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Bundled Procurement for Technology Acquisition and Future Competition

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Consider a buyer who would like to procure certain products for the current period and the underlying technologies so that he can become a supplier and compete with current suppliers in the future market. One potential procurement mechanism for such a buyer is to bundle the procurement project with technology acquisition. We propose a dynamic stochastic game-theoretic model that analyzes the optimal technology offer strategies of the asymmetric suppliers and highlights how the size of the current project, relative to the size of the future market, and supplier competition determine the effectiveness of the bundled procurement mechanism for the buyer. For the two-supplier case, we find that each supplier has a dominant technology offer strategy that is independent of the opponent's strategy. When the relative size of the project is small, suppliers only offer obsolete technologies even if their technologies are perfect substitutes. While suppliers offer better technologies as the project size increases, their responses in technology offers are not continuous with respect to the project size—once the project size reaches some threshold, suppliers' optimal responses jump to their best technologies. We also observe that the premium needed for technology acquisition under the bundled procurement mechanism can be negligible compared to the expected profit from the future market.

Keywords: procurement; game theory; technology transfer; China policy

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1. Introduction

Consider a buyer who would like to procure certain products for the current period and the technologies to compete in the future. A natural approach for this buyer is to procure the products and the technologies separately. Whereas the buyer may successfully leverage supplier competition in procuring the products, it is usually difficult for the buyer to acquire state-of-the-art technologies. The question, then, is: can the buyer leverage the product procurement and supplier competition to facilitate technology acquisition?

The above describes a situation that China has faced when contemplating strategies for developing its industries. Over the past quarter century, China has opened its market to the world and geared up for an unprecedented economic development. However, to be competitive on the national and international levels, China needs modern technologies. With the intention of supporting domestic reform and modernization efforts toward self-sufficiency in high-tech sectors, China's laws, regulations, and policies with regard to foreign investment and trade include numerous provisions and mandates for foreign technology transfer (Bureau of Export Administration 1999).

Understanding the real threat of future competition, foreign firms are naturally unwilling to trans-

fer their proprietary technologies, even if they are paid a seemingly high price. For example, Harbin Electric Machinery attempted to acquire the computational fluid dynamics software technology for turbine design at a price of \$30 million to no avail (Zhang et al. 2008). (This technology was later acquired via the Three Gorges project at a much lower price.) Indeed, the state-owned enterprises have had few successes in closing the technology gap through direct technology transfers. Whereas China has sustained an impressive economic growth rate over the past quarter century, with few exceptions its firms compete predominately through their lower costs in various labor-intensive industries rather than on advanced technologies (Hout and Ghemawat 2010).

In addition to its desire to equip its industries with modern technologies, China needs to build its infrastructure. In this process, the government and state-owned enterprises engaged in a number of large-scale industrial projects, most noticeably the Three Gorges Dam and the national high-speed rail system. These projects required advanced technologies and equipment that China lacked at the time. While having to rely on foreign firms to provide the technology capabilities for completing these projects, China had a keen interest in using these large-scale projects as an

opportunity for the state-owned enterprises to obtain the technologies. To this end, China adopted a novel procurement mechanism that bundled the projects with the technologies; under this mechanism, the winning supplier was mandated to transfer the underlying technologies to the state-owned enterprises who intended to compete with the current suppliers in the future (Zhang et al. 2008).

Evidence shows that China has been successful in applying such a bundled procurement mechanism to achieve its dual goals of completing projects and acquiring technologies. For example, with the completion of the left bank of the Three Gorges Dam in 2005, two state-owned manufacturers (Harbin Electric Machinery and Dongfang Electrical Machinery) have since become leading suppliers of hydropower equipment in the global market. Similarly, with the construction of its high-speed railway, China's CNR Corporation and CSR Corporation are now competing for projects in the global market, and in particular in the United States (Shirouzu 2010). This mechanism is also used to procure nuclear power reactors (Bradsher 2006). Over the years, China has become self-sufficient in reactor design and construction and continues to develop and plan additional reactors (Wong 2012).

The purpose of this paper is to analyze the effectiveness of this novel procurement mechanism and predict the outcome of such a bundled procurement mechanism. Within the domain of his available technologies, each supplier needs to decide the technology that goes into the current project and transfers to the buyer. We study the optimal technology offers of the asymmetric suppliers and model the process that determines the winning supplier and the transaction price. We are interested in understanding the incentives and economic factors that affect a supplier's choice of technology offer. By offering a better technology, a supplier would enhance his competitiveness or likelihood over other suppliers for securing the project. Nevertheless, such a choice helps to incubate a stronger future competitor, i.e., the current buyer. We wonder what suppliers' optimal technology offer strategies are in equilibrium. Who will be the winning supplier, and what is the transaction price? Under what conditions will the suppliers offer their best technologies? Does the buyer benefit from using a bundled procurement mechanism compared with procuring the product and the technology separately? By bundling, does the buyer need to pay a much higher price for the procurement project?

In trying to answer the above questions, we propose a stylized model that analyzes the optimal technology offers of the asymmetric suppliers and highlights how the relative size of the current project and supplier competition determine the effectiveness

of the bundled procurement mechanism. For the two-supplier case, we find that each supplier has a dominant technology offer strategy that is independent of the opponent's technology offer strategy. Suppliers' optimal technology responses are not necessarily continuous with respect to the size of the current project. When the buyer procures only the technology, or the size of the current project is small, our model predicts that suppliers only offer obsolete technologies, even if his opponent is a perfect substitute. When the size of the current project reaches some threshold, suppliers' optimal responses jump and the best technologies will be offered.

Our model further indicates that when the suppliers do offer their best technologies, the buyer would pay a slightly higher price under the bundled procurement mechanism compared to the procurement price for the project alone. Nevertheless, the premium for technology transfer is relatively small compared to the profit gained from the future market. Furthermore, this premium goes down to zero as supplier competition intensifies and the suppliers become substitutable with each other. These results indicate that the bundled procurement mechanism not only facilitates technology acquisition by enabling the buyer to leverage the product procurement and supplier competition, but it can also provide great profit to the buyer.

The remainder of this paper is organized as follows. In §2, we review the related literature. In §3, we propose the model for the bundled procurement mechanism. We then identify the suppliers' optimal technology offer strategies and compare procurement policies in §4. In §5, we provide some extensions, and we conclude in §6. In the online appendix (available as supplemental material at <http://dx.doi.org/10.1287/msom.2014.0517>), we present the technical proofs, additional extensions, and discussions for the Three Gorges project.

