Joint Bidding and Information Frictions*

Shanglyu Deng† Qiang Fu‡ Zenan Wu§

July 23, 2024

Abstract

Large-scale infrastructure projects often involve multiple component tasks and require a range of skills for execution. When procuring such projects, an auctioneer can either organize a combinatorial auction, allowing a firm to bid on the entire project or on individual components as independent entities, or require holistic proposals, whereby specialized firms form consortia to pool their expertise and bid jointly. This paper compares the performance of these two auction formats. In the absence of information frictions, a holistic procurement auction outperforms a combinatorial auction, achieving full allocative efficiency at lower procurement prices. However, information frictions can lead to non-assortative matching of firms or strategic behavior within consortia, causing the holistic procurement to underperform the combinatorial auction in terms of allocative efficiency and procurement price.

Keywords: Procurement Auctions; Complementarity; Joint Bidding; Information Frictions; VCG Auction.

JEL Classification Codes: D44, D82, H57.

---

*We thank seminar participants at University of Maryland and Shandong University for helpful discussions, suggestions, and comments. Deng thanks the Start-up Research Grant (SRG2023-00036-FSS) of the University of Macau and the 2024 seed grant from the Asia-Pacific Academy of Economics and Management (APAEM/SG/0002/2024) for financial support. Fu thanks the Singapore Ministry of Education Tier-1 Academic Research Fund (R-313-000-139-115) for financial support. Wu thanks the National Natural Science Foundation of China (Nos. 72222002 and 72173002), the Wu Jiapei Foundation of the China Information Economics Society (No. E21100383), and the Research Seed Fund of the School of Economics, Peking University, for financial support. Any remaining errors are our own. This paper takes material from Chapter 2 of Deng's dissertation, which benefited tremendously from Lawrence M. Ausubel's advice.

†Department of Economics, University of Macau, E21B Avenida da Universidade, Taipa, Macau, China, 999078. Email: sdeng@um.edu.mo.

‡Department of Strategy and Policy, National University of Singapore, 15 Kent Ridge Drive, Singapore, 119245. Email: bizfq@nus.edu.sg.

§School of Economics, Peking University, Beijing, China, 100871. Email: zenan@pku.edu.cn.

1 Introduction

Large-scale infrastructure projects, such as the construction of railways, bridges, expressways, and public utility facilities, require complex engineering solutions and multidisciplinary expertise. For instance, constructing an airport demands skills ranging from building terminals and runways to installing electrical and telecommunication networks. This compels contractors with complementary skills to form alliances or consortia, enabling them to pool their expertise and jointly bid for contracts. For example, the Grupo Unidos por el Canal consortium, composed of companies from Spain, Italy, and Belgium, was awarded the contract for the Panama Canal expansion due to their combined capabilities. Estache and Iimi (2008) study 221 public contracts for road, water and sewage, and electricity projects in 29 developing countries, finding that consortia account for about 25 to 30 percent of total bidders in procurement auctions for infrastructure projects.

Given the multifaceted nature of large projects, procurement agencies face critical decisions in designing auction rules. They may require holistic proposals that integrate all aspects of the project, as seen in the Dutch government's procurement for its offshore wind farm projects that accommodates only bidding entities that are capable of managing the project's full life cycle; the contract for one of the projects, Hollandse Kust Noord wind farm, was awarded to a joint venture formed by Shell and Eneco. The holistic approach would force specialized contractors to form consortia. Conversely, agencies might adopt a combinatorial auction format, allowing firms to bid on either the entire project, or individual components as independent entities without joining consortia.[1] This method can be exemplified by the Doha Metro project in Qatar, which permitted bids for specific tasks like tunneling, station construction, or rail systems. A similar strategy was also adopted by the I-595 Express Corridor Improvements Project that upgraded a major highway corridor in Florida, as well as the Sydney Light Rail Project.

These mixed observations raise important questions. For policymakers, which auction format could ensure allocative efficiency, i.e., awarding the contract to the most efficient firms? For procurement agencies, which auction format could generate lower procurement prices? This paper seeks to answer the above questions by comparing the performance of combinatorial auctions—which allow for specialized firms to bid on components—with holistic procurement auctions—which force joint bidding.

Joint bidding by competing firms has raised significant anti-competitive concerns and

[1] Combinatorial auctions, which allow bids for bundles or combinations of items, are helpful in addressing complementarity issues in various situations, such as the allocation of electromagnetic spectrum (see McMillan, 1994; Cramton, 2013; and Ausubel and Baranov, 2014; among many others) and airport time slots (Rassenti et al., 1982). See De Vries and Vohra (2003) for a survey.

triggered extensive regulatory oversight. In contrast, bidding consortia formed by *complementary* firms are viewed more favorably because such arrangement presumably facilitates collaboration.[2,3] However, our analysis suggests caution when it comes to joint bidding even by complementary firms. We demonstrate that the choice between combinatorial auctions and holistic procurement auctions crucially depends on the prevailing information environment.

We consider the procurement of a project that involves two component tasks, A and B.[4] While some firms are able to execute the entire project independently, the others specialize in either task A or task B. We refer to the former as type AB firms and the latter—i.e., those specialized in task $\alpha \in \{A, B\}$—as type α. If the auctioneer enforces a holistic approach, a type A firm must form a consortium with a type B partner to bid jointly.[5] The auctioneer may also organize a combinatorial auction, letting all firms submit independent bids, such that type AB firms bid on the entire project and type α firms bid on their respective specialized components; the auction mechanism decides whether to assign the entire project to a type AB firm or award component-specific contracts to specialized firms separately. We assume that the auctioneer values both allocative efficiency—which requires that the project be allocated to firms with the lowest completion costs—and procurement price. We then compare the performance of the two auction formats in these regards.

Our study highlights the vital role of information frictions in choosing the proper approach to procuring projects with multiple components. With holistic procurement, information frictions could emerge when specialized firms bid jointly. First, information friction could arise in the matching process when multiple type A firms and type B firms form consortia: Without knowing the private costs of potential partners, firms with lower costs may team up with complementary firms with high costs, causing inefficient matching outcome and inflating the procurement price. Second, information friction can also arise between matched firms: The firms within a consortium may not know each other's private cost; they thus behave *strategically* instead of seeking to maximize joint profit, which could also cause inefficiency

[2] In fact, while the Energy Policy and Conservation Act enacted in 1975 and the Outer Continental Shelf Lands Act Amendment of 1978 ban joint bidding by major oil companies for outer continental shelf (OCS) leases, the authority reserves the right to allow joint bidding by said companies on lands that have extremely high-cost exploration or development problems and on lands where exploration and development will not occur unless exemptions are granted (Millsaps and Ott, 1981).

