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Bid-Taker Power and Supply Base Diversification

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We study a buyer who periodically auctions off short-term supply contracts among her supply base. To mitigate significant cost shocks to procurement, the buyer can diversify her supply base by selecting suppliers from different regions. We find that the buyer's decision to diversify depends on her bid-taker power—that is, her ability to choose the auction mechanism. At one extreme, when the buyer has full bid-taker power and thus can dictatorially implement the optimal mechanism, she always prefers to diversify. At the other extreme, when the buyer uses a reverse English auction with no reserve price due to her lack of bid-taker power, she generally prefers to protect herself against potential price escalation from cost-advantaged suppliers by diversifying less. The managerial insight is that the more bid-taker power the buyer has to control price escalation from cost-advantaged suppliers the more she prefers a diversified supply base. This insight is shown to be robust to correlation between regional costs, ex ante asymmetry between regions, and intermediate levels of bid-taker power.

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1. Introduction

It is common for procurement managers (buyers) responsible for procuring an item to identify a *supply base*, a group of qualified suppliers that are capable of producing the item. Having a supply base allows the buyer to periodically reallocate (through a competitive bid process) the contract to whichever supplier currently offers the most attractive overall cost. In turn, the current overall cost offered by a supplier is often affected by the supplier's regional location.

For example, a Fortune 500 automotive parts manufacturer we interacted with externally sourced an entire category of cast metal parts from qualified suppliers. Castings suppliers tended to be located in developing countries (e.g., in Asia and South America). The parts were heavy and were therefore primarily shipped by sea, and the cost of shipping out of a supplier's region was important to the buyer. Shipping costs are affected by things like supply and demand for transport along key lanes as well as geopolitical events. For example, at their height Somali pirate attacks caused shipping insurance premiums for Asia to Europe ocean transport to increase tenfold (Costello 2008). The costs of material inputs for production can also depend on a supplier's region. For example, for a major class of parts purchased by the buyer, the cost of metal (e.g., iron and steel scrap) was a significant part of the total cost, and the buyer was moving to contracts where it would essentially reimburse suppliers for their costs of metal. Metal price differences across regions are driven by regional supply and demand and can be significant. For example, in August 2011 the price of steel was approximately 7% cheaper in the United States than in Germany, but by early 2012, it was 20% cheaper in Germany than in the United States (Farchy 2012). This type of price variation can have nontrivial effects on the buyer's cost for items such as castings where raw materials make up approximately 65% of a part's cost. (See IBISWorld 2013 for a prototypical cost breakdown.)

Regionality of costs has implications for the buyer's supply base design decision. Just because a certain region has attractive costs currently does not mean that a buyer can access those low costs. For example, suppose that our automotive buyer wishes to utilize a supplier in region A where metal prices and outbound shipping costs are currently extremely low. If she does not already have a qualified supplier in region A, she will not be able to do so. This is because, for all but the most extreme scenarios, augmenting a supply base with new suppliers is impractical because at many buyer firms we have worked with it can take months to find and qualify a new supplier, even for relatively standardized parts. Instead of frequently finding and qualifying new suppliers, buyers, including the large manufacturer we interacted with, build their supply base as a long-term strategic decision and then periodically use competitive tenders to find the current lowest-total-cost supplier. For such buyers, therefore, an important strategic decision arises when forming their supply base: Should the buyer's supply base include *similar* suppliers (selected from the same region) or *diversified* suppliers (selected from two different regions)?

Regional cost drivers exist in a variety of industries. For example, in the electronics industry, when the Asian supply of industrial petrochemical methyl ethyl ketone (used in circuit board production) was curtailed as a result of the Japanese earthquake of 2011, prices in Asia soared as the region relied on imports from elsewhere. Although prices increased globally as a result, the cost increases in Asia were particularly severe as supplies had to be shipped in from as far away as Europe; Asian prices spiked to 146% of those in Europe before setting to within 15% of prices in Europe five months later (ICIS 2011). In the textiles industry, regional costs can be affected by current country-specific taxes and tariffs. For example, citing human rights abuses the European Union (EU) voted to temporarily revoke Sri Lanka's "GSP plus" trading status in August 2010. The EU increased tariffs on Sri Lankan imports by as much as 18% (Bajaj 2010) and left them in effect until the Sri Lankan government instituted human rights reforms required by the EU. The design of a supply base is critically important when buyers face razor-thin margins, as they often do in the auto parts, electronics, and textiles industries.

Once a supply base is in place, periodically reauctioning contracts allows buyers to stay abreast of current best available pricing in the supply base; see, for example, the practitioner survey by Beall et al. (2003). Prototypical auction formats used in procurement practice include the reverse English format and the first-price sealed-bid format; for industrial studies documenting their use, see Beall et al. (2003) and Jap (2003, 2007). In the reverse English format (RE), the price decreases as the auction progresses and suppliers can respond by lowering their own bid. In contrast, in the first-price sealed-bid format (FS), each supplier simultaneously submits a best and final offer. The addition of a reserve price to either auction format (which we denote as RER and FSR, respectively) make for a total of four common auction formats. (The reverse Dutch auction is another format the authors have seen used in practice, whereby a price clock visible to all suppliers increases from zero and the first supplier to bid wins the contract at the current clock price. However, this format is strategically equivalent to a first-price sealed-bid auction (e.g., Krishna 2002, p. 4).)

Because there are a range of auction formats possible, an important question—which we address in this paper—is whether or not the particular format a buyer uses can influence her decisions about whether or not to diversify her supply base. The question is not innocuous because a buyer's auction format choice can depend on what we call the buyer's *bid-taker power* to set auction rules and commit to them. To understand why, consider the four standard mechanisms {RE, RER, FS, FSR}. The latter three are different from the first format (RE) in one key respect: the latter three all require commitment power on the part of the bid taker (the buyer). Namely, a bid taker using a first-price sealed-bid format must commit to ignore counteroffers made by losing bidders, and likewise, a bid taker using a reserve price must commit to not award the business to any bidder not meeting the reserve, no matter how much carrying out such a threat would cost the bid taker.

The flip side of the coin is that when bid takers are unable to make such commitments, the bidders bid anticipating that the only thing that matters in determining the price is a competing offer from another bidder, and offers will be entertained until no bidders wish to bid further—that is, the bidders will bid as if they are in an RE. Thus, RE is the appropriate model of price negotiation processes for bid takers who lack commitment power (Klemperer 2008).

Klemperer (2008) cites several reasons why bid takers in practice can lack the ability to design and commit to auction rules, including lobbying by bidders and the bid taker's own interorganizational issues. To understand this in a procurement setting, consider a buyer who solicits bids for a first-price sealed-bid auction. Suppose that after the auction, a losing supplier calls a high-level manager at the buyer firm and offers a price concession that would save the buyer firm a significant amount of money. If this high-level manager sees this as a beneficial opportunity (perhaps because short-term stock price is more important to the manager's bonus than long-term profits), he could command the lower-level manager running the bid-tendering process to consider the supplier's new offer. Of course, once suppliers anticipate that this kind of thing will happen, they simply bid from the outset as if they are competing in a reverse English auction—effectively, the buyer firm lacks the ability to commit to the first-price sealed-bid auction format. Similarly, consider a buyer using a reserve price; if no bids meet the reserve price, the buyer will have to forgo the contract (which could be costly for the buyer). Suppose suppliers anticipate that the buyer would not actually carry out this threat—instead, they expect the buyer would turn around and try to reauction the contract to the same set of suppliers with a higher reserve price. (Again, this could be due to interorganizational pressures to rerun the auction and simply get the material to the assembly lines that need it. That is, even at a higher price, it may not make sense to delay an entire production process for the want of one component.) Then a reserve price is not credible, and setting one is useless because the winning supplier would not let it truncate their payment.

The above are real-world situations that would be familiar to many buyers and suppliers in practice. Thus, they should be considered when seeking to understand whether or not a buyer should diversify her supply base. In our paper, we account for this by analyzing a buyer who lacks the ability to design and commit to auction rules and hence is only able to run a mechanism RE. We ask how this inability affects the buyer's supply base design decisions. At the same time, not every buyer lacks such power; indeed, we have worked with buyers who make it a point to consistently commit to their announced auction rules (sometimes over the protestations of internal constituents who do not grasp the notion that commitment sometimes involves turning down profitable opportunities ex post). To capture this in our paper, we also consider buyers who do have the ability to design and commit to standard auction rules. These buyers can run formats in the set {RE, RER, FS, FSR}. We ask how this ability affects these buyers' supply base design decisions. Extending the notion of commitment power even further, one can imagine buyers who have the ability to design and commit to any type of auction rules they wish to. In theory, such buyers run so-called optimal mechanisms (denoted as OPT), which involve things like biasing rules that tilt the competition in favor of high-cost suppliers. This benefits the buyer by forcing low-cost suppliers to compete more fiercely. Suppliers may resist such mechanisms because they view them as unfair, but if a buyer is large enough (e.g., Walmart), suppliers may have little choice but to play along. Thus, in our paper we also consider buyers who have the ability to run an optimal mechanism and ask how this power affects which supply base is optimal for such buyers.

