bid $b_i = c_0$ and informed sellers bid $b_i = c_0 - \frac{1-\alpha}{1+\lambda^B}\Delta S^R$.

The intuition for Proposition 3 is straightforward. If an informed seller reveals the design improvement to the buyer, the buyer auctions off project y^*. In this case, each seller bids $b_i = c(y^*)$ and all sellers get an expected payoff of zero. Thus, an informed seller is strictly better off if he does not reveal his information before the auction and bids more aggressively than the uninformed sellers. If he gets the contract, he will receive a strictly positive payoff in the renegotiation game. The reason is that the award procedure turns from a highly competitive situation (the auction) to a bilateral monopoly in which the seller has some bargaining power and gets fraction $1-\alpha$ of the renegotiation surplus. If he is the only seller who discovered possible project improvements, this *ex post* rent will not be competed away in the auction and he gets a strictly positive profit overall.[21]

To calculate the buyer's expected payoff from using a price-only auction, three cases have to be distinguished. With probability $(1-q)^n$, no seller finds the project improvement. In this case, all sellers bid $b_i = c_0$ and the buyer's payoff is $U^B = v_0 - c_0 = S_0$. With probability $nq(1-q)^{n-1}$, exactly one of the sellers finds y^*. In this case, the successful seller gets the contract at price $\bar{p} = c_0$, but then there is renegotiation. Thus, the buyer's payoff is $U^B = v_0 - c_0 + \alpha\Delta S^R = S_0 + \alpha\Delta S^R$. Finally, with probability $1-(1-q)^n - nq(1-q)^{n-1}$, two or more sellers are successful. In this case, competition in the auction drives down the price to $\bar{p} = c_0 - \frac{1-\alpha}{1+\lambda^B}\Delta S^R$, so the buyer's payoff is $U^B = S_0 + \alpha\Delta S^R + \frac{1-\alpha}{1+\lambda^B}\Delta S^R$.[22] Thus, the expected payoff of the buyer if she runs a price-only

[21] To induce the sellers to reveal their information early, the buyer could award bonus payments for the proposal of design improvements. However, this is equivalent to using a scoring auction. In fact, the optimal "bonus auction" and the optimal scoring auction described in Section 4 are outcome equivalent.

[22] The buyer's *ex post* utilities are directly obtained from Proposition 1. If a seller knows y^*, his price bid is obtained by solving $U^C = 0$.

auction is

$$\begin{aligned}EU_A^B &= (1-q)^n S_0 + nq(1-q)^{n-1}[S_0 + \alpha\Delta S^R] \\ &\quad + [1-(1-q)^n - nq(1-q)^{n-1}]\left[S_0 + \alpha\Delta S^R + \frac{1-\alpha}{1+\lambda^B}\Delta S^R\right] \\ &= S_0 + \Delta S^R\left\{\alpha[1-(1-q)^n] + \frac{1-\alpha}{1+\lambda^B}[1-(1-q)^n - nq(1-q)^{n-1}]\right\}. \end{aligned} \tag{13}$$

□ **Bilateral negotiations.** Instead of using a competitive tendering procedure, the buyer can also bilaterally negotiate a contract with one seller. We assume that the buyer randomly selects one of the n sellers and commits to negotiating with this seller only.[23] Again, the buyer and the seller first communicate about possible design improvements and then negotiate the contract.

Proposition 4 (bilateral negotiations). Suppose the buyer negotiates the procurement contract with one seller. If this seller observe the superior design y^*, he has a strict incentive to reveal it early to the buyer, that is, before the contract is signed.

The intuition for this result is again straightforward. If the contractor informs the buyer about the superior design, the parties will agree to trade the efficient project y^*, and the contractor gets fraction $1-\alpha$ of the surplus $S_0 + \Delta S^*$. If the contractor does not inform the buyer, the parties will contract on y_0 initially. At stage 2, the contractor will reveal his information in order to renegotiate the initial contract. However, renegotiation is inefficient. Therefore, the contractor will get fraction $1-\alpha$ of the renegotiation surplus $\frac{\Delta S^R}{1+\lambda^B}$, in addition to fraction $1-\alpha$ of the initial surplus S_0. This, however, is less than the surplus he would have received if he had revealed y^* right away.[24]

With probability q, the contractor observes the superior design y^*. In this case, the contractor shares this information with the buyer, who then obtains share α of the surplus generated by design y^*. With probability $1-q$, the contractor cannot come up with a design improvement and thus design y_0 is carried out. Again, the buyer obtains share α of the realized surplus. Thus, the buyer's expected payoff from bilateral negotiations is

$$\begin{aligned}EU_N^B &= (1-q)\alpha(v_0 - c_0) + q\alpha(v^* - c^*) \\ &= \alpha S_0 + q\alpha\Delta S^*. \end{aligned} \tag{14}$$

5. Comparison of procurement mechanisms

□ **Benchmark: complete procurement contracts.** A scoring auction is a complete contingent contract. By Proposition 2, it achieves early information revelation and thus it implements the most efficient design without costly renegotiation. Furthermore, it minimizes the information rent obtained by informed sellers. In contrast, a price-only auction implements design improvements only *ex post* after costly contract renegotiation. Bilateral negotiations induce early information revelation, but they leave a higher rent to the selected seller than competitive award procedures. Furthermore, if the buyer negotiates with one seller only, she never learns the (potentially valuable) information of the other sellers. Thus, the following proposition comes at no surprise.

Proposition 5 (scoring auctions). The scoring auction with scoring rule (11) strictly outperforms price-only auctions and bilateral negotiations.

[23] Without this commitment, the buyer would try to play out different sellers against each other and we are back to an auction.

[24] Note that this argument requires only that there is some inefficiency in the renegotiation process. It does not matter where the inefficiency is coming from and how it is modelled.

□ **Incomplete procurement contracts.** Suppose now that the buyer lacks the necessary information to award a complete contract *ex ante*. Should she then run a price-only auction or should she negotiate with just one seller? By Propositions 3 and 4, the buyer faces a trade-off between competition and information exchange.

In order to evaluate the pros and cons of negotiations in comparison to auctions, we have to compare the buyer's expected utilities under the two mechanisms, (13) and (14). A price-only auction outperforms bilateral negotiations if and only if $\Psi \equiv EU_A^B - EU_N^B > 0$, where

$$\Psi = (1-\alpha)S_0 + \Delta S^R \left\{ \alpha[1-(1-q)^n] + \frac{1-\alpha}{1+\lambda^B}[1-(1-q)^n - nq(1-q)^{n-1}] \right\} - \alpha q \Delta S^*. \tag{15}$$

This comparison yields our main result.

Proposition 6 (price-only auction vs. negotiations). The buyer strictly prefers a price-only auction to bilateral negotiations:

(a) if the renegotiation costs are small (λ^B, λ^C close to zero), and/or
(b) if she has little bargaining power (α close to 0).