2. Literature Review

We adopt a stylized dynamic game-theoretic model to study the procurement mechanism and winner determination problem when the buyer bundles the technology transfer with the procurement and competes with current suppliers in the future. Next, we briefly review the literature of technology transfer and procurement mechanisms.

Technology Transfer. The theoretical literature on technology transfer is vast. The early work typically adopts a static game-theoretic framework to study the optimal licensing behavior of the monopolist after a new technology or production process is developed and patented. The later work introduces oligopolistic competition and dynamic evolution of technology.

One of the earliest theoretical references on technology transfer, McGee (1966), points out that licensing can be beneficial to both parties because it lowers the industrial production costs. In general, the literature on monopoly inventors finds that if side payments are possible, technology transfer is possible whenever it raises industry profits, whether it is by reducing costs (Gallini and Winter 1985, Katz and Shapiro 1985), increasing demand (Shepard 1987), facilitating collusion (Shapiro 1985), reducing wasteful R&D spending (Gallini 1984), or deterring entry (Rockett 1990). Gallini and Wright (1990) consider the information asymmetry problem in technology transfer. La Manna (1993) extends the Cournot-Nash game model into an oligopoly setting and considers the business-stealing effect of technology transfer.

Technology transfer between developed nations and developing nations has also received much attention. Kabiraj and Marjit (1993) investigate technology transfer between a firm in a developed nation and a firm in a developing nation when the developing nation has a prohibitive tariff that prevents foreign entry. Marjit and Mukherjee (1998) consider the contractual arrangements with equity participation when the success rate of the technology in the developing nations is uncertain. Fess et al. (2009) analyze technology transfer across the border in a model of oligopolistic competition. Clean technology transfer between developing and developed nations (e.g., Dechezleprêtre et al. 2008 and Youngman et al. 2007) is an active research field that receives both political and regulatory attention.

Motivated by practice, we study the possibility of technology transfer and the effects of a bundled mechanism in an oligopoly setting. We find that the bundled procurement facilitates technology transfer, even in the absence of factors that have been traditionally examined in this literature.

Procurement Mechanisms. Procurement is one of the key functions of operations management. Common sourcing practices include auctions, negotiations, and contracts (Elmaghraby 2000). Facing multiple potential suppliers, a buyer may go through a multilateral negotiation (Nagarajan and Bassok 2008) or hold a reverse procurement auction, which has received much attention in recent years. For example, Chen et al. (2005) consider transportation costs for efficient multiunit auctions. Cachon and Zhang (2006) incorporate supplier lead time into the optimal auction mechanism design. Chen (2007) designs an optimal auction that determines both the purchase quantity and the price simultaneously. Wan and Beil (2014) analyze auction design under the impact of a regional cost shock. Chu (2009) designs truthful double auctions that support bundle synergy. Beil and Wein (2003) and Parkes and Kalagnanam (2005) study multiattribute

auctions under which the buyer cares about both the price and the nonprice attributes. Engelbrecht-Wiggans et al. (2007) study a setting in which the buyer can choose to evaluate bids based on price only or take other nonprice attributes into consideration. Kostamis et al. (2009) consider a setting in which the nonprice attribute is assigned by the buyer.

Various sourcing practices may also be combined to achieve the best procurement outcome. Engelbrecht-Wiggans and Katok (2006) consider the setting under which the buyer adopts both the reverse auction and noncompetitive contracts. Huh and Park (2010) consider a sequential auction-bargaining procurement model.

In our model, we utilize knowledge from auction theory to predict the multilateral negotiation outcome. What differentiates our paper from the above literature is that the suppliers in our setting need to decide the technology offer and consider the future implications of technology transfer because the buyer would like to acquire the technologies and become a future competitor.

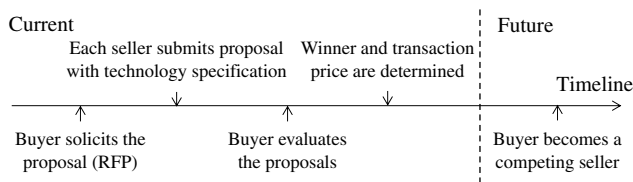
3. The Model

In this section, we propose a model for the bundled procurement mechanism under which the buyer not only procures the tangible goods but also acquires the intangible technologies from the suppliers so that she can compete with them in the future (hereinafter, the buyer will be referred to as “she” and the supplier will be referred to as “he”). We first describe the timeline of the events and then specify the relevant notations.

3.1. The Timeline

Consider a buyer who would like to procure certain products in the current period and the underlying technologies to compete in the future. The buyer can set up a bundled procurement in the current stage as follows: (i) the buyer first goes through the request for proposal (RFP) process, which specifies the size of the current procurement project; (ii) in response to the RFP, each supplier determines his technology offer and submits his proposal with the technology offer and ask price; (iii) given the proposals, the buyer evaluates the offers, taking into consideration the future profit; and (iv) after the evaluation, the buyer leverages the suppliers’ competing offers and demands the suppliers to lower their ask prices through a multilateral negotiation. At the end of this negotiation process, a winning supplier emerges, and the transaction price is determined for the bundled procurement. Figure 1 illustrates this timeline.

After the current stage, the buyer acquires the technology specified in the proposal from the winning supplier and competes with current suppliers in the future stage. Numerous future buyers may emerge

Figure 1 Timeline of the Events

and have procurement needs of different sizes at various time points. The procurement process in the future stage is identical to that in the current stage, except that we assume that there is no technology transfer in the future and only the buyer and the suppliers in the current stage will be the suppliers in the future stage. That is, when the future buyers evaluate the proposals, they only consider the benefit from the tangible goods as they do not acquire the intangible technologies. This assumption enables us to focus on the interplay among the current buyer and suppliers.

The suppliers can have different technological capabilities. When responding to the RFP, each supplier needs to decide his technology offer within his own technology domain. The buyer evaluates suppliers' offers based on her utility drawn from the procurement project in the current stage and the future profit from the technology transfer. The buyer's utility from the current stage increases stochastically with the value (or level) of the technology that goes into the project. The buyer's expected future profit from the technology transfer depends on the technology offer as well because the acquired technology determines her competitiveness in the future. Because the buyer aims to maximize the difference between the overall gain (from both the current stage and the future stage) and the ask price, the evaluation process enables the buyer to create a price adjustment term for each supplier based on his technology offer. A supplier with a higher price adjustment term would be able to demand a higher ask price, *ceteris paribus*. The price adjustment terms are truthfully revealed to the suppliers and utilized in a multilateral negotiation, which is, in spirit, similar to the open-bid format outlined in [Kostamis et al. \(2009\)](#). That is, during the negotiation, the buyer leverages the suppliers' competing offers and demands the suppliers to lower their ask prices gradually until all but one supplier has dropped out of the negotiation. At the end of this multilateral negotiation process, the last remaining supplier is the winning supplier and his final ask price is the transaction price.

