Bundled Procurement for (Free) Technology Acquisition and Future Gain
Leon Yang Chu*, Yunzeng Wang†
February 2011

We study the effectiveness of a procurement mechanism of a buyer that bundles the product procurement with the technology acquisition. We analyze the bidding behavior of rational suppliers and predict the outcome of such a bundling strategy. Using the two-supplier case, we find that each supplier has a dominant bidding strategy for the technology provision that is independent from the bidding strategy of the other supplier and solely depends on the technology difference of the suppliers and the ratio between the current project size and the future market size. When the buyer procures the technology separately or this ratio is low, the buyer would not be able to solicit the best technologies even if the suppliers’ technologies are perfect substitutes. As this ratio increases, suppliers provide better technologies. Furthermore, the suppliers’ behaviors are not continuous with respect to the ratio. Once the ratio crosses some threshold, the suppliers’ responses jump and the best technologies will be offered. We find that a ratio of 10% is sufficient for the suppliers to provide best technologies for most reasonable market conditions. When the suppliers provide their best technologies, the buyer would pay a slightly higher price for the current project under the bundling strategy; nevertheless, given the up-to-date technologies, the buyer will be adequately compensated for being able to compete as a supplier in the future market.

Key words: procurement mechanism, game theory, technology acquisition, multinomial logit model, China policy

1. Introduction

Consider a buyer of a product who would like to obtain the underlying technology so that he (hereinafter, the buyer will be referred to as “he,” while suppliers will be referred to as “she”) can compete with current suppliers in the future market to advance his own economic benefit. A natural approach for the buyer is to negotiate a price for a direct technology transfer. As the suppliers understand the potential future threat from the buyer, however, it is usually difficult for the buyer

* Marshall School of Business, University of Southern California, Los Angeles, CA 90089, leonyzhu@usc.edu
† Anderson Graduate School of Management, University of California, Riverside, CA 92521, yunzeng.wang@ucr.edu
to acquire state-of-the-art technology even with the presence of multiple technology providers. The question, then, is: how can the buyer leverage the competition existing among suppliers and acquire the state-of-the-art technology?

The above describes a situation that the Chinese government has faced when contemplating strategies for developing its industries. Over the past quarter century, the Chinese government 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, Chinese firms need state-of-the-art 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). Nevertheless, it has been hard for Chinese firms to close the technology gap, and Chinese consumers are usually stuck with products with out-of-date technologies. For example, auto manufacturers used to ship outdated factory equipment to China to produce older models no longer salable in the West in 80s and 90s — in the mid-90s, one of the most popular taxicabs in China was the Xiali, which was produced by Tianji Xiali and based on the 1987 Daihatsu Charade from Toyota.

Understanding the real threat of future competition, foreign firms are naturally unwilling to transfer their proprietary technologies, even if they are paid a seemingly high current price. For example, before the Three Gorges project, Harbin Electric Machinery attempted to acquire the computational fluid dynamics (CFD) software technology for turbine design at a price of $30 million to no avail (Zhang et al. 2008). Indeed, even though the Chinese economy has sustained an impressive 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).

1 The Three Gorges Dam complex in China is the world’s largest hydroelectric power station in generating capacity. The preparatory and first-phase construction spanned five years from 1993-1997. The second phase ran from 1998-2003 and focused on the generating units in the left bank and the permanent ship lock. The construction of the right bank’s power house, which would be the completion of the entire project, was planned for the third phase from 2003-2009.
In addition to trying to equip its industries with modern technologies, the Chinese government needs to build up its infrastructure. In this process, the government once engaged in a number of large-scale industry projects, most noticeably the Three Gorges Dam and the national high-speed rail system. These projects are large in scale and require advanced technologies and equipment that Chinese firms did not possess at the time. While having to rely on foreign firms to provide the capabilities for completing these projects, the Chinese government of course has a keen interest in using these projects as an opportunity to obtain the technologies. To this end, the government adopted an overall procurement strategy to bundle products (projects) with the underlying technologies. That is, when bidding for a project, suppliers are required to transfer their underlying technologies to Chinese state-owned firms that intend to compete with the current suppliers in the future market (Zhang et al. 2008).

Evidence shows that the Chinese government has been successful in applying such a procurement strategy to achieve its dual goals of completing projects and obtaining 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 suppliers of hydropower equipment, competing with other suppliers in the global market. Similarly, with the construction of its high-speed railway, China’s CNR Corp. and CSR Corp. are now competing for projects in the global market and, in particular, in the U.S. (Shirouzu 2010).

The purpose of this paper is to study the bidding behavior of rational suppliers and to predict the outcome of using a bundling strategy in procurement. Within the domain of her available technologies, a supplier can choose the underlying technology that goes into the current project and that is to be transferred to the buyer. We are interested in understanding the incentives and economic factors that affect a supplier’s choice of technology provision. While by offering a better technology a supplier would enhance her competitiveness or likelihood over other suppliers for securing the project, such a choice helps to incubate a stronger future competitor—i.e., the current

---

2 The Ministry of Railways (MOR) of China has started to build a national high-speed rail network, currently the world’s largest, with a top speed of 380 km/h (240 mph) after five rounds of “speed-up” campaigns from 1993 to 2004, which increased the national average passenger train speed from 48 km/h (30 mph) to 160 km/h (100 mph).
buyer. In equilibrium, we may ask, what are suppliers’ optimal bidding strategies? Under what conditions will they offer their best technologies? Does the buyer benefit from using a bundled procurement, compared with, say, procuring separately for the completion of the project for current consumption, and for technology transfer to participate in future competition? By bundling, does the buyer need to pay a much higher price on the current project?

In trying to answer the above questions, we offer a stylized model to capture the key elements of the economic environment for applying the bundling strategy. Consider a buyer who procures $k$ units of a tangible product that can be built with different technologies, where $k$ can be interpreted as the size of the project. There are $n$ suppliers of the product, each possessing her own technology domain and technology strength. The buyer issues a request for proposals (RFP) to all suppliers, who in response send in their individual bids. Suppliers bid for the project on two dimensions: a price for the project (or for delivering the $k$ units of the product) and the technology which is used to build the products and is also the technology to be transferred to the buyer at no additional charge. Suppliers can choose the technology to offer within their individual limitations of technology strength.

The buyer evaluates suppliers’ bids based on his utility drawn from the current consumption of $k$ units of the tangible products and his economic benefit from obtaining the underlying technology. The buyer’s utility of current consumption of the product stochastically increases with the technology level that goes into the product. The buyer’s economic benefit of obtaining technology depends (stochastically) on the technology level as well, since the obtained technology level determines his competitiveness on future market, the structure of which is to be described shortly. Thus, the buyer faces the problem of selecting one out of $n$ versions of the product differentiated by their technologies. We rely on a discrete choice model to resolve the buyer’s supplier evaluation and selection problem.

A key feature of our model is to endogenize the future market competition and its effect on players’ current decisions. First, there will be $n + 1$ future suppliers in the market, the current $n$ suppliers plus the current buyer. The future market is assumed to have a total discounted demand
size of $l$ units of the product. (In reality, future demands for the product occur over time, and $l$ here can be regarded as the total discounted demands based on some forecast about future demands and their timing of occurrences.) The future buyer of the product draws an uncertain utility from consumption of the product in the same way as the current buyer; the future buyer, however, is assumed to have no interest in obtaining the underlying technology. As such, with their individual technology strengths inherited from the current period, the $n + 1$ future suppliers bid for the opportunity to supply the $l$ units of the product. Such a future implication is taken into account differently for the current buyer and for current suppliers, in making their current decisions. For the current buyer, in selecting a supplier, he simply considers his current gain from consumption, future benefit associated with the technology transfer, and the ask price. For a current supplier, in deciding her bid, she trades her current gain, associated with her winning the current project over other suppliers, against her future loss of cultivating the new future competitor.

Solution to the general model of $n$ suppliers can get messy mathematically. By looking at simpler cases, however, we can still obtain rather interesting insights and predict outcomes of practical relevance. Specifically, using the two-supplier case, we find that each supplier has a dominant bidding strategy for the technology provision that is independent from the bidding strategy of the other supplier and solely depends on the technology difference of the suppliers and the ratio between the current project size and the future market size. The supplier with a stronger technology capability always chooses a better technology than the one with lower capability. However, both suppliers’ bidding behaviors are predominantly influenced by the ratio between the current project size and the future market size.

When the ratio between the current project size and the future market size is low, our model mimics the situation in which the buyer procures technology only, or it is not bundled with the purchase of products. For such a situation, the model predicts that no supplier offers good technology, even with the existence of multiple competing suppliers of the technology. This perhaps offers a partial explanation for why the Chinese government has not been particularly successful in acquiring state-of-the-art technologies early on.
As the ratio of current project and future market size increases, suppliers provide slightly better technologies. Once the ratio crosses some threshold, the suppliers’ responses jump and the best technology will be provided. We find that a ratio of 10% is sufficient for the suppliers to provide the best technologies for most reasonable market conditions. In Subsection 5.2, we will revisit the Three Gorges project and show that the project size is in line with the 10% threshold and that as such, it is not surprising based on our model that after the Three Gorges project, Chinese firms now have the technology to compete in the global market in the hydropower industry (Godrey 2009).