The buyer strictly prefers bilateral negotiations to a price-only auction:

(c) if renegotiation is highly inefficient (λ^B, λ^C large) while ΔS^* is sufficiently large, and/or
(d) if her bargaining position is very strong (α close to 1) and the probability with which sellers are aware of design improvements is large (q close to 1).

Moreover, the payoff advantage Ψ of running a price-only auction is increasing in the number of potential sellers n.

The advantage of bilateral negotiations is that they lead to early information revelation. How important early information revelation is depends on the inefficiencies of renegotiation. If renegotiation is efficient, running a price-only auction with at least two competing sellers always outperforms negotiating with one seller. If renegotiation is plagued by high inefficiencies, then bilateral negotiations outperform auctions even if there are many competing sellers in the auction. One advantage of running an auction is that it leads to a strong bargaining position of the buyer *ex ante*; that is, the buyer can exploit the competition between sellers to get a larger share of the *ex ante* surplus. Therefore, if the buyer's bargaining position is weak in bilateral negotiations, an auction is more likely to be superior. A second advantage of running an auction is that it increases the probability with which design improvements are implemented *ex post*. If there are sellers who know the set of superior designs, the auction selects one of these sellers as the contractor with probability one. The more sellers there are, the more likely it is that at least one of them is aware of the potential design improvements. Furthermore, the more sellers there are, the more likely it is that at least two sellers know y^*, in which case no information rent has to be paid to the contractor. Thus, the payoff advantage of running an auction is increasing in the number of sellers.

Proposition 6(c) also shows that negotiations are more likely to be optimal if the project is more complex. The more complex a project is, the more scope there is for potential design improvements, that is, the larger is ΔS^*. Furthermore, the more complex a projects is, the higher are the adjustment costs, that is, the parameters λ^B and λ^C are higher. This implies that, even though ΔS^* is high, the surplus from contract renegotiation, ΔS^R, is likely to be relatively low.

A buyer who has to decide whether to use a price-only auction or to negotiate does not know the possible design improvement. Nevertheless, a sophisticated buyer is aware that she is unaware and knows that the sellers might know project specifications that are more efficient than y_0. Proposition 6 assumes that the buyer knows the additional surplus that can be achieved by implementing a superior specification, either directly or indirectly via renegotiation. In the real world, the buyer has to form expectations about these values. An experienced buyer may have a rough idea of the likelihood and the value of possible project improvements from previous procurement situations.[25]

□ Extensions and robustness.

Heterogeneous information. Suppose sellers are not equally likely to discover the design improvement. For the sake of the argument, consider the extreme case where only seller 1 is aware of y^* with probability $q \in (0, 1)$, while all the other sellers are less experienced and are not aware of y^* with certainty, and suppose that the buyer knows this. Thus, if the buyer decides to negotiate with one seller, she will select seller 1 as the contractor. In this case, the payoff advantage Ψ of running an auction is reduced and negotiations outperform a price-only auction if and only if[26]:

$$q > \frac{1-\alpha}{\alpha} \frac{S_0}{\Delta S^* - \Delta S^R} > 0. \tag{16}$$

In other words, if sellers differ in their expertise and if this is known to the buyer, bilateral negotiations are "more likely" to be optimal. Companies often have a good idea which seller has the most expertise in providing the required product and thus is most likely to come up with an improved design.

Correlated success probabilities. So far, we assumed that the probability with which a seller finds the superior design is independent of the probabilities with which the other sellers do so, that is, the success probabilities are uncorrelated. Although correlation does not affect the performance of bilateral negotiation, it does affect the performance of the price-only auction. The more strongly success probabilities are correlated, the smaller is the probability that at least one seller finds the design improvement. This effect makes an auction less attractive. On the other hand, the more success probabilities are correlated, the smaller is the probability that exactly one seller finds the design improvement. If exactly one seller is aware of the superior design, this seller receives a rent in the auction. Thus, a reduction of the probability that exactly one seller is successful makes the auction more attractive. Which of the two effects dominates depends on the buyer's bargaining power and the efficiency loss if the price is increased. If α and λ^B are large, the successful seller does not get a high rent if he is the only one who is successful. In this case, the first effect outweighs the second and thus, the auction becomes less attractive as correlation increases. This is stated formally in the following proposition for the case of two sellers.

Proposition 7 (correlated probabilities). Let $n = 2$. The payoff advantage of running an auction Ψ is decreasing in the coefficient of correlation if and only if $(1-\alpha)/\alpha \leq 1 + \lambda^B$.

6. Incentives for finding project improvements

■ So far, we took the information structure as exogenously given. Different mechanisms may provide different incentives to sellers to investigate possible design improvements, however. In order to analyze these incentives, we augment stage 0 of the baseline model by an investment game. At stage 0, each seller can invest into finding a more efficient design than y_0. If a seller invests $q \geq 0$ at cost $k(q)$, he finds with probability q the superior design y^*. The investment cost function satisfies:

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[25] It is straightforward to model this in a stochastic fashion. Suppose that the superior design y^* is drawn stochastically out of a set Y, and so are the gains from implementing design improvements *ex ante* (ΔS^*), as well as the gains from implementing them *ex post* (ΔS^R). If the buyer forms unbiased expectations about ΔS^* and ΔS^R, then all our results regarding the optimal procurement mechanism still hold.

[26] In this case, $EU_N^B = \alpha S_0 + \alpha q \Delta S^*$ whereas $EU_A^B = (1-q)S_0 + q(S_0 + \alpha \Delta S^R) = S_0 + \alpha q \Delta S^R$. Note EU_N^B is the same as in (14) whereas EU_A^B is smaller than (13). Comparing EU_N^B and EU_A^B yields condition (16).

Assumption 2. The investment cost function, $k(q)$, is strictly increasing, convex, and satisfies the Inada conditions, that is,

(i) $k(0) = 0$, and for all $q > 0$: $k'(q) > 0$ and $k''(q) > 0$;
(ii) $\lim_{q \to 0} k'(q) = 0$, and $\lim_{q \to 1} k(q) = \infty$.

In order to obtain a closed-form solution and unambiguous comparative static results, we will sometimes impose the assumption of a quadratic cost function, that is, $k(q) = \frac{\kappa}{2} q^2$ with $\kappa > (1 - \alpha)\Delta S^*$.[27] In this section, we presume that a scoring auction cannot be used and thus focus on the comparison of bilateral negotiations and price-only auctions.

The outcome of renegotiation and the sellers' incentives for information disclosure are unaffected by how the probabilities are determined at stage 0. Thus, we can directly start investigating sellers' investment incentives under the two procurement mechanisms.