The paragraph above describes three types of buyers: buyers who lack the ability to design and commit to auction rules, buyers who can implement and commit to standard auction rules, and buyers who have full power to design and commit to any auction rules. Our paper considers all three types of buyers. The former (*weak* bid-taker power) can only run a format RE. The latter (*strong* bid-taker power) can run any format she chooses, so she naturally chooses the optimal mechanism (OPT). The middle (*intermediate* bid-taker power) can run any of the standard mechanisms {RE, RER, FS, FSR} but does not have the ability to run OPT.

In this paper, we examine whether the buyer's bid-taker power affects supply base diversification decisions and, if so, when and why. Formally, we pose the following research questions:

1. How does the buyer's bid-taker power—her ability or inability to implement various auction formats—affect her preference for or against supply base diversification?

2. Does the answer to question 1 depend on the distributions of supplier-specific and regional costs?

3. How do answers to the above questions depend on the amount of correlation between regions, the number of suppliers in each region, and ex ante asymmetry between regions?

Intuitively, one may expect that buyers with weaker bid-taker power want to diversify more because, without much ability to wring price concessions from suppliers, having access to regions with low costs would seem paramount. However, we find that this type of logic is turned on its head, and in fact, weaker buyers wish to diversify less. We explore why this is so and when and how the diversification decisions do or do not depend on the underlying business conditions. More detailed answers to the above research questions are summarized in §7. To our knowledge, this is the first paper to study the interplay between buyer bid-taker power and supply base design; related literature is discussed in §2. A base model with two suppliers is introduced in §3, auction preliminaries are provided in §4, and the supply base design decision is analyzed in §5. Section 6 extends the analysis to multiple suppliers, correlated regional costs, ex ante asymmetric regions, and multiplicative regional costs. All proofs are provided in the online supplement (available at http://dx.doi.org/10.1287/msom.2014.0477).

2. Literature Review

There is a large body of research on managing supply *availability* risks, stemming from uncertain lead times and yields (e.g., Anupindi and Akella 1993) or supplier disruption (e.g., Tomlin and Wang 2005; Dada et al. 2007; Tomlin 2006; Federgruen and Yang 2008, 2009; Yang et al. 2009, 2012). In contrast, we assume that suppliers are reliable but focus on managing supply *cost* risks, which are random impacts to the buyer's total cost arising from logistics costs, purchase prices, etc. Availability and cost risks can both be managed by having a cohort of qualified suppliers. When availability is the chief concern, the buyer can simultaneously order from multiple suppliers to reduce her risks of nondelivery (e.g., Federgruen and Yang 2008, 2009; Yang et al. 2012). However, the purpose of having these suppliers for managing cost risks is different. To manage cost risks, the buyer keeps multiple, prequalified suppliers in the supply base and reauctions periodically to sole source from whichever supplier currently offers the lowest total cost.

We study suppliers who strategically set prices, unlike most of the supply risk management literature that presumes that suppliers' prices are exogenous. One exception is Babich et al. (2007), which endogenizes suppliers' pricing decisions in a setting where a buyer allocates ordering quantities among suppliers with correlated default risks. They show that the buyer prefers suppliers with positively correlated default risks despite the loss of diversification benefits because default risk correlation increases supplier competition. We model supplier competition via procurement auctions in which suppliers possess private cost information, and we show how supplier competition can be affected by correlations across suppliers' regional costs. We find that the buyer's bid-taker power dictates her preference for the supply base design; a buyer with stronger bid-taker power prefers a more diversified supply base, which induces less correlation across suppliers' cost shocks.

A stream of work in operations management studies using long-term and option supply contracts to manage risk, including the risk of uncertain costs in the supply spot market (e.g., Kleindorfer and Wu 2003, Martínez de Albéniz and Simchi-Levi 2005). Having multiple suppliers is a kind of real option—the buyer can switch suppliers if one offers a better total cost. We study how best to manage this type of real option—namely, whether the buyer should use a pooled or diversified supply base strategy. In our setting, whether or not the buyer's real option is "in the money" depends on the buyer's ability to design and commit to auction rules (i.e., her bid-taker power). This is the focus of our paper and is absent from the extant operations literature on real options.

Our paper shows that the buyer's bid-taker power can profoundly impact its operational supply base design strategies. Recently, two other papers in the supply chain management literature examined the impact of buying firms' channel power on their supply chain decisions and performance. Feng and Lu (2012) show that when two competing buyers outsource to a common supplier they may gain more profit if their power relative to the supplier decreases, and Feng and Lu (2013) examine how the competing buyers' power affects their preference between using a common supplier and using exclusive suppliers. Unlike our paper, which focuses on decisions of a single buyer with competing suppliers, these papers examine competing buyers. As such they use a different yard stick for measuring buyer power—namely, the buyer's clout relative to its supplier in bilateral bargaining situations, modeled by the well-known asymmetric Nash bargaining model (Roth 1979). By contrast, the buyer's power in our paper means its "bid-taker power," defined in Klemperer (2008, p. 602) as "skillful use of the bid-taker's monopsonistic power to design and run the [auction] contest" and the capability to "precommit his future behaviour." In analyzing how the buyer's power affects its optimal supply base design strategy, we compare a weak buyer, who can only use a reverse English auction without reserve price, with a strong buyer, who can run an optimal auction. The spirit of this comparison can be traced to the prominent work of Bulow and Klemperer (1996), who in a symmetric setting show that a weak auctioneer running an English auction with no reserve price earns more in expectation than a strong auctioneer running an optimal auction with one fewer bidder.

Many papers examine cost reduction via supply base competition. Elmaghraby (2007) surveys industry practices in designing and running procurement auctions, and Elmaghraby (2000) surveys operations and economics research on competitive sourcing strategies, including auctions. Grey et al. (2005) discuss the role of e-marketplaces within long-term buyer-supplier relationships. Our paper considers a buyer who finds the lowest-total-cost supplier by periodically auctioning off short-term supply contracts among a stable supply base. Recent work on the use of auctions in supply chains include Chen and Vulcano (2008), which studies a supplier's auction to sell capacity and compares first- and second-price auction formats, and Li (2013), which studies how the number of suppliers and the buyer's capacity investment therein, along with her pricing-decision timing, affect supplier competition and cost-reduction effort. We study multiple auction formats and the buyer's supply base design decisions, focusing on understanding how the former affects the latter.

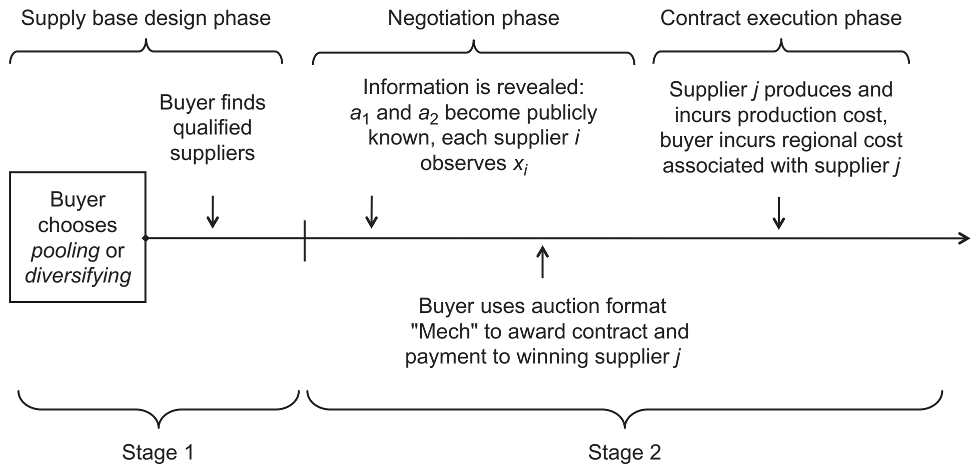
3. Base Model

In our base model, we consider a buyer forming a supply base of two suppliers, potentially selected from two different but ex ante symmetric geographic *regions*, indexed by $r = 1, 2$. In §6, we extend our analysis to the cases where $N > 2$ suppliers form the supply base and/or the two regions might be ex ante asymmetric. Figure 1 depicts our model's sequence of events, comprised of two stages. In stage 1 (supply base design), the buyer designs her supply base, and in stage 2 (contract award), costs are realized, the buyer holds an auction, and the buyer incurs a total procurement cost.