For several reasons, we restrict our attention to the model setting under which the suppliers decide the technology offers before the price negotiation. First, we observed that both the products procured and the technologies transferred were rather complicated under the large-scale infrastructure projects

by the Chinese government. Because of the local conditions, China typically demanded performance specifications that were unheard of at the time of procurement. As a result, instead of offering some "off-the-shelf" technology, the supplier's proposal outlined an action plan with technology and knowledge involved as well as time and money needed. Both creating and evaluating such a plan could be complicated tasks, which make dramatic technology offer change impractical. Second, we observed that while minor technical adjustments did happen during the negotiation process, the focus of the negotiation process was mainly on the nontechnology factors, like price, financing, and contract terms. Typically, the most notable achievement of the negotiation process on the buyer side was price reduction, which also indicates that the initial ask prices were less relevant. Third, the theoretic model provides a dominant technology offer strategy result, which implies that even if the supplier is given an opportunity to revise his technology offer, he would still choose the same technology value. Therefore, we believe that the technology offer commitment assumption closely resembles the real-life situation and has a minor impact on our analysis.

While we have described a bundled procurement mechanism as a dynamic stochastic game with complete information among a buyer and a given set of suppliers, this process in fact allows the suppliers to opt out. It can also be used to evaluate supplier behavior and procurement outcome when the buyer procures only tangible goods or only intangible technologies. If a supplier decides not to participate in the bundled procurement, he can submit an extremely inferior technology (say, technology that has a value of negative infinity), and the abysmally low evaluation of this technology offer would ensure that the supplier loses the procurement project. If we want to evaluate supplier behavior and procurement outcome when the buyer acquires only tangible goods, we can investigate the case when the expected size of the future market drops to zero. If we want to evaluate the supplier behavior and procurement outcome when the buyer acquires only the intangible technologies, we let the size of the current project drop to zero. By evaluating these two extreme cases, we can calibrate the benefit of the bundled procurement mechanism.

3.2. The Notation

Assume that a total of n suppliers compete for the procurement project in the current stage and we index them as players from 1 to n . We index the current buyer as player 0; this buyer will become a supplier and compete with the current suppliers in the future.

Let k be the size of the current procurement need (e.g., k units of the tangible product are being procured). While numerous future buyers may emerge and have procurement needs of different sizes at various time points, let l be the expected total discounted future market size. We define $\alpha \equiv k/l \in [0, \infty)$ “current weight ratio,” which captures the relative size of the current project.

A total of n suppliers compete in the current stage. Each supplier is capable of offering technologies with different values. Let \bar{v}_i denote the maximum technology value of supplier i ($i = 1, 2, \dots, n$). We assume that supplier i can offer a technology with value v_i and submit an initial ask price p_i if and only if $v_i \leq \bar{v}_i$ (note that v_i can be negative). To simplify the exposition, we normalize the cost of the procurement project for all suppliers under all technologies to be 0. Thus, the suppliers are indifferent between quitting and undertaking the procurement project at price 0 in the absence of future market concerns. In the online appendix, we relax this zero-cost assumption and show that only the difference between the technology value and the cost matters. We further show that all the results continue to hold when the suppliers have private cost-saving information.

A total of $n + 1$ suppliers—that is, the original n suppliers and the current buyer—compete in the future stage. We assume that the n original suppliers retain their maximum technology value \bar{v}_i , while the current buyer’s maximum technology value \bar{v}_0 is v_i , acquired from winning supplier i ’s technology offer. Abstracting away from a specific technology advancement model, we are able to focus on how to leverage competition in this base model. In §§5.1 and 5.3, we discuss the implication of technology adoption failure and technology advancement.

For both the current stage and the future stage, the buyer’s utility increases with the technology value. Specifically, the buyer derives a per-unit utility $U_i(v) = v + \epsilon_i$ from the tangible goods with technology value v when contracting with supplier i , where ϵ_i is a random term realized during the evaluation process. Valuation uncertainty may arise because of the complexity of the procurement project and the nontechnology factors because of the detailed contract terms (e.g., the change order process and the arbitration process), financing options (coverage ratio and duration), corporate culture, and international political dynamics. Notice that $U_i(v)$ captures the social welfare generated from the tangible goods in the current stage because we have normalized the costs to zero. We assume that ϵ_i is independently drawn from some known distribution F_i . Index i runs from 1 to n for the current stage and 0 to n for the future stage, respectively. (The independence assumption has no bearing on our results, although it simplifies the exposition.)

Table 1 Summary of the Notation

Notation	Definition	Functional relationships
k	The size of current procurement need	
l	The discounted future market size	
α	Current weight ratio	$\alpha \equiv k/l \in [0, \infty)$
\bar{v}_i	Supplier i ’s maximum technology value	
v_i	Supplier i ’s technology offer	$v_i \leq \bar{v}_i$
p_i	Supplier i ’s per-unit ask price	
F_i	Valuation uncertainty distribution of supplier i	
ϵ_i	Valuation uncertainty of supplier i	$\epsilon_i \sim F_i$
$U_i(v)$	Buyer’s per-unit utility from supplier i with technology value v	$U_i(v) = v + \epsilon_i$
$V_i(v)$	Expected per-unit future profit of player i when $\bar{v}_0 = v$	
$V(v)$	Expected per-unit future profit of all the players when $\bar{v}_0 = v$	$V(v) \equiv \sum_{i=0}^n V_i(v)$

Given that the current buyer acquires a technology with value v , we use $V_i(v)$ to represent the expected per-unit future profit for player i ($i = 0, 1, \dots, n$). We also define $V(v) \equiv \sum_{i=0}^n V_i(v)$ as the expected per-unit future profit for all the players. Table 1 summarizes the notation used. Notice that the dynamic game model is essentially defined through $2n + 2$ parameters: α captures the relative size of the current project and \bar{v}_i s and F_i s determine the intensity of supplier competition.