□ **Incentives for finding project improvements.**

Negotiation. Suppose that the buyer decided to negotiate with one seller. In this case, the contractor will reveal a design improvement before the contract is signed, and his expected utility is given by

$$EU_N^C = (1 - \alpha)S_0 + q(1 - \alpha)\Delta S^* - k(q). \tag{17}$$

The contractor's optimal investment under negotiation, q^N, is characterized by the first-order condition

$$k'(q^N) = (1 - \alpha)\Delta S^*. \tag{18}$$

The probability of finding a project improvement is increasing in the bargaining power of the contractor $(1 - \alpha)$ and in the surplus generated by his investment (ΔS^*).

Auction. If the buyer runs a price-only auction, a seller can make a positive profit only if he is the only seller who found a design improvement. In this case, he wins the auction at $\bar{p} = c_0$. After the contract is signed, he reveals the design improvement and renegotiates. Thus, a seller's expected profit is given by

$$EU_A^i = q_i \prod_{j \neq i} (1 - q_j) \frac{1 - \alpha}{1 + \lambda^B} \Delta S^R - k(q),$$

for given investments of all sellers $j \neq i$. In the symmetric equilibrium, all sellers choose the same success probability q^A, which is implicitly characterized by

$$k'(q^A) = (1 - q^A)^{n-1} \frac{1 - \alpha}{1 + \lambda^B} \Delta S^R. \tag{19}$$

As in the case of negotiations, the probability of success is increasing in the bargaining power of the seller and in the value generated by the investment. However, now there is an additional effect. An increase of the adjustment costs λ^B and λ^C reduces the renegotiation surplus ΔS^R and the payoff going to the contractor, which reduces each seller's incentives to invest.

□ **Comparison of price-only auction with bilateral negotiation.** A seller who negotiates with the buyer and who is successful in finding a project improvement gets $(1 - \alpha)$ of the surplus generated by the efficient design. A seller who participates in an auction and is successful in finding a superior design obtains at most $(1 - \alpha)$ of the renegotiation surplus, which is smaller than ΔS^*. Moreover, the supplier benefits from his investment only if he wins the auction. Comparing (18) and (19) yields:

[27] With a quadratic cost function, $\kappa > (1 - \alpha)\Delta S^*$ ensures that in equilibrium, the probability of finding a project improvement is smaller than 1.

Proposition 8. The success probability of a seller with whom the buyer negotiates is always higher than the success probability of a seller who participates in an auction, no matter how many potential sellers there are, that is, for all $n \geq 2$,

$$q^N > q^A. \tag{20}$$

Proposition 8 shows that there is a second trade-off. The auction reduces the price that the buyer has to pay as compared to negotiations, but it also reduces the incentives of each seller to invest into finding project improvements.

The buyer is not interested in the investment incentives of each individual seller, but rather in the aggregate probability of implementing a design improvement *ex post*. With negotiation, the contractor's individual investment, q^N, is also the probability with which the design improvement is implemented *ex post*, but this is not the case for the auction. Let $Q^A \equiv 1 - (1 - q^A)^n$ denote the probability that at least one seller finds y^*. Because an auction always selects a seller who found a design improvement (if such a seller exists), Q^A is also the probability that the design improvement is implemented *ex post* if the buyer runs an auction.

Proposition 9 (probability of implementing design improvement). The probability of implementing the design improvement:

(i) is larger with negotiations than with an auction, that is, $q^N > Q^A$, if λ^B and/or λ^C are sufficiently large,
(ii) is smaller with negotiations than with an auction, that is, $q^N < Q^A \ \forall\, n \geq 2$, if $\lambda^B = \lambda^C = 0$ and $k(q) = \frac{\kappa}{2}q^2$ with $\kappa > \frac{(1-\alpha)(1+\sqrt{5})}{2}\Delta S^*$.

The proposition shows that there are parameter values such that the probability of implementing the design improvement is larger if the buyer chooses to negotiate. This is easiest to see for the case where $(1-\alpha)\Delta S^*$ is large but renegotiation costs are very high, so that ΔS^R is close to 0. In this case, if the buyer runs an auction, sellers have almost no incentives to investigate design improvements. However, if the buyer chooses to negotiate the procurement contract, the contractor has a strong incentive to invest because he gets $(1-\alpha)\Delta S^*$ if he is successful. On the other hand, if renegotiation is highly efficient, the probability of implementing design improvements tends to be larger with an auction.

Now we can compare the overall performance of the two mechanisms. If the buyer negotiates with one seller, her expected payoff is

$$EU_N^B = \alpha S_0 + q^N \alpha \Delta S^*. \tag{21}$$

If, on the other hand, the buyer runs a price-only auction, her expected payoff is given by

$$EU_A^B = S_0 + \alpha Q^A \Delta S^R + \frac{1-\alpha}{1+\lambda^B}\left[Q^A - nq^A(1-q^A)^{n-1}\right]\Delta S^R. \tag{22}$$

The following proposition follows immediately from comparing (21) and (22) and shows that the main result from our baseline model, Proposition 6, carries over to the situation with endogenous investments.

Proposition 10 (price-only auction vs. bilateral negotiation). The buyer strictly prefers a price-only auction to bilateral negotiation:

(a) if the renegotiation cost is small (λ^B, λ^C close to 0) and if the probability that at least one seller will find the design improvement is larger with an auction than with renegotiation, and/or
(b) if she has little bargaining power (α close to 0).

The buyer strictly prefers bilateral negotiation to a price-only auction:

(c) if renegotiation is very inefficient (λ^B, λ^C large) while ΔS^* is sufficiently large, and/or
(d) her bargaining power is very strong (α is close to 1) and sellers' cost function is not too convex ($k''(0)$ close to zero).

Auctions outperform negotiations if renegotiation is relatively efficient. In this case, the fact that sellers will not reveal possible design improvements early if the buyer runs an auction is not too costly for the buyer. Furthermore, even though each seller participating in the auction has a smaller incentive to investigate possible design improvements than the one seller with whom the buyer negotiates, the probability that at least one seller will find the design improvement can be larger with an auction than with negotiations (by Proposition 9). Hence, in this case, running an auction yields a strictly higher payoff for the buyer. The buyer also prefers the auction if her bargaining position is weak. The auction makes sure that she gets at least $S_0 > 0$ no matter how small α, whereas her payoff from negotiation (and renegotiation) goes to zero if α goes to zero.

On the other hand, if renegotiation is very inefficient, sellers have almost no incentives to investigate design improvements if there is an auction. In this case, the buyer's payoff from the auction is approximately given by S_0, whereas she would get $\alpha S_0 + \alpha q^N \Delta S^*$ if she negotiates. Thus, if the potential for a design improvement (ΔS^*) is sufficiently large, the buyer prefers to negotiate.