Our model further indicates that the buyer would pay a slightly higher price for the current project if bundling is chosen; nevertheless, he will be adequately compensated by competing capably on future projects given the up-to-date technologies. The same insights extend to the case in which there are multiple suppliers, under which similar thresholds can be derived.

The remainder of the paper is organized as follows. In Section 2, we review the related literature, and in Section 3, we discuss the trading mechanism and set up the analytical model. We identify the supplier’s optimal bidding strategy and compare procurement policies in Section 4. Section 5 provides some extensions and examines the empirical data on the Three Gorges project, and Section 6 concludes.

2. Literature Review

Both procurement and technology transfer have been studied extensively in the literature. Our model investigates the bundled procurement mechanism and considers the future implications of technology transfer. As a result, we will draw elements from three areas of the literature: procurement mechanisms, rent-seeking games, and discrete choice modeling.

Procurement Mechanisms. The operations-management community has studied procurement mechanisms extensively. With advances in information technology, auctions now play a more and more important role, along with other common sourcing practices such as negotiations and contracts (Elmaghraby 2000). Krishna (2002) provides an excellent treatment of auction theory. Procurement auctions often have features different from the classic auction setting analyzed in the
economics literature. For example, Chen et al. (2005) consider transportation costs for the efficient multi-unit 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. Wan and Beil (2008) analyze auction design under the impact of the regional cost shock. Chu (2009) designs truthful double auctions that support bundle synergy. Our work here is most closely related to the multi-attribute auction (some examples are Beil and Wein 2003, Parkes and Kalagnanam 2005), under which the buyer cares about both the price and the non-price 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 non-price attributes into consideration. Kostamis et al. (2009) consider a setting in which the non-price attribute is assigned by the buyer.

What differentiates our paper from the above literature is that we consider the future implications of the procurement auction when the technology is transferred along with the products. Technology transfer has been securitized in the economics literature. Nevertheless, in the literature, the buyer typically owns the technology and the focus is on the cost-benefit trade-off of transferring an incumbent’s technology over to a second supplier (Riordan and Sappington 1989). In this paper, the buyer initially does not own the technology and would like to acquire the technology to become a future supplier.

Rent-seeking and Patent Race Game. The competition among the suppliers reminds us of the literature of rent-seeking and patent race games. In the future market, all of the players will utilize available technologies to seize the potential market share, which may be modeled as a patent race game (Loury 1979; Dasgupta and Stiglitz 1980). From the suppliers’ point of view, the current procurement resembles the classic rent-seeking game (Tullock 1967, 1980), in the sense that each supplier may increase the winning probability (for the current procurement) by offering a better technology, which is costly (for the future). Similar to Harris and Vickers (1985), in our model, suppliers are heterogeneous and may have different technology capabilities.

In the rent-seeking/patent race game literature, the award for winning is usually a constant and independent of the players’ behavior. Consequently, one only needs to model the winning
probabilities. In this paper, we would like to highlight the competition leverage the buyer may use, and we would like to model the winner’s reward as the outcome of the competition among the suppliers. Therefore, the winning supplier’s transaction price is the price point when other suppliers drop out of the competition. As we will see, if we only have two suppliers, the winner’s reward can be calculated as the difference of the social welfare with the winning supplier’s participation vs. without her participation following the insight from the second price auction (and in general the renowned VCG scheme) in the auction literature (Krishna 2002). As a result, we not only need to model the winning probabilities but also to model the buyer’s utility for each potential technology choice. This leads to the discrete choice model for the buyer’s evaluation process.

**Discrete Choice Model.** Discrete choice model, and specifically the multinomial logit model (hereinafter, MNL) have been used extensively in the operations community to model consumer choice. Talluri and van Ryzin (2004) study the optimal policy structure via a general discrete choice model for consumer behavior in the revenue-management context. Basuroy and Nguyen (1998) consider the market share equilibrium using a MNL model. van Ryzin and Mahajan (1999) apply the MNL model to investigate the optimal assortment structure. Their model is further extended by Mahajan and van Ryzin (2001), Hopp and Xu (2008), and Saure and Zeevi (2009).

Following the discrete choice model, we assume that a total of $n$ sellers exists and that seller $i$ can provide some utility $u_i$ ($i = 1, 2, \cdots, n$) to the buyer. The utility derived from alternative $i$ is $U_i = u_i + \epsilon_i$ for the buyer. One way to view this model is that $u$ represents the known part of the utility and is defined over observable characteristics, and $\epsilon$ is a random variable reflecting the imperfect knowledge of the utility function of the buyer. The random term $\epsilon$ can also purely come from noise and imperfection of the evaluation process. By incorporating a stochastic decision rule, we avoid discontinuity in the winner selection process.

Under the MNL model, $\epsilon_i$ are i.i.d. according to the double exponential distribution: $F(x) = Pr(\epsilon_i \leq x) = e^{-e^{-(\frac{x}{\mu}+\gamma)}}$, where $\gamma$ is Euler’s constant ($\gamma \approx 0.5772$) and $\mu$ is a positive constant. This distribution is chosen because this is the unique distribution that satisfies the choice axiom (Luce 1959) and the axiom of invariance with uniform expansion of the choice set (Yellott 1977).
Furthermore, when $\mu$ approaches zero, this stochastic decision rule converges to the deterministic decision rule.

Straightforward algebra shows that the probability that $U_i$ is the highest among the $n$ choices (i.e., seller $i$ is the winner) is $P(i) = \frac{e^{u_i/\mu}}{\sum_{j=1}^{n} e^{u_j/\mu}}$. The expected maximum utility among the $n$ choices is $E[\max\{U_i\}] = \mu \ln(\sum_{i=1}^{n} e^{u_i/\mu})$, where $u = (u_1, u_2, \cdots, u_n)$. For detailed properties of the MNL model, please refer to *Discrete Choice Theorem of Product Differentiation* (Anderson et al. 1992).

3. **Modeling the Trading Mechanism and the Future Gain**

Multiple sellers compete on a procurement project. The buyer not only wants to procure the products for the consumption in the current period but also would like to acquire the underlying technology from the sellers so that he can compete in the future market. We are interested in whether the buyer can benefit from procuring the products and the technologies as a bundle. We will first model the trading mechanism.

3.1. **The Trading Mechanism**

Consider a procurement setting in which one buyer needs to procure certain products and/or technologies from multiple sellers. The buyer first goes through the request for proposal (RFP) process; given the proposals, the buyer evaluates the offers, and leverages these competing offers to get the best deal.

One way to model and implement the above process is through an open descending auction format: (1) all the sellers first determine their technologies choices for the procurement project, then seller $i$ submits her proposal with technology choice $t_i$ and some (extremely high) initial ask price; (2) the buyer evaluates all the technology proposals, and for seller $i$’s proposal the per-unit utility $U(t_i)$ is assigned stochastically; (3) based on the evaluations and current prices, the buyer announces the current winner, whose proposal maximizes the difference between the expected total gain (from the current consumption and the future gain) and the ask price, and allows other sellers to lower their prices; (4) repeat step (3) until no seller updates the ask price; (5) the buyer procures from the winning seller at her final ask price for the products and/or the technology. Fig. 1 illustrates this timeline.
When the buyer only procures for the current consumption and does not participate in the future competition, the above process is essentially a second-price auction. To see this, notice that after the sellers made their technology choices and the uncertainty of the evaluation processes is resolved, seller $i$ would quit the competition when his ask price $p_i$ reaches his cost $c_i$ for his technology choice $t_i$. The buyer will always pick the seller that offers the greatest benefit—that is, the difference between the utility of the product and the ask price. As a result, the most efficient seller (who provides the largest social gain) will be the winning seller and the second most efficient seller will be the last seller to drop out of the competition. The gain of the buyer is essentially the social gain when the second most efficient seller is chosen, while the gain of the winning seller is the difference of the social gains with her participation and without her participation.

For readers who may not be familiar with the auction literature, the calculation of gains can be illustrated by the following three-seller example. Assume $U(t_1) = t_1 = 50$, $c_1 = 30$; $U(t_2) = t_2 = 40$, $c_2 = 25$; and $U(t_3) = t_3 = 30$, $c_3 = 15$. Seller 1 is the most efficient seller, who offers a social gain of $20(= 50 - 30)$. Even though $U(t_2)$ and $U(t_3)$ are different, seller 2 and seller 3 both provide a social gain of $15(= 40 - 25 = 30 - 15)$. The buyer is indifferent from the three sellers as long as $p_1 = p_2 + 10 = p_3 + 20$. As the competition drives down the ask prices, both seller 2 and seller 3 will quit the competition when $p_1 = 35$ (while $p_2 = 25$ and $p_3 = 15$). The most efficient seller wins, and the social gain is split between the winning seller and the buyer. The buyer’s gain is $50 - 35 = 15$, which is the social gain of seller 2 (or seller 3), as this is the gain she can secure without seller 1. Seller 1’s gain is $35 - 30 = 5$, which is the difference of the social gain of seller 1 and the social gain.
without seller 1, that is, the additional contribution to the social gain by seller 1.

One important feature of the above process is that it enables the cost discovery for the buyer, which means that the buyer can implement the process without knowledge of the sellers’ costs. Although we will study a game-theory model with complete information when considering technology acquisition, the buyer can be less sophisticated based on this procurement process, which alleviates the restriction of the complete information assumption.