In line with the technology transfer literature, we study a dynamic stochastic game with complete information and focus on how the bundled procurement mechanism can help the buyer leverage competition and ensure technology transfer. The model assumes that the buyer can estimate the value of the supplier’s technologies but that she lacks the detailed knowledge and technology know-how to provide the solutions, which closely resembles the situation the Chinese firms have faced. We also point out that, in practice, the buyer does not need to know the exact information to decide whether to adopt the bundled procurement or not because the decision is insensitive with respect to the parameters under reasonable market conditions.

4. The Analysis

We analyze this dynamic game using the standard backward induction method. We start with the future stage and first calculate the expected future profit for each player assuming that the current buyer acquires some technology with value v . We then investigate how the winner and the transaction price are determined in the current stage. Lastly, we study the optimal technology offer strategies of the suppliers and the effectiveness of the bundled procurement mechanism.

Before starting the formal analysis, it is beneficial to point out that the initial ask prices do not play

a role in the analysis because the transaction price is determined by the fierce competition among the suppliers. It is in each supplier's best interest to start with a sufficiently high initial ask price as the supplier always lowers the ask price during the negotiation process. Thus, the key decision for each supplier is the technology offer decision.

4.1. Expected Future Profit

In the future stage, the buyers only procure the tangible goods, not the intangible technologies. Assume that the current buyer acquires a technology with value v in the current stages. We show that the aforementioned procurement process in the future stage is equivalent to a second-price auction with all $n + 1$ suppliers offering their own maximum technology values.

First, it is straightforward to see that supplier i offers the maximum technology value \bar{v}_i in the future stage because the buyers do not procure the intangible technologies. Given that the future buyer's per-unit utility $U_i(v) = v + \epsilon_i$, offering a higher v increases the utility of the buyer and enables the supplier to charge a higher transaction price. Thus, offering the maximum technology value \bar{v}_i is the dominant strategy for supplier i ($i = 0, 1, \dots, n$).

Furthermore, after the uncertainty is resolved and made public to the suppliers, the buyer can maintain all the ask prices such that she is indifferent among all the $n + 1$ suppliers and can demand lower ask prices from the suppliers during the negotiation. Supplier i would quit the competition when his ask price reaches his cost, which is normalized to 0. It turns out that the most efficient supplier (who has the largest $\bar{v}_i + \epsilon_i$) would be the winning supplier and the transaction price is his ask price when the second most efficient supplier drops out of the competition. It is well-known from the auction literature (e.g., see Krishna 2002) that under this case, the payoff of the buyer is essentially the social welfare when the second most efficient supplier is selected, whereas the payoff of the winning supplier is the difference of the social welfare with and without the participation of the supplier.

PROPOSITION 1. *The expected per-unit future profit of a player is the difference of the expected social welfare with his participation and without his participation, $V_i(v) = E[\max_{j=0, \dots, n} \{\bar{v}_j + \epsilon_j\}] - E[\max_{j=0, \dots, n, j \neq i} \{\bar{v}_j + \epsilon_j\}]$, where $\bar{v}_0 = v$.*

Given that the expected discounted future market size is l , the expected future profit for player i is $lV_i(v)$, and the expected future profit for all the players is $lV(v)$, when the current buyer acquires a technology with value v . Lemma 1 states that as the potential future competitor (i.e., the buyer) gets a technology with a higher value, the expected future profits of the current suppliers decrease.

LEMMA 1. *$V_0(v)$ is (weakly) increasing in v and $V_i(v)$ ($i = 1, 2, \dots, n$) is (weakly) decreasing in v .*

4.2. Current Winner Determination

To investigate which supplier would be the winning supplier, we first examine when a supplier drops out during the negotiation process. To highlight the interplay among the competing suppliers and the buyer, we focus on the case of two suppliers (i.e., $n = 2$) in the remainder of §4.

During the negotiation process, suppose that supplier i has offered a technology with value v_i ($i = 1, 2$) and the random variables ϵ_i ($i = 1, 2$) have been realized. Let us call the supplier who offers a higher v value the technology leader and the one with a lower v value the technology follower. When the buyer does not acquire the technologies, each supplier would drop out of the negotiation process when his ask price reaches his cost, which is normalized to 0. Lemma 2 describes the suppliers' behavior when the buyer acquires the technologies.

LEMMA 2. *Technology leader would drop out of the competition at an ask price (weakly) above zero, and technology follower would drop out of the competition at an ask price (weakly) below zero.*

Recall that the supplier is indifferent between undertaking the procurement project and quitting at price 0 in the absence of technology transfer concerns. When the suppliers care about their future profits, which is a (weakly) decreasing function of the technology value acquired by the current buyer (Lemma 1), both suppliers would like the buyer to acquire a technology with a lower value. As a result, the technology leader would bid more conservatively and drop out before the price reduces to zero, while the technology follower would bid more aggressively and be willing to take a (small) current loss. The analysis of Lemma 2 enables us to establish the following theorem:

THEOREM 1. *The supplier who provides the larger aggregate gain—i.e., $kU_i(v_i) + lV(v_i)$ —wins the procurement ($i = 1, 2$). Furthermore, if supplier i wins and supplier j loses, supplier i 's total expected profit is $(kU_i(v_i) + lV(v_i)) - (kU_j(v_j) + lV(v_j)) + lV_i(v_j)$, and supplier j 's total expected profit is $lV_j(v_i)$.*

Notice that $U_i(v_i)$ is the per-unit social welfare for the current stage when supplier i wins the procurement, whereas $V(v_i)$ captures the total expected per-unit profit in the future market for all three players. Theorem 1 states that winning supplier i needs to ensure a reasonable payoff for both the buyer and the opponent via a larger aggregate gain. Losing supplier j 's expected profit is $lV_j(v_i)$, and winning supplier i 's expected total profit is the difference between

the aggregate gain when he is selected versus the other supplier is selected plus $IV_i(v_i)$, which is supplier i 's reserved future profit. Theorem 1 holds as long as the current buyer and suppliers can estimate the expected future profits as functions of the technology value transferred. The result does not depend on the functional form established in Proposition 1.

4.3. Technology Offer Strategy

Based on Theorem 1, we can now study the optimal technology offer strategies of the suppliers. Theorem 2 summarizes the main finding.

