Sourcing for Supplier Effort and Competition

Cuihong Li

Cuihong.Li@business.uconn.edu
School of Business, University of Connecticut, 2100 Hillside Road, Storrs, CT 06269

As suppliers provide more value in today’s supply chains, eliciting supplier cost-reduction efforts and inducing supplier competition are two important levers for a buyer to reduce sourcing costs. In this paper, we study a buyer’s sourcing strategy considering supplier effort and competition. The buyer has two instruments in her strategy: the composition of the supply base and the contracting mechanism. In our model, two suppliers are available to be included in the supply base. The buyer invests in the suppliers’ capacity, facing uncertain market demand. The suppliers invest cost-reduction efforts, the realized production cost to be uncertain and private information. In the supply base design, the buyer determines the number of suppliers (one or two) in the supply base, and the capacity to be invested in each supplier. In the contracting mechanism design, the buyer chooses the time of price and capacity decisions, either before or after suppliers’ effort investment.

We find that a supply base with symmetric capacity is effective at inducing supplier competition, while a supply base with asymmetric capacity is better at motivating supplier effort, when the capacity is invested before supplier effort. As a result, the buyer may invest in capacity for only one supplier (sole sourcing), equal capacities for both suppliers (symmetric dual sourcing), or positive but unequal capacities for both suppliers (asymmetric dual sourcing), even though the suppliers are ex ante identical. We characterize the conditions for each structure, and show that asymmetric dual sourcing should be considered only with uncertain demand. As the buyer’s investment influences supplier competition, we find that increasing demand uncertainty may cause the supply base structure to shift away from dual sourcing towards sole sourcing, while reducing the total capacity. Finally, we investigate the buyer’s joint decisions concerning the supply base and contracting mechanism. We find that, as supplier cost uncertainty or the cost of supplier effort increases, the buyer prefers greater supplier competition in the supply base and favors more decision delays in the contracting mechanism. In the result, sole sourcing combined with capacity and price commitments, and dual sourcing combined with ex post capacity and price decisions, often emerge as two optimal sourcing strategies.

Keywords: sourcing, supply base, contracting mechanism, competition, information, incentives
1. Introduction

Manufacturers increasingly rely on suppliers to create value, reduce costs, and improve products or services (Gottfredson et al., 2005). In the automotive industry, most OEMs create only 30-35 percent of value internally (Maurer et al., 2004). As OEMs give suppliers more design and production responsibilities, suppliers’ improvement and innovation efforts become a major source for OEMs to enhance the quality and functionality of their products while reducing manufacturing costs (Nelson et al., 1998; Nelson et al., 2001; Ellram and Choi, 2000). A supplier’s improvement effort may include investment in human capital such as technical specialists (Dewar and Dutton, 1986), learning-before-doing activities such as preparation and training, simulation, pretesting, and prototyping (Pisano, 1996), or the use of better equipment, information technology, or operating procedures (Carrillo and Gaimon, 2002). The effort often requires substantial investment of resources while facing uncertain outcomes (Carrillo and Gaimon, 2004). Thus motivating suppliers to invest improvement efforts is not always easy.

In order to induce supplier effort, many manufacturers have reduced their supply base (Duffy, 2005). A small supply base allows an OEM to build deeper trust and foster close supplier relationships, thereby encouraging suppliers to dedicate more resources to improve their performance (Dyer, 2000; Liker and Choi, 2004). For example, in 2005, Ford planned to overhaul its supply system by offering larger contracts to a smaller group of suppliers, in order to motivate suppliers to provide the best technology to Ford (McCracken, 2005). In 2006 Airbus had to trim its supply base, “in hoping to forge durable relationships so contractors can make long-term investment plans to improve the quality of their products and increase efficiency.” (Michaels, 2006)

Certain commitments from the OEM to a supplier may also help to motivate supplier effort. Expecting a supplier’s cost to fall following his innovation effort, the buyer may or may not adjust the price in response to cost improvements, adopting cost-contingent prices or price commitments. A cost-contingent price may extract the margin achieved in the supplier’s effort, whereas a price commitment rewards a supplier’s effort by its return. In practice, US auto makers tend to follow the approach of cost-contingent pricing, while Japanese car manufacturers typically follow the policy of price commitments (McMillan, 1990). Besides the price commitment, when suppliers face uncertainty in the buyer’s demand, some form of commitments that promises higher quantity may also induce greater upfront investment of supplier effort. When Chrysler planned to launch new models in 2009, one of the biggest hurdles came from suppliers being reluctant to spend money up front to develop and make parts for the models (Boudette and Bennett, 2009). The suppliers were hesitating
because Chrysler was not to guarantee certain production volumes while they were unsure of how well the vehicle would sell.

While OEMs have realized the advantages of supply base reduction, a smaller supplier number is not necessarily better. First, a small supply base adversely affects the benefits of a competitive marketplace (Duffy, 2005). When fewer suppliers compete for a contract, a buyer (OEM) has less bargaining power in negotiations with the suppliers, which may cause a higher purchasing cost for the buyer (McMillan, 1990). Supplier competition is especially beneficial when estimating a supplier’s cost is difficult. This is the case when a supplier serves as a system integrator for a complex subsystem. In the automotive industry, increasingly, suppliers provide not merely small parts but completely assembled and tested systems; as the modularization of vehicles continues, they are expected to deliver even more complex systems, such as the entire roof systems, integrated interiors, complete doors, and trunk lids. The integrated systems are much harder for OEMs to price and evaluate than simple parts (Maurer et al., 2004). For such products, supplier competition helps the buyer to form reasonable expectations of supplier cost, thereby discovering a fair price (Duffy, 2005; McMillan, 1990).

Second, supplier competition allows flexibility of supplier selection, mitigating supplier performance risks. A supplier’s performance may vary due to changes in the internal or external environment. The internal changes may pertain to such factors as the management and financial status. Management change is an important factor leading to productivity change (Lieberman et al., 1990). The financial distress of a supplier results in performance deterioration in the form of price increases, delivery delays, employee turnover, quality issues, etc. (Harvey et al., 2009). The external changes may include fluctuations of labor, logistics, and material costs, or performance uncertainty of sub-suppliers. Such variations, called procurement risks by Chopra and Sodhi (2004), cause unanticipated changes in the buyer’s acquisition costs. The uncertainty of supplier capability may also be caused by the uncertain outcome of innovation and process improvement (Choi and Krause, 2006; Carrillo and Gaimon 2004); Gerwin (1988) defines three types of uncertainty in the innovation process: technical, financial, and social. With multiple competing suppliers in the supply base, a buyer is able to respond to supplier performance changes by adjusting her business allocation among suppliers (Duffy, 2005). For example, both Toyota and Cisco maintain more suppliers than they need in their supplier networks, so that they can “keep the resulting higher costs in check by monitoring and benchmarking suppliers against each other” (Chopra and Sodhi, 2004). Nike developed a worldwide subcontracting system that allowed the company to quickly relocate production and disassociate itself with factories that failed to meet standards of performance or where price changes rendered an uncompetitive product (Donaghu
and Barff, 1990).