In stage 1, the buyer chooses between the *pooling* strategy (selecting both suppliers in the same region) and the *diversifying* strategy (selecting suppliers in different regions). The buyer's supply base design decision involves choosing a strategy. In designing her supply base, the buyer's objective is to minimize her expected total procurement cost in stage 2. Because designing the supply base amounts to a long-term decision (in practice, frequently finding and qualifying new suppliers is often impractical because of costly and time-consuming supplier qualification screening processes), the above two-stage model also captures settings where the second stage periodically repeats. Solving our two-stage incarnation is a notationally clean way to model a buyer designing a supply base that she plans to repeatedly draw upon when making contract awards in the future.

In stage 2, to find which supplier offers her the best overall cost, the buyer runs an auction to award an indivisible short-term contract to one of the suppliers in the supply base. This setup is most appropriate when

Figure 1 **Sequence of Events in the Model**



the buyer procures commodity items from suppliers, who do not fully rely on the buyer's contract to keep afloat. To keep the analysis focused and tractable, we assume that the buyer does not store inventory and does not have in-house production, and hence she must contract with one supplier in stage 2. This could model, for example, a buyer who produces relatively short life-cycle products and relies on suppliers for key components.

In stage 2, there are two types of costs associated with each supplier $i = 1, 2$. The first type is production cost, denoted by x_i, which is supplier i's firm-specific cost of fulfilling the contract that the buyer is auctioning off in stage 2. This cost is supplier i's private information and could depend on its inventory level, capacity utilization, working capital position, etc. Following auction theoretic conventions, we assume that costs $x_i \in [0, 1]$ are independent and identically distributed across suppliers according to a commonly known distribution F having a positive and finite density f, and that F is regular, i.e., $x + F(x)/f(x)$ increases in x. The latter assumption ensures a pure-strategy implementation of the optimal mechanism (described in §4) and is satisfied, for example, by all logconcave f, including uniform, normal, logistic, and exponential distributions (Bagnoli and Bergstrom 2005).

The second type of cost associated with each supplier i is a region-specific cost a_i. As explained in §1, regional costs can correspond to various things: a_i could be the cost of transporting goods from supplier i's region, the cost of procuring steel in supplier i's region, etc. For expositional clarity, we will assume that the buyer directly incurs a_i as an additive procurement expense when sourcing from supplier i. It is straightforward to reinterpret the model for the case when suppliers bear the regional costs (e.g., the supplier pays the shipping cost or the steel cost), and extending this notion further, §6.3 allows regional cost factors to enter suppliers' cost structure in a multiplicative way.

To be practical, the production cost x_i and the regional cost a_i are, naturally, estimates of the costs that would be incurred when executing the contract during stage 2. These costs are used during the negotiation phase at the outset of stage 2. For example, suppose a_i captures shipping costs and the contract up for bid is for 100 containers of goods delivered over three months. If along the shipping lane from supplier i to the buyer the per container cost for shipments during the next three months is \$1,250, then $a_i = \$125{,}000$. The cost estimate a_i is based on the available information at the time when the contract is bid. In other words, if just prior to stage 2 there were recent pirate attacks along the shipping lane that impacted shipping insurance rates, then the per container shipping costs might be higher, say \$2,000, and $a_i = \$200{,}000$. The allocation of the buyer's contract and the contract payment are determined through supplier competition in an auction at the outset of stage 2. The auction is followed by contract execution, when the actual production and regional costs are incurred. The winning supplier receives the fixed contract payment (per the outcome of the auction) and then incurs the actual production cost during stage 2, and the buyer pays the fixed contract payment and then incurs the actual regional cost during stage 2. For concision in the sequel, we refer to x_i and a_i as costs rather than estimated costs.

When designing her supply base in stage 1, the buyer does not know what the a_i's will be in stage 2. This reflects the discussion above that a supply base is durable and used by the buyer to periodically reauction her contract; thus one should think of stage 2 in the model as simply a prototypical future auction stage after the buyer has already designed her supply base. Accordingly, when designing her supply base in stage 1, the buyer relies on her priors over the a_i's. In the base model, we assume that each region is ex ante symmetric. We let $s \stackrel{\text{def}}{=} |a_1 - a_2|$ denote the *regional cost difference* and let G denote the distribution of s. Obviously, if the buyer decides to locate both suppliers in the same region, then $a_1 = a_2$ and thus s is trivially equal to zero. If the suppliers are located in different regions, then a_1 and a_2 can be different so s can be positive. We allow the a_i's to be correlated even if the suppliers are chosen from different regions; such correlation would be captured in the distribution G. Whereas production cost x_i is supplier i's private information, we assume that at the outset of stage 2 the regional costs a_i's become publicly known. This captures situations where regional cost is largely driven by public information, such as the prevailing insurance and shipping rates along a sea lane.

In what follows, we call $x_i + a_i$ supplier i's *total cost*, that is, supplier i's production cost adjusted by the additive regional cost a_i. Let $\mathbf{x} \stackrel{\text{def}}{=} (x_1, x_2)$ and $\mathbf{a} \stackrel{\text{def}}{=} (a_1, a_2)$.

4. Preliminaries: Buyer's Bid-Taker Power and Available Auction Mechanisms

At the outset of stage 2, the buyer holds an auction among the suppliers who—as is standard in the auction literature—are assumed to bid in a way that maximizes their expected profit. As described in §1, which auction format(s) the buyer can choose depends on her bid-taker power, which we write as $\mathcal{M} \subseteq \{\text{RE}, \text{RER}, \text{FS}, \text{FSR}, \text{OPT}\}$. Let $\pi^{\text{Mech}}(\mathbf{x}, \mathbf{a})$ denote the buyer's total procurement cost given that she uses auction mechanism "Mech" in stage 2. At the outset of stage 2, the buyer observes $\mathbf{a}$ and obviously would choose to run whichever available mechanism will minimize her expected total cost, incurring an expected total cost of $\min_{\text{Mech}\in\mathcal{M}} E_{\mathbf{x}}[\pi^{\text{Mech}}(\mathbf{x}, \mathbf{a})]$.

Working backward to the buyer's stage 1 supply base decision, the buyer chooses whichever strategy—pool or diversify—minimizes her expected total cost. Thus, the buyer's expected stage 1 total cost equals

$$\min\left(E_{\mathbf{a}\mid\text{pool}}\left\{\min_{\text{Mech}\in\mathcal{M}} E_{\mathbf{x}}[\pi^{\text{Mech}}(\mathbf{x}, \mathbf{a})]\right\},\right.$$
$$\left. E_{\mathbf{a}\mid\text{diversify}}\left\{\min_{\text{Mech}\in\mathcal{M}} E_{\mathbf{x}}[\pi^{\text{Mech}}(\mathbf{x}, \mathbf{a})]\right\}\right).$$

The objective of this paper is to characterize which decision—pool or diversify—minimizes this cost. To do so, we begin by characterizing the costs in stage 2, namely, costs associated with various mechanisms. Throughout the paper, $X_{k:n}$ denotes the kth lowest order statistic out of n independent random draws from distributions F, $\bar{X}_{k:n}$ denotes the respective expectation, and $\mathbb{1}_{\{A\}}$ denotes the indicator function of event A.

4.1. Reverse English Auction Without/With Reserve (RE/RER)

As explained in §1, for a buyer who lacks the ability to design and commit to auction rules, the negotiation process devolves into a reverse English auction without a reserve price (RE). During the auction, when a supplier bids a price, his regional cost is added to yield the supplier's total-cost bid; for example, if a supplier i with regional cost $a_i^t = \$125{,}000$ offers a price bid of \$500,000 to execute the contract, his total-cost bid is \$625,000. During the auction, each supplier sees his competitor's current total-cost bid and can lower his own price bid if his current total-cost bid is not lower. The auction ends when no bidder wishes to lower his bid further, and the winner is paid his winning price bid. It is a weakly dominant strategy for a supplier to stay in the auction until he either wins or the total-cost bid reaches his true total cost $x_i + a_i$ (see, e.g., Maskin and Riley 2000). Thus, the auction ends when the second-lowest total-cost supplier drops out at his true total cost *second* $\min_{i=1,2}\{x_i + a_i\}$, where second $\min\{\cdot\}$ denotes the second-lowest value in the set and is simply the higher total cost in the two-supplier case. We use "second-min" for generality, useful in §6.1. The lowest total-cost supplier j wins the auction ($j = \arg\min_{i=1,2}\{x_i + a_i\}$, ties are broken evenly) and receives a payment $Pay(\text{RE}) \stackrel{\text{def}}{=} \text{second}\min\{x_i + a_i, i = 1, 2\} - a_j$. We also study cases where the buyer can impose the optimal reserve price in a reverse English auction (RER). Because the buyer must contract with a supplier, if the buyer uses a reserve price, it is always optimal to set it at the worst possible supplier cost type, i.e., at 1. The RER auction proceeds as before, and it remains optimal for bidders to bid down to their true total cost before dropping out, but the buyer's payment is truncated by 1 from above; i.e., $Pay(\text{RER}) \stackrel{\text{def}}{=} \text{second}\min\{x_i + a_i, 1 + a_i, i = 1, 2\} - a_j$. Under either RE or RER, adding the winner's regional cost a_j to the payment yields the buyer's total cost:

$$\pi^{\text{RE}}(\mathbf{x}, \mathbf{a}) = \text{second}\min\{x_i + a_i, i = 1, 2\}; \tag{1a}$$

$$\pi^{\text{RER}}(\mathbf{x}, \mathbf{a}) = \text{second}\min\{x_i + a_i, 1 + a_i, i = 1, 2\}. \tag{1b}$$