THEOREM 2. *Supplier i 's optimal technology offer strategy $v_i^* \in (-\infty, \bar{v}_i]$ maximizes $kv_i + IV(v_i)$, or equivalently $k(v_i + E[\epsilon_i]) + IV(v_i)$, the expected aggregate gain.*

Theorem 2 holds for any distribution F_i and offers a dominant technology offer strategy that is independent of the opponent's technology offer strategy. When supplier i decides the optimal technology offer, he needs to balance the current profit and the future threat. When the future market is irrelevant (i.e., $l = 0$), we obtain the classic second-price auction result under which all suppliers provide their highest technology values $\{\bar{v}_i\}_{i=1,\dots,n}$. With the future market ($l > 0$), the best strategy is to maximize the aggregate gain, taking into account both the current period and the future market. Understanding the threat from the upcoming price negotiation, the suppliers should "soften the blow" the technology transfer will inflict on the opponent when determining the technology offer and maximize the aggregate gain for all three players. It is also worthwhile to point out that Theorem 2 holds as long as the current buyer and suppliers can estimate the expected future profits as functions of the technology value transferred. That is, even if the future profit function V_i does not follow the specific functional form derived in Proposition 1 (e.g., because the supplier selection process in the future market has different concerns), maximizing the aggregate gain is still the dominating technology offer strategy for the suppliers. Notice that the dominant strategy result implies that when the uncertainty is independent of the supplier's technology offer, even if the supplier is given an opportunity to revise his technology offer after the realization of the uncertainty, he would still choose the same technology value because it is the value that optimally balances the trade-off between the current profit and the future threat.

Theorem 2 is derived when only two suppliers compete for the procurement project. When we have more than two suppliers (i.e., $n > 2$), the aggregate gain continues to play an important role in the determination of the suppliers' technology offers. Specifically, one can show that offering the highest technology value is a dominant strategy for supplier i if doing so maximizes the aggregate gain for

all the players (i.e., $v_i = \bar{v}_i$ maximizes $kv_i + IV(v_i)$ on $(-\infty, \bar{v}_i]$).

4.4. The Impact of Project Size α

We now investigate how parameter α impacts each supplier's optimal technology offer for the case of two suppliers. Without loss of generality, we assume $\bar{v}_1 \geq \bar{v}_2$. The following corollary is due to Theorem 2.

COROLLARY 1. *v_i^* is a (weakly) increasing function of α .*

Corollary 1 formalizes the intuition that as the current procurement project becomes more important, the suppliers are less concerned with the future competition and offer higher technology values. To better understand how suppliers respond to α , we establish a threshold for α above which all the suppliers offer the technology with the highest values in §4.4.1, and we show that the optimal technology offer is not continuous with respect to α in §4.4.2.

4.4.1. A Conservative Threshold of α . We show that $\alpha = 1$ is sufficiently large to induce the suppliers to offer their best technologies under arbitrary distribution F_i .

THEOREM 3. *For $\alpha \geq 1$, offering technology value \bar{v}_i is supplier i 's optimal strategy.*

While Theorem 3 holds for any distribution F_i , this bound is too conservative and requires the current project to be (weakly) larger than the future market. The bound is tight if the supplier selection rule is deterministic.

COROLLARY 2. *When the evaluation process is deterministic, i.e., $\epsilon_i = 0$, offering $\min\{\bar{v}_i, \tilde{v}\}$ when $\alpha < 1$ and \bar{v}_i when $\alpha \geq 1$ is a dominant technology offer strategy for supplier i , where \tilde{v} is the opponent's maximum technology value (i.e., $\tilde{v} = \bar{v}_j$, where $j \neq i$).*

Under the deterministic case, the supplier with the highest technology value always wins the procurement and captures the entire industry profits. Thus, the current project needs to be (weakly) larger than the future market to induce this supplier to surrender the technology and the future market. Under this case, the buyer would not benefit from the bundled procurement even if she acquires the best technology because the escalated competition would diminish the industry profits. For the bundled procurement to be preferred, the current buyer needs competition among current suppliers and a sizable project that enables the buyer to leverage supplier competition. In §4.6 and the online appendix, we establish the threshold value of α for popular discrete choice models.

Theorem 3 and Corollary 2 in fact hold for an arbitrary number of suppliers. When we have more than two suppliers, \tilde{v} in Corollary 2 becomes the highest value in $\{\bar{v}_j\}_{j=1,\dots,n, j \neq i}$.

4.4.2. The Discontinuity of the Technology Offer.

Given that we are dealing with a continuous model, one would naturally conjecture that the technology value offered by each supplier is a continuous function of α . This turns out to be false even for the symmetric supplier case.

THEOREM 4. Suppose that $\bar{v} = \bar{v}_1 = \bar{v}_2$ and ϵ_i ($i=0, 1, 2$) are continuous i.i.d. random variables, (i) $V'(\bar{v}) = 0$ and (ii) the suppliers' optimal technology offer v is not continuous with respect to α as long as $V(\bar{v}) < \sup\{V(v) | v \leq \bar{v}\}$.

The discontinuity exists so long as there exists some lower level of technology at which the combined expected future profits of the suppliers would be higher than they would be at the maximum level of technology. This condition ensures that the suppliers would not offer the highest technology value \bar{v} when no tangible goods are being procured by the current buyer, which is consistent with the challenges the Chinese firms have faced when they try to acquire the state-of-the-art technologies through direct technology transfer.

Corollary 1 indicates that when α is small, the suppliers are likely to offer low technology values. The numerical studies in §4.6 and the online appendix show that the optimal value v approaches $-\infty$ as α approaches 0 and the overall future industry profit function $V(v)$ is usually decreasing in v when v is small, i.e., when the current buyer becomes a weak technology player in the future market. When v is small, it is unlikely for the current buyer to win future procurement projects, and her existence intensifies competition and diminishes the industry profits. Therefore, the overall future industry profit is maximized when the current buyer is absent (i.e., $\bar{v}_0 = -\infty$).

When v is large, the overall future industry profit can be increasing in v as the industry becomes more competent. To understand this point, imagine the current buyer is endorsed with some technology with v much larger than the current suppliers' highest technology value, $\max\{\bar{v}_1, \dots, \bar{v}_n\}$. Under this case, a larger v would make the buyer and the industry more competent in the future stage and create a higher future industry profit. It turns out that when v is close to $\max\{\bar{v}_1, \dots, \bar{v}_n\}$, the incremental contribution of the technology value transferred to the overall future industry profit becomes neutralized under the symmetric case (as reported by Theorem 4) and in fact can be positive under the asymmetric case. This is because when the current buyer acquires some advanced technology (i.e., v close to $\max\{\bar{v}_1, \dots, \bar{v}_n\}$), she becomes sufficiently competent and has a reasonably large chance to secure procurement contracts in the future. Her competency contributes to the industry competency and the overall industry profit. As a

result, despite the fact that all the existing suppliers would face lower future profits because of the intensified competition, the overall future industry profit can be (weakly) increasing in the technology value transferred.