For the suppliers in the supply base, a buyer often invests in relationship-specific resources to improve their capabilities, as a part of supplier development. A common type of investment is specific assets. Toyota invested in production capacity and technology for its suppliers as a way to enhance its relationship with them and lessen management risks as its sales grew. In recent years, it invested in the equipment for its new brake system supplier, ADVICS, and for its new power steering supplier, Fabes (CAPS, 2005). Hyundai Motors also assisted its suppliers in expanding capacity to improve their delivery capability, as a stage of supplier development (Hahn et al., 1989). Generally, it is common in the automotive industry that an OEM invests in a supplier’s assets that are customized or dedicated to the buyer’s need, including facilities in close proximity to the buyer’s sites, physical assets such as customized machinery, tools, and equipment, or personnel delegated to the supplier’s site (Dyer, 2000, 1997). Although such specific assets may not determine a supplier’s entire capacity, they affect the rate at which the supplier can produce for the buyer.

The fact that a buyer invests in resources for a supplier may often be associated with a long-term supplier relationship, which typically features a sole-sourcing commitment with no supplier competition. However, a buyer investing in suppliers does not necessarily exclude supplier competition. In fact, even Japanese automakers, who are known for their substantial relationship-specific investment in their suppliers (Dyer, 1996), often impose competition on their suppliers, especially when sourcing a new product (McMillan, 1990). Such a situation, in which the buyer collaborates with a few suppliers that are in competition for the buyer’s business, can be regarded as an intermediate case between a typical arms-length relationship and a long-term relationship. It may be called a performance-based partnership (Mair, 2000), parallel sourcing (Richardson, 1993), or durable arms-length relationship (Dyer et al., 1998).

In this paper, we study a buyer’s sourcing strategy when considering supplier cost-reduction efforts and competition. We focus on two dimensions of the sourcing strategy: the supply base and the contracting mechanism. When designing the supply base, should the buyer include one or more suppliers? In addition, how much resource should the buyer invest in each supplier? In designing the contracting mechanism, the buyer is concerned with the time of specifying contracts. Specifically, should the buyer commit the resources to invest in a supplier and the price at which to source from a supplier before the suppliers invest their efforts, or should she make these decisions contingent on the realization of supplier performance following their efforts? The ex post decisions allow flexibility and responsiveness, but may hold-up a supplier’s investment of effort as a supplier is usually in a weak bargaining position relative to the buyer (Williamson, 1985; McMillan 1990): Since the supplier’s effort cost is already sunk when the contract is determined, the buyer would
demand a contract that may not cover the investment cost. Expecting this result, the supplier would be reluctant to invest effort upfront. To avoid the hold-up problem, the buyer may choose to make ex ante commitments on the contract, thereby giving up the benefit of responsive decisions.

Our goal is to develop an understanding of the buyer’s optimal sourcing strategy concerning both the supply base and contracting mechanism design. Focusing on the impact of the buyer’s sourcing strategy on supply base performance, we assume two ex ante identical suppliers may join the buyer’s supply base. Both the buyer and the two suppliers can invest resources to improve suppliers’ capabilities: The buyer invests in suppliers’ capacity, facing uncertain market demand. The suppliers exert cost-reduction efforts, the realized cost to be uncertain and private information of the supplier. We analyze and compare three sourcing mechanisms that differ on the time of capacity investment and price decisions: 1) the base mechanism, in which the buyer invests in (commits to) supplier capacity before suppliers invest their effort, with the purchasing prices negotiated (via an optimal auction) afterwards, 2) the ex ante price commitment mechanism, in which the buyer commits to both the price and capacity before suppliers invest their effort, and 3) the ex post capacity investment mechanism, in which the buyer leaves both the price and capacity to be determined after suppliers’ effort investment. Under each mechanism, the buyer may choose to include one (sole sourcing) or both suppliers (dual sourcing) in the supply base, and, in the case of dual sourcing, the buyer may invest in equal (symmetric dual sourcing) or unequal (asymmetric dual sourcing) capacities for the suppliers. For each contracting mechanism, we analyze the outcome of supplier effort and supplier competition for a given supply base, which leads to the derivation of the optimal supply base design. Then we compare the three contracting mechanisms, investigating the buyer’s choice of contracting mechanism along with the supply base design. Below we summarize our major results and contribution.

Our study of the sourcing strategy is concerned with the incentive of supplier effort, which has not been considered in the literature as a major factor in supply base design. As the supply base design is driven by both values of supplier effort and competition, the buyer benefits from both asymmetry and symmetry between suppliers in their capacities, when the capacity is invested ex ante before suppliers’ efforts. An asymmetric supply base delivers value from suppliers’ cost-reduction effort, while a symmetric supply base is effective at inducing supplier competition. As a result, we find that the buyer may maximize supplier asymmetry by adopting sole sourcing, maximize supplier symmetry by adopting symmetric dual sourcing, or reach a balance by choosing asymmetric dual sourcing, even though suppliers are ex ante identical. Among these three structures, asymmetric dual sourcing may emerge as an optimal structure only with uncertain demand; without demand uncertainty,
the buyer should choose between sole sourcing and symmetric dual sourcing.

We consider the buyer investing in suppliers’ capacities, which not only improve their delivery capability, but also shape the competition between suppliers when invested ex ante. In our result, increasing demand uncertainty may shift the optimal supply base structure away from dual to sole sourcing, while reducing total capacity, when the cost of supplier effort is low. The reason is that increasing demand uncertainty dampens supplier competition, thus reducing the value of redundant capacity investment in maintaining supplier competition.

Finally, we study the joint decision on the supply base structure and contracting mechanism, investigating the relationship between these two designs. Both the supply base and contracting mechanism affect supplier effort and supplier competition: Sole sourcing and ex ante decisions enhance the buyer’s incentive power to motivate supplier effort, while dual sourcing and ex post decisions improve the buyer’s pricing power to contract based on suppliers’ cost realizations. In the result, we find that the buyer prefers ex ante price commitment along with sole sourcing when a supplier’s production cost uncertainty is low or the marginal cost of supplier effort is small, but favors ex post capacity investment along with dual sourcing in the opposite situations. Therefore, the supply base and contracting mechanism should be considered jointly, with their designs reinforcing the strength of each other.