3.2. The Notation of the Bundling Model

Assume that a total of \( n \) sellers compete in the procurement project, and we index them as players from 1 to \( n \). We index the current buyer as player 0, who will compete in the future market with current sellers.

Following the discrete choice model, the buyer can derive a per-unit utility \( U(t_i) = t_i + \epsilon_i \) from seller \( i \)'s technology choice \( t_i \), where \( \epsilon_i \) represents the uncertainty in the evaluation process and is independently drawn from some known distribution \( F_i \). Seller \( i \) may offer different levels of technologies \( t_i \), which may have different cost \( c_i(t_i) \). We call the difference of the technology and the cost, the technology strength, \( s_i = s_i(t_i) = t_i - c_i(t_i) \). Assume that seller \( i \)'s maximum technology strength (i.e., most cost-effective technology) is \( \bar{s}_i \). To simplify the analysis, we assume that it is possible for seller \( i \) to offer a technology \( t_i \) such that \( t_i - c_i(t_i) = s_i \) for any \( s_i \leq \bar{s}_i \) (notice that \( s_i \) can be negative). Later, it will become clear that the key technology choice decision for seller \( i \) is to determine \( s_i \).

To model the interaction of the future market, we assume that \( n + 1 \) players— that is, the original \( n \) sellers and the current buyer— will compete in the future market using the same trading mechanism outlined in Section 3.1, where \( \epsilon_i \) follows the same distribution \( F_i \), and the technology offered by player 0 would have an uncertainty term \( \epsilon_0 \sim F_0 \) during the evaluation process. To highlight the impact of technology transfer, we will assume that the \( n \) sellers retain the same technology strengths \( \{\bar{s}_i\}_{i=1,...,n} \) while the buyer obtains technology \( t_i \) and technology strength \( \bar{s}_0 = s_i(t_i) \) from winning seller \( i \). Let \( V_i \) denote the per-unit profit for player \( i \) in the future market \( (i = 0,1,...,n) \). If no further technology transfer is concerned, the expected per-unit future
profit of a seller is the difference of the expected social gains with her participation and without her participation, as illustrated in Section 3.1. Under this situation, each seller would offer the technology with the highest strength, and the expected per-unit future profit of player $i$ is $E[\max_{j=0,\ldots,n} \{ \bar{s}_j + \epsilon_j \}] - E[\max_{j=0,\ldots,n,j\neq i} \{ \bar{s}_j + \epsilon_j \}]$. Instead of writing future profit $V_i$ as a function of technology $t_j$ that is acquired by the buyer from winning seller $j$ in the procurement contract, we may highlight the underlying technology strength and write $V_i(s)$ to denote the per-unit future profit for player $i$ when the current buyer acquires technology strength $\bar{s}_0 = s$. We also define $V(s) \equiv \sum_{i=0}^n V_i(s)$ as the expected per-unit profit for all the players.

Let $k$ denote the size of the current procurement need (e.g., $k$ units of the tangible products will be acquired), and let $l$ denote the discounted future market size. We define $\alpha \equiv k/l \in [0, \infty)$, “current weight ratio,” that captures the importance of the current period. The total gain of the buyer for choosing alternative $i$ is $k(U(t_i) - p_i) + lV_0(s_i(t_i))$, where $p_i$ is seller $i$’s per-unit price.

As the sellers lower their ask prices, the buyer always picks the seller who offers the largest gain. The total gain of seller $i$ is $k(p_i - c_i) + lV_i(s_i(t_i))$ if seller $i$ wins the current procurement project, and $lV_i(s)$ if the buyer acquires technology strength $s$ from other sellers. Table 1 summarizes the notation used.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Definition</th>
<th>Functional Rationshipship</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_i$</td>
<td>Technology choice of seller $i$</td>
<td>$c_i \sim F_i$, $i = 0\ldots n$</td>
</tr>
<tr>
<td>$c_i(t_i)$</td>
<td>Per-unit cost of seller $i$ for technology choice $t_i$</td>
<td>$U(t_i) = t_i + \epsilon_i$, $i = 1\ldots n$</td>
</tr>
<tr>
<td>$\epsilon_i$</td>
<td>Uncertainty in the evaluation process for player $i$</td>
<td>$s_i(t_i) = t_i - c_i(t_i)$, $i = 1\ldots n$</td>
</tr>
<tr>
<td>$U(t_i)$</td>
<td>Buyer’s per-unit utility derived from $t_i$</td>
<td></td>
</tr>
<tr>
<td>$s_i$</td>
<td>Technology strength choice of seller $i$</td>
<td></td>
</tr>
<tr>
<td>$\bar{s}_i$</td>
<td>Player $i$’s maximum technology strength</td>
<td></td>
</tr>
<tr>
<td>$p_i$</td>
<td>Per-unit price of seller $i$</td>
<td></td>
</tr>
<tr>
<td>$V_i(s)$</td>
<td>Expected per-unit profit of player $i$ in future market when the buyer acquires technology strength $\bar{s}_0 = s$</td>
<td></td>
</tr>
<tr>
<td>$V(s)$</td>
<td>Expected per-unit profit of all players in future market</td>
<td>$V_i = E[\max_{j=0,\ldots,n} { \bar{s}_j + \epsilon_j }]$</td>
</tr>
<tr>
<td>$k$</td>
<td>The size of current procurement need</td>
<td>$-E[\max_{j=0,\ldots,n,j\neq i} { \bar{s}_j + \epsilon_j }]$</td>
</tr>
<tr>
<td>$l$</td>
<td>The discounted future market size</td>
<td></td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Current weight ratio</td>
<td>$V(s) \equiv \sum_{i=0}^n V_i(s)$</td>
</tr>
</tbody>
</table>

$\alpha \equiv k/l \in [0, \infty)$
4. Bidding Behavior and Policy Comparison

To gain some insight on the interaction among the competing sellers and the buyer, we focus on the case of two sellers (i.e., \( n = 2 \)) in this paper. We will first investigate which seller would win the procurement contract given the technology choices and uncertain evaluations. After that, we determine the optimal bidding strategy for each seller under a general discrete-choice model. Finally, we study the seller’s optimal bidding strategy and evaluate the procurement policies under the MNL model.

4.1. Winner Determination

Assume that seller \( i \) chooses \( t_i \) (and subsequently \( c_i = c_i(t_i) \) and \( s_i = t_i - c_i \) \((i = 1, 2)\)) and that random variables \( \epsilon_i \) \((i = 1, 2)\) are realized. We first investigate which seller would be the winning seller and at what price the transaction will be conducted.

Seller 1 will drop out the competition if the price \( p_1 \) is so low that \( k(p_1 - c_1) + lV_i(s_1) \leq lV_i(s_2) \); the left-hand-side is the sum of the current gain and the expected future gain if seller 1 is the winning seller, and the right-hand-side is the expected future gain if seller 2 is the winning seller. Similarly, seller 2 will drop out if the price \( p_2 \) is so low that \( k(p_2 - c_2) + lV_2(s_2) \leq lV_2(s_1) \). Notice that the buyer always picks seller \( i \) with higher \( k(U(t_i) - p_i) + lV_0(t_i) \).

**Lemma 1.** \( V_i(s) \) is a decreasing function of \( s \) for \( i = 1, 2, \cdots, n \).

All the proofs are available in the Appendix.

Lemma 1 says that as the potential future competitor (i.e., the buyer) gets a technology with higher strength, the expected future gain for the current seller decreases. As a result, if \( s_1 < s_2 \), seller 1 would be willing to take a current loss to compete with seller 2 to avoid facing a stronger competitor in the future, while seller 2 would drop out before the current profit reduces to zero.

**Theorem 1.** The seller who provides the larger total social gain—i.e., \( k(U(t_i) - c_i) + lV(s_i) \)—wins the procurement contract. Furthermore, if seller \( i \) wins and seller \( j \) loses, seller \( i \)’s total expected gain is \( k(U(t_i) - c_i) + lV(s_i) - [k(U(t_j) - c_j) + lV(s_j)] + lV_i(s_j) \).
Notice that $V(s_i) \equiv V_0(s_i) + V_1(s_i) + V_2(s_i)$ captures the total expected per-unit profit in the future market for all the players, while $U(t_i) - c_i = s_i + \epsilon_i$ represents the per-unit social gain for the current period. Let seller $i$ be the winning seller and seller $j$ be the losing seller. The losing seller $j$’s expected per-unit future gain is $V_j(s_i)$, and the expected total gain is $LV_j(s_i)$. The winning seller $i$’s expected total gain is the difference between the total social gain (among the three players) when she is selected vs. the other seller is selected plus $lV_i(s_j)$, which is essentially the reserved future profit. That is, winning seller $i$’s expected total gain can be written as $k(s_i + \epsilon_i) + lV(s_i) - [k(s_j + \epsilon_j) + lV(s_j)] + lV_i(s_j)$.

4.2. Bidding Strategy

**Theorem 2.** Seller $i$’s optimal bidding strategy is to maximize $ks_i + lV(s_i)$ on $(-\infty, \bar{s}_i]$ because the (ex post) gain for seller $i$ would be $\max\{k(s_i + \epsilon_i) + lV(s_i) - [k(s_j + \epsilon_j) + lV(s_j)], 0\} + lV_i(s_j)$ when the other seller offers technology strength $s_j$.