[3] In 2018, the Italian Competition Authority (ICA) cleared the joint bidding agreement for the contract manufacturing of plasma therapeutic products derived from blood donations between Grifols and Kedrion on the ground that the two barely compete with each other in the relevant market.

[4] Our results remain qualitatively robust if multiple tasks are involved.

[5] We prioritize allocative efficiency as an outcome measure of the procurement and thus assume second-price auctions when joint bidding is allowed, as first-price auctions are known to be inefficient with asymmetric bidders (which is the relevant case for our analysis).

and elevate the procurement price.

We begin with a base case that assumes away information friction. As a result, firms are assortatively matched; those within each consortium share their cost information, so they place joint bid to maximize total profit. In this case, the holistic procurement auction delivers superior performance over the combinatorial auction: The former approach achieves full allocative efficiency at a lower expected procurement price (Proposition 1).

However, information friction complicates the comparison. We consider two cases, each of which depicts one type of information friction mentioned above. The first examines the role played by the information friction entailed by the matching process—such that type A and type B firms are matched randomly—while assuming that cost information is shared within each consortium. In this case, joint bidding undermines allocative efficiency. Further, the auctioneer may also suffer a higher procurement price on average: When the numbers of specialized firms are sufficiently large, the combinatorial auction outperforms holistic procurement auction in terms of the expected procurement price (Proposition 2).

We then move on to explore the case of information friction within consortia. To isolate its role, we abstract away the friction embedded in the matching process and focus on a setting with only one type A firm, one type B firm, and one type AB firm, which corresponds to the "local-local-global (LLG)" model in the auction literature (see, e.g., Krishna and Rosenthal, 1996; Ausubel and Baranov, 2020).[6] In this case, the type A and the type B firms in the consortium do not share cost information, while acting strategically to maximize their own profits. The scenario is equivalent to a case of subcontracting, with one firm being the prime contractor and the other the subcontractor. The former proposes a mechanism to elicit private information from the latter and offers a transfer payment. The usual *double marginalization* problem arises because the parties within the consortium maximize their own profits sequentially (Proposition 3). As a result, the holistic procurement auction causes inefficiency and could lead to higher procurement prices than the combinatorial auction (Proposition 4) due to firms' strategic behavior under information friction.

Our results not only provide theoretical insights but also generate useful implications for policy and practice. We discuss them in the Concluding Remarks.

Relation to Literature This paper is primarily related to the literature on joint bidding. The previous literature has conventionally examined joint bidding by firms that are able to finish the entire project on their own and would otherwise compete against each other. These studies thus highlight the anti-competitive effects of joint bidding. In contrast, a burgeoning literature examines scenarios in which joint bidding could catalyze synergy among

[6] The type A and type B firms are viewed as local bidders, and the type AB firm a global bidder.

bidders—e.g., information sharing (DeBrock and Smith, 1983; Levin, 2004; Mares and Shor, 2008; Mares and Shor, 2012), capital pooling (Hoffman et al., 1991), and value creation or ownership-sharing (Marquez and Singh, 2013)—and explores the tension between the synergy enabled by joint bidding and its anti-competitive effects. Our paper joins this research stream by considering firms that possess complementary skills and could join forces to bid on projects with multiple components. We compare combinatorial auctions—which accommodate specialized firms as independent bidders—to auctions that require holistic proposals and thus require joint bidding of specialized firms. Our results demonstrate that the choice of auction format could depend on the information friction involved in the environment.

When information friction arises within a consortium, the interaction between the allied firms resembles that in a subcontracting arrangement. Our paper is thus connected with the literature on subcontracting. This strand of literature has explored a broad array of issues, ranging from how subcontracting affects auction outcomes (Gale, Hausch and Stegeman, 2000; Marion, 2015; Jeziorski and Krasnokutskaya, 2016); and how the formats of procurement auctions affect entry and subcontracting behavior (Branzoli and Decarolis, 2015); to how contract renegotiation or "bid-shopping" affects the performance of auctions in the presence of subcontracting (Bajari and Tadelis, 2001; Miller, 2014; Deneckere and Quint, 2024). Our interest, however, lies in whether an auction that would lead to joint bidding or subcontracting is the preferred approach to organizing a procurement auction when bidders exhibit complementarity.

The project in our context consists of two component tasks. Our paper can thus conceptually be linked to the literature on the auctioneer's bundling choice (see, e.g., Chakraborty, 1999; Manelli and Vincent, 2007; Li, Sun, Yan and Yu, 2015; and Chen and Li, 2018), which usually arises when the concerned items are complementary. Our setting requires that the two component tasks be procured together. We implicitly assume that procuring them in separate auctions is either infeasible (e.g., due to excessive administrative hurdles or potential hold-up problems), or not economic (e.g., individually capable firms enjoy significant cost-savings by finishing the entire project). Our focus is to compare alternative ways to involve complementary firms in a single auction.

The rest of the paper is organized as follows. Section 2 presents the primitives of the model and preliminary analysis of a base case that compares the holistic procurement auction without information friction to combinatorial VCG auction. Section 3 analyzes auctions with information friction. Section 4 concludes. Omitted proofs are provided in the Appendix.

2 Model and Preliminaries

In this section, we first lay out the primitives of the model, then present the analysis of the base case.

2.1 Primitives

An auctioneer seeks to procure a project comprised of two components, A and B. There are N_A firms specialized in component A, N_B firms specialized in component B, and N_{AB} firms that can handle both. We denote the cost of a representative firm (α, i) by c_i^α, where $\alpha \in \{A, B, AB\}$ and $i \in \{1, 2, \ldots, N_\alpha\}$. A firm's cost is privately known, but it is commonly known that c_i^α is distributed according to a cumulative distribution function $F_i^\alpha(\cdot)$ on $[\underline{c}^\alpha, \overline{c}^\alpha]$, with an associated probability density function $f_i^\alpha(\cdot)$. Throughout the paper, we assume that $f_i^\alpha(c) > 0$ for $c \in [\underline{c}^\alpha, \overline{c}^\alpha]$ and is continuous. Moreover, it is natural to assume that $\overline{c}^{AB} > \underline{c}^A + \underline{c}^B$ and $\overline{c}^A + \overline{c}^B > \underline{c}^{AB}$.