Finally, if the buyer has all the bargaining power, no seller is going to invest into finding design improvements. In this case, there is no difference between the two procurement mechanisms. However, if, starting at $\alpha = 1$, the bargaining power of the buyer is reduced, then the investment incentive of the seller with whom the buyer negotiates is differently effected than the incentives of sellers in the auction. In particular, if the cost function is not too convex and α is close to 1, negotiation is accompanied with higher investment incentives than the auction. More precisely, the reduction in α has a strictly positive first-order effect on the buyer's payoff if she negotiates with one seller, whereas the first-order effect is zero if she runs an auction.

7. Competitive dialogue

■ The importance of early information exchange in the procurement of complex goods has been explicitly acknowledged by the European Commission. In 2004, the European Commission introduced a new procurement mechanism called "Competitive Dialogue" in order to better align the interests of the buyer with possible solutions that the sellers have to offer (Hebly and Lorenzo van Rooij, 2006). This new procedure is "meant for the procurement of complex projects, of which technical, legal and/or financial solutions are not objectively specifiable by the contracting authority" (Hoezen, Voordijk, and Dewulf, 2012).

The Competitive Dialogue can be described as a two-stage procedure. At the first stage, the buyer engages in bilateral communication about the project with potential suppliers. The parties may discuss shortcomings and possible improvements of the provisionally preferred solution proposed by the buyer—y_0 in our model. The buyer may also use the information provided by potential contractors to refine her evaluation of certain nonprice criteria, and to evaluate the qualifications of the sellers. At the second stage, the buyer defines objective criteria that will be used to determine the successful contractor and collects tenders. She may, under certain conditions, restrict the set of possible suppliers to those who are most qualified to complete the project.

The Competitive Dialogue gives some discretion to the buyer. In many cases, buyers simply invite sellers to make suggestions for project improvements and then compile these suggestions into an improved design (Haugbølle, Pihl, and Gottlieb, 2015). Thereafter, the contractor is determined by an auction that is either exclusively based on price, or on price and a few simple measures of quality (such as time of completion of the project). This procedure is close to the price-only auction with precontract communication analyzed in Section 4. Given our results, it seems unlikely that this procedure enhances early contractor involvement in the design of the project. In fact, Hoezen and Doree (2008) report "that the competitive dialogue is an ambivalent procedure: both parties involved in the procedure balance between the wish to cooperate and the sensed need of keeping information to themselves because of competition."

However, some buyers implemented the Competitive Dialogue differently (Haugbølle, Pihl, and Gottlieb, 2015). They used the dialogue stage to communicate with the sellers not so much about ideas for possible project improvements but rather about which nonprice criteria are important, how these criteria should be measured, and how they should be weighted in the auction. This allows the buyer to specify a scoring function without requiring sellers to give away all their private information before the buyer committed to a compensation mechanism. This way, the Competitive Dialogue may lead to a situation that is closer to the scoring auction we discussed as a benchmark than to a price-only auction. In this case, potential contractors are more likely to reveal their ideas in the procurement process.[28]

8. Conclusions

■ In this article, we analyzed the performances of different procurement mechanisms for complex goods. We focused on two aspects of the procurement problem: (i) Sellers often have superior information about the optimal design, and (ii) the inefficiencies of contract renegotiation. In such an environment, the buyer wants to use a mechanism that induces early information exchange in order to avoid costly renegotiation. At the same time, she wants to use a competitive process in order to keep the price as low as possible. If the buyer can specify all relevant design characteristics in a complete contingent scoring rule, an optimal scoring auction induces sellers to propose the optimal design early and to minimize information rents.

However, for the procurement of complex goods, scoring auctions cannot always be used. In many cases, the buyer lacks prior information about potential design improvements and is unable to specify a proper scoring function. In these cases, the two most commonly observed procurement mechanisms are price-only auctions and negotiations with a single seller. Our analysis highlights two important benefits of using bilateral negotiations. First, negotiations give an incentive to the seller to reveal possible design improvements early. In contrast, in a price-only auction, all bidders prefer not to reveal this information before the contract is signed. Thus, a contract that was allocated by an auction is more likely to be renegotiated, which is often very costly. Second, bilateral negotiations give stronger incentives to investigate potential design improvements. A price-only auction diminishes the return of this investment because the surplus of a design improvement is reduced in the inefficient renegotiation process. Furthermore, each seller has a diminished incentive to invest because he benefits from his investment only if he is the only seller finding the improvement. On the other hand, because there are several sellers participating in the auction, there is also a sampling effect which may increase the probability that at least one seller finds the project improvement. On balance, if renegotiation is very costly, then it is likely that negotiations will implement project improvements with a higher probability. These arguments may explain why negotiations are so often used to allocate private procurement contracts.

To keep the analysis simple, our model abstracts from many real-world complications that affect the trade-off between auctions and negotiations. We assumed that all sellers have the same cost function and that uninformed sellers can produce superior designs exactly at the same costs as informed sellers. A well-known result is that an auction selects the seller with the lowest cost. Thus, if heterogeneity in costs are large, then a price-only auction is likely to outperform negotiations. Moreover, if uninformed sellers cannot produce the superior designs at the same costs as informed suppliers, this softens the incentives of informed sellers to withhold their information prior to

[28] See Uttam and Roos (2015) for an interesting case study where the Competitive Dialogue procedure did create several innovative proposals.

the auction. We also ignored the possibility of favoritism and collusion. It is often argued that an important benefit of auctions is that they make favoritism and collusion more difficult. In fact, this is the reason why there are legal rules in many countries that require competitive tendering in public procurement. However, in a recent article, Gretschko and Wambach (2016) show that an auction may be more prone to favoritism than negotiations.[29]

It would be very interesting to analyze second-best procurement mechanisms if some but not all characteristics of possible design improvements can be specified in a scoring function, and how these auctions compare to multistage mechanisms that combine an innovation contest, in which a fixed prize is given for the best design proposal (as in architectural competitions) with a subsequent price-only auction.[30] These are important and fascinating topics for future research, but they are beyond the scope of this article.

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[29] In Gretschko and Wambach (2016), the buyer has to delegate the procurement process to an agent, who may bias the auction rules or the negotiation outcome in order to favor his most preferred seller. The authors show that biasing the auction rules may be more harmful than biasing the negotiation outcome.

[30] See Che and Gale (2003) and Scotchmer (2005) for many examples of such contests and an analysis of their optimal characteristics.