Notice that Theorem 2 holds for any distribution $F_i$ and offers a dominant bidding strategy for any realization of the random variables. When seller $i$ decides on the optimal technology provision, she needs to balance the current gain and the future gain. It turns out that the best strategy is to maximize the social welfare, taking into account both the current period and the future market. (When the future market is irrelevant (i.e., $l = 0$), we obtain the classic second-price auction result, under which all sellers provide their highest strengths $\{\bar{s}_i\}_{i=1,\cdots,n}$).

It is possible that multiple technology strength $s$ maximizes $ks + lV(s)$ on a given range. We assume that all the sellers have the same preference when picking the technology strength choice among multiple optimal solutions.

**Corollary 1.** The technology leader (i.e., the seller with higher $\bar{s}$) offers a technology strength no less than that of the technology follower.

Corollary 1 says that the technology leader offers a higher technology strength because she can choose more advanced technology and achieve a higher social gain compared with the technology follower.
To study the seller’s strategy for given $k$ and $l$, recall that $\alpha \equiv k/l \in [0, \infty)$, which is the current weight ratio that captures the importance of the current period.

**Corollary 2.** As $\alpha$ increases, every seller offers a technology choice with higher strength.

Corollary 2 formalizes the intuition that as the current procurement becomes more important, the sellers are less concerned with the future competition and offer a higher technology strength. As $\alpha$ gets higher and higher, all the sellers will offer the technology with the highest strengths.

**Theorem 3.** For $\alpha \geq 1$, offering the technology with the highest strength $\bar{s}_i$ is seller $i$’s optimal bidding strategy.

Theorem 3 illustrates that $\alpha = 1$ is sufficient to induce the sellers to offer their best technologies. This result holds for any distribution $F_i$, and this bound can be too conservative. Indeed, the worst-case bound $\alpha = 1$ is only obtained when the seller selection rule is deterministic—i.e., the seller offering the highest technology strength always wins the procurement contract. In real life, this would imply that a dominant seller captures essentially the entire market. When a seller is capable of capturing the entire market, the current project must be at least as important as the total future market to induce the seller to surrender the technology (i.e., $\alpha = 1$). To better model the real life in which various sellers holds different market shares, we apply the MNL model.

### 4.3. The Multinomial Logit Model

A classic model for stochastic decision rule is the multinomial logit model, under which $\epsilon_i$ are i.i.d. according to the double exponential distribution: $F(x) = Pr(\epsilon_i \leq x) = e^{-e^{-(\frac{x}{\mu} + \gamma)}}$, where $\gamma$ is Euler’s constant ($\gamma \approx 0.5772$) and $\mu$ is a positive constant (the mean and variance of this distribution are zero and $\mu^2 \pi^2/6$, respectively). Notice that when $\mu$ approaches zero, this stochastic decision rule converges to the deterministic decision rule.

Under the MNL model, the probability that seller $i$ is the most efficient and offers the highest $(s_i + \epsilon_i)$ among a seller set $S$ is $P(i) = \frac{e^{s_i/\mu}}{\sum_{j \in S} e^{s_j/\mu}}$. For the two-seller case, we define the normalized technology gap as $\Delta \equiv \frac{\bar{s}_1 - \bar{s}_2}{\mu}$. If technology transfer is not allowed and both sellers always provide
their best technologies, the winning probabilities of the two sellers can be written as $e^{\frac{\Delta}{\sigma_1}}$ and $e^{\frac{1}{\sigma_2}}$, respectively. Notice that these probabilities can also be viewed as the proxy for market shares.

The expected value of $\max_{j \in S} \{s_j + \epsilon_j\}$ is $\mu \ln(\sum_{j \in S} e^{s_j/\mu})$ under the MNL model. As a result, 

$$V_0(s) = \mu \ln(e^{s_1/\mu} + e^{s_2/\mu} + e^{s/\mu})$$

$$V_1(s) = \mu \ln(e^{s_1/\mu} + e^{s_2/\mu} + e^{s/\mu})$$

Recall that the social future gain $V(s) = V_0(s) + V_1(s) + V_2(s)$.

**Lemma 2.** $V(s)$ is quasi-convex with respect to $s$.

In the future market, all the players compete with their highest technology strengths. When $s$ is small, the chance of the current buyer becoming the future winner is slim, and his existence only reduces the potential gain of the future winner, which is the difference between the highest $(\bar{s}_i + \epsilon_i)$ and the second highest $(\bar{s}_i + \epsilon_i)$. Thus, as $s$ increases, $V(s)$ decreases for small $s$. When $s$ becomes large, however, the buyer is more likely to be the future winner; at this point, by providing the buyer a higher technology strength, it increases the difference between the future winner and the followers and increases players’ total future gain $V$.

We can further show not only that $V(s)$ is first decreasing then increasing as indicated by Lemma 2 (which is a first-order property), but also that $V(s)$ is at first concave then convex (which is a second-order property).

**Lemma 3.** There exists one threshold such that $V(s)$ is concave when $s$ is under this threshold and convex when $s$ is above this threshold.

Fig. 2 illustrates the shape of $V(s)$ for $\Delta = 0$ (both $\bar{s}_1$ and $\bar{s}_2$ are normalized to 0 and $\mu$ is set to 1 without loss of generality) and $\Delta = 0.5$ ($\bar{s}_1 = 0.5$, $\bar{s}_2 = 0$, and $\mu = 1$). In Fig. 2(a), both sellers can choose $s$ from $-\infty$ to 0. In Fig. 2(b), seller 2 can choose $s$ from $-\infty$ to 0, and seller 1 can choose $s$ from $-\infty$ to 0.5.

Recall that $\alpha \equiv k/l \in [0, \infty)$ and each seller maximizes $\alpha s + V(s)$ on $(-\infty, \bar{s})$. The seller’s optimal bidding strategy $s$ is either on the boundary $\bar{s}$ or satisfies that $\alpha + (V(s))'_s = 0$. Given Lemma 3, $\alpha s + V(s)$ has at most one internal local maximum solution.
Figure 2  Future profit $V(s)$ graphs.

**Corollary 3.** When both sellers choose internal solution, they offer the same level of technology strength.

When $\alpha = 0$, both sellers would provide a technology with $s = -\infty$—i.e., no technology transfer can be achieved. As $\alpha$ increases, the sellers would first choose the internal solution, which increases as $\alpha$ increases as $V(s)$ is concave for small $s$. When $\alpha$ crosses some threshold, the technology leader’s choice jumps to the boundary $\bar{s}$ because $V(s)$ is convex for large $s$. As $\alpha$ continues to increase, the technology follower’s choice may jump to the (lower) boundary $\bar{s}$ as well.

Fig. 3 illustrates how to determine the optimal $s$ graphically for $\Delta = 0$ and $\Delta = 0.5$. For each $\alpha$, we can draw a tangent line with slope $-\alpha$ and find the internal tangent point. As $\alpha$ increases and the tangent line becomes steeper, the line will pass through $(\bar{s}, V(\bar{s}))$, at which point the seller’s choice jumps from the internal solution to the boundary. In Fig. 3(b), the tangent lines that pass $(\bar{s}_1, V(\bar{s}_1))$ and $(\bar{s}_2, V(\bar{s}_2))$ are highlighted. An interesting note is that the technology leader would jump at a lower $\alpha$. This is due to the fact that the technology leader has a larger feasible region and is able to capture a higher current gain and increase the future social gain $V(s)$ by offering the state-of-the-art technology. Fig. 4 illustrates how technology provision varies as $\alpha$ varies for $\Delta = 0$ and $\Delta = 0.5$. Notice that before the jump, the technology provision $s$ is quite inferior because
Figure 3  Finding optimal $s$ through tangent line.

$(\bar{s} - s)/\mu$ is usually greater than 1.5, which translates into a winning probability, or a market share, $(\frac{e^{s/\mu}}{e^{s_1/\mu} + e^{s_2/\mu} + e^{s/\mu}})$ less than 10% in the future market for the current buyer.

Figure 4  Optimal $s - \alpha$ graphs.

While the technology leader’s bidding strategy always jumps from an internal solution to the boundary solution, the technology follower’s bidding strategy may not demonstrate the jump if
his whole feasible region lies within the concave region. We can determine the critical value of $\Delta$ above which the technology follower’s choice would be continuous with respect to $\alpha$.

**Corollary 4.** While the technology leader’s choice always jumps with respect to $\alpha$, the technology follower’s choice jumps if and only if $\Delta$ is no more than $1.439$.

![Image](image_url)

**Figure 5** Optimal $\Delta - \alpha$ graph and corresponding implied market share graph.

It is important to know what $\alpha$ value would be sufficient for the buyer to induce the highest technology strength from the seller. One can find the $\alpha(\Delta)$ by solving $\alpha$ (or equivalently the tangent line) for each $\Delta$ value. Fig. 5(a) shows the $\Delta - \alpha$ graph that specifies the minimum $\alpha(\Delta)$ needed to induce seller 1 to offer the highest technology strength $\bar{s}_1$ for given $\Delta$. When $\Delta = 0$, $\alpha = 0.0568$ induces both sellers to offer the best technology. $\alpha = 0.1$ is sufficient for $|\Delta| < \ln(2) = 0.693$, which corresponds to the case in which the technology leader’s implied market share is twice as large as the market share of the technology follower. To capture the whole scope of $\Delta$, the $x$-axis in Fig. 5(b) is the implied market share $\frac{\Delta}{e^\Delta + 1}$, which varies from 0 to 1 as $\Delta$ varies from $-\infty$ to $\infty$. As $\Delta$ approaches $\infty$, $\alpha$ approaches 1, the worst-case bound shown in Theorem 3.