Let $\boldsymbol{x} := (x_1^A, \ldots, x_{N_A}^A, x_1^B, \ldots, x_{N_B}^B, x_1^{AB}, \ldots, x_{N_{AB}}^{AB})$ denote the allocation outcome, where $x_i^\alpha \in \{0, 1\}$ indicates whether a firm (α, i) is selected to deliver task $\alpha \in \{A, B, AB\}$. The set of all feasible allocations is given by

$$X = \left\{ \boldsymbol{x} \in \{0,1\}^{N_A+N_B+N_{AB}} \;\middle|\; \begin{array}{l} x_i^A + x_j^B = 1 \text{ for some } 1 \leq i \leq N_A \text{ and } 1 \leq j \leq N_B \text{ or} \\ x_k^{AB} = 1 \text{ for some } 1 \leq k \leq N_{AB}. \end{array} \right\}.$$

The efficiency of a given allocation $\boldsymbol{x} \in X$ is measured by the actual cost of finishing the project, $\boldsymbol{c} \cdot \boldsymbol{x}$, where $\boldsymbol{c} := (c_1^A, \ldots, c_{N_A}^A, c_1^B, \ldots, c_{N_B}^B, c_1^{AB}, \ldots, c_{N_{AB}}^{AB})$.

The auctioneer could organize a combinatorial auction, such that a type A or type B firm can bid independently on a specific component of the project. Alternatively, the auction can only accept holistic solutions, such that specialized contractors have to form consortia to bid jointly, which we refer to as a holistic procurement auction. We model the former as a VCG auction; the latter is depicted as a second-price sealed-bid auction (SPA). Note that a second-price auction is a special case of VCG auction for a single item, which ensures the consistency of our comparison across two auction formats. The two auction formats are then compared in terms of allocative efficiency and expected procurement price, which are considered as the primary performance measures for the auctioneer.

2.2 Combinatorial Auction: VCG Framework

We adopt the VCG framework to model the combinatorial auction. A VCG auction always awards the project to firms with the lowest completion costs, so it can be viewed as a natural candidate for the choice of project allocation mechanism.

A VCG auction can formally be described in our context as follows. Given a bid profile $\widehat{\boldsymbol{c}} := (\widehat{c}_1^A, \ldots, \widehat{c}_{N_A}^A, \widehat{c}_1^B, \ldots, \widehat{c}_{N_B}^B, \widehat{c}_1^{AB}, \ldots, \widehat{c}_{N_{AB}}^{AB})$, the resultant allocation $\boldsymbol{x}^*$ is given by $\boldsymbol{x}^* = \arg\min_{\boldsymbol{x} \in X} \widehat{\boldsymbol{c}} \cdot \boldsymbol{x}$,[7] and the payment bidder (α, i) receives is the positive externality it imposes on other firms, which amounts to $\min_{\boldsymbol{x}_{-(\alpha,i)}} \widehat{\boldsymbol{c}}_{-(\alpha,i)} \cdot \boldsymbol{x}_{-(\alpha,i)} - \widehat{\boldsymbol{c}}_{-(\alpha,i)} \cdot \boldsymbol{x}^*_{-(\alpha,i)}$. It is well known that truthful bidding is a weakly dominant strategy in the VCG auction, so we focus on the equilibrium in which every bidder reports truthfully. The following can be obtained.

Remark 1. ***(Krishna and Perry, 1998)*** *Among all mechanisms that are efficient, incentive compatible and individually rational, the VCG auction minimizes the expected procurement price.*

Remark 1 is due to Krishna and Perry (1998). It states that a combinatorial auction attains the minimum procurement price while ensuring allocative efficiency, when it adopts the VCG auction rule. This lays a foundation for our choice of the VCG auction for the modeling of a combinatorial auction.

2.3 Base Case: Holistic Procurement Auction without Information Friction

We assume that each firm's cost is independently distributed and privately known, which requires additional specifications on the matching process and information structure when firms bid as consortia. As discussed previously, two types of information frictions could arise. First, information friction could emerge when specialized firms are matched into consortia. Second, the firms within a consortium may not share their private cost information.

In this part, we focus on the simple scenario in which information friction is absent. We then compare the performance of the holistic procurement auction to that of the combinatorial auction. This serves as base case for the subsequent analysis of joint bidding with information friction. The following defines the associated matching and information structure.

Assumption 1. ***(Frictionless Joint Bidding)*** *Suppose that (i) type A firms and type B firms are assortatively matched and (ii) when a type A firm and a type B firm form a bidding consortium, they share their private cost information and seek to maximize their joint profit.*

[7] If there are ties (i.e., multiple minimizers of $\widehat{\boldsymbol{c}} \cdot \boldsymbol{x}$), one of the minimizers is selected randomly.

Firms are sorted into consortia in a cost-efficient manner. The firms within a consortium know each other's cost, and each consortium behaves as an integrated contender for the entire project. We model this procurement mechanism as a second-price sealed-bid auction (SPA). Focusing on the truthful bidding equilibrium, we obtain the following.

Proposition 1. *Under Assumption 1, the holistic procurement auction is efficient and always leads to a strictly lower expected procurement price than the combinatorial auction.*

Proposition 1 states that without information friction, the holistic procurement auction outperforms the combinatorial auction: It ensures allocative efficiency, while leading to a lower procurement cost for the auctioneer.

To see the intuition, it is useful to examine a simple example with complete information. Suppose that the auction involves one firm of each type, with $N_A = N_B = N_{AB} = 1$, $c_1^A = c_1^B = 1$, and $c_1^{AB} = 3$. The combinatorial auction—a VCG auction in our context—would allocate the project to the two specialized firms; the payment to each firm equals the externality it imposes on other firms, i.e., the difference in the costs born by other firms without and with the firm's presence. Note that the auctioneer compensates the specialized firms *twice* in the combinatorial VCG auction. Specifically, firm $(A, 1)$ receives a payment of $3 - 1 = 2$: Without firm $(A, 1)$, firm $(AB, 1)$ must finish the project and incur a cost of 3; with firm $(A, 1)$, firm $(B, 1)$ incurs a cost of 1. Similarly, firm $(B, 1)$ is also paid 2. The procurement price thus amounts to 4. In contrast, viewing the holistic second-price auction as a form of the VCG auction to buy a single item, the auctioneer only compensates the externality of the consortium *once*. In this example, the externality imposed by the consortium is 3, so the procurement price is 3. Proposition 1 generalizes this insight and verifies that the externality imposed by merged firms is lower than the sum of externalities imposed by independent specialized firms.

3 Analysis: Joint Bidding with Information Friction

We now examine the scenarios in which information frictions emerge in joint bidding. As previously mentioned, two types of information frictions could arise: One concerns the matching process, while the other does the coordination between the specialized firms within a consortium. Sections 3.1 and 3.2 each focus on one type of information friction to highlight its role. The analysis shows that the holistic procurement auction that adopts SPA rules is no longer efficient in the presence of either type of information friction and could result in higher expected procurement prices than the combinatorial auction.