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Appendix A

□ **This Appendix contains the detailed proofs of Propositions 1–10.** *Proof of Proposition 1.* Under Assumption 1, it is always optimal for the parties to adjust the design from y_0 to y^*. The renegotiation price p^R maximizes the generalized Nash product, that is, it solves (6), and thus is given by (see also Herweg and Schmidt, 2015)

$$p^R = \bar{p} + \frac{1-\alpha}{1+\lambda^B}\left[v(y^*) - v_0\right] + \alpha(1+\lambda^C)\left[c(y^*) - c_0\right].$$

This price gives rise to the expected payoffs (8) and (9). Note that the payoffs can be rewritten as

$$U^B = v_0 - \bar{p} + \alpha \Delta S^R > v_0 - \bar{p} \tag{A1}$$

$$U^C = \bar{p} - c_0 + \frac{1-\alpha}{1+\lambda^B}\Delta S^R > \bar{p} - c_0. \tag{A2}$$

Thus, both parties get a payoff that is higher than their payoffs if they stick to $(y_0, \bar{p})$. □

Proof of Proposition 2. By standard arguments used for second-price auctions, an optimal bid in a second-score auction maximizes the score subject to the bidder's break-even constraint. By offering a lower score, a seller reduces his probability of winning without affecting the contract in case of a win. Offering a higher score increases the probability of winning. Now, in the additional cases where this seller wins, he has to match a score that does not allow him to break-even. Finally, note that the solution to the score maximization problem is independent of the behavior of the competing sellers. Thus, this bidding strategy is a (weakly) dominant strategy.

An uninformed seller can propose only design y_0 and thus bids $(y, p) = (y_0, c_0)$. An informed bidder can decide whether to bid y^* or y_0. If he proposes y^* and wins, the initial contract specifies design y^* because it is optimal to match the second highest score by sticking to the design bid and adjusting the price. In this case, there is no scope for renegotiation and thus, the optimal price bid is $p = c^*$. If an informed bidder bids y_0 and wins, then there is scope for renegotiation. Thus, the price bid that allows the seller to break-even should the bid be finalized as contract is $p = c_0 - \frac{1-\alpha}{1+\lambda^B}\Delta S^R$. By construction of the scoring function, both bids yield the same score, $G(y^*, c^*) = S_0 + \frac{1-\alpha}{1+\lambda^B}\Delta S^R = G(y_0, c_0 - \frac{1-\alpha}{1+\lambda^B}\Delta S^R)$, and the same payoff to a successful bidder. Thus, it is a Bayesian Nash equilibrium that all informed sellers bid $(y, p) = (y^*, c^*)$. When the score for bidding design y^* is increased by ϵ, with $\epsilon > 0$ but close to zero, then there is a unique (weakly) dominant bidding strategy: $(y, p) = (y^*, c^*)$.

In order to derive the buyer's expected payoff, three cases have to be considered. First, if no seller is informed, the buyer obtains the surplus generated by design y_0. This happens with probability $(1-q)^n$. If two or more sellers are informed, the successful bidder has to produce y^* at price $p = c^*$ and does not get a rent. Thus, the buyer obtains the full surplus generated by design y^*. If exactly one seller is informed, this seller obtains a rent of $\frac{1-\alpha}{1+\lambda^B}\Delta S^R$. This case happens with probability $nq(1-q)^{n-1}$. Hence,

$$EU_B^{SA} = (1-q)^n S_0 + [1-(1-q)^n - nq(1-q)^{n-1}](S_0 + \Delta S^*) + nq(1-q)^{n-1}\left[S_0 + \Delta S^* - \frac{1-\alpha}{1+\lambda^B}\Delta S^R\right], \tag{A3}$$

which can be simplified to the expression provided in the proposition.

The scoring rule (11) is optimal for the buyer among all quasilinear scoring rules satisfying (i) and (ii) because it minimizes the rents left to sellers. Note that the winner obtains a rent only if he is the only one who learned y^*. The rent the winner obtains in this case is the lowest feasible rent, so that the seller prefers to offer y^* instead of y_0. □

Proof of Proposition 3. If one of the sellers informs the buyer about y^*, the buyer will run the auction on project y^* and each seller makes a profit of 0. In this case, the buyer's payoff is $U_B = S_0 + \Delta S^*$ and thus, auctioning off design y^* is optimal.

If no seller informs the buyer about y^*, the buyer will auction off project y_0. Suppose that in this case, seller i wins the auction and knows about the possible project improvement. He will then renegotiate at stage 2, and his payoff in the auction (A) after renegotiation (R) is

$$U^C(AR) = \bar{p} - c_0 + \frac{1-\alpha}{1+\lambda^B}\left[(v^* - v_0) - (1+\lambda^B)(1+\lambda^C)(c^* - c_0)\right]. \tag{A4}$$

Thus, in the (reduced-form game of the) second-price auction, it is a (weakly) dominant strategy for seller i to bid

$$b_i = c_0 - \frac{1-\alpha}{1+\lambda^B}\left[(v^* - v_0) - (1+\lambda^B)(1+\lambda^C)(c^* - c_0)\right]. \tag{A5}$$

If there are two or more sellers who found the project improvement, one of them wins the auction and all sellers make an expected profit of zero. Similarly, if no seller found the project improvement, all sellers will bid $b_i = c_0$ and make an expected profit of zero. However, if seller i is the only seller who found the project improvement, then he wins the auction at price $\bar{p} = c_0$. In this case, his profit is

$$U^C(AR) = \frac{1-\alpha}{1+\lambda^B}\left[(v^* - v_0) - (1+\lambda^B)(1+\lambda^C)(c^* - c_0)\right] > 0. \tag{A6}$$

Hence, it is optimal for all sellers who found the project improvement not to reveal this information before the auction takes place. □

Proof of Proposition 4. If the seller reveals y^* to the buyer, the parties solve

$$\max_{y \in \{y_0, y^*\}, p} [v(y) - p]^\alpha \cdot [p - c(y)]^{1-\alpha}. \tag{A7}$$

The solution to this problem is $y^* = \arg\max\{v(y) - c(y)\}$ and $p^* = c(y^*) + (1-\alpha)(v^* - c^*)$, so the seller's payoff in the negotiation game (N) if he knows y^* and informs (I) the buyer immediately is

$$U^C(NI) = (1-\alpha)(v^* - c^*). \tag{A8}$$

If the seller does not inform the buyer about possible project improvements (either because he did not find them or because he chose not to reveal y^* to the buyer), then the GNBS implies that the parties will agree to trade project y_0 at price $\bar{p} = c_0 + (1-\alpha)(v_0 - c_0)$.[31] However, if the seller did find y^*, he will reveal it at stage 2 and renegotiate (R). In this case, the parties renegotiate to the contract characterized by Proposition 1, and the seller's payoff is

$$U^C(NR) = \bar{p} - c_0 + \frac{1-\alpha}{1+\lambda^B}\left[(v^* - v_0) - (1+\lambda^B)(1+\lambda^C)(c^* - c_0)\right] \tag{A9}$$

$$= (1-\alpha)\left\{v_0 - c_0 + \frac{v^* - v_0}{1+\lambda^B} - (1+\lambda^C)(c^* - c_0)\right\}. \tag{A10}$$