**Corollary 5.** As $\Delta$ approaches $+\infty$, $\alpha(\Delta)$ approaches 1; as $\Delta$ approaches $-\infty$, $\alpha(\Delta)$ approaches $\frac{1}{2}$. 
4.4. Policy Comparison

We study the buyer’s policy selection under the MNL model. If the buyer tries to acquire the current consumption and the technology separately, we can view these as extreme cases with $\alpha = \infty$ and $\alpha = 0$. If the procurement is done separately, the sellers will provide the best technologies for the current consumption (because no concern is given to the potential future competition), while the sellers provide no technology ($s = -\infty$) for the technology acquisition despite the same competition pressure. (Once again, this perhaps offers a partial explanation for why the Chinese government has not been particularly successful in acquiring state-of-the-art technologies early on.) Under this case, the buyer’s expected gain only comes from the current consumption, which equals the expected social gain provided by the second-most-efficient seller in the current procurement—i.e.,

$$E[\min\{k(\bar{s}_1 + \epsilon_1), k(\bar{s}_2 + \epsilon_2)\}] = k\mu \ln\left(\frac{e^{(x_1 + x_2)}}{e^{x_1/\mu} + e^{x_2/\mu}}\right).$$

To study the bundling strategy, let us first assume that $\alpha$ is large enough so that both sellers offer their highest technology strengths. Let seller 1 be the technology leader and seller 2 be the technology follower—i.e., $\bar{s}_1 \geq \bar{s}_2$. Concerned with the future competition, the effective cost of seller 1 would shift up $lV(\bar{s}_2) - lV(\bar{s}_1)$ and the effective cost of seller 2 would shift down $lV(\bar{s}_2) - lV(\bar{s}_1)$ according to the winner selection rule identified in Theorem 1. Therefore, excluding the future market gain, the expected current gain for the buyer would be the expectation of $\min\{k(\bar{s}_1 + \epsilon_1) - l(V(\bar{s}_2) - V(\bar{s}_1)), k(\bar{s}_2 + \epsilon_2) - l(V(\bar{s}_1) - V(\bar{s}_2))\}$.

Therefore, the current gain of the buyer (that is, the gain from the current consumption minus the project cost) would be $k\mu \ln\left(\frac{e^{(x_1 + x_2 + V(\bar{s}_2) - V(\bar{s}_1))}}{e^{(x_1 + V(\bar{s}_1) - V(\bar{s}_2))} + e^{(x_2 + V(\bar{s}_2) - V(\bar{s}_1))}}\right)$. Notice that when $\bar{s}_1 = \bar{s}_2$, the buyer can secure the same current gain, acquire the state-of-the-art technology, and obtain the future gain for free.

The bundling has two effects on the current gain calculation. First, the effective strength of the technology leader is decreased since $V(\bar{s}_2) > V(\bar{s}_1)$, while the effective strength of the technology follower is increased as $V(\bar{s}_1) < V(\bar{s}_2)$. This move intensifies the competition and plays to the

$$E[\min\{k(\bar{s}_1 + \epsilon_1), k(\bar{s}_2 + \epsilon_2)\}] = E[k(\bar{s}_1 + \epsilon_1) + k(\bar{s}_2 + \epsilon_2)] = E[\max\{k(\bar{s}_1 + \epsilon_1), k(\bar{s}_2 + \epsilon_2)\}] = k(\bar{s}_1 + \bar{s}_2) - E[\max\{k(\bar{s}_1 + \epsilon_1), k(\bar{s}_2 + \epsilon_2)\}] = k(\bar{s}_1 + \bar{s}_2) - k\mu \ln\left(\frac{e^{x_1/\mu} + e^{x_2/\mu}}{e^{x_1/\mu} + e^{x_2/\mu}}\right) = k\mu \ln\left(\frac{e^{x_1/\mu} + e^{x_2/\mu}}{e^{x_1/\mu} + e^{x_2/\mu}}\right)$$

given the MNL model.
buyer’s advantage because $e^x$ is convex and the denominator would be smaller. Second, we have $V_1(\bar{s}_2) - V_1(\bar{s}_1) > V_2(\bar{s}_2) - V_2(\bar{s}_1)$, and incentive distortion on the technology leader is greater than that on the technology follower and the numerator is reduced as the buyer is more likely to be matched with seller 2, who may offer a lower per-unit utility $(s + \epsilon)$ for the current consumption. We show that the second effect dominates the first effect and that the current gain of the buyer is reduced under bundling.

**Theorem 4.** Excluding the future gain, the buyer’s current gain would be weakly reduced if bundling is adopted and both suppliers provide the highest technology strength. Furthermore, the per-unit loss of current gain is a monotone decreasing function of the current weight ratio $\alpha$.

Theorem 4 offers a “no-free-lunch” result as the buyer needs to pay a non-negative price to acquire the technology and obtain the future gain. The buyer can get the technology for free if and only if the two suppliers are perfect technology substitutes. In general, the buyer would pay a small price, which decreases as $\alpha$ increases and reaches zero when $\alpha = \infty$ and no future market is considered.

The buyer acquires technology from either seller 1 or seller 2. With probability $e^{(s_1 + V_1(\bar{s}_1) - V_1(\bar{s}_2))/\mu} / e^{(s_1 + V_1(\bar{s}_1) - V_1(\bar{s}_2))/\mu + (s_2 + V_2(\bar{s}_2) - V_2(\bar{s}_1))/\mu}$, seller 1 wins the procurement contract, and the buyer would gain technology strength $\bar{s}_1$; with probability $e^{(s_2 + V_2(\bar{s}_2) - V_2(\bar{s}_1))/\mu} / e^{(s_1 + V_1(\bar{s}_1) - V_1(\bar{s}_2))/\mu + (s_2 + V_2(\bar{s}_2) - V_2(\bar{s}_1))/\mu}$, seller 2 wins, and the buyer would gain technology strength $\bar{s}_2$. The buyer’s expected future gain is

$$l \left( \frac{(s_1 + V_1(\bar{s}_1) - V_1(\bar{s}_2))/\mu}{e^{(s_1 + V_1(\bar{s}_1) - V_1(\bar{s}_2))/\mu + (s_2 + V_2(\bar{s}_2) - V_2(\bar{s}_1))/\mu}} V_0(\bar{s}_1) + \frac{(s_2 + V_2(\bar{s}_2) - V_2(\bar{s}_1))/\mu}{e^{(s_1 + V_1(\bar{s}_1) - V_1(\bar{s}_2))/\mu + (s_2 + V_2(\bar{s}_2) - V_2(\bar{s}_1))/\mu}} V_0(\bar{s}_2) \right).$$

**Theorem 5.** The buyer’s expected per-unit future gain is a positive (weakly) increasing function of the current weight ratio $\alpha$.

The expected per-unit future gain is a constant with respect to $\alpha$ when $\Delta = 0$ because the buyer is indifferent from the sellers’ technologies. When $\Delta \neq 0$, a higher $\alpha$ increases the buyer’s chance to secure the technology from the technology leader.

In Fig. 6, we present the expected per-unit current cost and the expected per-unit future benefit of the bundling policy when $\mu$ is normalized to 1. The $x$-axis for both graphs is $\Delta$. In Fig. 6(a), the
Figure 6 Per-unit cost and benefit of bundling under $\alpha = 0.1$ and 0.15.

per-unit cost and benefit curves are only drawn for $|\Delta| \leq \ln(2)$ as this is the range within which the sellers would offer the best technologies under $\alpha = 0.1$; in Fig. 6(b), $\alpha = 0.15$ is sufficient for the sellers to offer the best technologies under the entire range $|\Delta| \leq 1$. At $\Delta = 0$, the buyer can acquire the technology for free and earn the highest expected per-unit future benefit $\ln(3/2) = 0.405$ (which can be calculated via a three-symmetrical-seller setting). The cost of acquiring technology under the bundling policy increases as $\Delta$ deviates from 0, while the benefit decreases as $\Delta$ deviates from 0. The deterioration of the performance can be explained by the increase of the heterogeneity of the sellers, which reduces the underlying competition that the buyer can leverage. Following Theorems 4 and 5, the per-unit curves become flatter as $\alpha$ increases from 0.1 to 0.15. The total cost of acquiring technology through bundling is negligible compared with the total gain from the future market — the expected total net gain is tens and hundreds of times the total current cost, as the current procurement has a small size compared with the future market ($\alpha = 0.1$ and 0.15).