3.1 Information Friction in Matching Process

We now consider information friction embedded in the matching process. That is, specialized firms do not have enough information about their potential partners, and each of them is randomly matched to a partner. We maintain part (ii) of Assumption 1 and assume that firms within a consortium share cost information and cooperate frictionlessly upon the formation of the alliance.

To simplify the analysis, we assume that there are an equal number N of type A and type B firms. The following ensues.

Proposition 2. *Suppose that $N_A = N_B = N \geq 2$, $N_{AB} \geq 0$, and that type A firms and type B firms are randomly matched to bid for the project jointly when the auction requires holistic proposals. The following statements hold:*

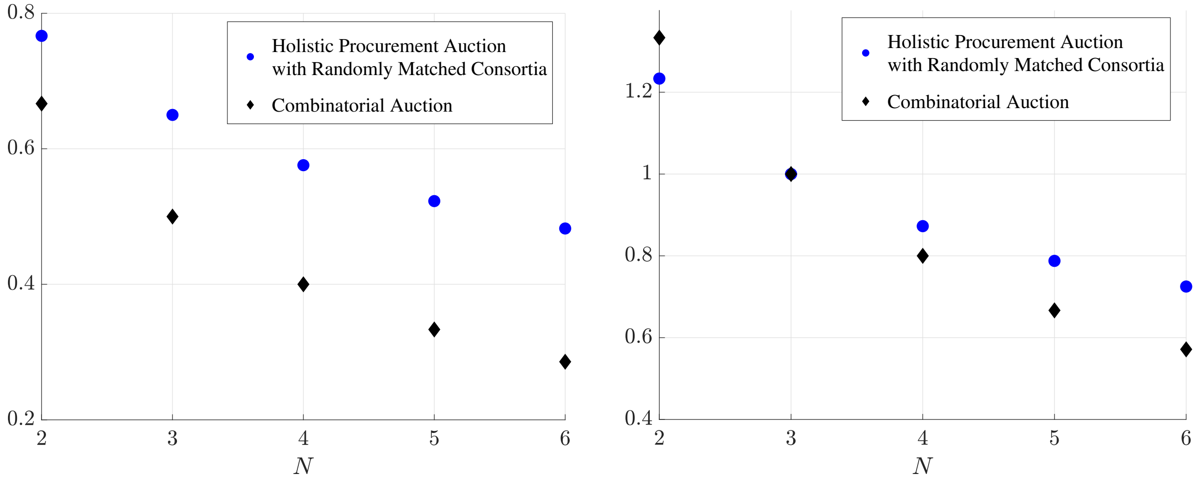
(i) The holistic procurement auction is no longer efficient.

(ii) Suppose further that firms within each type $\alpha \in \{A, B\}$ have the same cost distribution. There exists $\underline{N} \in \mathbb{N}_+$ such that the expected procurement price in the holistic procurement auction is strictly higher than that in the combinatorial auction for all $N \geq \underline{N}$.

Proposition 2(i) is intuitive. Cost-efficient firms could be matched to incompetent partners, which jeopardizes the allocative efficiency of the auction. Obviously, the least costly type A firm may not be matched to the least costly type B firm. The inefficient matching could elevate bidders' costs and soften the competition, thereby inflating the procurement price. Proposition 2(ii) contends that the expected procurement price of the holistic procurement auction exceeds that of the combinatorial auction when the numbers of specialized firms, N, are sufficiently large. To put this intuitively, the more firms to be matched, the more significant the inefficiency incurred in the matching process, and the more severe the distortion to the competition.

Proposition 2 is established in a limit case with N approaching infinity. The following parameterized example provides a visual account of the proposition and indicates that the cutoff $\underline{N}$ does not need to be very large.

Example 1. Suppose that $N_A = N_B = N \geq 2$, $N_{AB} = 0$. The private costs, c_i^α, with $\alpha \in \{A, B\}$ and $i \in \{1, \dots, N\}$, are independently and uniformly distributed on $[0, 1]$. Further, suppose that in the holistic procurement auction, type A firms and type B firms are randomly matched to form N bidding consortia.



(a) Expected completion costs.

(b) Expected procurement prices.

Figure 1: Expected completion costs and procurement prices in the holistic procurement auction and the combinatorial auction in Example 1.

Figure 1(a) demonstrates the efficiency loss in the SPA caused by random matching. When there are no less than 4 pairs of type A and type B firms, Figure 1(b) shows that the expected procurement price in the holistic procurement auction exceeds that in the combinatorial auction. With $N = 6$, the expected completion cost in the holistic procurement auction is 69% more than that in the combinatorial auction, and its expected procurement price 27% higher.

3.2 Information Friction within a Bidding Consortium

We now examine the case with information friction within a bidding consortium: Its members do not share cost information; they collaborate in an incentive-compatible way instead of seeking to maximize joint profit. To highlight the role played by such information friction, we abstract away the matching process by focusing on a simple setting with $N_A = N_B = N_{AB} = 1$, which corresponds to the LLG model in the literature.

In the holistic procurement auction, the costs of firms $(A, 1)$ and $(B, 1)$ remain privately known after they form a consortium, and each firm seeks to maximize its own profit. The collaboration can be interpreted as a form of a subcontracting arrangement. Without loss of generality, we let firm $(A, 1)$ be the prime contractor and responsible for designing a subcontracting mechanism to elicit the cost information from the subcontractor, firm $(B, 1)$; firm $(A, 1)$ then comes up with a bid on behalf of the consortium. We refer to this case as *strategic* joint bidding to distinguish it from the case of frictionless joint bidding, as described by Assumption 1(ii).

More formally, the timing of the auction game is as follows. Prior to the auction, the prime contractor announces its subcontracting mechanism, which consists of a bidding rule $\widehat{c}(c_1^A, c_1^B)$ and a transfer rule $t(c_1^A, c_1^B)$. The prime contractor also reveals its own cost type c_1^A to the subcontractor.[8] So the subcontractor knows that the subcontracting scheme, conditional on the prime contractor's type, is $(\widehat{c}(c_1^A, \cdot), t(c_1^A, \cdot))$. Then the subcontractor reports its cost to the prime contractor. Given the reported cost $\widehat{c}_1^B$, the prime contractor submits a bid of $\widehat{c}(c_1^A, \widehat{c}_1^B)$ and pays the subcontractor $t(c_1^A, \widehat{c}_1^B)$.[9] Meanwhile, firm $(AB, 1)$ submits its bid $\widehat{c}_1^{AB}$. Finally, the auction concludes according to the standard second-price rule.

Our analysis adopts the solution concept of principals' equilibrium proposed by Myerson (1982). This equilibrium notion requires that given firm $(AB, 1)$'s bidding strategy, the subcontracting mechanism maximizes the prime contractor's expected profit subject to the subcontractor's incentive compatibility, which ensures its truthful reporting. Also, given the bidding rule in the subcontracting mechanism and the belief that the subcontractor reports truthfully, firm $(AB, 1)$'s bidding strategy maximizes its expected profit.