The rest of the paper is organized as follows. We review the relevant literature in Section 2, and present the model in Section 3. The supply base design under each of the three sourcing mechanisms is analyzed in Sections 4, 5, and 6. Then in Section 7 we compare the three mechanisms and summarize the buyer’s optimal sourcing strategy. We present several model extensions in Section 8, and conclude in Section 9.

2. Literature review

We consider the supply base design and contracting mechanism as two incentive instruments that influence suppliers’ cost-reduction efforts. The supply chain management literature considering incentive alignment mostly focuses on contract design as the incentive instrument. See Cachon (2003) and Chen (2003) for a review of this literature; some recent papers extend the contract design issue to a procurement setting with multiple competing suppliers (Cachon and Zhang, 2006; Li and Scheller-Wolf, 2009). The papers that consider supplier effort to improve costs or other capabilities usually assume that the supplier effort or the capability achieved from the effort is observable. Thus, the contract typically contains terms that depend on the effort (Roels et al., 2010) or on the realized capability (Kim et al. 2007; Corbett et al., 2005; Plambeck and Taylor, 2006). In our model, neither a supplier’s cost-reduction effort nor the realized cost is observable, which limits the buyer’s instruments in
contract design. Thus, instead of focusing on contract design, we adopt simple contracts, but investigate the influence of the supply base design and the contracting mechanism.

We compare the performance of ex ante and ex post contracting mechanisms in the presence of supplier competition. Our model differs from such papers as Van Mieghem (1999), Bernstein and Kök (2009), and Kim and Netessine (2009), which investigate the contracting mechanism assuming a single supplier. By considering supplier competition, we examine the relationship between the contracting mechanism and supply base design.

In our paper, the buyer’s capacity investment for suppliers is an important part of the supply base design. The role of the buyer’s investment is different from those in Iyer et al. (2005) and Zhu et al. (2007), who both consider the buyer’s commitment of resources before the investment of a single supplier. Iyer et al. (2005) show that the buyer’s investment serves as a tool to reduce the agency cost when the buyer’s resources and supplier capability are complementary. Zhu et al. (2007) reveal that either the buyer or the supplier, but not both, will invest substitutable quality improvement effort. In our model, the buyer’s capacity investment for a supplier increases the return of the supplier’s own cost-reduction effort, but reduces the return of the other supplier’s effort. Therefore, the buyer’s investment is a strategic tool that shapes supplier competition and affects supplier effort incentive. The role of the buyer’s investment is also different from those in Wang et al. (2009) and Li and Debo (2009a,b), who focus on the buyer’s investment but do not consider that of the supplier. In Wang et al. (2008), the buyer’s investment in supplier reliability is an alternative option to dual sourcing. In Li and Debo (2009a,b), the buyer’s investment in the supplier’s (transferable or untransferable) capacity influences future competition between the incumbent and entrant suppliers.

When suppliers make investment in anticipation of future competition, the investment decision depends on the procurement mechanism used by the buyer to allocate demand and negotiate contracts with competing suppliers. The existing papers that study the relationship between suppliers’ investment and the procurement mechanism include Li et al. (2006), Cachon and Zhang (2007), Li and Gupta (2007), and Dasgupta (1990). All these papers assume that the supply base is exogenously given. We differ by considering supply base design as an endogenous decision. This decision influences supplier investments and shapes the follow-up auction mechanism designed by the buyer. Thus, the supply base design can be considered as a strategic decision, with the auction mechanism as a tactical decision, both influencing supplier investments, but on different levels.

In our paper, the supply base design trades off the benefits from supplier competition and those from supplier effort. Because of supplier effort concerns, sole sourcing can be optimal even if the capacity is free. The existing literature on supply base design has considered
the value of supplier competition, but in a tradeoff with other factors, such as supplier qualification costs (Riordan, 1996), supplier diversification (Wan and Beil, 2008), inefficiency of purchasing from higher-cost suppliers (Klotz and Chatterjee, 1995; Lewis and Yildirim, 2002). Considering nonstrategic suppliers, the supply base design in Agrawal and Nahmias (1997) is concerned with yield uncertainty and the fixed costs associated with each supplier. In our paper, suppliers invest efforts simultaneously before they bid for the contract; the supply base design influences the equilibrium of supplier efforts. The economics literature has analyzed the effort investment of a single incumbent supplier, who expects future competition from an entrant supplier (Rob, 1986; Stole, 1994; Laffont and Tirole, 1988). With a single supplier investing effort, the strategic interaction between suppliers is different from ours.

3. Model

A downstream firm (the “buyer”) sources an essential input to her final product from external suppliers. Each unit of the final product requires a unit of the input from the supplier(s). The product is sold at unit price \( r \). The demand of the product, \( X \), is uncertain, and is drawn from a probability distribution \( G(\cdot) \), with density \( g(\cdot) \), on the range \([d, \bar{d}]\). We assume \( X \) has an increasing failure rate, i.e., \( g(x)/(1 - G(x)) \) is increasing. This property is satisfied by many well-known distributions, such as uniform, normal, and exponential distributions (Bagnoli and Bergstrom, 2005). Let \( \mu_d \) and \( \sigma_d \) be the mean and standard deviation of \( X \), and \( X = \mu_d + \sigma_d X_0 \), where \( X_0 \) is a random variable with zero mean and standard deviation equal to one.

The buyer may use two upstream firms, Supplier 1 and Supplier 2, as her suppliers. The buyer invests in a supplier’s specific assets that enhance his delivery capability.\(^1\) In order to emphasize the impact of the buyer’s investment on the supply base performance, we strengthen the relationship by assuming that the buyer’s investment fully determines a supplier’s production capacity.\(^2\) The investment of a unit of capacity costs the buyer \( k \). Besides the capacity and purchasing costs, all other costs of the buyer are normalized to zero. Define \( S(Q) \equiv \mathbb{E}[\min(X, Q)] \) as the expected demand covered by supplier capacity \( Q \).

We assume the buyer has strong bargaining power relative to the suppliers. This can be considered as the case in the automotive industry, where the automakers are typically larger firms that hold greater stakes in the supply chain than the parts suppliers. In a strong

\(^1\)In the automotive industry, the buyers are usually financially more powerful than the suppliers. Therefore, it is typically the buyer, but not supplier, that invests in and owns the specific capacity (Autobeat, 2002; Dyer 1997).

\(^2\)This assumption can be relaxed by introducing a supplier’s exogenous base capacity, without changing the nature of the game. The buyer’s investment will then expand a supplier’s capacity on top of this base capacity. Our model assumes a supplier’s base capacity is equal to zero.
bargaining position, the buyer offers the suppliers contracts that the suppliers may accept or reject. If a supplier rejects the buyer’s offers, he earns the reservation profit, which is normalized to be zero.