The fact that the overall future industry profit can be either decreasing or increasing depends on the value of technology transferred results in a rather dichotomous optimal technology offer response: when α is small, while better technologies are offered as α increases (Corollary 1), the suppliers are concerned about the competition and they only offer technologies with low values; when α crosses some threshold, the supplier's optimal response jumps to the technology with the highest value because raising a competent future technology leader enables a higher overall future industry profit and a higher aggregate gain (i.e., $\alpha v + V(v)$), which can be shared by the suppliers through higher ask prices. There exists an intermediate range of technology values that are never optimal to offer.

4.5. The Effectiveness of the Bundled Procurement Mechanism

Does the current buyer benefit from a bundled procurement mechanism? To answer this question, we compare different procurement mechanisms and study the buyer's policy selection problem. Because it is unlikely for the buyer to acquire technologies when she procures only intangible technologies, we compare the outcome under the bundled procurement mechanism with the outcome when the buyer procures only tangible goods.

When the buyer procures only tangible goods, both suppliers provide technologies with the highest value, and the buyer's expected payoff only comes from the current stage, which equals $E[\min\{k(\bar{v}_1 + \epsilon_1), k(\bar{v}_2 + \epsilon_2)\}]$. Under the bundled procurement mechanism, the buyer's expected payoff is the aggregate gain minus the suppliers' payoffs, which equals $E[\min\{k(v_1 + \epsilon_1) + IV(v_1), k(v_2 + \epsilon_2) + IV(v_2)\}] - IV_1(v_2) - IV_2(v_1)$ by Theorem 1, where v_1 and v_2 are the optimal technology offers of the suppliers. Suppose that α is sufficiently large so that offering the highest technology value is the suppliers' optimal response. Under this case, the suppliers make the same technology offers under both mechanisms. The buyer would enjoy a future profit under the bundled procurement mechanism but no future profit when she procures only tangible goods. How much additional premium does the buyer need to pay to acquire the technologies under the bundled procurement mechanism? The next proposition shows that it can be free if the suppliers are symmetric.

PROPOSITION 2. Suppose that the technology offers $v_1 = v_2 = \bar{v}_1 = \bar{v}_2$, the buyer's expected payoff in the current stage is the same under the bundled procurement mechanism and under the mechanism that procures only tangible goods despite the fact that the buyer would enjoy a future profit under the bundled procurement mechanism.

Proposition 2 implies that when the current buyer is able to induce the suppliers to offer their highest technology values under the bundled procurement mechanism, the additional premium for the technologies can be negligible when the intensity of supplier competition is high. Therefore, the bundled procurement mechanism can dominate the traditional procurement mechanism if the buyer can leverage the supplier competition via a sufficiently large procurement project.

4.6. Numerical Studies Under the Multinomial Logit Model

To gain a better understanding on the required size of the procurement project and the effectiveness of the bundled procurement to the buyer, we study the multinomial logit model (hereinafter, MNL). Under MNL, ϵ_i are i.i.d. according to the double exponential distribution: $F(x) = e^{-e^{-(x/\mu + \gamma)}}$, where μ is a positive scalar constant and γ is Euler's constant that ensures a zero mean. The MNL model rises as a natural candidate in empirical studies when discrete choice analysis is conducted for the supplier selection problem (Verma and Pullman 1998, van der Rhee et al. 2009, Tam and Hui 2001, Watt et al. 2010). In the online appendix, we consider an alternative discrete choice model called the multinomial probit model, under which the random term follows the normal distribution.

Under MNL, we define the normalized technology gap as $\Delta \equiv (\bar{v}_1 - \bar{v}_2)/\mu$ for the two-supplier case. If

technology transfer is not allowed and both suppliers always offer their best technologies, it is straightforward to show that the winning probabilities and the market shares of the two suppliers can be written as $e^\Delta/(e^\Delta + 1)$ and $1/(e^\Delta + 1)$, respectively (Anderson et al. 1992). The dynamic game under the MNL model is essentially defined through two parameters: α captures the relative size of the current project, and Δ captures the intensity of supplier competition.

Figure 2 illustrates how the optimal technology value v^* varies as a function of α for $\Delta = 0$ and $\Delta = 0.5$. As described by Theorem 4, the optimal technology offer is not continuous with respect to α and jumps to the highest technology value once α reaches some threshold. Prior to the jump, the current buyer would be quite incompetent in the future market (e.g., the current buyer would have a future market share less than 8.2% prior to the jump when $\Delta = 0$).

Figure 3(a) specifies the minimum α needed to induce supplier 1 to offer the highest technology value \bar{v}_1 for a given Δ . For example, when $\Delta = 0$, $\alpha \geq 0.0568$ induces supplier 1 to offer \bar{v}_1 . To capture the whole scope of Δ , the x -axis in Figure 3(b) is the implied market share $e^\Delta/(e^\Delta + 1)$, which varies from 0 to 1 as Δ varies from $-\infty$ to ∞ . As Δ approaches ∞ and we approach the deterministic case under which supplier 1 captures the entire industry profits, α approaches 1 (Theorem 3 and Corollary 2). The function $\alpha(\Delta)$ is quite flat when $|\Delta|$ is small and the two suppliers' market shares are comparable. Specifically, when $|\Delta| < \ln(2) = 0.693$, which corresponds to the case in which the technology leader's implied market share is at most twice as large as that of the technology follower, $\alpha = 10\%$ is sufficient to induce the suppliers to offer their highest technology values.