The seller's utility if he renegotiates is smaller than his utility if he informs the buyer before the contract is signed if and only if $U^C(NI) > U^C(NR)$, which is equivalent to

$$v^* - c^* > v_0 - c_0 + \frac{v^* - v_0}{1+\lambda^B} - (1+\lambda^C)(c^* - c_0) \tag{A11}$$

[31] Strictly speaking, if the seller knows y^* but does not inform the buyer about it, initial negotiation takes place with asymmetric information. The GNBS is a concept for bargaining under symmetric information. The seller does not reveal his information, thus, both parties behave as if they agree that trading specification y_0 is optimal. This is exactly what is characterized by the GNBS in this case. In Appendix B, we show that the identical result can be obtained for a bargaining game where the asymmetric information is taken explicitly into account.

$$\iff (v^* - v_0)\frac{\lambda^B}{1+\lambda^B} + \lambda^C(c^* - c_0) > 0. \tag{A12}$$

The above inequality is always satisfied because $v^* > v_0$ and $c^* > c_0$. □

Proof of Proposition 5. First, we show that the scoring auction is better than the price-only auction. It holds that

$$EU_A^B \le S_0 + \Delta S^R[1-(1-q)^n] - \Delta S^R\frac{1-\alpha}{1+\lambda^B}nq(1-q)^{n-1}. \tag{A13}$$

Thus, $EU_A^B \le EU_{SA}^B$ because $\Delta S^R \le \Delta S^*$. The inequality is strict if $\Delta S^R < \Delta S^*$.

The buyer's expected utility from running a scoring auction can be bounded from below:

$$EU_{SA}^B \ge S_0 + \alpha\Delta S^*[1-(1-q)^n] + (1-\alpha)[1-(1-q)^n - nq(1-q)^{n-1}]\Delta S^R. \tag{A14}$$

By noting that $1-(1-q)^n - nq(1-q)^{n-1} > 0$ and $1-(1-q)^n > q$, we can immediately conclude that $EU_{SA}^B \ge EU_N^B$. Again, the inequality is strict for $\Delta S^R < \Delta S^*$. □

Proof of Proposition 6. The buyer strictly prefers to run an auction if and only if $\Psi = EU_A^B - EU_N^B > 0$, where

$$\Psi = (1-\alpha)S_0 + \Delta S^R\left\{\alpha[1-(1-q)^n] + \frac{1-\alpha}{1+\lambda^B}[1-(1-q)^n - nq(1-q)^{n-1}]\right\} - \alpha q\Delta S^*. \tag{A15}$$

(a) If renegotiation costs are small, that is, $\lambda^B \to 0$ and $\lambda^C \to 0$, then $\Delta S^R \to \Delta S^*$. Hence, we have

$$\Psi = (1-\alpha)S_0 + \Delta S^*\left\{\alpha(1-q)\left[1-(1-q)^{n-1}\right] + (1-\alpha)\left[1-(1-q)^n - nq(1-q)^{n-1}\right]\right\} > 0. \tag{A16}$$

(b) For $\alpha \to 0$, we have

$$\Psi = S_0 + \Delta S^R\left\{\frac{1}{1+\lambda^B}[1-(1-q)^n - nq(1-q)^{n-1}]\right\} > 0. \tag{A17}$$

(c) If renegotiation costs are very large, $\Delta S^R \approx 0$. In this case, we have

$$\Psi = (1-\alpha)S_0 - q\alpha\Delta S^*, \tag{A18}$$

which is negative for ΔS^* sufficiently large.

(d) For $\alpha \to 1$, we have

$$\Psi = \Delta S^R[1-(1-q)^n] - q\Delta S^*, \tag{A19}$$

which is negative for q sufficiently close to 1.

To complete the proof, we show that $\partial\Psi/\partial n \ge 0$ (with strict inequality if $\Delta S^R > 0$). Taking the partial derivative of Ψ with respect to n yields

$$\frac{\partial\Psi}{\partial n} = \Delta S^R\left\{-\alpha\ln(1-q)(1-q)^n + \frac{1-\alpha}{1+\lambda^B}\left[-\ln(1-q)(1-q)^n - q(1-q)^{n-1} - nq(1-q)^{n-1}\ln(1-q)\right]\right\}. \tag{A20}$$

Rearranging the above expression leads to

$$\frac{\partial\Psi}{\partial n} = -\Delta S^R(1-q)^{n-1}\left\{\alpha\ln(1-q)(1-q) + \frac{1-\alpha}{1+\lambda^B}[\ln(1-q)(1-q) + q + nq\ln(1-q)]\right\}. \tag{A21}$$

Thus, $\partial\Psi/\partial n \ge 0$ if

$$\ln(1-q)(1-q) + q + nq\ln(1-q) \le 0. \tag{A22}$$

The above inequality is hardest to satisfy for $n = 2$ (lowest possible n) and thus, $\partial\Psi/\partial n \ge 0$ if

$$\Gamma(q) \equiv \ln(1-q)(1+q) + q \le 0. \tag{A23}$$

Noting that $\Gamma(q)$ is strictly decreasing and approaches 0 for $q \to 1$ completes the proof. □

Proof of Proposition 7. The information of supplier $i \in \{1, 2\}$ is denoted by $I_i \in \{0, 1\}$, where $I_i = 1$ means that supplier i is aware of y^* and $I_i = 0$ means that he is unaware. Let $\rho \in [0, 1]$ denote the Pearson correlation coefficient.[32] The correlated probabilities are displayed in the following probability table:

TABLE A1 Correlated Probability Table for $n = 2$

	$I_2 = 0$	$I_2 = 1$	$\sum$
$I_1 = 0$	$(1-q)[\rho + (1-\rho)(1-q)]$	$q(1-q)(1-\rho)$	$1-q$
$I_1 = 1$	$q(1-q)(1-\rho)$	$q[\rho + (1-\rho)q]$	q
$\sum$	$1-q$	q	1

For $\rho \to 0$, the success probabilities are uncorrelated, whereas for $\rho \to 1$, we have perfect correlation. The buyer's expected utility from negotiation is independent of the degree of correlation ρ. The buyer's expected utility from running an auction is

$$EU_A^B(\rho) = (1-q)[\rho + (1-\rho)(1-q)]S_0 + 2q(1-q)(1-\rho)\left[S_0 + \alpha\Delta S^R\right] + q[\rho + (1-\rho)q] \times \left[S_0 + \alpha\Delta S^R + \frac{1-\alpha}{1+\lambda^B}\Delta S^R\right].$$