Each supplier can invest effort to reduce his production cost. The effort, such as the activities to improve the production process, quality control, subcontracting, or tooling and product design, is not observable to the buyer nor to the other supplier. The cost of supplier effort $e$ is characterized by an increasing convex function $\varphi(e)$, with $\varphi'(e) > 0$, $\varphi'(0) < 1$, and $\varphi''(e) > 0$. The realization of a supplier’s production cost is uncertain, due to uncertainty of the outcome of cost-reduction efforts and variations in the supplier’s internal and external environments; the realized production cost $\gamma_i$ of Supplier $i$ is a random cost $c_i$ reduced by his effort $e_i$: $\gamma_i = c_i - e_i$. The random cost $c_i \in [c, \bar{c}]$ is drawn from a probability distribution $F_i(\cdot)$, density $f_i(\cdot)$, and is called the supplier’s type. We focus on the idiosyncratic sources of cost uncertainty (such as the uncertainty related to the management, logistics, lower-tier suppliers, or improvement outcome) rather than the common sources, because the former sources provide the benefit of supplier competition—they are more difficult to observe, causing the challenge of pricing, and allow the cost uncertainty faced by the buyer to be mitigated by supplier competition. Thus we assume the distributions $F_i(\cdot)$ are independent across suppliers. In addition, we assume the distributions are identical, $F(\cdot) \equiv F_1(\cdot) = F_2(\cdot)$. Thus, the suppliers are ex ante identical, facing the same effort cost $\varphi(e)$ and the same production cost distribution for given effort $e$. This allows us to focus on the endogenous impact of the buyer’s sourcing strategy on the two suppliers’ performance. The realized production cost $\gamma_i$ is a supplier’s private information, although the distribution $F_i(\cdot)$ is common knowledge. In line with the mechanism design literature, we assume $F_i(\cdot)$ is log-concave, i.e., $F_i(\cdot)/f_i(\cdot)$ is increasing. This condition is also satisfied by a wide variety of commonly used distributions (Bagnoli and Bergstrom, 2005).

We consider three mechanisms that differ in the timing of the buyer’s capacity investment and price decisions. In the base mechanism, the buyer makes capacity investment first. Then suppliers invest cost-reduction efforts, followed by the realization of their costs. Finally, the buyer negotiates with the suppliers to determine prices. In the ex ante price commitment mechanism, the price decision is moved forward, both the price and capacity being determined before suppliers invest efforts. In the ex post capacity investment mechanism, the

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3While a buyer can also invest in resources, such as engineering support or training programs, to help improve a supplier’s efficiency, in this paper we focus on the effort initiated by a supplier, since the improvement pertains to the activities performed by the supplier, and thus requires great commitment on the part of the supplier (Handfield et al., 2000).

4Such an additive form of cost reduction allows tractable analysis. See similar assumptions used by Kim et al. (2007) and Dasgupta (1990). In Section 8.1, we show that the major results hold qualitatively with a fractional form of cost reduction.
capacity decision is postponed, both the price and capacity being determined after supplier effort investment and the realization of supplier costs. The sequences of events in the three mechanisms are illustrated in Figure 1.

**Figure 1: Sequences of events in the three contracting mechanisms**

In the following, we describe the details of these three mechanisms separately.

**Base mechanism:** Let the capacity invested for Supplier $i$ be $Q_i$, $i = 1, 2$. Supplier $i$ is excluded from the supply base if $Q_i = 0$. Denote by $Q \equiv (Q_1, Q_2)$ the suppliers’ capacity profile, and $\bar{Q} \equiv Q_1 + Q_2$ the total capacity of suppliers. Observing $Q$, each supplier $i$ invests effort $e_i$; denote by $e \equiv (e_1, e_2)$ the suppliers’ effort profile. Then the production cost $\gamma_i$ of each supplier $i$ is realized; let $\gamma \equiv (\gamma_1, \gamma_2)$ be the profile of suppliers’ realized costs. Finally, the demand $x$ is realized, and the buyer negotiates with the suppliers to determine the quantity sourced from and the price paid to each supplier. While there can be many different negotiation mechanisms, for the buyer with strong bargaining power but uninformed of suppliers’ costs, an optimal auction mechanism is one that maximizes the buyer’s profit (Myerson, 1981).

According to the revelation principle, we restrict the consideration of an optimal auction to direct auction mechanisms that satisfy incentive compatibility (IC) and individual rationality (IR), without loss of generality. Under this mechanism, the buyer offers each supplier $i$ a menu of contracts parameterized by the suppliers’ cost profile $\gamma$: $(q_i(\gamma), t_i(\gamma))$, where $q_i$ is the quantity and $t_i$ the payment for Supplier $i$. Suppliers report their costs given the contract menus. Based on the reported cost profile $\hat{\gamma} \equiv (\hat{\gamma}_1, \hat{\gamma}_2)$, each supplier $i$ is awarded the contract $(q_i(\hat{\gamma}), t_i(\hat{\gamma}))$. The buyer designs the contract menus to maximize her profit, subject to the constraints of IC and IR. The IC constraint implies that a supplier optimizes his own expected profit by reporting his true cost. The IR constraint warrants a supplier to
receive at least his reservation profit (which is normalized to be zero) by participating in the auction.

Since a supplier’s effort is not observable to the buyer nor to the other supplier, the efforts and auction mechanism (contract menus) are determined simultaneously. In the equilibrium for a given capacity profile, each supplier’s effort is his best response to the other supplier’s effort and the buyer’s auction mechanism, and the buyer’s auction mechanism is her best response to the suppliers’ effort profile.

**Ex ante price commitment:** In this mechanism, the contract price is specified before suppliers’ costs are realized. Because it is difficult for the parties to write a court-enforceable complete contract with the terms contingent on every possible state of the outcome (Grossman and Hart, 1986), we focus on non-contingent prices. In other words, for each supplier the buyer commits to a price that is independent of the realization of suppliers’ costs. As a supplier takes the risk of his cost uncertainty, we allow a supplier to quit his contract after observing his cost. With zero reservation profit, a supplier will quit if and only if the contract price is lower than his cost.