4.2. First-Price Sealed-Bid Auction Without/With Reserve (FS/FSR)

When the buyer has the ability to make a binding commitment to reject renegotiation offers, she can hold a first-price sealed-bid auction with no reserve price (FS). In such an auction, each supplier i makes a single, "best and final" sealed price bid, denoted by b_i. The contract winner is supplier j with the lowest total-cost sealed bid, that is, $j = \arg\min_{i=1,2}\{b_i + a_i\}$, and the winner j is paid his price bid b_j. Let $\beta_i^{\text{FS}}(x_i, \mathbf{a})$ denote supplier i's Bayesian Nash equilibrium bid. In our analysis, we also study cases where the buyer can impose a credible reserve price when using a first-price sealed-bid auction whereby price bids above 1 are rejected (FSR). In such a case, the equilibrium bidding strategy is denoted by $b_i = \beta_i^{\text{FSR}}(x_i, \mathbf{a})$. Hence,

$$\pi^{\text{FS}}(\mathbf{x}, \mathbf{a}) = \min_{i=1,2}\{\beta_i^{\text{FS}}(x_i, \mathbf{a}) + a_i\}; \tag{2a}$$

$$\pi^{\mathrm{FSR}}(\mathbf{x}, \mathbf{a}) = \min_{i=1,2}\{\beta_i^{\mathrm{FSR}}(x_i, \mathbf{a}) + a_i, 1 + a_i\}. \tag{2b}$$

In general, strategies β^{FS} and β^{FSR} are characterized by differential equations and are not amenable to closed-form analysis because of ex ante (regional cost) asymmetry between bidders; for details, see the online supplement, where we describe an approach to numerically solve β_i^{FS} and β_i^{FSR}. Fortunately, we are interested in characterizing the buyer's optimal diversification decision, for which a closed-form expression for suppliers' bidding strategies is not always needed.

4.3. Optimal Mechanism (OPT)

When the buyer has full bid-taker power, she can offer a join-or-leave-it mechanism such that both suppliers will participate and the buyer's expected total procurement cost is minimized. Let $\psi(x_i) \stackrel{\mathrm{def}}{=} x_i + F(x_i)/f(x_i)$ denote supplier i's *virtual cost*, and let $\psi(x_i) + a_i$ denote supplier i's *virtual total cost*. Using a standard mechanism design approach (Myerson 1981), it is straightforward to show that the optimal mechanism can be implemented by a modified reverse clock auction that proceeds as follows: the auction begins at calling price $\psi(1) + \max_{i=1,2}\{a_i\}$ and continuously drops. Each bidder signals their willingness to stay in the auction or drop out, and the auction ends when at most one bidder remains in the auction. Let p be the calling price when the auction ends. The last bidder remaining in the auction, say bidder j, wins and is paid $Pay(\mathrm{OPT}) \stackrel{\mathrm{def}}{=} \min\{\psi^{-1}(p - a_j), 1\}$, and ties are broken evenly. Suppliers have a dominant strategy of staying in the auction until the calling price reaches their true virtual total cost. Formally, the auction awards the contract to supplier j having the lower virtual total cost, i.e., $j = \arg\min_{i=1,2}\{\psi(x_i) + a_i\}$ (ties are broken evenly) at a payment price of $\min\{\psi^{-1}(p - a_j), 1\}$, where $p = \min_{i \neq j}\{\psi(x_i) + a_i\}$, and the buyer's total procurement cost is

$$\pi^{\mathrm{OPT}}(\mathbf{x}, \mathbf{a}) = \min\{\psi^{-1}(p - a_j), 1\} + a_j. \tag{3}$$

In other words, the optimal mechanism compares suppliers not on true total cost but instead on virtual total cost. Moreover, the payment is truncated from above by an optimal reserve price of 1.

5. Optimal Supply Base Design Strategies

The buyer solves her supply base design problem at the outset of the horizon in stage 1, and at that moment, she does not know what the value of the regional costs will be in the future stage 2. She does know that her supply base design determines her suppliers' regional cost correlations. Pooling yields equal regional cost among suppliers, whereas diversifying engenders regional cost disparities. The regional cost (dis)parity affects her total procurement cost. To see this, suppose suppliers were pooled in region 1. If region 1 happens to have lower regional cost, the pooling buyer "wins" by securing the lower regional cost in stage 2 no matter which supplier wins the contract, but if region 1 has higher regional cost, the pooling buyer "loses" by suffering the higher regional cost no matter which supplier wins the contract. By contrast, diversifying ensures that the buyer always has access to a supplier in whichever region has a lower regional cost.

We formalize the above intuition and analyze the buyer's supply base design problem. Without loss of generality, we assume that the diversifying strategy has supplier 1 from region 1 and supplier 2 from region 2 and that the pooling strategy has both suppliers from region 1. Given a pair of realized regional costs under the diversifying strategy $(\tilde{a}_1, \tilde{a}_2)$, the pair under the pooling strategy is thus $(\tilde{a}_1, \tilde{a}_1)$. When region 1 experiences a larger cost shock than region 2 (namely, $\tilde{a}_1 \geq \tilde{a}_2$), choosing the diversifying strategy would have saved the buyer money, resulting in a *diversifying upside*, equal to

$$\begin{aligned}&[\pi^{\mathrm{Mech}}(\mathbf{x}, (\tilde{a}_1, \tilde{a}_1)) - \pi^{\mathrm{Mech}}(\mathbf{x}, (\tilde{a}_1, \tilde{a}_2))]\mathbb{I}(\tilde{a}_1 \geq \tilde{a}_2)\\ &\quad= [\pi^{\mathrm{Mech}}(\mathbf{x}, (\tilde{s}, \tilde{s})) - \pi^{\mathrm{Mech}}(\mathbf{x}, (\tilde{s}, 0))]\mathbb{I}(\tilde{a}_1 \geq \tilde{a}_2),\end{aligned} \tag{4}$$

where $\tilde{s} = |\tilde{a}_1 - \tilde{a}_2|$; see the online supplement for the derivation. Conversely, when region 1 experiences a smaller cost shock than region 2 (i.e., $\tilde{a}_1 < \tilde{a}_2$), choosing the diversifying strategy would have resulted in a disbenefit for the buyer, the *diversifying downside*, equal to

$$\begin{aligned}&[\pi^{\mathrm{Mech}}(\mathbf{x}, (\tilde{a}_1, \tilde{a}_2)) - \pi^{\mathrm{Mech}}(\mathbf{x}, (\tilde{a}_1, \tilde{a}_1))]\mathbb{I}(\tilde{a}_1 < \tilde{a}_2)\\ &\quad= [\pi^{\mathrm{Mech}}(\mathbf{x}, (0, \tilde{s})) - \pi^{\mathrm{Mech}}(\mathbf{x}, (0, 0))]\mathbb{I}(\tilde{a}_1 < \tilde{a}_2).\end{aligned} \tag{5}$$

By ex ante symmetry between a_1 and a_2, we have

$$\text{expected diversification upside} = \tfrac{1}{2}E_{(\mathbf{x},\mathbf{s})}[\pi^{\mathrm{Mech}}(\mathbf{x}, (s, s)) - \pi^{\mathrm{Mech}}(\mathbf{x}, (s, 0))], \quad \text{and}$$

$$\text{expected diversification downside} = \tfrac{1}{2}E_{(\mathbf{x},\mathbf{s})}[\pi^{\mathrm{Mech}}(\mathbf{x}, (0, s)) - \pi^{\mathrm{Mech}}(\mathbf{x}, (0, 0))].$$

The buyer prefers the diversifying strategy if the expected diversification upside exceeds the expected diversification downside; otherwise, she prefers the pooling strategy. Thus, the buyer's decision depends on the regional costs only through the distribution of the regional cost difference, s. We will use this concept throughout the paper. Formally, we have the following lemma.

Lemma 1. *For* $Mech \in \{RE, RER, FS, FSR, OPT\}$, *diversifying is optimal if and only if*

$$\begin{aligned}&\tfrac{1}{2}E_{(\mathbf{x},\mathbf{s})}[\pi^{\mathrm{Mech}}(\mathbf{x}, (s, s)) + \pi^{\mathrm{Mech}}(\mathbf{x}, (0, 0))]\\ &\quad> E_{(\mathbf{x},\mathbf{s})}[\pi^{\mathrm{Mech}}(\mathbf{x}, (s, 0))].\end{aligned} \tag{6}$$

The left-hand side of expression (6) represents the buyer's expected total procurement cost under pooling; both suppliers always have equal regional cost (either the higher or lower regional cost, with equal chance). The right-hand side of expression (6) represents the buyer's expected total procurement cost under diversifying; the suppliers have unequal regional costs, with one supplier enjoying a regional cost advantage over the other supplier.