To simplify the equilibrium analysis, we impose a standard regularity condition on the subcontractor's cost distribution, which is given by Assumption 2.

Assumption 2. ***(Regular Cost Distribution)*** The subcontractor's virtual cost, $\tilde{c}_1^B := c_1^B + \frac{F_1^B(c_1^B)}{f_1^B(c_1^B)}$, is weakly increasing in c_1^B.

It is straightforward to see that bidding truthfully is a weakly dominant strategy for firm $(AB, 1)$ in the SPA: It maximizes firm $(AB, 1)$'s expected profit regardless of the mechanism chosen by the prime contractor. We obtain the following.

Proposition 3. *In the principals' equilibrium of the auction game, the type AB firm bids $\widehat{c}_1^{AB,*}(c_1^{AB}) = c_1^{AB}$, and the type A firm, as the prime contractor, adopts the bidding rule of $\widehat{c}^*(c_1^A, c_1^B) = c_1^A + \tilde{c}_1^B$—where $\tilde{c}_1^B$ is the type B firm's virtual cost—and the transfer rule of $t^*(c_1^A, c_1^B) = \bar{F}_1^{AB}(\widehat{c}^*(c_1^A, c_1^B))c_1^B + \int_{c_1^B}^{\bar{c}_1^B} \bar{F}_1^{AB}(\widehat{c}^*(c_1^A, x))dx$, with $\bar{F}_1^{AB}(\cdot) := 1 - F_1^{AB}(\cdot)$.*

The firms in the consortium, as prime contractor and subcontractor, maximize their respective profits sequentially. The strategic behavior causes the usual double marginalization problem. As a result, the consortium's equilibrium bid, $c_1^A + \tilde{c}_1^B$, exceeds its actual cost,

[8]Because the prime contractor is risk-neutral and its cost type is not correlated with the subcontractor's, it is without loss of generality to let the prime contractor reveal its type truthfully when announcing the mechanism (see Proposition 11 in Maskin and Tirole, 1990).

[9]The transfer happens regardless of the result of the auction. This is without loss of generality as both the prime contractor and the subcontractor are risk-neutral.

$c_1^A + c_1^B$. When determining its bidding rule, the prime contractor factors in the information rent that must be surrendered to the subcontractor in exchange of the latter's truthful reporting, which, in turn, elevates the consortium's bid. The following ensues.

Proposition 4. *The holistic procurement auction is inefficient. Moreover, when firm $(AB, 1)$ is very strong and likely to win—with $\Pr(c_1^{AB} \leq c_1^A + \tilde{c}_1^B) \to 1$—the holistic procurement auction leads to a higher expected procurement price than the combinatorial auction.*

The first part of Proposition 4 follows immediately from the fact that the consortium bids above its actual cost. To establish its second part, it suffice to note that when firm $(AB, 1)$ wins, the procurement price is $c_1^A + c_1^B$ in the combinatorial auction; in contrast, the auctioneer instead pays $c_1^A + \tilde{c}_1^B$ in the holistic procurement auction.

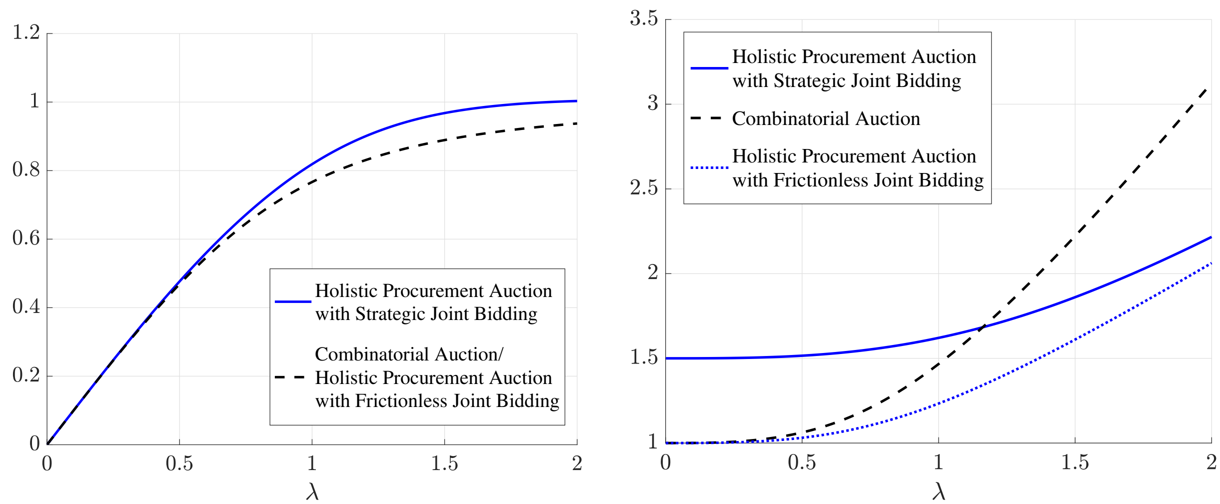
Again, we use a parametrized example to illustrate the results in Proposition 4.

Example 2. *Suppose that c_1^A and c_1^B are independent and uniformly distributed on $[0, 1]$. The distribution of c_1^{AB} is the same as that of $\lambda(c_1^A + c_1^B)$, where $\lambda > 0$ captures the relative strength of firm $(AB, 1)$ and the union of firms $(A, 1)$ and $(B, 1)$. Specifically, Firm $(AB, 1)$ becomes stronger as λ decreases.*

Figure 2(a) compares the expected completion costs in the holistic procurement auction vis-à-vis those in the base case with frictionless joint bidding and in the combinatorial auction. As predicted by Proposition 4, information friction leads to inefficient allocations.

Figure 2(b) compares expected procurement prices across different cases. By Proposition 4, when firm $(AB, 1)$ is ex ante sufficiently strong—with a small λ in this example—the combinatorial auction outperforms the holistic procurement auction in terms of expected procurement price. The figure demonstrates that this does not require an excessively strong firm $(AB, 1)$ and could emerge even for some $\lambda > 1$, in which case the consortium is ex ante stronger than firm $(AB, 1)$. Obviously, the comparison depends on the magnitude of information friction involved. Recall by Proposition 1 that without information friction, the holistic procurement auction outperforms the combinatorial auction; the same could presumably be expected when information friction is mild.

One remark is in order before we close this section. To highlight the role played by information friction within consortia and the resultant double marginalization problem, we abstract away the information friction involved in the matching process by focusing on a LLG model with one pair of specialized firms. Our result nevertheless qualitatively extends to settings with multiple specialized firms. We do not present the analysis for brevity, but the details are available upon request.