The reason that we allow a supplier to quit is two-fold: First, it is hard to enforce a price lower than the supplier’s cost. A supplier may breach the contract when the actual cost turns out to be too high compared with the pre-negotiated price. For example, Navistar and Collins & Aikman, two top suppliers of Ford, cut off their supply to Ford in disputes over prices that required them to sell parts at a loss (McCracken and Glader, 2007; McCracken 2006). Furthermore, suppliers are able to shed unprofitable contracts by seeking bankruptcy reorganization or selling ownership to private-equity investors (McCracken and Glader, 2007; McCracken 2006; Harvey et al., 2009). Second, allowing suppliers to quit brings a fair comparison of the ex ante price commitment mechanism with the base mechanism; the latter guarantees suppliers positive ex post profits so that they voluntarily participate in the auction after observing their costs. In Section 8.3, we consider the situation when a supplier is not allowed to quit.

In the ex ante price commitment mechanism, the buyer first decides the capacity investments \( Q \equiv (Q_1, Q_2) \) and unit purchasing prices \( p \equiv (p_1, p_2) \) offered to each supplier. Receiving the capacity and price commitments, the suppliers invest cost-reduction efforts \( e \equiv (e_1, e_2) \). Then suppliers’ production costs \( \gamma \equiv (\gamma_1, \gamma_2) \) are realized, and suppliers choose to quit or stay. Finally, the demand \( x \) is realized and the buyer decides the quantity sourced from each staying supplier. We differentiate the notations for the ex ante price commitment mechanism with a superscript “\( P \)”. 

**Ex post capacity investment:** In this mechanism, the buyer first decides to invite one or two suppliers to join the supply base. Then, the suppliers in the supply base invest cost-
reduction efforts. After suppliers’ costs are realized, an auction is conducted to determine the capacity investment and purchasing price for each supplier. Finally, the demand is realized, and the contracts are executed. The auction mechanism can be specified by a menu of contracts \((Q_i(\gamma), p_i(\gamma), t_i(\gamma))\) offered to each supplier \(i\) in the supply base, where \(Q_i(\gamma)\) is the capacity investment, \(p_i(\gamma)\) the unit price, and \(t_i(\gamma)\) the fixed payment for supplier \(i\) when suppliers report costs \(\gamma\). We differentiate the notation for the ex post capacity investment mechanism by the superscript “\(C\)”.

These three mechanisms are analyzed in Sections 4, 5 and 6, respectively. They are compared in Section 7.

4. Base mechanism

We first analyze the buyer’s profit for given capacity investment in §4.1, and then present the result of supply base design in §4.2.

4.1 Analysis for given capacity profile \(Q\)

For given capacity profile \(Q = (Q_1, Q_2)\), the analysis is performed in three steps. In §4.1.1, we analyze the auction mechanism as the buyer’s best response to supplier effort profile \(e\). Then, in §4.1.2, we derive the equilibrium of suppliers’ efforts based on the buyer’s best-response auction mechanism. Finally, in §4.1.3, we analyze the buyer’s profit as a function of \(Q\), given the equilibrium of the auction mechanism and suppliers’ efforts. Since the suppliers are ex ante identical, without loss of generality we assume \(Q_1 \geq Q_2\), i.e., Supplier 1 is equipped with larger capacity than Supplier 2.

4.1.1 Best-response auction mechanism for given effort profile \(e\)

For a supplier’s type \(c_i\) and effort \(e_i\), we define \(J_i(c_i, e_i) \equiv c_i - e_i + \frac{F_i(c_i)}{J_i(c_i)}\) as the supplier’s virtual cost, which can be interpreted as the true cost inflated by information rent (Myerson, 1981). Since \(F_i(\cdot)\) is log-concave, \(J_i(c_i, e_i)\) is increasing in \(c_i\) and decreasing in \(e_i\). We assume the buyer’s revenue is large enough to cover the capacity cost and the highest possible virtual cost of a supplier: \(r > k + J_i(\bar{c}_i, 0)\) for \(i = 1, 2\). This assumption implies that it is always profitable for the buyer to source from a supplier to satisfy demand, even if the supplier has the lowest possible efficiency; therefore, no supplier cutoff needs to be considered. Let \(-i\) denote the other supplier as opposed to Supplier \(i\).

Recall that the auction mechanism is defined by a menu of contracts \((q_i(\gamma), t_i(\gamma))\) for each supplier \(i\), where \(q_i\) is the quantity and \(t_i\) is the payment, both parameterized on the profile of suppliers’ reported costs \(\gamma\). Anticipating supplier efforts \(e = (e_1, e_2)\), the buyer offers
contract menus that correspond to supplier costs distributed on the range \([c_i - e_i, \bar{c}_i - e_i]\), \(i = 1, 2\). Note the virtual cost of a supplier \(i\) with cost realization \(\gamma_i\) is \(J_i(\gamma_i + e_i, e_i)\). The optimal auction design is shown in Lemma 1. All proofs are in Appendix A.

**Lemma 1** Given capacity profile \(Q\) and supplier effort profile \(e\):

i) The best-response auction mechanism for realized demand \(x\) is specified by

\[
q_i(\gamma) = \begin{cases} 
\min (x, Q_i) & \text{if } J_i(\gamma_i + e_i, e_i) \leq J_{-i}(\gamma_{-i} + e_{-i}, e_{-i}) \\
\min ((x - Q_{-i})^+, Q_i) & \text{otherwise} \end{cases}
\]  

(1)

\[
t_i(\gamma) = \int_{\gamma_i}^{\bar{c}_i - e_i} q_i(\rho_i, \gamma_{-i}) d\rho + \gamma_i q_i(\gamma),
\]  

(2)

where \(\gamma\) is restricted to \(\gamma_i \in [c_i - e_i, \bar{c}_i - e_i], i = 1, 2\).

ii) From this auction mechanism, the buyer’s expected profit, excluding the capacity cost, is

\[
U(Q, e) = rS(\bar{Q}) - \sum_{i=1,2} \mathbb{E} \left[ J_i(e_i, e_i) S(Q_i) + J_{-i}(c_{-i}, e_{-i}) (S(\bar{Q}) - S(Q_i)) \right]
\]

(3)

\[
\left| J_i(e_i, e_i) \leq J_{-i}(c_{-i}, e_{-i}) \right| \cdot \Pr \left[ J_i(e_i, e_i) \leq J_{-i}(c_{-i}, e_{-i}) \right]
\]

iii) Supplier \(i\) will report cost \(c_i - e_i\) if his actual cost is below this level, and quit if his actual cost is above \(\bar{c}_i - e_i\); otherwise he will report truthfully.