In the above discussion, we show the benefit of the bundling policy if $\alpha$ is large enough to induce the sellers to offer the best technologies. This restriction is non-trivial because the bundling policy can backfire if the sellers do not offer the state-of-the-art technologies. Consider the case in which $\Delta = 0$, $k = 0.05$, and $l = 1$ (i.e., $\alpha = 0.05$). Both sellers would offer a technology strength $-1.946\mu$
lower than the highest technology strength. As a result, the expected total current consumption loss is $0.05 \times 1.946 \mu = 0.0973 \mu$. With a technology strength gap of $1.946 \mu$, the winning probability of the buyer in the future market is $\frac{e^{-1.946}}{1+1+e^{-1.946}} = 6.666\%$, and the expected per-unit future gain is $\mu \ln\left(\frac{1+1+e^{-1.824}}{1+1}\right) = 0.06899 \mu$. The total future gain is $1 \times 0.06899 \mu = 0.06899 \mu$, which is lower than the total cost $0.0973 \mu$.

5. Further Discussion

In this section, we consider the possibility that the buyer may fail to adopt the transferred technology. We also revisit the Three Gorges project to see whether the project is large enough to induce the suppliers to provide the state-of-the-art technologies.

5.1. The Likelihood of Technology Adoption

In the previous discussion, we assumed that the buyer will always successfully adopt the technology from the winning seller and compete with current sellers in the future market. Nevertheless, technology adoption usually comes with quite a high failure rate due to various factors such as human resources deficiencies, system incompatibility, etc. In this section, we introduce a success rate $p$ 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.

Originally, when seller 1 competes with seller 2, seller 1 will drop out if the price $p_1$ is so low that $k(p_1 - c_1) + lV_1(s_1) \leq lV_1(s_2)$. Now, with probability $(1 - p)$, the buyer will fail to adopt the technology and the future market competition does not depend on the technology provision in the current period. Therefore, seller 1 will drop out if the price $p_1$ is so low that $k(p_1 - c_1) + plV_1(s_1) \leq plV_1(s_2)$, where $V_1(s)$ is defined as before, assuming the buyer acquires technology strength $s$. That is, the sellers can discount the future market competition by discounting the relevant future market size.

Not only will the sellers discount the future market size but the buyer will discount the future market size as well. To see this, the buyer would pick seller $i$ with higher $k(U(t_i) - p_i) + lV_0(s_i)$ when he always successfully adopts the technology. Given the success rate $p$, the buyer would pick seller $i$ with higher $k(U(t_i) - p_i) + plV_0(s_i)$, effectively discounting the future market size to $pl$. 
As a result, when choosing the technology strength, the sellers have the dominant strategy to maximize $ks + plV(s)$, and all previous results will hold once we replace $l$ with $pl$.

With $p \in (0, 1)$, the buyer essentially has a larger effective $\alpha$, and the sellers are less concerned with the future competition and offer better technologies. As $p$ decreases, the buyer’s future profitability decreases. A probability $p(<1)$ would be most beneficial to the buyer if the original current weight ratio (i.e., $k/l$) is insufficient to induce the sellers to supply the best technologies, while the low success rate can convince the sellers to provide the best technologies.

5.2. The Three Gorges Project

In this section, we revisit our motivating story on the Three Gorges project and the hydropower industry. Hydropower is a mature industry that has witnessed a modest growth rate. Table 2 lists the worldwide installed capacity of hydroelectricity (U.S. Energy Information Administration) from 1980 to 2005. The international bidding for the Three Gorges Dam (left bank) commenced in June 1996, and the left bank of the dam became fully operational in 2005. We see that from 1980 to 1995, the annual growth rate was 2.07%. During the next ten-year period, when the Three Gorges Dam (left bank) was constructed, we have a similar annual growth rate of 2.09%.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (GW)</td>
<td>462</td>
<td>477</td>
<td>493</td>
<td>506</td>
<td>522</td>
<td>538</td>
<td>552</td>
<td>569</td>
<td>583</td>
<td>573</td>
<td>576</td>
<td>580</td>
<td>590</td>
</tr>
<tr>
<td>Capacity (GW)</td>
<td>602</td>
<td>616</td>
<td>628</td>
<td>638</td>
<td>652</td>
<td>660</td>
<td>679</td>
<td>692</td>
<td>702</td>
<td>717</td>
<td>734</td>
<td>752</td>
<td>772</td>
</tr>
</tbody>
</table>

The left bank of the Three Gorges Dam was scheduled to install 14 hydro-generators, each with a capacity of 700 megawatts. Responding to the call of proposals in 1996, major international hydroelectric power equipment suppliers assembled themselves into consortiums in a bid to outpower each other (Lu 1996). The two most competitive consortiums are the consortium of GE Canada, Voith, and Siemens, and the consortium of ABB from Switzerland, Kvaerner Industries AS from Norway, and the Anglo-French GEC Alstom. GEC Alstom changed its name to Alstom in 1998 when the group was introduced on the Paris Stock Exchange. In 1999, ABB and Alstom of France merged their power-generation divisions; Siemens and Voith Hydro merged their hydropower divisions; and Kvaerner Energy sold its hydropower business to GE Hydro (Probe International 2007).
third of the worldwide hydroelectric capacity, respectively.

To evaluate whether the Three Gorges project can induce the consortiums to offer the state-of-the-art technologies, we use the capacity (gigawatts) of the project vs. discounted future projected capacity growth as a measure for the current weight ratio \( \alpha \), and we use the market share ratio of the consortiums as a measure for the technology gap \( \Delta \) between the bidders (Subsection 4.3).

The left bank of the Three Gorges project has a designed capacity of 9.8 GW, which was completely operational by 2005, while the hydropower industry had installed a capacity of 628 GW worldwide by 1995, before the commence of the international bidding. A hydropower project takes years to construct, and large hydropower projects like Three Gorges can take over ten years to complete. Therefore, we assume that it takes five years for the buyer to be able to learn and compete in the future market. As a result, the discounted future capacity growth (GW) can be written as

\[
\sum_{i=T+1}^{\infty} Mg(1+g)^{L-1}(1+r)^{-i} = \frac{(1+g)^{L+T}}{(1+r)^T} \frac{g}{r-g} M,
\]

where \( M = 628 \) (GW) is the worldwide capacity in 1995, \( L = 10 \) is number of years between 1995 and 2005 when the generators became operational, \( T = 5 \) is number of years for the buyer to adopt the technology, \( g \) is the growth rate, and \( r \) is the discount rate. The term \( Mg(1+g)^L \) is the forecasted capacity growth in 2005 before the commencement of the bidding. To reflect the fact that the buyer needs time to master the technology, the summation starts from \( i = T+1 \) instead of \( i = 1 \). According to the historic trend available in 1995, the growth rate \( g \) is set at 2.1%. A 15% discount rate would imply a discounted future capacity of 69.4 GW and \( \alpha = 9.8/69.4 = 14.1\% \), which justifies the bundling strategy. Even if we choose a fairly low discount rate of 10%, the implied discounted future capacity would be 141.6 GW and \( \alpha = 9.8/141.6 = 6.92\% \), which still can justify the bundling strategy given that the competing consortiums have similar market shares and implied technology strengths. The consideration of potential technology adoption failure (Subsection 5.1) and managers’ focus on short-term gain may further support the adoption of the bundled procurement mechanism.
In 2004, Alstom, Harbin Electric Machinery, and Dongfang Electric Machinery each won four units out of the 12 hydro-generators on the right bank of the Three Gorges project. China has become self-sufficient in the design and production of the hydropower stations, and Chinese firms are now building 19 of the 24 largest hydropower plants currently under construction worldwide (Godrey 2009).

6. Concluding Remarks

In this paper, we study a procurement mechanism in which the buyer would like to procure the technologies with the tangible products and compete with current suppliers in the future market. The bidding behaviors of the suppliers when the buyer requests both the products and the technologies as a bundle were examined. We found that for the two-supplier case, each supplier has a dominant bidding strategy for the technology provision that is independent from the bidding strategy of the other supplier and solely depends on the technology difference of the suppliers and the ratio between the current project size and the future market size. When the ratio is low, the suppliers provide inferior technologies. As the ratio increases, the suppliers provide slightly better technologies. Once the ratio crosses some threshold, the suppliers’ responses jump and the best technologies will be provided. We find that a ratio of 10% is sufficient for the suppliers to provide best technologies for most reasonable market conditions. While the buyer would pay a slightly higher price for the current project under the bundling strategy, the buyer will be adequately compensated by his ability to compete as a supplier for future projects given the up-to-date technologies.

Appendix. Proofs

Proof of Lemma 1  As $s$ increases, the current buyer would be a stronger competitor for current suppliers (i.e., players 1 to $n$). Both the probability that $\hat{s}_i + \epsilon_i$ being the highest and the current buyer’s lead over the second highest bidder decrease. As a result, the future profit of seller $i (= 1, \cdots, n)$ decreases as the future competition gets stronger.
Proof of Theorem 1  
Without loss of generality, let us assume that seller 1 provides the larger total social gain, i.e., \( k(U(t_1) - c_1) + l(V_0(s_1) + V_1(s_1) + V_2(s_1)) \geq k(U(t_2) - c_2) + l(V_0(s_2) + V_1(s_2) + V_2(s_2)) \).