To quantify the effectiveness of the bundled procurement mechanism, we compare the buyer's expected profit under the bundled procurement with

Figure 2 (Color online) Optimal Technology Value v^* as a Function of α (at $\mu = 1$)

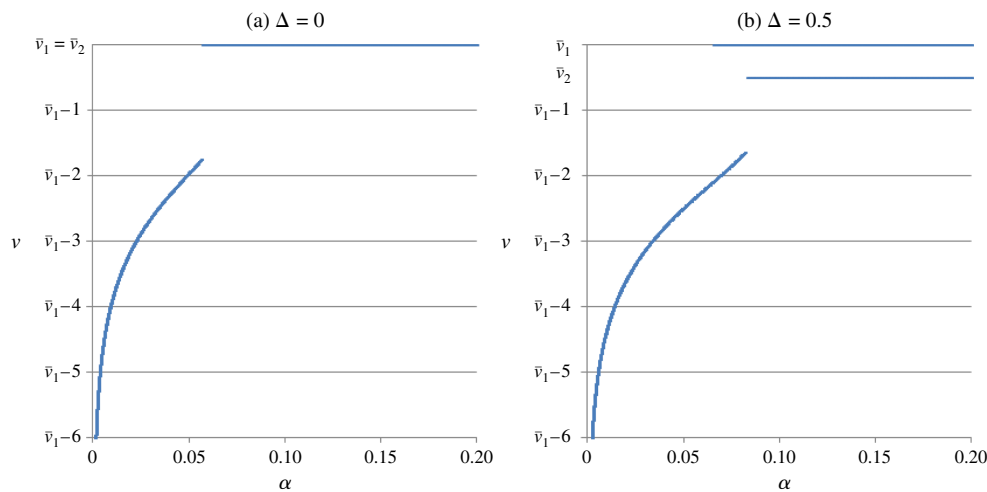
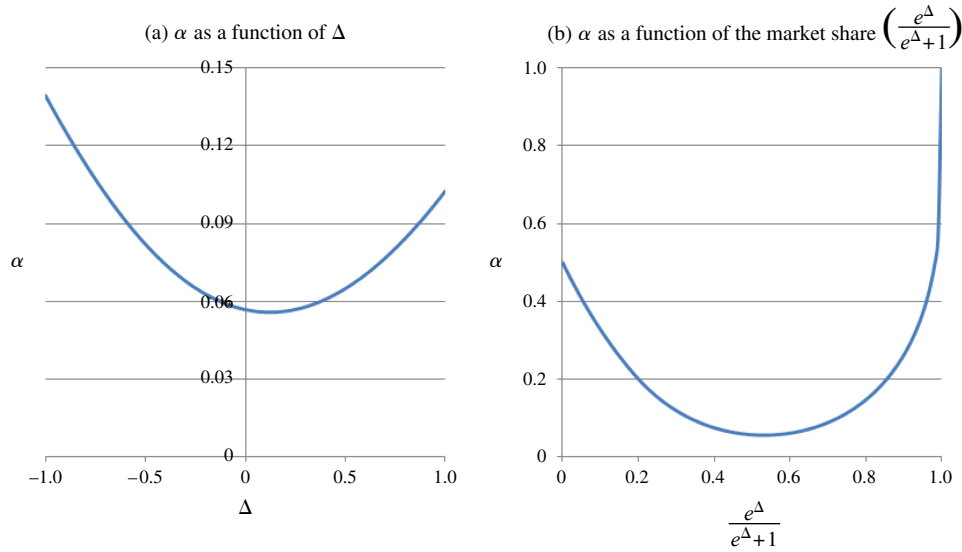


Figure 3 (Color online) Minimum α Such That $v^* = \bar{v}_1$ for Supplier 1

the profit when she procures only tangible goods. We find that when $|\Delta| \leq 1$, the bundled procurement is preferred if and only if $\alpha \geq \alpha(|\Delta|)$, i.e., α is large enough to induce the technology leader to offer his highest technology value. When $|\Delta|$ increases, procuring only tangible goods can be preferred even if α is greater than 1 and both suppliers offer their respective highest technology values. Under this case, the technology leader essentially has a monopoly position while technology transfer results in a duopoly, which reduces the industry profits. When $|\Delta| \leq 1$, $\alpha \geq \alpha(\Delta)$ and $\alpha \geq \alpha(-\Delta)$, we also calculate the buyer's expected future profit from the technology acquisition and the expected cost for the technology acquisition in the current stage (i.e., the procurement cost under the bundled procurement mechanism minus the procurement cost when the buyer only procures the tangible goods). We observe that the cost for the technology acquisition is relatively small compared to the expected profit from the future market. Furthermore, this cost goes down to zero as supplier competition intensifies and the suppliers become substitutable with each other (Proposition 2).

5. Further Discussion

In this section, we consider various extensions of the model. Additional extensions on cost parameters and private cost-saving information is available in the online appendix.

5.1. Technology Adoption Failure

In the original model, we assume that the buyer always adopts the technology successfully from the winning supplier and competes with current suppliers in the future. Nevertheless, technology adoption

usually comes with a high failure rate. In this section, we introduce a success rate ρ for the buyer's technology adoption and show that the players only need to discount the future market size l accordingly in the decision-making process.

Recall that supplier i 's per-unit expected future profit is $V_i(v)$ when the current buyer acquires a technology with value v . Originally, when supplier i competes with supplier j in the negotiation process, supplier i drops out if the ask price p_i is so low that $kp_i + lV_i(v_i) \leq lV_i(v_j)$. Now, with probability $(1 - \rho)$, the buyer will fail to adopt the technology, and the future market competition does not depend on the technology offer in the current stage. Therefore, supplier i drops out if the ask price p_i is so low that $kp_i + \rho lV_i(v_i) \leq \rho lV_i(v_j)$. That is, the suppliers can take the adoption probability into consideration by discounting the relevant future market size.

Not only do the suppliers discount the future market size, but the buyer discounts the future market size as well. To see this, during the negotiation process, the buyer prefers supplier i with higher $k(U_i(v_i) - p_i) + lV_0(v_i)$ when she always adopts the technology successfully. Given the success rate ρ , the buyer prefers supplier i with higher $k(U_i(v_i) - p_i) + \rho lV_0(v_i)$, effectively discounting the future market size to ρl . As a result, when deciding the technology offers, each supplier's dominant strategy is to maximize $kv + \rho lV(v)$, and all the results continue to hold once we replace l with ρl .

With $\rho \in (0, 1)$, the buyer essentially has a larger effective α , and the suppliers are less concerned with the future competition and offer better technologies. As ρ decreases, the buyer's future profitability decreases. A probability $\rho (< 1)$ can, in fact, be beneficial to the buyer if the original current weight

ratio (i.e., k/l) is insufficient to induce the suppliers to supply the best technologies, while the low success rate can convince the suppliers to offer their best technologies.

5.2. Bargaining Power

In the original model, we assume that the winning supplier has absolute bargaining power relative to the buyer, i.e., the supplier retains the entire incremental aggregate gain because of his participation as his profit. In this section, we relax this assumption and consider bargaining power.