As shown in Equ. (1), the suppliers are compared by their virtual costs. The supplier with the lower virtual cost wins the competition by supplying as much of the buyer’s demand as possible subject to his capacity constraint. The supplier with the higher virtual cost loses, and receives only the demand overflow beyond the winner’s capacity. The payment rule (2) is designed to induce suppliers to voluntarily participate in the auction and report their true costs. Recall \(S(Q) = \mathbb{E} [\min(X, Q)]\) and \(\bar{Q} = Q_1 + Q_2\). Based on this demand allocation rule, the expected volume provided by Supplier \(i\) as a winner is \(S(Q_i)\), and as a loser is \(S(\bar{Q}) - S(Q_{-i})\). As shown in Equ. (3), the buyer’s expected profit takes suppliers’ virtual costs as their effective costs.

For later use, we define

\[
A(Q) = 2S(Q_1) - S(\bar{Q}) \quad \text{and} \quad B(Q) = S(Q_1) + S(Q_2) - S(\bar{Q}).
\]

\(A(Q)\) is the expected quantity difference between the larger supplier as the winner, \(S(Q_1)\), and the smaller supplier as the loser, \(S(\bar{Q}) - S(Q_1)\). \(B(Q)\) is the expected quantity difference for Supplier \(i\) between when he is the winner, \(S(Q_i)\), and when he is the loser, \(S(\bar{Q}) - S(Q_{-i})\). It can be shown that, for given total capacity \(\bar{Q}\), \(A(Q)\) increases while \(B(Q)\) decreases in the capacity difference \(Q_1 - Q_2\) between the two suppliers.
Recall that the buyer designs the mechanism in Lemma 1 i) under her anticipation of suppliers’ efforts $e_i$, or equivalently, under her anticipation of supplier $i$’s cost distribution on the range $[c_i - e_i, \bar{c}_i - e_i]$. As a supplier chooses the effort to maximize his own profit, we must analyze the utility of a supplier $i$ if he deviates from the effort $e_i$. In this case, a supplier’s actual cost may fall out of the range. Specifically, a supplier’s cost may be even lower than the lower bound $c_i - e_i$ if his effort is greater than $e_i$, or higher than the upper bound $\bar{c}_i - e_i$ if his effort is less than $e_i$. Lemma 1 iii) shows that a supplier will report the lower-bound cost if his actual cost is lower than this level, quit if his cost is higher than the upper bound, and report his true cost if it is within the range. Given such responses, for a supplier with cost realization $\gamma_i$, the expected profit from the auction, excluding the cost of effort, can be written as:

$$u_i(\gamma_i, Q, e) = \begin{cases} 
\mathbb{E}_{\gamma_i - e_i} \left[ t_i (c_i - e_i, \gamma_i - e_i) - \gamma_i q_i (c_i - e_i, \gamma_i - e_i) \right] & \text{if } \gamma_i < c_i - e_i \\
\mathbb{E}_{\gamma_i - e_i} \left[ t_i (\gamma_i, \gamma_i - e) - \gamma_i q_i (\gamma_i, \gamma_i - e) \right] & \text{if } \gamma_i \in [c_i - e_i, \bar{c}_i - e_i] \\
0 & \text{else } \gamma_i > \bar{c}_i - e_i 
\end{cases} \quad (4)$$

Using $u_i(\gamma_i, Q, e)$, we are able to analyze a supplier’s profit as a function of his effort, given the auction mechanism designed for an effort profile $e$. This enables our analysis of the equilibrium of supplier efforts in § 4.1.2.

### 4.1.2 Equilibrium efforts

If the auction mechanism is designed in response to supplier efforts $e=(e_1, e_2)$ and Supplier $i$ invests effort $e_i$, then Supplier $i$’s expected profit as a function of his own effort $\hat{e}_i$, including the cost of effort, is $\hat{\Pi}_i(\hat{e}_i, Q, e) \equiv \mathbb{E}_{c_i} [u_i(c_i - \hat{e}_i, Q, e)] - \varphi(\hat{e}_i)$. The supplier efforts $e_1$ and $e_2$ constitute an equilibrium for given $Q$ if $\hat{\Pi}_i(\hat{e}_i, Q, e)$ is maximized at $\hat{e}_i = e_i$ for both $i = 1, 2$.

For tractability of analysis, hereafter we assume a supplier’s type $c_i$ follows a uniform distribution on $[c, \bar{c}]$ with $\Delta \equiv \bar{c} - c$. The supplier cost uncertainty $\Delta$ can be interpreted as the complexity of the product: It is usually difficult to predict the total production cost for a complex product consisting of many subcomponents. In addition, we assume a quadratic form of the cost function of supplier effort: $\varphi(e) = ae^2/2$, where $a > 0$ is a constant. The marginal cost of supplier effort $a$ can be interpreted as the maturity of production technology: It is hard to improve a mature technology as the operation is likely finalized. Given that the auction mechanism and supplier efforts are determined simultaneously, a pure strategy equilibrium of such decisions may not exist.\(^5\)

\(^5\)To see this, let the supplier type be a constant $c$ (i.e., $\Delta = 0$). If a supplier invests effort $e$ in a pure-strategy equilibrium, the buyer will always propose a price $p = c - e$, which leaves the supplier a total profit $-\varphi(e)$. Expecting such a strategy of the buyer, the supplier will not invest any effort, resulting in $e = 0$. 

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equilibrium, we further assume that $\Delta$ or $a$ is sufficiently high: $a\Delta \geq \mu_d$. Under these assumptions, the suppliers’ equilibrium efforts are characterized in Lemma 2.\textsuperscript{6}

**Lemma 2** i) Given the supplier capacity profile $Q$,

\[
e_1 (Q) = \frac{S(\bar{Q})}{2a} + \Delta \eta (Q) \quad \text{and} \quad e_2 (Q) = \frac{S(\bar{Q})}{2a} - \Delta \eta (Q)
\]

constitute the unique equilibrium of supplier efforts, where $\eta (Q) \in \left[ 0, \frac{S(Q_1)}{2a\Delta} \right]$ is uniquely defined by

\[
A(Q) - (1 - \eta)^2 B(Q) = 2a\Delta \eta. \tag{6}
\]

ii) $e_i (Q)$ increases with $Q_i$ and decreases with $Q_{-i}$.

Lemma 2 reveals how the buyer can influence suppliers’ efforts through her capacity investment. Lemma 2 i) shows $e_1 \geq e_2$, i.e., the larger-capacity supplier (Supplier 1) always invests more effort than the smaller supplier (Supplier 2). In addition, the average effort of suppliers, $(e_1 + e_2) / 2 = S(\bar{Q}) / (2a)$, depends only on the total capacity $\bar{Q}$, but not on the capacity allocation between suppliers. The greater the total capacity, the higher the average effort. The difference of supplier efforts, $e_1 - e_2 = 2\Delta \eta$, depends on the capacity allocation according to Equ. (6). Based on Lemma 2 ii), a supplier is motivated to invest more effort when he is equipped with larger capacity or the opponent is equipped with smaller capacity. This implies that, for given total capacity, larger capacity difference causes a larger effort difference between suppliers. As we shall see in §4.1.3, not only the average effort, but also the difference in efforts, affects the buyer’s profit.