We argue that if the above inequality holds strictly, seller 2 would drop out of the competition, and seller 1 would be the winner at equilibrium. If seller 1 drops out and seller 2 wins, the exit price of seller 1 must be \( p_1 \) such that \( IV_1(s_2) \geq k(p_1 - c_1) + IV_1(s_1) \), while the seller 2 must offers a low \( p_2 \) such that \( k(U(t_2) - p_2) + IV_0(s_2) \geq k(U(t_1) - p_1) + IV_0(s_1) \). Furthermore, \( p_2 \) must be high enough so that seller 2 stays in the competition—i.e., \( k(p_2 - c_2) + IV_2(s_2) \geq IV_2(s_1) \). Adding up the three inequalities, one has \( k(U(t_2) - c_2) + l(V_0(s_2) + V_1(s_2) + V_2(s_2)) \geq k(U(t_1) - c_1) + l(V_0(s_1) + V_1(s_1) + V_2(s_1)) \), and we reach a contradiction.

Therefore, at equilibrium, seller 2 would drop out of the competition and seller 1 would be the winner. The exit price of seller 2, \( p_2 \) is \( c_2 - (IV_2(s_2) - IV_1(s_1))/k \). To win the contract, seller 1 can offer the highest \( p_1 \) such that \( k(U(t_1) - p_1) + IV_0(s_1) \geq k(U(t_2) - p_2) + IV_0(s_2) \) (or undercut this price slightly so that the inequality holds strictly). Therefore, \( p_1 = U(t_1) + l(V_0(s_1) + V_2(s_1))/k - [(U(t_2) - c_2) + l(V_0(s_2) + V_2(s_2))/k] \).

Seller 1’s total current and future profit is \( k(p_1 - c_1) + IV_1(s_1) = k(U(t_1) - c_1) + l(V_0(s_1) + V_1(s_1) + V_2(s_1)) - [k(U(t_2) - c_2) + l(V_0(s_2) + V_1(s_2) + V_2(s_2)) + IV_1(s_2)] \).

When both sellers offer the same \( k(U(t_i) - c_i) + l(V_0(s_i) + V_1(s_i) + V_2(s_i)) \), \( p_2 = c_2 - (IV_2(s_2) - IV_1(s_1))/k \) and \( p_1 = c_1 - (IV_1(s_1) - IV_1(s_2))/k \), while the buyer is indifferent in selecting either seller.

Proof of Theorem 2  
By the proof of Theorem 1, if \( k(s_i + \epsilon_i) + IV_i(s_i) \) is lower than \( k(s_i + \epsilon_j) + IV_i(s_j) \), seller \( i \) would lose and obtain \( IV_i(s_j) \); if \( k(s_i + \epsilon_i) + IV_i(s_i) \) is higher, seller \( i \) can capture the difference in additional to the benchmark profit \( IV_i(s_j) \). Under both scenarios, we can write seller \( i \)’s total gain as \( \max\{k(s_i + \epsilon_i) + IV_i(s_i) - [k(s_j + \epsilon_j) + IV_i(s_j)], 0\} + IV_i(s_j) \).

To maximize seller \( i \)’s total gain, the optimal bidding strategy is simply to maximize \( k(s_i + IV_i(s_i)) \).

Proof of Corollary 1  
Without loss of generality, assume that \( \tilde{s}_1 \geq \tilde{s}_2 \)—i.e., seller 1 is the technology leader. Let \( s_2 \) be seller 2’s technology strength choice—i.e., \( s_2 \) maximizes \( ks + IV(s) \) on \( (-\infty, \tilde{s}_2] \). Seller 1 would prefer \( s_2 \) over anything less than \( s_2 \). Therefore, the technology leader would offer a technology strength no less than that of the technology follower.

Proof of Corollary 2  
To maximize \( ks + IV(s) \), it is equivalent to maximize \( \alpha s + V(s) \). It suffices to show that if \( \alpha s + V(s) \geq \alpha' s' + V(s') \) for \( s > s' \), \( \alpha' s + V(s) > \alpha' s' + V(s') \) for any \( \alpha < \alpha' \). This is true because \( (\alpha' - \alpha)(s - s') > 0 \).
Proof of Theorem 3  By Corollary 2, it suffices to show that the result holds for $\alpha = 1$; that is, $\hat{s}_i$ maximizes $s_i + V(s_i)$ on $(-\infty, \hat{s}_i)$.

Notice that because $\epsilon_i$ are drawn independently, we can study the marginal impact of $s_i$ on $V(s_i)$ as if all the $\epsilon_i$ ($i = 0, \cdots, n$) have been realized with the specified density. It suffices to show that a small unit increase in $s_i$ would result in at most a unit decrease for $V(s_i)$ under all possible $\epsilon_i$ realizations.

Case I. $\hat{s}_0 + \epsilon_0 = s_i + \epsilon_0$ is the highest among all sellers in the future market. Under this case, a unit increase in $s_i$ in fact translates into a unit increase for $V(s_i)$.

Case II. $\hat{s}_0 + \epsilon_0 = s_i + \epsilon_0$ is the second highest among all sellers in the future market. Under this case, a unit increase in $s_i$ translates into a unit decrease for $V(s_i)$.

Case III. Otherwise, a unit increase in $s_i$ has no impact on $V(s_i)$.

Therefore, seller $i$’s optimal strategy is to provide technology strength $\hat{s}_i$, when $\alpha = 1$. Notice that when the selection rule is deterministic (i.e., $\epsilon_i = 0$), $\alpha \geq 1$ is needed for the strongest seller (i.e., seller with the highest $\hat{s}$) to provide the technology with the highest strength.

Proof of Lemma 2  $(V(s))' \equiv 3 \frac{e^{\epsilon_i/\mu}}{e^{\epsilon_i/\mu} + e^{\epsilon_j/\mu} + e^{\epsilon_k/\mu}} - \frac{e^{\epsilon_j/\mu}}{e^{\epsilon_j/\mu} + e^{\epsilon_k/\mu} + e^{\epsilon_i/\mu}} = 1 + \frac{e^{\epsilon_1/\mu}}{e^{\epsilon_1/\mu} + e^{\epsilon_2/\mu} + e^{\epsilon_3/\mu}} - \frac{3e^{\epsilon_1/\mu}}{e^{\epsilon_2/\mu} + e^{\epsilon_3/\mu} + e^{\epsilon_4/\mu}}$.

To study the sign of $(V(s))'$, we multiply the right-hand-side by $(e^{\epsilon_1/\mu} + e^{\epsilon_2/\mu} + e^{\epsilon_3/\mu})(e^{\epsilon_2/\mu} + e^{\epsilon_3/\mu} + e^{\epsilon_4/\mu})$, and the expression will become a third-degree polynomial of $e^{\epsilon_i/\mu}$. To simplify the algebra, let $x \equiv e^{\epsilon_i/\mu}$, $a \equiv e^{\epsilon_1/\mu}$, and $b \equiv e^{\epsilon_2/\mu}$. The polynomial can be written as $(x + a + b)(x + a)(x + b) + a(x + b)(x + a + b) + b(x + a)(x + a + b) - 3(a + b)(x + a)(x + b) = x^3 + (-a^2 + ab - b^2)x$. The derivative would only be equal to zero at $e^{\epsilon_i/\mu} = 0$ and $e^{\epsilon_i/\mu} = \sqrt{e^{2\epsilon_1/\mu} + e^{2\epsilon_2/\mu} - e^{(\epsilon_1 + \epsilon_2)/\mu}}$ (the root $e^{\epsilon_i/\mu} = \sqrt{e^{2\epsilon_1/\mu} + e^{2\epsilon_2/\mu} - e^{(\epsilon_1 + \epsilon_2)/\mu}}$ is discarded). Furthermore, the derivative is negative when $s$ is approaching negative infinity and positive when $s$ is approaching positive infinity. Therefore, $V(s)$ is quasi-convex with respect to $s$.

Proof of Lemma 3  $(V(s))'' \equiv \frac{e^{\epsilon_i/\mu}}{e^{\epsilon_i/\mu} + e^{\epsilon_j/\mu} + e^{\epsilon_k/\mu}} - \frac{e^{\epsilon_j/\mu}}{e^{\epsilon_j/\mu} + e^{\epsilon_k/\mu} + e^{\epsilon_i/\mu}} + 3 \frac{e^{\epsilon_i/\mu}}{e^{\epsilon_1/\mu} + e^{\epsilon_2/\mu} + e^{\epsilon_3/\mu}} - \frac{3e^{\epsilon_i/\mu}}{e^{\epsilon_2/\mu} + e^{\epsilon_3/\mu} + e^{\epsilon_4/\mu}}$.

To study the sign of $(V(s))''$, we multiply the right-hand-side by $\mu e^{-\epsilon_i/\mu}(e^{\epsilon_i/\mu} + e^{\epsilon_j/\mu})(e^{\epsilon_2/\mu} + e^{\epsilon_3/\mu})^2(e^{\epsilon_3/\mu} + e^{\epsilon_4/\mu})^2$, and the expression will become a fourth-degree polynomial of $e^{\epsilon_i/\mu}$. To simplify the algebra, let $x \equiv e^{\epsilon_i/\mu}$, $a \equiv e^{\epsilon_1/\mu}$, and $b \equiv e^{\epsilon_2/\mu}$. The polynomial can be written as $3(a + b)(a + x)^2(b + x)^2 - a(b + x)^2(a + b + x)^2 - b(a + x)^2(a + b + x)^2 = 3(a + b)(x^2 + (a + b)x + ab)^2 - ((a + b)x^2 + 4abx + ab(a + b))(x^2 + 2(a + b)x + (a + b)^2) = 3(a + b)(x^4 + 2(a + b)x^3 + ((a + b)^2 + 2ab)x^2 + 2ab(a + b)x + a^2b^2) - ((a + b)x^4 + (2(a + b)^2 + 4ab)x^3 + ((a + b)^3 + 9ab(a + b))x^2 + 6ab(a + b)^2x + ab(a + b)^3) = 2(a + b)x^4 + 4(a^2 + ab + b^2)x^3 + (a + b)(2a^2 + ab + 2b^2)x^2 + ab(a + b)(-a^2 + ab - b^2)$.
Notice that at \( x = 0 \) (i.e., \( s = -\infty \)), the right-hand-side is negative. As \( s \) and \( x \) increase, the left-hand-side is monotone increasing and is positive when \( s = \max\{s_1, s_2\} \) and \( x = \max\{a, b\} \). Therefore, there exists one threshold such that \( V(s) \) is concave when \( s \) is under this threshold and convex when \( s \) is above this threshold.