5.1. Buyer with Zero Bid-Taker Power

Before we apply Lemma 1 to find the buyer's optimal supply base design strategy under RE, we review the intuition behind the diversifying strategy. Diversifying imparts disparity among suppliers' regional costs, and the buyer can potentially benefit from such disparity because she can contract with the supplier with lower regional cost. Therefore, it is intuitive that in a case where regional cost risk is high (large and likely regional cost shocks), one might expect that diversifying can be especially beneficial.

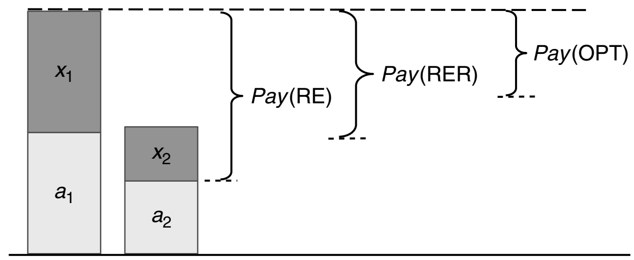
Surprisingly, we find that rather than diversifying the supply base, a weak buyer prefers to have both suppliers in the same region:

Proposition 1. *For any F and G, when mechanism RE is used, the buyer's optimal supply base design is pooling, that is, each supplier is located in the same region.*

Perhaps more surprising, the buyer's preference for pooling her supply base persists for any supplier cost distribution and any regional cost distribution. In other words, it is never optimal to spread out the regional cost risk by diversifying when the buyer uses mechanism RE, even if large supply shocks are likely. Technically, this is because $E_{\mathbf{x}}[\pi^{\mathrm{RE}}(\mathbf{x}, (s, 0))] \geq \frac{1}{2}E_{\mathbf{x}}[\pi^{\mathrm{RE}}(\mathbf{x}, (s, s)) + \pi^{\mathrm{RE}}(\mathbf{x}, (0, 0))]$ holds for any F and $s > 0$. The intuition is that mechanism RE fully exposes the buyer to windfall profit taking by an advantaged supplier with lower regional cost. We illustrate this with an example.

To highlight the windfall profit taking under the diversifying strategy, consider a case where $x_1 > x_2$, $a_1 > a_2$. Supplier 2 has a regional cost advantage and wins the auction because $x_2 + a_2 < x_1 + a_1$. The auction ends when supplier 1 drops out. Supplier 2 is paid the auction ending price, $x_1 + a_1$, minus his regional cost a_2. Thus, the payment in this example equals $x_1 + s$. (This is shown graphically in Figure 2.) In other words, the advantaged supplier 2 ends up charging the buyer a price that includes the entire regional cost difference, s, no matter how large s is. This happens because the buyer relies solely on suppliers' total-cost competition to drive down the auction price and does not have power to curb the advantaged supplier's windfall profit taking. Ultimately, the buyer's total procurement cost is $x_1 + s$ (contract payment), plus a_2 (the winner's regional cost), totaling to $x_1 + a_1$. This is the same total cost she would have paid if both suppliers were in region 1.

Figure 2 **The Buyer's Payment to the Advantaged Supplier Under Three Mechanisms**



Idealistically, diversifying could benefit the buyer by guaranteeing her access to a supplier having the lowest regional cost, compared with just a 50% chance of having such a supplier under the pooling strategy. However, the example shows that supplier windfall profits compromise this diversification logic because the buyer can wind up paying according to the costlier region. Thus, the usual diversification intuition is turned on its head; instead of benefiting the buyer by limiting her costs to that of the cheaper region, diversifying can inflate her costs by exposing her to costs set according to the costlier region. In fact, Proposition 1 proves that under RE, the buyer is never better off diversifying.

5.2. Buyer with Intermediate Bid-Taker Power

We now consider a buyer with moderate power, who can choose a mechanism, among all four standard options {RE, RER, FS, FSR} to minimize her expected total procurement cost. It is generally difficult to determine whether the buyer should choose the first-price mechanism FSR or the second-price mechanism RER, and we refer readers to Maskin and Riley (2000), who address the question under certain technical conditions. Our analysis does not depend on which particular mechanism within this set is cost minimizing for the buyer.

It is important to highlight that a moderate power buyer can make commitments that may seem innocuous but are not. Recalling the discussion in §1, consider the reserve price. A supplier who wins the contract at the reserve price knows that his competitor's total cost is excessive. Consequently, he could demand a higher payment—after all, he knows the buyer's other option (i.e., contracting with the competing supplier) is less attractive. A reserve price amounts to the buyer drawing a line in the sand and refusing to succumb to such demands, regardless of how expensive it would be to actually carry out this threat.

Recall our earlier intuition about why the buyer would want to diversify. Diversifying imparts disparity among suppliers' regional costs, and the buyer can potentially benefit from such disparity because she can contract with the supplier with lower regional cost. Therefore, it is intuitive that in a case where regional cost risk is high (large and likely regional cost shocks), one might expect that diversifying can be especially beneficial. Yet, with mechanism RE, we saw that the buyer never found it optimal to diversify. Will the same happen when the buyer has moderate bid-taker power?

We will show that such a buyer can find it optimal to diversify, in contrast to the universal preference for pooling under mechanism RE.

Proposition 2. *Suppose the buyer has two suppliers and can choose any of the standard auction formats {RE, RER, FS, FSR}. If the regional cost difference is likely to be larger than the gap between the reserve price and the highest supplier production cost (namely, if* $\text{Prob}(s > 2(1 - X_{2:2}))$ *is sufficiently large), then the buyer finds diversification optimal.*

The intuition behind Proposition 2 is that the reserve price can truncate large payments (e.g., in the case illustrated in Figure 2 the payment under RER is $\min\{1, x_1 + s\}$, which is lower than that under RE). Therefore diversifying is optimal when regional cost risk is high. Interestingly, what matters is the likely size of the regional cost difference compared with the difference between the reserve price and the higher supplier cost, $X_{2:2}$. This is illustrated in the middle panel of Figure 3. Consider a case where there is no uncertainty in supplier costs. Because we defined 1 to be the upper bound of supplier costs, this means both suppliers have cost 1 and hence $X_{2:2} = 1$. As the figure shows, diversifying is always optimal in this case. The intuition is that diversifying imparts disparity among suppliers' regional costs, and the buyer benefits from such disparity because she can then (a) contract with the supplier with lower regional cost and (b) use the reserve price to curb the opportunistic pricing by this supplier.

The distance between the reserve price and the higher cost, $1 - X_{2:2}$, reflects the amount of windfall profit that an opportunistic supplier can take before the reserve price truncates it. On the other hand, the benefit the buyer gets from a diversifying upside is s, but the chance of a diversification upside is only one-half. Therefore, what matters is the comparison between $s/2$ and $1 - X_{2:2}$. Consider what happens when there is ample room for opportunistic pricing ($1 - X_{2:2}$ is large). In such settings, as the middle panel of Figure 3 reveals, the regional cost difference must be large to make diversifying worthwhile. Otherwise, the opportunistic pricing will absorb the benefits of diversifying, so the intuition is like the RE case and the buyer finds it optimal to pool.

The above discussion reveals the role played by the reserve price in driving the buyer to diversify. Indeed, the left panel of Figure 3 would look similar if the buyer were restricted to using FS alone, and the middle panel of Figure 3 would look similar if the buyer were restricted to format FSR alone or RER alone. We omit the figures for brevity, but the intuition is as explained above regarding the reserve price as an effective means to truncate large payments.