(a) Expected completion costs.

(b) Expected procurement prices.

Figure 2: Expected completion costs and procurement prices in the holistic procurement auction and the combinatorial auction in Example 2.

4 Concluding Remarks

In this paper, we examine and compare alternative auction approaches to procuring projects consisting of multiple component tasks. The auctioneer can either organize a combinatorial auction that allows specialized firms to bid on component tasks or require holistic proposals, forcing specialized firms to form consortia and bid on the entire project collectively. Our analysis shows that the holistic procurement auction outperforms the combinatorial auction when information friction is absent: The holistic procurement achieves efficient allocation of the project and also renders a lower expected procurement price. However, our further analysis calls for caution with the holistic procurement approach when information friction is present. Information friction could distort the matching of specialized firms, leading competent firms to partner with incompetent peers; it may also arise between firms within a consortium, causing the usual double marginalization problem due to firms' strategic behavior. In either case, the combinatorial auction—which accommodates specialized firms as independent bidding entities—leads to greater allocative efficiency and possibly lower expected procurement prices.

Our analysis demonstrates the key role played by information friction and yields ample implications for the administration of procuring complex projects. The choice of auction format could critically depend on the severity of information friction involved in the process of forming consortia and subsequent collaboration within consortia.

Imagine, for instance, a mature market with a relatively small set of established firms that have a long history of interactions. Our results imply that a holistic approach could be a preferred choice given the mild information friction. Conversely, in a market with substantial turnover, more significant information friction would arguably arise due to the lack of interaction between incumbents and entrants. Our results would instead endorse a combinatorial auction format. Furthermore, consider a project that adopts nascent technologies, novel components, or engineering concepts. Information friction is more likely to emerge because of the uncertainty caused by experimentation and learning associated with innovation, which thus calls for a combinatorial approach.

References

Ausubel, Lawrence M. and Oleg Baranov, "Core-selecting auctions with incomplete information," *International Journal of Game Theory*, 2020, *49* (1), 251–273.

_ and Oleg V. Baranov, "Market design and the evolution of the combinatorial clock auction," *American Economic Review*, 2014, *104* (5), 446–451.

Bajari, Patrick and Steven Tadelis, "Incentives versus transaction costs: A theory of procurement contracts," *RAND Journal of Economics*, 2001, *32* (3), 387–407.

Branzoli, Nicola and Francesco Decarolis, "Entry and subcontracting in public procurement auctions," *Management Science*, 2015, *61* (12), 2945–2962.

Chakraborty, Indranil, "Bundling decisions for selling multiple objects," *Economic Theory*, 1999, *13* (3), 723–733.

Chen, Yongmin and Jianpei Li, "Bundled procurement," *Journal of Public Economics*, 2018, *159*, 116–127.

Cramton, Peter, "Spectrum auction design," *Review of Industrial Organization*, 2013, *42*, 161–190.

De Vries, Sven and Rakesh V. Vohra, "Combinatorial auctions: A survey," *INFORMS Journal on Computing*, 2003, *15* (3), 284–309.

DeBrock, Larry M. and James L. Smith, "Joint bidding, information pooling, and the performance of petroleum lease auctions," *The Bell Journal of Economics*, 1983, *14* (2), 395–404.

Deneckere, Raymond and Daniel Quint, ""Bid Shopping" in Procurement Auctions with Subcontracting," *Working Paper*, 2024.

Estache, Antonio and Atsushi Iimi, "Joint bidding in infrastructure procurement," *World Bank Policy Research Working Paper No. 4664*, 2008.

Gale, Ian L., Donald B. Hausch, and Mark Stegeman, "Sequential procurement with subcontracting," *International Economic Review*, 2000, *41* (4), 989–1020.

Hoffman, Elizabeth, James R. Marsden, and Reza Saidi, "Are joint bidding and competitive common value auction markets compatible? Some evidence from offshore oil auctions," *Journal of Environmental Economics and Management*, 1991, *20* (2), 99–112.

Jeziorski, Przemyslaw and Elena Krasnokutskaya, "Dynamic auction environment with subcontracting," *RAND Journal of Economics*, 2016, *47* (4), 751–791.

Krishna, Vijay and Motty Perry, "Efficient mechanism design," *Penn State University, Mimeo*, 1998.

_ and Robert W Rosenthal, "Simultaneous auctions with synergies," *Games and Economic Behavior*, 1996, *17* (1), 1–31.

Levin, Dan, "The competitiveness of joint bidding in multi-unit uniform-price auctions," *RAND Journal of Economics*, 2004, *35* (2), 373–385.

Li, Sanxi, Hailin Sun, Jianye Yan, and Jun Yu, "Bundling decisions in procurement auctions with sequential tasks," *Journal of Public Economics*, 2015, *128*, 96–106.

Manelli, Alejandro M. and Daniel R. Vincent, "Multidimensional mechanism design: Revenue maximization and the multiple-good monopoly," *Journal of Economic Theory*, 2007, *137* (1), 153–185.

Mares, Vlad and Mikhael Shor, "Industry concentration in common value auctions: Theory and evidence," *Economic Theory*, 2008, *35* (1), 37–56.

_ and _ , "On the competitive effects of bidding syndicates," *The B.E. Journal of Economic Analysis & Policy*, 2012, *12* (1).

Marion, Justin, "Sourcing from the enemy: Horizontal subcontracting in highway procurement," *Journal of Industrial Economics*, 2015, *63* (1), 100–128.

Marquez, Robert and Rajdeep Singh, "The economics of club bidding and value creation," *Journal of Financial Economics*, 2013, *108* (2), 493–505.

Maskin, Eric and Jean Tirole, "The principal-agent relationship with an informed principal: The case of private values," *Econometrica*, 1990, *58* (2), 379–409.

McMillan, John, "Selling spectrum rights," *Journal of Economic Perspectives*, 1994, *8* (3), 145–162.

Miller, Daniel P., "Subcontracting and competitive bidding on incomplete procurement contracts," *RAND Journal of Economics*, 2014, *45* (4), 705–746.

Millsaps, Steven W. and Mack Ott, "Information and bidding behavior by major oil companies for Outer Continental Shelf leases: Is the joint bidding ban justified?," *Energy Journal*, 1981, *2* (3), 71–90.

Myerson, Roger B., "Optimal coordination mechanisms in generalized principal-agent problems," *Journal of Mathematical Economics*, 1982, *10* (1), 67–81.

Rassenti, Stephen J., Vernon L. Smith, and Robert L. Bulfin, "A combinatorial auction mechanism for airport time slot allocation," *The Bell Journal of Economics*, 1982, *13* (2), 402–417.