It is worth noting that our result of positive supplier effort is obtained for unobservable supplier effort. In this condition, the supplier efforts and auction mechanism are determined simultaneously; the auction mechanism is designed based on the buyer’s anticipation of supplier efforts. If supplier effort is observable, then a supplier will not invest any effort: In this case, the auction mechanism is determined in response to supplier efforts. For any effort of the supplier, the buyer would deduct the expected cost reduction achieved by the supplier from the price offer, leaving the supplier zero benefit from his effort. This eliminates a supplier’s incentive to invest observable effort.

\textsuperscript{6}The uniform cost distributions (see, for example, Klotz and Chatterjee, 1995 and Lewis and Yildirim, 2002) and quadratic effort cost functions (see, for example, Kim et al., 2007) are often used in the literature to lend tractable analytical expressions. For more general forms of $F(c)$ and $\varphi(e)$, a unique equilibrium of supplier efforts can be identified as $\varphi'(e_i) = S(Q_i) - B(Q) E_{c_i} [F(c_i - e_i + e_{-i})]$ for $i = 1, 2$, and all qualitative results hold, if $\varphi''(e) \geq \mu_d \max_{c \in \mathbb{Z}} \{ f(c) \}$ for any $e \geq 0$. Then for the buyer, the best-response strategy is to offer a price $p = c$. However, expecting such a price, the supplier will invest positive effort $e$ to maximize his total profit $e - \varphi(e)$. Thus, a pure strategy equilibrium does not exist under $\Delta = 0$. 

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4.1.3 Buyer’s profit

The buyer’s expected profit as a function of the capacity investment profile $Q$ is $\Pi(Q) = U(Q, e) - k\bar{Q}$, where $U(Q, e)$ is defined in Equ. (3). Replacing $e$ with the equilibrium of supplier efforts as characterized in Lemma 2, $\Pi(Q)$ can be transformed to:

$$\Pi(Q) = \left( r - \bar{c} + \frac{S(\bar{Q})}{2a} \right) S(\bar{Q}) - k\bar{Q} + \frac{2(1 - \eta(Q))^3}{3} B(Q) + \Delta \eta(Q) A(Q),$$

where $\eta(Q)$ is defined by Equ. (6).

The buyer’s total profit can be interpreted in three parts. The first part depends only on the total capacity but not on capacity allocation between suppliers. This part can be regarded as the profit that the buyer would receive if the two suppliers were combined as one, keeping the same total capacity $\bar{Q}$ and (average) cost reduction effort $S(\bar{Q}) / (2a)$. With a single supplier, the buyer would pay a price according to the least efficient type $\bar{c}$, due to information asymmetry. The second part of the profit is related to the benefit gained from supplier competition. For given total capacity investment, a smaller capacity difference between the suppliers (resulting in greater $B(Q)$ and lower $\eta(Q)$) intensifies supplier competition, reducing information rent as well as mitigating supplier-cost uncertainty. We refer to this part as the benefit of supplier symmetry. The third part is related to supplier effort. For given total capacity, enlarging the capacity difference between suppliers (resulting in greater $A(Q)$ and higher $\eta(Q)$) leads the larger supplier (Supplier 1) to increase and the smaller supplier (Supplier 2) to decrease their efforts, without affecting the average effort. Such effort changes benefit the buyer, since Supplier 1 provides more quantity on expectation than Supplier 2, for his larger capacity and greater effort. We call this part of profit the benefit of supplier asymmetry.

If the buyer invests in equal capacities for the suppliers, then $\eta(Q) = 0$ and there is no benefit of supplier asymmetry; the buyer’s profit reduces to

$$\Pi(Q,Q) = \left( r - \bar{c} + \frac{S(2\bar{Q})}{2a} \right) S(2\bar{Q}) - 2k\bar{Q} + \frac{2}{3}(2S(Q) - S(2Q)).$$

If the buyer invests for only one supplier, then $B(Q) = 0$, and the benefit of supplier symmetry goes away; the buyer’s profit reduces to:

$$\Pi(Q,0) = \left( r - \bar{c} + \frac{S(Q)}{2a} \right) S(Q) - kQ + \frac{S(Q)^2}{2a}.$$
4.2 Optimal supply base structure

The optimal supplier capacity profile \((Q_1^*, Q_2^*)\) maximizes the buyer’s profit, as characterized in Equ. (7). The solutions can be classified in three types: *Sole sourcing* (S), in which only one supplier receives positive capacity investment \((Q_1^* > 0 \text{ and } Q_2^* = 0)\), *symmetric Dual sourcing* (sD), in which the two suppliers receive positive and equal capacity investments \((Q_1^* = Q_2^* > 0)\), and *asymmetric Dual sourcing* (aD), in which the two suppliers receive positive but unequal capacity investments \((Q_1^* > Q_2^* > 0)\). Note that S is the most asymmetric and sD the most symmetric of the three structures. The aD structure is an intermediate choice between S and sD. Proposition 1 reveals the condition for each structure to emerge in the optimal supply base design (based on small demand uncertainty).

**Proposition 1**

i) When demand is certain and equal to \(\mu_d\), sD is optimal with \(Q_1^* = Q_2^* = \mu_d\) if \(\frac{a}{\sigma_d} \geq \frac{\mu_d}{2a} + k\), otherwise S is optimal with \(Q_1^* = \mu_d\), \(Q_2^* = 0\).

ii) When demand uncertainty \(\sigma_d\) is positive and small, there exist \(k_1, k_2\) and \(\hat{a}\), with \(k_1 < k_2\) if and only if \(a > \hat{a}\), such that:

   ii-1) when \(k \leq k_1\), sD is optimal, with \(Q_1^* = Q_2^*\) and both \(Q_1^*\) and \(Q_2^*\) approaching \(\mu_d\) as \(\sigma_d\) reduces to zero;

   ii-2) when \(k \in (k_1, \max(k_1, k_2))\), aD is optimal, with \(Q_1^*\) approaching \(\mu_d\) and \(Q_2^*\) approaching zero as \(\sigma_d\) reduces to zero;

   ii-3) when \(k \geq \max(k_1, k_2)\), S is optimal, with \(Q_2^* = 0\), and \(Q_1^*\) approaching \(\mu_d\) as \(\sigma_d\) reduces to zero.