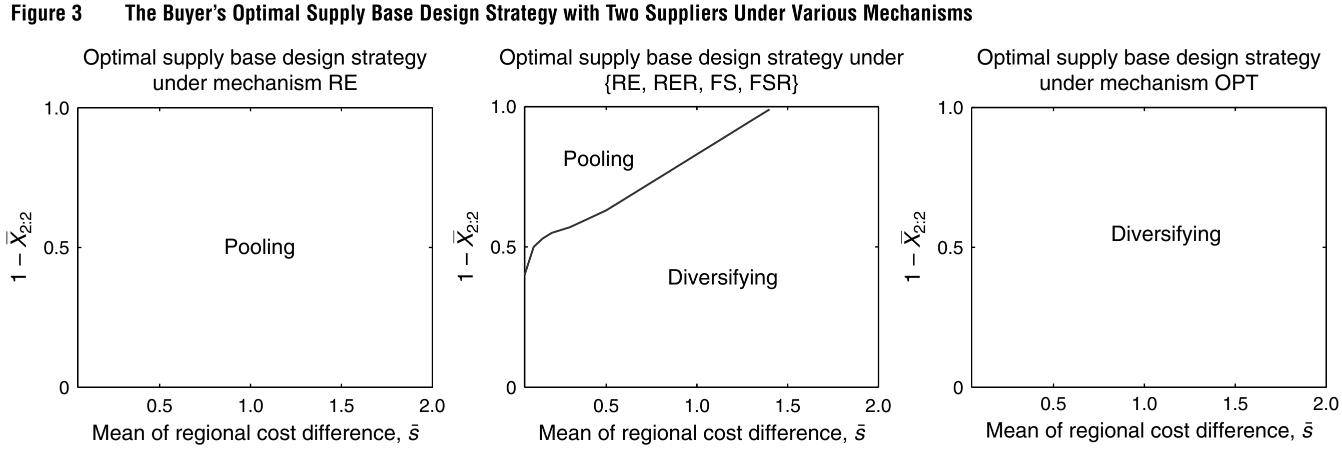
5.3. Buyer with Full Bid-Taker Power

To implement the optimal mechanism, the buyer needs to use the optimal reserve price and compare suppliers via virtual total cost bids, instead of via true total cost bids as in the other four mechanisms {RE, RER, FS, FSR}. Mechanism OPT biases against advantaged suppliers to reduce their payment. As an illustration of this, return to the example in Figure 2: Despite enjoying a regional cost advantage, under OPT supplier 2 only wins the auction if

$$x_2 \in \{x_2 \mid \psi(x_2) + a_2 \le \psi(x_1) + a_1\} \subset \{x_2 \mid x_2 + a_2 \le x_1 + a_1\}, \tag{7}$$

where the proper subset relation follows because $\psi(x) > x$ and $\psi(\cdot)$ is increasing. If supplier costs are

Figure 3 The Buyer's Optimal Supply Base Design Strategy with Two Suppliers Under Various Mechanisms



uniformly distributed, the virtual cost function is $\psi(x) = 2x$, so OPT compares virtual total costs $2x_1 + a_1$ and $2x_2 + a_2$. This implies that supplier 2 with lower regional cost can win the contract only if $x_2 < x_1 + (a_1 - a_2)/2$, as opposed to $x_2 < x_1 + (a_1 - a_2)$ under mechanisms RE/RER or $b_2 < b_1 + (a_1 - a_2)$ under mechanisms FS/FSR. Furthermore, the OPT payment rule implies that upon winning, supplier 2 is only paid $\min\{1, x_1 + (a_1 - a_2)/2\}$. For this example the payment is graphically illustrated in Figure 2, where we see that the payment under OPT is substantially smaller than that under RE and RER/FSR.

The interesting question we ask now is whether this additional use of biasing rules will result in diversification being more preferred by the buyer. We have the following result.

Proposition 3. *For any F and G, when mechanism OPT is used, the buyer's optimal supply base design is diversifying, that is, each supplier is located in a different region.*

Remarkably, we see that under the mechanism OPT the buyer's preference is *always* for diversification. The buyer benefits from regional cost disparity—and therefore seeks it out by diversifying—because mechanism OPT allows so little windfall profit taking by the supplier with a regional cost advantage. Thus, a moderate power buyer, choosing among {RE, RER, FS, FSR}, diversifies more than a buyer using RE, and a buyer using OPT diversifies even more than a moderate power buyer. In other words, what we see here is that as the buyer's bid-taker power increases she prefers more diversification.

Before moving on, consider a different setting. In a vertically integrated supply chain, the buyer always finds it optimal to diversify the supply base. To see why this is the case, suppose that supplier 1 has lower production cost than supplier 2. Note that the buyer in the vertically integrated supply chain always uses the supplier with the lowest total cost and has a total cost equal to this lowest supplier's total cost. If both suppliers are located in the same region, supplier 1 would always be used and supplier 2 would never be used; however, if supplier 2 is located in a different region, it is possible that supplier 2 winds up having a lower total cost than supplier 1, which would benefit the supply chain. Interestingly, the buyer using OPT prefers the same policy as in the vertically integrated supply chain. However, because of the biasing rule it deploys, mechanism OPT can result in transacting with the supplier with higher total cost (evidenced by the proper subset relation in (7)), which the vertically integrated supply chain would never do.

5.4. Summarizing: Buyer Bid-Taker Power Does Affect Diversification Preference

In addressing research question 1, §§5.1–5.3 suggest that the buyer's bid-taker power has a profound impact on her optimal supply base diversification decision. We find that strong buyers prefer to diversify the most (always), weak buyers prefer to diversify the least (never), and moderately strong buyers are in the middle (diversify sometimes). Figure 3 illustrates this finding. The plots use production cost distribution $F(x) = x^v$, $v > 0$, and the vertical axes depict $1 - \bar{X}_{2:2}$, which is monotone as v increases from 0 to infinity. In the plots, the regional costs follow an exponential distribution, so the regional cost difference s follows the same exponential distribution as the regional costs. Formally, the distribution is $G(s) = 1 - e^{-s/\bar{s}}$, where $\bar{s}$ is the distribution's mean. Addressing research question 2, we see that for a buyer with two suppliers, the supply base design decision is only sensitive to the underlying production and regional cost distributions when the buyer is moderately strong. Surprisingly, weak buyers prefer to pool their two suppliers in a single region even when large regional cost disparities are likely.

Finally, we conduct a numerical study, using dollar values, to show that the profit implications of proper diversification decisions can be large. Consider a manufacturer (buyer) who sells a part for \$100. Suppose that, per part, the manufacturer's sales and marketing cost is \$20, logistics and other regional costs (such as regionally varying raw material costs) follow an exponential distribution with a lower bound of \$25, and supplier idiosyncratic production costs (based on the supplier's machine utilizations, labor levels, efficiency, etc.) follow a power function distribution over [\$30, \$40] with a mean of \$32.

To quantitatively measure the implications of the pooling and the diversifying strategies, we use the buyer's expected profit under pooling as the baseline, and then compute the percentage of profit change if she chooses diversifying. Accordingly, the percentage will be negative when pooling is optimal and positive when diversifying is optimal. Table 1 summarizes the numerical results for the three levels of buyer power.

For example, the results indicate that when the average regional cost is \$30, a weak buyer (using RE) would improve her profit margin by 12% if she chooses

Table 1 **Profit of Pooling vs. Diversifying for a Buyer Selling a Part for \$100**

	Mean of regional cost distribution, $\bar{s}$			
Buyer bid-taker power	\$28.6	\$30	\$33	\$35
Weak (%)	−7	−12	−31	−59
Intermedidate (%)	−1	−1	3	15
Strong (%)	3	6	17	35

pooling instead of diversifying, and the profit margin improvement increases in her average regional cost, reaching 59% if the average regional cost becomes $35. As expected, the numerical results are consistent with our theoretical findings: pooling is optimal for a weak buyer (Proposition 1), diversifying is optimal for a strong buyer (Proposition 3), and a buyer with intermediate power finds pooling optimal when the regional cost is stochastically small but finds diversifying optimal otherwise (Proposition 2).

6. Robustness of Buyer Bid-Taker Power/Diversification Insight

Our main insight thus far is that stronger buyers prefer to diversify more than weaker buyers. The purpose of this section is to answer research question 3 by showing that this general insight remains valid even in more complex settings than the one considered above.

6.1. Supply Base with Multiple Suppliers

For $N > 2$ suppliers in the supply base, we wish to compare pooling all N suppliers in region 1, or using a diversifying strategy that has, without loss of generality, $N_1 \in \{1, \ldots, \lfloor N/2 \rfloor\}$ suppliers in region 1 and $N - N_1$ suppliers in region 2. The following proposition shows that key insights from the previous section extend to the multiple supplier case, along with some interesting changes. Let $X_{2:1}$ denote 1 for notational convenience.