Appendix: Proofs

Proof of Proposition 1

Proof. For a given realization of cost profile $\boldsymbol{c} = (c_1^A, \ldots, c_{N_A}^A, c_1^B, \ldots, c_{N_B}^B, c_1^{AB}, \ldots, c_{N_{AB}}^{AB})$, we assume without loss of generality that $c_1^A < \cdots < c_{N_A}^A$ and $c_1^B < \cdots < c_{N_B}^B$. Because every bidding consortium and every type AB firm bids truthfully in equilibrium, the project is assigned efficiently. That is, firms $(A, 1)$ and $(B, 1)$ win if $c_1^A + c_1^B < c_1^{AB}$ and firm $(AB, 1)$ wins if $c_1^A + c_1^B > c_1^{AB}$.

We first show that the holistic procurement auction leads to a lower procurement price realization by realization. Consider the following three cases:

Case (i): $\boldsymbol{c_1^{AB} \leq c_1^A + c_1^B}$. The procurement price is $\min\{c_1^A + c_1^B, c_2^{AB}\}$ in both the holistic procurement auction and the combinatorial auction.

Case (ii): $\boldsymbol{c_1^{AB} \geq c_2^A + c_2^B}$. The procurement price is $c_2^A + c_2^B$ in both auctions.

Case (iii): $\boldsymbol{c_2^A + c_2^B > c_1^{AB} > c_1^A + c_1^B}$. Firms $(1, A)$ and $(1, B)$ win in both auctions. In the combinatorial auction, the payment to firm $(1, A)$ is $\min\{c_1^{AB} - c_1^B, c_2^A\}$ and the payment to firm $(1, B)$ is $\min\{c_1^{AB} - c_1^A, c_2^B\}$. So the procurement price is $\min\{c_1^{AB} - c_1^B, c_2^A\} + \min\{c_1^{AB} - c_1^A, c_2^B\}$. In the holistic procurement auction, the payment to the consortium consisting of firms $(1, A)$ and $(1, B)$ is c_1^{AB}. Note that

$$\begin{aligned} c_1^{AB} - c_1^B + c_1^{AB} - c_1^A &> c_1^{AB}, \\ c_1^{AB} - c_1^B + c_2^B &> c_1^{AB}, \\ c_2^A + c_1^{AB} - c_1^A &> c_1^{AB}, \\ c_2^A + c_2^B &> c_1^{AB}. \end{aligned}$$

As a result, $\min\{c_1^{AB} - c_1^B, c_2^A\} + \min\{c_1^{AB} - c_1^A, c_2^B\} > c_1^{AB}$. Therefore, the procurement price is strictly higher in the combinatorial auction than in the holistic procurement auction.

Since Case (iii) occurs with a positive probability, the expected procurement price in the holistic procurement auction is strictly lower than that in the combinatorial auction. $\square$

Proof of Proposition 2

Proof. Part (i) of the proposition is obvious and it remains to prove part (ii). Let $f^\alpha(\cdot)$ and $F^\alpha(\cdot)$ respectively denote the probability distribution and cumulative distribution functions of type α firms.

It is without generality to assume that $\underline{c}^A = \underline{c}^B = 0$. In the holistic procurement auction, because type A firms and type B firms are randomly matched, each bidding consortium's cost distribution is the same as that of $c_1^A + c_1^B$. This distribution can be described by the support $[0, \bar{c}^A + \bar{c}^B]$, the probability distribution $f^C(\cdot)$, and cumulative probabilities $F^C(\cdot)$, where the superscript C stands for "Consortium." In particular, for each $x \in [0, \bar{c}^A + \bar{c}^B]$, it holds that

$$F^C(x) = \int_{u+v \leq x} f^A(u) f^B(v) du dv. \tag{A1}$$

Denote the m-th lowest cost among all joint bidding consortia by $c_{(m)}^C$ and the m-th lowest cost among all type $\alpha \in \{A, B, AB\}$ firms by $c_{(m)}^{\alpha}$. We show below that for every realization of $c_{(1)}^{AB}$—i.e., the minimum cost among all type AB firms—the limit of the expected procurement price in the holistic procurement auction is higher than that in the combinatorial auction.

Case (i): $\boldsymbol{c_{(1)}^{AB} \leq g_1^C = g_1^A + g_1^B}$. In this case, the type AB firm with the lowest cost wins with certainty in both auctions. (Ties may arise if $c_{(1)}^{AB} = g_1^C = g_1^A + g_1^B$, but they do not matter for the analysis of procurement prices.) For every realization of cost profiles, the procurement price in the holistic procurement auction is $\min\{c_{i^\dagger}^A + c_{j^\dagger}^A, c_{(2)}^{AB}\}$, where $i^\dagger$ and $j^\dagger$ are respectively the indices of the type A firm and the type B firm comprising the consortium with the lowest cost. The procurement price in the combinatorial auction is $\min\{c_{(1)}^A + c_{(1)}^A, c_{(2)}^{AB}\}$. Clearly, the procurement price in the combinatorial auction is weakly lower than in the holistic procurement auction.

Case (ii): $\boldsymbol{c_{(1)}^{AB} > g_1^C = g_1^A + g_1^B}$. Fixing a realization of $c_{(1)}^{AB}$, the expected procurement price in the holistic procurement auction—which we denote by EP^{SPA}—can be bounded from below by

$$\begin{aligned}
EP^{SPA} =& \Pr\left(c_{(2)}^C < c_{(1)}^{AB}\right) \mathbb{E}\left[c_{(2)}^C \middle| c_{(2)}^C < c_{(1)}^{AB}\right] + \Pr\left(c_{(2)}^C \geq c_{(1)}^{AB}\right) \mathbb{E}\left[\max\{c_{(1)}^C, c_{(1)}^{AB}\} \middle| c_{(2)}^C \geq c_{(1)}^{AB}\right] \\
\geq& \Pr\left(c_{(2)}^C < c_{(1)}^{AB}\right) \mathbb{E}\left[c_{(1)}^C \middle| c_{(2)}^C < c_{(1)}^{AB}\right] + \Pr\left(c_{(2)}^C \geq c_{(1)}^{AB}\right) \mathbb{E}\left[c_{(1)}^C \middle| c_{(2)}^C \geq c_{(1)}^{AB}\right] \\
=& \mathbb{E}\left[c_{(1)}^C \middle| c_{(1)}^{AB}\right] = \mathbb{E}\left[c_{(1)}^C\right],
\end{aligned}$$

where the inequality follows from the fact that $c_{(1)}^C \leq c_{(2)}^C$ and $c_{(1)}^C \leq \max\{c_{(1)}^C, c_{(1)}^{AB}\}$, and the last equality from the fact that $c_{(1)}^C$ and $c_{(1)}^{AB}$ are independent.