Under the standard Nash bargain, the supplier and the buyer split the incremental gain over status quo utilities in fixed proportions that depend on bargaining power. Let $\beta_i \in (0, 1)$ ($i = 1, \dots, n$) be the share of supplier i and $(1 - \beta_i)$ be the share of the buyer, i.e., $\beta_i/(1 - \beta_i)$ is the bargaining power of supplier i relative to that of the buyer in the current stage. Let $\gamma_i \in (0, 1)$ ($i = 0, \dots, n$) be the (expected) share of player i and $(1 - \gamma_i)$ be the share of the buyer in the future stage. The player's status quo utility in the future stage is zero.

We first analyze player i 's future profit. In the future stage, the buyer can demand the suppliers to lower their ask prices in a fashion such that she is indifferent among any offers. When a supplier no longer lowers his ask price, he would "drop out" according to the earlier auction terminology. In the actual multilateral negotiation process, the buyer would not force out the suppliers (i.e., any supplier can theoretically be a winner before the contract is signed), and his offer may serve as a valid status quo utility for the buyer. As the buyer continues to demand lower ask prices, higher status quo utilities are revealed as more suppliers cease to lower the ask prices. When only one supplier is willing to lower the ask price, this supplier is the most efficient supplier, and the buyer's status quo utility is the social welfare without the most efficient supplier. The buyer and the most efficient supplier share the incremental gain depending on their bargaining power. Thus, supplier i 's per-unit expected future profit becomes $\gamma_i V_i(v)$ instead of $V_i(v)$. Denote $\gamma V(v) \equiv \sum_{i=0}^n \gamma_i V_i(v)$, the expected per-unit industry profit under bargaining power.

Now consider the current stage under the two-supplier case. The buyer can demand the suppliers to lower their ask prices in a fashion such that she is indifferent among the two offers (i.e., $k(U_i(v_i) - p_i) + l\gamma_0 V_0(v_i) = k(U_j(v_j) - p_j) + l\gamma_0 V_0(v_j)$ ($i, j = 1, 2, i \neq j$)). Without loss of generality, assume that supplier i ceases to lower his ask price before supplier j ; the price p_i must be so low that $kp_i + l\gamma_i V_i(v_i) \leq l\gamma_i V_i(v_j)$. The fact that supplier j is willing to lower his price implies that $l\gamma_j V_j(v_i) \leq kp_j + l\gamma_j V_j(v_j)$. Adding up the

three inequalities reveals that supplier i would first cease to lower the ask price if and only if he provides a smaller aggregate gain (i.e., $kU_i(v_i) + l\gamma V(v_i) \leq kU_j(v_j) + l\gamma V(v_j)$). When supplier i ceases to lower his ask price, his offer provides the status quo utilities for both the current buyer and supplier j . The status quo utility of supplier j is $l\gamma_j V_j(v_i)$, and the status quo utility of the buyer is $k(U_i(v_i) - p_i) + l\gamma_0 V_0(v_i)$, where p_i is such that $kp_i + l\gamma_i V_i(v_i) = l\gamma_i V_i(v_j)$. Supplier j and the buyer split the incremental gain $(kU_j(v_j) + l\gamma V(v_j)) - (kU_i(v_i) + l\gamma V(v_i))$ according to the parameter β_j . As a result, choosing v that maximizes the aggregate gain $(kv + l\gamma V(v))$ is the dominant technology offer strategy for the suppliers.

It is interesting to note that β_i and γ_i have totally different implications. The parameter γ_i governs how the industry profits vary with v , and the players care less about the future market with a smaller $\gamma_i \in (0, 1)$. While $\beta_i \in (0, 1)$ changes the profit allocation among the players, it has no bearing on the supplier's strategic decision on technology provision.

5.3. Technology Advancement

We have proposed a stylized model to study the effectiveness of the bundled procurement mechanism and to evaluate the role of supplier competition in technology transfer. As a result, no technology advancement is assumed. Whereas this assumption may be appropriate for mature industries with no major breakthrough expected, it will not be appropriate for all the industries. In this section, we discuss the implication of technology advancement and how the industry-specific technology advancement model can be incorporated into the proposed model.

First, consider the case that all the players can advance the technologies and improve the values by some common value a . That is, the maximum technology value for current supplier i in the future stage would be $\bar{v}_i + a$ and the maximum technology value for the current buyer in the future stage would be $v + a$, where v is the current winning supplier's technology offer. In this case, all the results continue to hold. To see this, notice that the winning supplier's profit is derived through a negotiation process under which only the difference of technology values matters. When all the suppliers' technology values increase by the same amount, the buyer's payoff increases but not those of the suppliers'. Therefore, the expected future profit functions remain the same, and all the results continue to hold.

Now consider the case that the technology advancements are idiosyncratic and stochastic. That is, the maximum technology value for current supplier i in the future stage would be $\bar{v}_i + a_i$ and the maximum technology value for the current buyer in the future

stage would be $v + a_0$, where v is the current winning supplier's technology offer and $(a_i)_{i=0,1,\dots,n}$ follows some known joint distribution. This distribution represents the industry-specific knowledge on how each player may advance the technology and whether the industry is expecting a major breakthrough. If such information is available, it can be easily incorporated into the proposed model by updating the functional form of the expected future profit functions V_i . The insights we learned for the general discrete choice model will continue to hold, e.g., each supplier has a dominant technology offer strategy that maximizes the expected aggregate gain under the two-supplier case (i.e., Theorem 2).

The technology advancement discussed in this section actually encompasses both performance enhancement and cost reduction. For a model explicitly considering the cost parameters, refer to the online appendix.

6. Concluding Remarks

In this paper, we presented a procurement mechanism in which the buyer would like to procure intangible technologies with tangible products and compete with current suppliers in the future. We examined the technology offer strategies of the suppliers under this procurement mechanism and found that for the two-supplier case, each supplier has a dominant technology offer strategy that is independent of the opponent's technology offer strategy. When this size of the procurement project is small, the suppliers only offer obsolete technologies, even if the suppliers are perfect substitutes. Whereas suppliers offer better technologies as the size increases, the suppliers' technology offers are not continuous with respect to the size. Once the size reaches some threshold, the supplier's optimal response jumps and the best technology will be offered. When the suppliers offer their best technologies, the premium for technology transfer can be negligible compared to the profit from the future market.

Supplemental Material

Supplemental material to this paper is available at <http://dx.doi.org/10.1287/msom.2014.0517>.

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