Proposition 4. *With $N > 2$ suppliers, compared with the strategy in which she pools all suppliers in a single region, the buyer would prefer diversifying by placing N_1 suppliers in one region and $N - N_1$ suppliers in the other region if*

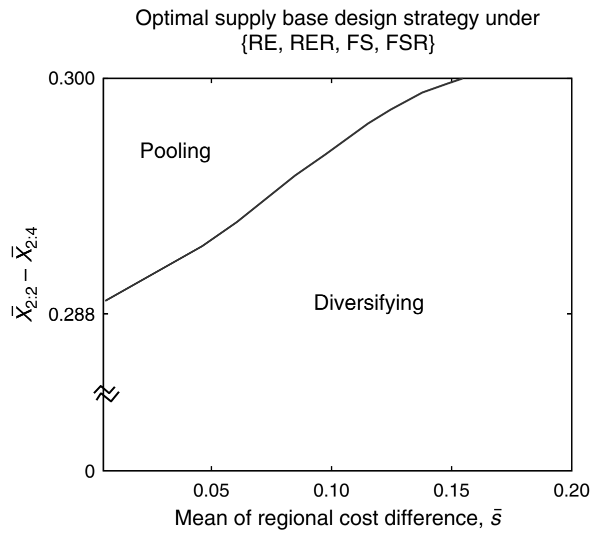
(i) *she has the ability to utilize optimal mechanism OPT;*

(ii) *she has the ability to choose any of the standard auction formats {RE, RER, FS, FSR} and the regional cost difference is likely to be large relative to the gaps between the second-best production cost across all suppliers and second-best production cost within each region, namely,* $\text{Prob}(s > X_{2:N_1} + X_{2:N-N_1} - 2X_{2:N})$ *is sufficiently large; and*

(iii) *she is restricted to use mechanism RE but has at least two suppliers in each region and the condition in part* (ii) *holds.*

Part (i) extends Proposition 3, and part (ii) extends Proposition 2. In particular, the buyer's preference for diversifying depends on her ability to stem windfall profit taking by a supplier who has the lower regional cost. Our analysis of the general N supplier case also yields new insights. Per part (iii), with more than two suppliers the buyer may find it optimal to diversify even under RE, but with just two suppliers, she would never do so (Proposition 1). The intuition is that the buyer can have more than one supplier in the same region when the buyer's supply base includes more than two suppliers, so she expects less severe windfall profit taking by advantaged suppliers due to the competition among multiple suppliers with low regional cost. As a result, compared with the two-supplier case, the N supplier case makes diversifying more attractive to the buyer. Interestingly, it can be optimal for a weak buyer to diversify even when she does not have at least two suppliers in each region. Namely, in some cases it can be optimal for the buyer using RE to diversify even when one of her regions contains just a single supplier; see Proposition 4's proof in the online supplement for conditions for when the buyer using RE prefers diversifying to pooling even if $N_1 = 1$. However, diversifying is still not always optimal, as seen in Figure 4, which depicts a weak buyer's supply base design preference when she has a supply base with four suppliers. The plot uses $G(y) = 1 - e^{-y/\bar{s}}$ and $F(x) = x^v$, $v > 0.5$ (as v increases $\bar{X}_{2:2} - \bar{X}_{2:4}$ decreases monotonically). Note the resemblance to the middle panel of Figure 3; the intuition is analogous.

Figure 4 **The Buyer's Optimal Supply Base Design Strategy with Four Suppliers, Under Mechanisms {RE, RER, FS, FSR}**



To conclude our study of the N supplier case, we explore the "optimal diversifying strategy." This is relevant when $N \geq 4$ so the buyer could place at least $\lfloor N/2 \rfloor$ in both regions. Namely, the buyer may wish to know what is the optimal $N_1 \in \{1, \ldots, \lfloor N/2 \rfloor\}$. For simplicity, we focus on the most relevant cases—that is, those in which the regional cost difference s is significantly large so that the potential savings from optimizing the supply base is also large. We have the following proposition.

Proposition 5. *Suppose there are $N \geq 4$ suppliers. If* $\text{Prob}(s \geq 1)$ *is sufficiently large, then the buyer's optimal diversifying strategy sets $N_1 = \lfloor N/2 \rfloor$.*

The proposition states that, for the most important cases (namely, when the regional cost difference s is likely to be large), the buyer's optimal diversification strategy is to use an "equal split" no matter what mechanisms the buyer has access to. The intuition is straightforward; balance is favored because, as more suppliers are added to a region, competition within that region intensifies and adding another supplier has little chance to impact the price in that region.

6.2. Ex Ante Asymmetric Regions

Supplier regions might not be ex ante symmetric. For example, suppose one region is "onshore" and is characterized by high production costs and low regional costs, while the other region is "offshore" and has low production costs but high regional costs. To investigate the buyer's supply base design problem in such a case, consider a setting where the buyer has two suppliers. The buyer could choose to have both suppliers in the onshore region, both suppliers in the offshore region, or one supplier in each region. Let $F_{(r)}$ denote the production cost distribution, and let $C_{(r)}$ denote the regional cost distribution for the regions indexed by $r = 1, 2$ (in the sequel, subscripts in parentheses refer to the region). We will assume independence of production costs and regional costs. The descriptions of the mechanisms are as before, except in the optimal mechanism, $\psi(x_i)$ is replaced by $\psi_{(r)}(x_i) \stackrel{\text{def}}{=} x_i + F_{(r)}(x_i)/f_{(r)}(x_i)$ for each region r supplier i. We describe a result for the two-supplier case, where if there are two suppliers in a region r, we denote the distribution of the higher total cost of the two suppliers as $L_{(r)}(z) \stackrel{\text{def}}{=} \int_{-\infty}^{\infty} F_{(r)}^2(z-y)\, dC_{(r)}(y)$.

Proposition 6. *Suppose regions are ex ante asymmetric and the supply base has two suppliers.*

(i) *Whenever the buyer finds it optimal to pool, she selects both suppliers in region $r^* = \arg\min_{r=1,2}\{\int_{-\infty}^{\infty} z\, dL_{(r)}(z)\}$.*

(ii) *Suppose the buyer can only utilize mechanism RE. Then she always finds it optimal to pool, no matter what the distributions of the regions' costs.*

(iii) *Suppose the buyer can utilize mechanism OPT. Suppose $F_{(1)} = F_{(2)}$, and $a_{(2)} = \alpha + \delta + \lambda\epsilon$, where α follows distribution $C_{(1)}$, ϵ is a random variable with zero mean and finite variance, and δ and λ are positive constants. All else fixed, for any λ, a positive threshold $\hat{\delta}(\lambda)$ exists such that the buyer prefers to pool in region 1 if $\delta > \hat{\delta}(\lambda)$; otherwise, she prefers diversifying. Furthermore, $\hat{\delta}(\lambda)$ increases in λ, which means larger λ can only make diversifying more preferable.*

Interestingly, part (ii) says that it is never optimal for a weak buyer to use a portfolio of one onshore supplier and one offshore supplier. This preference for pooling matches what we saw in the case of ex ante symmetric regions. By contrast, we find that regional asymmetry can change the decision of a strong buyer. (Recall that a strong buyer always wishes to diversify when regions are ex ante symmetric.) The reason is intuitive: If the regions are ex ante asymmetric, one region may be so comparatively bad that the buyer would never choose to locate suppliers there. This explains why as δ becomes large (regional costs in region 2 become large), the buyer eventually favors pooling (and she would pool in region 1). Proposition 6 also clearly shows that the effect of ex ante regional asymmetry can be complex. In particular, for a buyer using OPT, more variability in a region's cost (larger λ) encourages diversification. This is because the strong buyer can enjoy the benefit of a low cost draw and use its power to curb windfall payments even in the event of a high cost draw. The intuition is exactly as we have explained earlier in the paper. Finally, regardless of which auction format the buyer uses, part (i) states that whenever the buyer finds it optimal to pool, she does so in whichever region minimizes the higher expected total cost among the suppliers.

The above paragraph highlights the complexity of the optimal diversification strategy in the presence of ex ante asymmetric regions, with two suppliers. Extending this logic, with N suppliers one would expect that Propositions 4 and 5 need not apply as before if regions are ex ante asymmetric. It is not surprising that adding additional complicating assumptions, such as ex ante asymmetric regions, can make the analysis much more complicated and dependent on things like how comparatively good or bad the regions are relative to each other, as we saw above. However, the main intuition developed earlier still applies, and despite adding such complicating assumptions, we can show that our paper's key insight—the effect of bid-taker power on diversification—survives. In particular, we have a last categorical result.

Proposition 7. *Consider sets $\mathcal{M}_2 \subset \mathcal{M}_1 \subseteq \{RE, RER, FS, FSR, OPT\}$; namely, $\mathcal{M}_1$ and $\mathcal{M}_2$ are two subsets of mechanisms available to the buyer, and $\mathcal{M}_1$ contains $\mathcal{M}_2$. Regardless of the regional ex ante asymmetry, regional correlation, and the number of suppliers, if the buyer prefers diversifying under $\mathcal{M}_2$, she also prefers diversifying under $\mathcal{M}_1$, holding all else constant. If the buyer prefers pooling under $\mathcal{M}_1$, then she also prefers pooling under $\mathcal{M}_2$, holding all else constant.*

6.3. Multiplicative Regional Cost Factors

Regional cost in our model represented costs incurred directly by the buyer when doing business with a supplier. If instead the supplier incurred the regional cost, the regional cost is simply reinterpreted as a commonly known cost factor for suppliers within that region. It is straightforward to show that when the regional cost factor enters a supplier's costs in an additive fashion, the analysis and insights would not change in any meaningful way. However, it is less clear what might happen if the regional costs entered suppliers' costs in a nonadditive way. In this subsection, we explore this question. We assume that supplier i's cost to fulfill the buyer's contract equals $a_i x_i$, where x_i captures the supplier's idiosyncratic factors and is the supplier's private information, and a_i captures the public and region-specific factors that affect the supplier's cost. For example, a_i can capture the regional labor and energy costs, and x_i captures the labor productivity and energy efficiency that are affected by the supplier's management and production technology.