The expected procurement price in the combinatorial auction is lower than $\mathbb{E}\left[c_{(2)}^A + c_{(2)}^B\right]$, since this is the expected procurement price without type AB firms' bids. Therefore, it suffices to show that $\mathbb{E}\left[c^A_{(2)}+c^B_{(2)}\right]<\mathbb{E}\left[c^C_{(1)}\right]$ when N is sufficiently large.

Carrying out the algebra, we can obtain that

$$\begin{aligned}
\mathbb{E}\left[c^C_{(1)}\right] &= \int_0^{\overline{c}^A+\overline{c}^B}\left[1-F^C(x)\right]^{N-1}dx,\\
\mathbb{E}\left[c^\alpha_{(2)}\right] &= \int_0^{\overline{c}^\alpha}\left[1+(N-1)F^\alpha(x)\right]\left[1-F^\alpha(x)\right]^{N-1}dx,\ \alpha\in\{A,B\}.
\end{aligned}$$

There exists $\varepsilon>0$ such that $\frac{f^\alpha(0)}{2}\le f^\alpha(x)\le 2f^\alpha(0)$ for each $x\in[0,\varepsilon]$ and $\alpha\in\{A,B\}$. Moreover, $\frac{f^\alpha(0)x}{2}\le F^\alpha(x)\le 2f^\alpha(0)x$. Therefore, for $\alpha\in\{A,B\}$, we have that

$$\begin{aligned}
\mathbb{E}\left[c^\alpha_{(2)}\right] &= \int_0^{\overline{c}^\alpha}\left[1+(N-1)F^\alpha(x)\right]\left[1-F^\alpha(x)\right]^{N-1}dx,\\
&= \int_0^{\varepsilon}\left[1+(N-1)F^\alpha(x)\right]\left[1-F^\alpha(x)\right]^{N-1}dx\\
&\quad+\int_\varepsilon^{\overline{c}^\alpha}\left[1+(N-1)F^\alpha(x)\right]\left[1-F^\alpha(x)\right]^{N-1}dx\\
&\le \int_0^{\varepsilon}\left[1+2(N-1)f^\alpha(0)x\right]\left[1-\frac{f^\alpha(0)x}{2}\right]^{N-1}dx+N\left[1-F^\alpha(\varepsilon)\right]^{N-1}\overline{c}^\alpha\\
&= \frac{10}{Nf^\alpha(0)}+o\left(\frac{1}{N}\right).
\end{aligned}\tag{A2}$$

On the other hand, for each $x\in[0,\varepsilon]$, it follows from (A1) that

$$F^C(x)=\int_{u+v\le x}f^A(u)f^B(v)dudv\le\int_{u+v\le x}4f^A(0)f^B(0)uvdudv=2f^A(0)f^B(0)x^2,$$

which in turn implies that

$$\begin{aligned}
\mathbb{E}\left[c^C_{(1)}\right] &= \int_0^{\overline{c}^A+\overline{c}^B}\left[1-F^C(x)\right]^{N-1}dx\\
&\ge \int_0^{\varepsilon}\left[1-F^C(x)\right]^{N-1}dx\\
&\ge \int_0^{\varepsilon}\left[1-2f^A(0)f^B(0)x^2\right]^{N-1}dx\\
&= \sqrt{\frac{\pi}{8f^A(0)f^B(0)}}\times\frac{1}{\sqrt{N}}+o\left(\frac{1}{\sqrt{N}}\right).
\end{aligned}\tag{A3}$$

Combining (A2) and (A3), we can conclude that $\mathbb{E}\left[c^A_{(2)}+c^B_{(2)}\right]<\mathbb{E}\left[c^C_{(1)}\right]$ when N is sufficiently large. $\square$

Proof of Proposition 3

Proof. Given that firm $(AB, 1)$ bids truthfully, the subcontractor's payoff with a report $\widehat{c}_1^B$ is as follows:

$$\pi_1^B(\widehat{c}_1^B; c_1^B) = t\big(c_1^A, \widehat{c}_1^B\big) - \bar{F}_1^{AB}\left(\widehat{c}\big(c_1^A, \widehat{c}_1^B\big)\right) c_1^B.$$

Incentive compatibility requires that $c_1^B \in \arg\max_{\widehat{c}_1^B} \pi_1^B(\widehat{c}_1^B; c_1^B)$, which implies that $\frac{\partial \pi_1^B(c_1^B)}{\partial c_1^B} = -\bar{F}_1^{AB}(\widehat{c}(c_1^A, c_1^B))$, where $\pi_1^B(c_1^B) := \pi_1^B(c_1^B; c_1^B)$. It is clear that the prime contractor will set $t(c_1^A, \bar{c}^B) = 0$. Therefore, we have that

$$\pi_1^B(c_1^B) = \int_{c_1^B}^{\bar{c}^B} \bar{F}_1^{AB}\left(\widehat{c}\big(c_1^A, x\big)\right) dx,$$

which implies that

$$t(c_1^A, c_1^B) = \bar{F}_1^{AB}\left(\widehat{c}\big(c_1^A, c_1^B\big)\right) c_1^B + \int_{c_1^B}^{\bar{c}^B} \bar{F}_1^{AB}\left(\widehat{c}\big(c_1^A, x\big)\right) dx. \tag{A4}$$

Since the prime contractor can set the transfer rule according to (A4) for a given bidding rule to ensure incentive compatibility, we consider its optimal choice of the bidding rule. As is standard in the mechanism design literature, the bidding rule also needs to be increasing in c_1^B for the incentive compatibility constraint to be satisfied. We ignore the monotonicity constraint for now and show below that it is satisfied in the optimum. The prime contractor's expected payoff, with the expectation taken over c_1^B, is

$$\mathbb{E}_{c_1^B}\left[\int_{\widehat{c}\left(c_1^A, c_1^B\right)}^{\bar{c}^{AB}} \big(x - c_1^A\big) dF_1^{AB}(x) - t\big(c_1^A, c_1^B\big)\right].$$

By plugging (A4) into the expression and changing the order of integration, the prime contractor's expected payoff can be rewritten as

$$\mathbb{E}_{c_1^B}\left[\int_{\widehat{c}(c_1^A, c_1^B)}^{\bar{c}^{AB}} \big(x - c_1^A - \tilde{c}_1^B\big) dF_1^{AB}(x)\right].$$

It is evident that the above integral is maximized by setting $\widehat{c}(c_1^A, c_1^B) = c_1^A + \tilde{c}_1^B$, which is increasing in c_1^B by Assumption 2. □

Proof of Proposition 4

Proof. See main text. □