Taking the partial derivative with respect to ρ yields:

$$\frac{\partial EU_A^B}{\partial \rho} = (1-q)q\left[\frac{1-\alpha}{1+\lambda^B} - \alpha\right]\Delta S^R, \tag{A24}$$

which completes the proof. □

Proof of Proposition 8. We show that q^N and q^A are indeed characterized by (18) and (19), respectively. Obviously, EU_N^C is strictly concave in q and thus, q^N is fully described by (18). It is also readily established that a seller's optimal response under an auction is characterized by the first-order condition. It remains to be shown that a symmetric pure-strategy equilibrium of the investment game always exists. Seller i's optimal investment q_i^* maximizes

$$q_i \Pi_{j\neq i}(1-q_j)\frac{(1-\alpha)\Delta S^R}{1+\lambda^B} - k(q). \tag{A25}$$

First, note that seller i never chooses $q_i = 1$, because $\lim_{q\to 1} k(q) = \infty$. This implies that $\Pi_{j\neq i}(1-q_j) =: X > 0$. With $X > 0$ and $k'(0) = 0$, it always pays off for a seller to invest a small amount, that is, $q_i > 0$, which implies that $X \in (0, 1)$. The reaction function of firm i is implicitly characterized by the first-order condition:

$$X\frac{(1-\alpha)\Delta S^R}{1+\lambda^B} = k'(q^R(X)). \tag{A26}$$

Implicit differentiation with respect to X yields

$$\frac{dq_i^R}{dX} = \frac{(1-\alpha)\Delta S^R}{k''(q_i)(1+\lambda^B)} > 0. \tag{A27}$$

Note that X is decreasing in q_j for all $j \neq i$, so that i invests less if its rivals invest more. In the limit, we have $\lim_{X\to 0} q_i^R(X) = 0$ and $\lim_{X\to 1} q_i^R(X) = \bar{q} > 0$, with $\frac{(1-\alpha)\Delta S^R}{1+\lambda^B} = k'(\bar{q})$. The reaction functions are all symmetric and continuously decreasing, and approach zero if $\Pi_{j\neq i}(1-q_j) \to 1$. Thus, a symmetric q^A exists at which all reaction functions intersect each other. □

Proof of Proposition 9.

(i) $q^N > Q^A(n)$ for all $n \geq 2$: By (10), we know that if λ^B and/or λ^C are sufficiently large, then $\Delta S^R \approx 0$. Furthermore, $q^A(n)$ is fully characterized by first-order condition (19), which requires

$$k'(q^A) = (1-q^A)^{n-1}\frac{1-\alpha}{1+\lambda^B}\Delta S^R.$$

$\Delta S^R \to 0$ implies $q^A \to 0$ for all $n \geq 2$, which implies $Q^A(n) \to 0$ for all $n \geq 2$. On the other hand, q^N, which is fully characterized by (18), is independent of λ^B and λ^C. Thus, if λ^B and/or λ^C are sufficiently large, then $Q^A(n) \approx 0 < q^N$ for all $n \geq 2$.

[32] $\rho = cov(I_1, I_2)/[\sigma(I_1)\sigma(I_2)]$, where $cov(\cdot)$ denotes the covariance and $\sigma(\cdot)$ the standard deviation.

(ii) $Q^A(n) > q^N$ for all $n \geq 2$: We know that if $\lambda^B = \lambda^C = 0$, then $\Delta S^R = \Delta S^*$. Suppose that $k(q) = \frac{\kappa}{2}q^2$. In this case, using equation (18), we obtain

$$q^N = \frac{1-\alpha}{\kappa}\Delta S^*.$$

Furthermore, by (19), we have for $n = 2$

$$\kappa q^A = (1-q^A)(1-\alpha)\Delta S^* \;\Leftrightarrow\; q^A = \frac{(1-\alpha)\Delta S^*}{\kappa + (1-\alpha)\Delta S^*},$$

which implies

$$Q^A(2) = 1-(1-q^A)^2 = q^A(2-q^A) = \frac{(1-\alpha)^2(\Delta S^*)^2 + 2(1-\alpha)\kappa\Delta S^*}{[\kappa + (1-\alpha)\Delta S^*]^2}.$$

Thus, $Q^A(2) > q^N$ if and only if

$$\frac{(1-\alpha)^2(\Delta S^*)^2 + 2(1-\alpha)\kappa\Delta S^*}{[k + (1-\alpha)\Delta S^*]^2} > \frac{1-\alpha}{\kappa}\Delta S^*.$$

The above inequality is satisfied if and only if

$$\kappa > \frac{(1-\alpha)(1+\sqrt{5})}{2}\Delta S^*.$$

It remains to be shown that $Q^A(n) > q^N$ for all $n \geq 2$. As will be shown below, it holds that $dQ^A/dn > 0$ iff $(1-q^A)k''(q^A) - k'(q^A) > 0$. Using the quadratic cost function and the fact that $dq^A/dn < 0$, this is the case if and only if

$$q^A(2) = \frac{(1-\alpha)\Delta S^*}{\kappa + (1-\alpha)\Delta S^*} < \frac{1}{2},$$

which is equivalent to $\kappa > (1-\alpha)\Delta S^*$. Note that $(1-\alpha)(1+\sqrt{5})\Delta S^*/2 > (1-\alpha)\Delta S^*$. Hence, if $\kappa > (1-\alpha)(1+\sqrt{5})\Delta S^*/2$, then $Q^A(n) > q^N$ for all $n \geq 2$.

Finally, we show that: $dQ^A/dn > 0$ iff $(1-q^A)k''(q^A) - k'(q^A) > 0$. Let $Q \equiv 1-(1-q^A(n))^n$. In the following, we often suppress the superscript A and the dependence of n, that is, we write q instead of $q^A(n)$. In the symmetric equilibrium, each seller's probability of finding the project improvements is given by

$$(1-q)^{n-1} = \frac{1+\lambda^B}{(1-\alpha)\Delta S^R}k'(q).$$

Thus, Q can be written as

$$Q = 1-(1-q)k'(q)\frac{1+\lambda^B}{(1-\alpha)\Delta S^R}.$$

Differentiating Q with respect to n yields

$$\frac{dQ}{dn} = \underbrace{-\frac{1+\lambda^B}{(1-\alpha)\Delta S^R}}_{<0}\underbrace{\frac{dq}{dn}}_{\leq 0}[(1-q)k''(q) - k'(q)].$$

Hence, $dQ/dn > 0$ if and only if the term in square brackets is positive. □

Proof of Proposition 10. Comparing (21) and (22), we have that $EU_A^B > EU_N^B$ if and only if

$$\Psi = \underbrace{(1-\alpha)S_0}_{>0} + \underbrace{\alpha[Q\Delta S^R - q^N\Delta S^*]}_{?} + \underbrace{\frac{1-\alpha}{1+\lambda^B}[Q - nq^A(1-q^A)^{n-1}]\Delta S^R}_{>0} > 0. \tag{A28}$$

(a) The first and the third term of this expression are clearly positive, so consider the second term. If $\lambda^B = \lambda^S = 0$, then $\Delta S^R = \Delta S^*$. Thus, $Q(n)\Delta S^R - q^N\Delta S^* = (Q(n) - q^N)\Delta S^*$. If $Q(n) > q^N$, this term is strictly positive and the auction outperforms negotiations. Only if the incentive effect of negotiations is very strong, that is, if $q^N > Q(n)$, is it possible that the sum of the three terms becomes negative.
(b) If α goes to zero, the second term goes to 0, whereas the first term goes to S_0. Thus, $\Psi > 0$.
(c) If λ^B and λ^S are sufficiently large so that $\Delta S^R \approx 0$, then the buyer prefers to negotiate if $(1-\alpha)S_0 < q^N\alpha\Delta S^*$. This is equivalent to $\Delta S^* > [(1-\alpha)/\alpha]\,(S_0/q^N)$.