Let F's domain be denoted as $[l, u]$, $l, u \in \mathbb{R}^+$ (with multiplicative costs one cannot without loss of generality renormalize F to the unit interval as we did for additive costs). In the online supplement, we formally adapt each of the five mechanisms to the multiplicative regional cost model. In the additive model, the regional cost difference s was the difference between regional costs, $|a_1 - a_2|$. For the multiplicative regional cost model, we define the regional cost ratio $\eta = \max\{a_1/a_2, a_2/a_1\}$, which measures the regional "difference" when the regional factors enter suppliers' costs multiplicatively. We now show that our results extend:

Proposition 8. *Propositions* 1–7 *hold*, *with the following adjustments to account for multiplicative regional costs*: *In Proposition* 2, *the expression* "$\text{Prob}(s > 2(1 - \bar{X}_{2:2}))$" *is replaced by* "$\text{Prob}(\eta > (2u)/\bar{X}_{2:2} - 1)$"; *in Proposition* 4(ii), "$\text{Prob}(s > \bar{X}_{2:N_1} + \bar{X}_{2:N-N_1} - 2\bar{X}_{2:N})$" *is replaced by* "$\text{Prob}(\eta > (\bar{X}_{2:N_1} + \bar{X}_{2:N-N_1})/\bar{X}_{2:N} - 1)$"; *in Proposition* 5, "$\text{Prob}(s \geq 1)$" *is replaced by* "$\text{Prob}(\eta l/u \geq 1)$"; *and in Proposition* 6, $L_{(r)}(z) = \int_{-\infty}^{\infty} F_{(r)}^2(z/y)\, dC_{(r)}(y)$.

7. Concluding Discussion

The cost of purchasing from a supplier depends not only on the supplier's individual efficiencies, but also on costs associated with the supplier's region. These regional costs—such as the cost of transporting goods from the supplier or the prevailing price of raw materials in the supplier region—thus need to be considered carefully by buyer firms, many of whom are under unrelenting pressure to manage overall cost. When designing a supply base, the buyer firm has an opportunity to proactively mitigate some regional cost risk; it can strategically reduce the cost correlation across suppliers by diversifying, i.e., choosing suppliers from different regions.

This is a natural strategy in line with the conventional wisdom that it is best to avoid putting all one's eggs in one basket. But is it the right strategy? In this paper, we answer this question in light of the fact that when using a supply base it is common that the buyer's payment to her supplier is determined via a competitive bidding process (auction). Importantly, not all auctions are equally effective at creating outcomes favorable to buyers, and which auction the buyer can run depends on its "bid-taker power," namely, its ability to design and commit to auction rules.

One might intuitively think that for those cases where the buyer is less able to secure favorable outcomes in the auction and would generally pay a higher price that diversification makes the utmost sense because it helps the buyer contain costs. However, our results show that this can be exactly the wrong thing to do. In fact, we find that buyers who have weaker bid-taker power should be less apt to diversify than buyers with stronger bid-taker power. The reason lies in the fact that for weak buyers the upside benefit of diversification—having a significantly cost-advantaged supplier—can be undermined by this supplier's windfall profit taking.

In this paper, we introduce the natural concept that greater bid-taker power endows the buyer with access to a wider range of possible auction formats. We consider the most common auction formats used in practice—reverse English without a reserve price, reverse English with a reserve price, first-price sealed-bid without a reserve price, and first-price sealed-bid with a reserve price—as well as the theoretical optimal mechanism. We model three levels of bid-taker power: weak, intermediate, and strong, which involve having access to only the first format, access to the first four formats, or access to all five formats, respectively. Our answers to the three research questions outlined in the introduction are as follows.

Addressing research question 1, we find that for strong buyers, windfall profit taking is curbed and consequently the buyer finds it optimal to avail herself of the ability to locate suppliers in two different regions. However, at the other extreme, when the buyer is weak, supplier windfall profit taking can be severe, and consequently the buyer can find it optimal to pool suppliers in the same region. For buyers with intermediate bid-taker power, the ability to impose a reserve price helps truncate windfall supplier profits, thereby encouraging diversification.

Addressing research question 2 (how the buyer's diversification decision depends on cost distributions), we find that, remarkably, a weak buyer's preference for pooling holds regardless of the cost distributions when she has two suppliers. Surprisingly, such buyers facing the prospect of large, likely regional cost shocks are still better off not diversifying. Conversely, a strong buyer prefers to diversify no matter what the cost distributions are. However, the cost distributions do affect the diversification decisions of buyers with intermediate bid-taker power as well as weak buyers with more than two suppliers. Such buyers prefer to diversify when the regional cost difference is likely to be large.

In addressing research question 3 (the effect of correlated regional costs, number of suppliers, and ex ante asymmetry between regions), we find that introducing correlation across regional costs generally leaves the buyer's supply base design decision unchanged, but it can affect the buyer's decision when her bid-taker power is intermediate or when she is weak but has more than two suppliers. In those cases, correlation can encourage or discourage diversification, depending on whether or not it increases the likelihood of a large regional cost difference. In general, competition among a larger number of suppliers weakens windfall profit taking and thus encourages diversification. We also examine ex ante asymmetry across regions. Although asymmetry can complicate the tactics of supply base design by making one region comparatively worse than another, it generally leaves the main strategic finding unchanged—namely, buyers with more bid-taker power prefer to diversify more. Finally, we show that the above holds regardless of whether the regional costs are additive (such as transportation costs) or multiplicative (such as energy costs).

To summarize all of the above, we find that regardless of the number of suppliers, the correlation between regions, or the ex ante asymmetry between regions, strong buyers prefer to diversify the most weak buyers prefer to diversify the least and that the optimal diversification preferences of buyers with intermediate bid-taker power are in the middle. The magnitude importance of proper diversification decisions can be large. In our numerical studies illustrated in Table 1, supply base design optimization can improve a manufacturer's profit margin by approximately 6% to 60%, depending on her bid-taker power.

Our paper establishes a link between buyer bid-taker power and diversification preferences, which has important managerial implications for how buyers diversify. It shows that, for strong buyers, supply base diversification can be a useful tool to mitigate cost shocks in the supply base. However, the same is not true for weaker buyers. A takeaway is that weaker buyers may wish to explore other means of diversifying their supply cost risks, such as locking in long-term contracts for things like steel prices and transportation. We have worked with many buyers who are reluctant to engage in making such bets because typically buyer organizations lack the expertise to make well-informed decisions about how to do so, and mistakes can be extremely costly if prices move in the wrong direction. For such buyers, supply base diversification can seem an appealing alternative because the logic of supplier diversification and using the competition in a supply base to find market pricing is a familiar one to procurement professionals. However, our paper shows the flaw in such reasoning for weak buyers. (Of course, the focus here is cost minimization. If supply availability is the main criterion and the buyer is worried about disruptions, then diversification may become desirable even if it results in increased costs.)

In a similar vein, to the extent that the buyer can anticipate regional cost shocks, she may choose to speculatively purchase inventory to avoid future cost spikes, e.g., impending logistic cost increases in a certain country. Interestingly, our analysis suggests that the usefulness of such a strategy depends on the buyer's bid-taker power. Speculative inventory might behoove a buyer with little bid-taker power, who might use it to help avoid paying windfall profits to cost advantaged suppliers. On the other hand, speculative inventory would likely be of much less benefit to a buyer with strong bid-taker power, who could contract with cost-advantaged suppliers without paying an undue price premium, thereby reducing the speculative benefits of holding inventory. To keep our analysis focused and tractable we ignored the buyer's inventory decisions. We leave a detailed analysis of the interplay between inventory decisions, buyer bid-taker power, and supply base design to our future work.

For notational simplicity in the paper, we modeled just a single future stage 2, but our analysis extends to capture periodic reauctioning simply by allowing stage 2 to repeat. At the outset of the time horizon, the buyer anticipates that in a prototypical future auction stage the regional costs follow distribution G. This setup allows the possibility that regional costs are autocorrelated across periods. However, one might also suppose that at the outset the buyer predicts period dependence for regional costs (e.g., summer transportation costs are higher than in winter). Similarly, one might also wish to capture cases where the production cost distribution F is time variant. The majority of our results are robust to such possibilities because the results hold regardless of regional cost distribution G and production cost distribution F. For other results, such as Proposition 2 and part (ii) of Proposition 4 where the optimal strategy depends on the cost distributions, we suspect that if G and/or F are time variant, the optimal supply-base design decision simply depends on the "long-term average" behavior of the cost distributions.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/msom.2014.0477.

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