**Proof of Corollary 3** \( \alpha s + V(s) = (V(s))'' \). By Lemma 3, the function is first concave and then convex and has at most one internal local maximum solution. If both sellers offer an internal solution, they must both offer this local maximum solution.

**Proof of Corollary 4** To find out when the technology follower’s choice stops to jump, we solve \( (V(s))'' = 0 \) with \( \bar{s}_1 > \bar{s}_2 = s \). Define \( x \equiv e^{s/\mu}, a \equiv e^{\bar{s}_1/\mu}, \) and \( b \equiv e^{\bar{s}_2/\mu} \). \( (V(s))'' = 0 \) implies \( \frac{a}{(a+x)^2} + \frac{b}{(b+x)^2} = \frac{3(a+b)}{(a+b+x)^2} \). Without loss of generality, we can set \( \bar{s}_2 = 0 \) and solve the equation for \( x = b = 1 \); we have \( \frac{a}{(a+1)^2} + \frac{1}{4} = \frac{3(a+1)}{(a+2)^2} \) or \( a^4 - 2\alpha^3 - 7\alpha^2 - 8a - 8 = 0 \). The polynomial equation has a unique positive root \( a = 4.2167 \). Therefore, \( e^\Delta = e^{(\bar{s}_1 - \bar{s}_2)/\mu} = 4.2167 \), and the threshold translates into 1.439.

When the normalized technology gap \( \Delta \) is larger than 1.439, the technology follower’s decision would be on the concave part of the \( V(s) \) curve and no jump would occur.

**Proof of Corollary 5** As \( \Delta \to +\infty \), to find out \( \alpha(\Delta) \) that induces the jump of technology choice for technology leader seller 1, we solve \( s \) and \( \bar{s}_1 \) that offer the same total social benefit, while the derivative at \( s \) is also zero. That, \( \alpha(\bar{s}_1 - s) = V(s) - V(\bar{s}_1) \) and \( \alpha + 1 + \frac{e^{s_1/\mu}}{e^{s_1/\mu} + e^{s_2/\mu}} + \frac{e^{s_2/\mu}}{e^{s_1/\mu} + e^{s_2/\mu}} - 3\frac{e^{s_1/\mu} + e^{s_2/\mu}}{e^{s_1/\mu} + e^{s_2/\mu} + e^{s_3/\mu}} = 0 \). Define \( x \equiv e^{s/\mu}, a \equiv e^{\bar{s}_1/\mu}, \) and \( b \equiv e^{\bar{s}_2/\mu} \), we can rewrite the equations as \( (1 + \alpha)x^3 + 2\alpha(a + b)x^2 + (1 + 3\alpha)ab - (1 - \alpha)(a^2 + b^2)x + ab(a + b) = 0 \) and \( \alpha(\bar{s}_1 - s) = V(s) - V(\bar{s}_1) \).

Notice that the third-degree polynomial has one negative root and two positive roots; the large positive root corresponds to a local minimum, while we want to solve the small positive root. As \( \Delta \to +\infty \), \( b/a \to 0 \). Therefore, \( x/b \) (i.e., \( e^{(s - \bar{s}_2)/\mu} \)) converges to \( \frac{1}{1 - \alpha} \) for the small positive root. For any \( \alpha < 1 \), \( V(s) - V(\bar{s}_1) \) divided by \( \mu\Delta \) approaches 1 as \( \Delta \to +\infty \), while \( \alpha(\bar{s}_1 - s) \) divided by \( \mu\Delta \) approaches \( \alpha < 1 \) as \( \Delta \to +\infty \). That is, for any \( \alpha < 1 \), the internal solution would be superior than the boundary solution when \( \Delta \) is sufficiently large. Therefore, \( \alpha(\Delta) \to 1 \) as \( \Delta \to +\infty \) given that \( \alpha = 1 \) is superior for all scenarios by Theorem 3.

As \( \Delta \to -\infty \), seller 1 is the technology follower and when \( \Delta < -1.439 \), seller 1’s technology choice would be on the concave part of the \( V(s) \) (Corollary 4). Therefore, it suffices to calculate the derivative \( (V(s))' \) at \( s = \bar{s}_2 \) and let \( \Delta \) approach \( -\infty \), which is lim(1 + \( e^{s_1/\mu} \) \( e^{s_2/\mu} \) \( e^{s_3/\mu} \) \( e^{s_2/\mu} \) \( e^{s_3/\mu} \) \( e^{s_3/\mu} \)) = lim(1 + \( e^{s_1/\mu} \) \( e^{s_2/\mu} \) \( e^{s_3/\mu} \) \( e^{s_3/\mu} \) \( e^{s_3/\mu} \)) = \( e^{(s_1 + s_2 + s_3)/\mu} \).
Notice that \(e^{(V_1(s_2) - V_1(s_1))/\mu} = \left(\frac{\alpha e^\mu - 2e^\mu s_2 + 2e^\mu s_1}{2e^\mu + 2e^\mu s_2 + 2e^\mu s_1}\right)\) and \(e^{(V_2(s_2) - V_2(s_1))/\mu} = \left(\frac{\alpha e^\mu + 2e^\mu s_2 - 2e^\mu s_1}{2e^\mu + 2e^\mu s_2 + 2e^\mu s_1}\right)\).

Recall \(\alpha = \frac{k}{\mu}\). The difference is \(k\mu \ln \left(\frac{e^{x_2 + 1/2} + e^{x_1 + 1/2}}{e^{x_2 + 1/2} - e^{x_1 + 1/2}}\right)\). The expression becomes \(-k\mu \ln (f(\Theta, \beta))\), where \(f(\Theta, \beta) = \left(\frac{(\Theta + 1)(\Theta + 2)}{2(\Theta + 2)}\right)^\beta + \frac{1}{\Theta + 1} \left(\frac{(\Theta + 2)(\Theta + 3)}{2(\Theta + 2)}\right)^\beta\). It suffices to show that \(f(\Theta, \beta) = 1\).

We show that the derivative with respect to \(\beta\) is positive. Notice that \(f(\cdot, 0) = 1\), and therefore \(f(\Theta, \beta) = 1\). As \(\beta\) is a monotone decreasing function of \(\alpha\) on \((0, \infty)\), this result implies the loss of current gain for acquiring technology is monotone decreasing in \(\alpha\).

When \(\Delta = 0\) (and \(\Theta = 1\)), the expression is zero as \(f(1, \cdot) = 1\). We prove for the case \(\Theta > 1\), and the case for \(\Theta < 1\) can be done similarly. When \(\Theta > 1\), \(\left(\frac{(\Theta + 2)(\Theta + 3)}{2(\Theta + 2)}\right) < 1 < \left(\frac{(\Theta + 2)(\Theta + 1)}{2(\Theta + 1)}\right)\), the first term in the derivative is negative and the second term is positive. The derivative is minimized at \(\beta = 0\). It suffices to show that \(\left(\frac{(\Theta + 1)(\Theta + 2)}{2(\Theta + 2)}\right)^\beta + \frac{1}{\Theta + 1} \left(\frac{(\Theta + 2)(\Theta + 3)}{2(\Theta + 2)}\right)^\beta\) is positive. Notice that \(f(\cdot, 0) = 1\), and therefore \(f(\Theta, \beta) = 1\). As \(\beta\) is a monotone decreasing function of \(\alpha\) on \((0, \infty)\), this result implies the loss of current gain for acquiring technology is monotone decreasing in \(\alpha\).

**Proof of Theorem 5**

The expected future gain is a weighted average of two positive terms; therefore, it is positive. When \(\Delta = 0\), the expected per-unit future gain is \(V_0(s_1) = V_0(s_2)\). For \(\Delta \neq 0\), without of loss of generality, assume \(\Delta > 0\) so that \(V_0(s_1) > V_0(s_2)\). It suffices to show that as \(\alpha\) increases, the probability that the buyer would acquire technology from seller 1 increases—i.e., \(e^{(x_1 + 1/2) - (x_2 + 1/2)}/\mu\) is increasing in \(\alpha\), or \(V_2(s_2) - V_2(s_1) - V_2(s_2) + V_2(s_1)\) is decreasing in \(\alpha\). The statement is true because \(V_2(s_2) - V_2(s_1) - V_2(s_2) + V_2(s_1) > 0\) due to \(s_1 > s_2\).

**References**