(d) If $\alpha = 1$, then $q^N = q^A = 0$. Therefore, the buyer's payoff is $\bar{v} - \bar{c}$, no matter whether she negotiates or runs an auction. If α is reduced (starting from $\alpha = 1$), the effect on the buyer's payoff from running an auction is given by

$$\begin{aligned}\frac{\partial EU_A^B}{\partial \alpha} &= [1-(1-q^A)^n]\Delta S^R + \alpha n(1-q^A)^{n-1}\frac{dq^A}{d\alpha}\Delta S^R \\ &\quad - \frac{1}{1+\lambda^B}[1-(1-q^A)^n - nq^A(1-q^A)^{n-1}]\Delta S^R + \frac{1-\alpha}{1+\lambda^B} \\ &\quad \times \left\{ n(1-q^A)^{n-1}\frac{dq^A}{d\alpha} - n\left[\frac{dq^A}{d\alpha}(1-q^A)^{n-1} - (n-1)(1-q^A)^{n-2}\frac{dq^A}{d\alpha}\right]\right\}\Delta S^R. \end{aligned} \tag{A29}$$

By evaluating this term at $\alpha = 1$, we obtain that $q^A(1) = 0$ and $dq^A(1)/d\alpha = 0$, because $\ln(1 - q^A(1)) = \ln(1) = 0$. Therefore,

$$\left.\frac{\partial EU_A^B}{\partial \alpha}\right|_{\alpha=1} = 0. \tag{A30}$$

Thus, the first-order effect from reducing α at $\alpha = 1$ is zero. On the other hand, the effect on the buyer's payoff from negotiating is given by

$$\begin{aligned}\left.\frac{\partial EU_N^B}{\partial \alpha}\right|_{\alpha=1} &= \bar{S} + q^N(\alpha)\Delta S^* + \alpha\frac{\partial q^N}{\partial \alpha}\Delta S^* \\ &= \bar{S} + q^N(1)\Delta S^* + \alpha\frac{-\Delta S^*}{k''(q^N(1))}\Delta S^* \\ &= \bar{S} + 0\cdot\Delta S^* - \frac{(\Delta S^*)^2}{k''(0)}, \end{aligned} \tag{A31}$$

because $\lim_{\alpha\to 1} q^N(\alpha) = 0$. Thus, if $k''(0)$ is sufficiently close to zero, $\partial U_N^B/\partial\alpha\big|_{\alpha=1} < 0$. The buyer's payoff increases, but now the first-order effect of a reduction of α is strictly positive. Thus, for α close to 1, negotiations are better than auctions. □

Appendix B

□ **In this Appendix we analyze a noncooperative bargaining game.** In the article, we employ the GNBS in order to determine the outcome of initial negotiation as well as *ex post* renegotiation. Initially, negotiation takes place under asymmetric information if the contractor knows the superior project y^*, but has not informed the buyer about it at stage 1 of the game. The GNBS does not take this asymmetric information explicitly into account. In the following, we discuss an alternative bargaining game which takes the asymmetric information explicitly into account and show that it is isomorphic to the application of the GNBS.

Suppose the bargaining game at stage 1 and the renegotiation game at stage 2 proceed as follows: at the beginning of stage 1, nature determines the party that can make take-it-or-leave-it (TIOLI) offers throughout the game (at stage 1 and stage 2). The buyer can make the TIOLI offer with probability $\alpha \in (0, 1)$, and the contractor makes the TIOLI offer with the converse probability $1 - \alpha$.

With asymmetric information being only an issue with bilateral negotiations, we will focus on negotiation as procurement mechanism in the following. First, suppose the draw by nature determined that the contractor can make the offers. If the initial contract specifies y_0 at price $\bar{p}$ and the contractor is aware of y^*, there is scope for renegotiation at stage 2. When the contractor proposes the specification y^*, the highest price he can demand is

$$p^R = \bar{p} + \frac{v^* - v_0}{1+\lambda^B}. \tag{B1}$$

The contractor's utility from this offer is

$$\begin{aligned} U^C &= p^R - c^* - \lambda^C[c^* - c_0] \\ &= \bar{p} + \lambda^C c_0 + \frac{1}{1+\lambda^B}\left[v^* - v_0 - (1+\lambda^C)(1+\lambda^B)c^*\right]. \end{aligned} \tag{B2}$$

If the contractor has not revealed y^* at the beginning of date 1, the optimal offer at date 1 is specification y_0 and price $\bar{p} = v_0$. Thus, the contractor's utility amounts to

$$U^C = v_0 + \lambda^C c_0 + \frac{1}{1+\lambda^B}\left[v^* - v_0 - (1+\lambda^C)(1+\lambda^B)c^*\right]. \tag{B3}$$

If, on the other hand, the buyer can make the TIOLI offer, the contractor receives a zero utility. Thus, the contractor's expected utility from disclosing his private information at stage 1 is

$$EU^C(NR) = (1-\alpha)(v_0 - c_0) + \frac{1-\alpha}{1+\lambda^B}\left\{v^* - v_0 - (1+\lambda^C)(1+\lambda^B)\left[c^* - c_0\right]\right\}. \tag{B4}$$

Note that (B4) is equal to (A10).

Now, suppose the contractor revealed y^* at stage 1. If the contractor makes the TIOLI offer, he offers y^* at price $\bar{p} = v^*$. His payoff in this case is

$$U^C = v^* - c^*. \tag{B5}$$

If the buyer can make the offers, then $U^C = 0$. Thus, the contractor's expected utility from revealing his information at stage 1 is

$$EU^C(NI) = (1-\alpha)(v^* - c^*). \tag{B6}$$

Recall that (B6) is equal to (A8).

Under the alternative bargaining game, the contractor's expected payoffs from information disclosure and information revelation are exactly the same as those obtained by applying the GNBS. Thus, the contractor here has a strict incentive to reveal his private information at stage 1, that is, $EU^C(NI) > EU^C(NR)$.