Proposition 1 i) shows that, when demand uncertainty is zero, the buyer should choose only between sD and S; aD is never optimal. In this case, sD is better than S if the supplier cost uncertainty \(\Delta\) or marginal cost of effort \(a\) is relatively high, or the capacity cost \(k\) is relatively low. Under such conditions, the value of supplier competition is significant in reducing information rent and mitigating supplier cost uncertainty faced by the buyer (\(\Delta\) high), the benefit of supplier asymmetry in inducing supplier effort is small (\(a\) high), and the cost for the buyer to invest capacity in both suppliers to induce competition is low (\(k\) low). Note for \(a\) or \(\Delta\) sufficiently small, the condition for sole sourcing, \(\frac{\Delta}{3} < \frac{\mu_d}{2a} + k\), can hold for \(k = 0\). In other words, even if capacity is free, the buyer may invest in capacity for only one supplier in order to motivate supplier effort.

While the buyer facing deterministic demand should maximize the benefit either from supplier competition or from supplier effort by choosing between sD and S, she may trade off these two benefits by adopting aD when facing uncertain demand. As shown in Proposition 1 2-ii), aD is optimal if the cost of effort is sufficiently high (\(a > \hat{a}\), resulting in \(k_1 < k_2\)) and the capacity cost is intermediate (\(k_1 < k < k_2\)), with (small) demand uncertainty. Under
such conditions, aD is superior to S because the effort cost is high enough to allow the buyer to give up some supplier asymmetry (which is less effective in motivating supplier effort when $a$ is higher), and the capacity cost is low enough for the buyer to invest in both suppliers to induce supplier competition and meanwhile buffer against demand uncertainty. The structure aD is also superior to sD because the capacity cost is still too high to justify the greater capacity redundancy required for sD. Therefore, even though suppliers are ex ante identical, the optimal solution involving both suppliers may not be symmetric when demand is uncertain.

If the cost of effort is sufficiently low ($a \leq \hat{a}$, resulting in $k_1 \geq k_2$), then the benefit of supplier asymmetry will be so substantial that aD should be replaced with S. In this case, as shown in Proposition 1 2-i) and 2-iii), the buyer should choose only sD (if $k \leq k_1$) or S (if $k > k_1$) even with uncertain demand. The two threshold capacity costs, $k_1$ and $k_2$, define the boundaries between sD and aD/S and between aD and S. It can be shown that both $k_1$ and $k_2$ increase in $a$ and $\Delta$. This suggests that increasing $a$ or $\Delta$ makes sD (S) more (less) favorable, similar as in the case with certain demand.

While Proposition 1 is based on small demand uncertainty $\sigma_d$, through numerical experiments we find the results hold in general situations where $\sigma_d$ can be large. As a numerical example, Figure 2 demonstrates the supply base structure under different $k$ and $a$ values for significant demand uncertainty.

![Figure 2: The optimal supply base structure based on $k$ and $a$. $r = 5$, $c = 2$, $\bar{c} = 3$, demand following a uniform distribution on $[1.5, 2.5]$.](image)

The results in Proposition 1 complement Riordan (1996). Assuming unit demand and supplier cost-reduction effort occur after contracting, Riordan (1996) shows that the buyer should fully qualify either a single supplier or both suppliers, resulting in our single sourcing or symmetric dual sourcing structures. In that model, sole sourcing is driven only by capacity cost concerns, but not by the incentive of supplier effort. Considering the influence of supply
base design on suppliers’ cost-reduction effort, we show that sole sourcing can be optimal even if capacity is free, and that demand uncertainty introduces asymmetric dual sourcing. Proposition 2 further investigates the impact of demand uncertainty.

**Proposition 2** With demand uncertainty $\sigma_d$ remaining small, and the marginal effort cost $a$ sufficiently low, increasing $\sigma_d$ leads to the optimal supply base shifting from $sD$ to $S$ along with total capacity reduction.

When $a$ is small, based on Proposition 1 the supply base structure varies between $sD$ and $S$. Proposition 2 indicates that the structure $S$ along with small capacity is increasingly preferred to $sD$ along with large capacity, as demand uncertainty rises (while remaining relatively low). This is somewhat counter-intuitive, as one may think that dual sourcing and a larger supply base would be preferable in an environment with more volatile demand because they help to counter demand uncertainty. A major reason for this result is the negative effect of demand uncertainty on supplier competition: Recall that in $sD$ the inefficient (higher-cost) supplier receives the demand overflow beyond the efficient (lower-cost) supplier’s capacity. Since the expected demand overflow increases in $\sigma_d$, the inefficient supplier receives more quantity with greater demand uncertainty. This weakens the benefit of supplier competition. As a result, the buyer is less willing to invest in redundant capacity to maintain supplier competition, shifting away from $sD$ towards $S$. The redundant capacity in dual sourcing to stimulate supplier competition may be called *strategic capacity*, while the capacity used to meet uncertain demand may be called *operational capacity*. Our result suggests that, when designing the supply base capacity, the buyer should be concerned not only with operational capacity, but also with strategic capacity. While greater demand uncertainty typically calls for a greater buffer of operational capacity (when revenue is not too low), it may lower the value of the strategic capacity, resulting in the reduction of the total capacity.

When $a$ is high, however, the result can be different from that in Proposition 2. With $a$ higher, it is less effective to motivate supplier effort through capacity investment. Thus higher $a$ reduces the capacity investment in $S$, making demand satisfaction a greater concern. But increasing demand uncertainty also weakens the the relative advantage of $sD$ in demand satisfaction, because even the capacity in $sD$ may not be sufficient to cover all demand when $\sigma_d$ is high. In our numerical study, we find that increasing $\sigma_d$ may cause the supply base to change in different directions: Increasing $\sigma_d$ up to a certain level improves the preference for $sD$ rather than for $S/aD$, but the direction may reverse if $\sigma_d$ increases further.
5. **Ex ante price commitment mechanism**

In this mechanism, the buyer must determine the prices \( p = (p_1, p_2) \) and capacities \( Q = (Q_1, Q_2) \) committed to the suppliers, before the suppliers invest their cost-reduction efforts and realize their costs. Without loss of generality, we assume Supplier 1 receives a lower price than Supplier 2, \( p_1 \leq p_2 \). In §5.1 we analyze the suppliers’ efforts and present some structural properties of the buyer’s decision. Then in §5.2 we investigate the supply base structure.

### 5.1 Analysis

After the costs are realized, a supplier \( i \) will stay if and only if his cost is lower than the price committed by the buyer, \( p_i \geq c_i - e_i \). The buyer will source as much as possible from Supplier 1 (the lower-price supplier), with only the demand overflow sourced from Supplier 2 (the higher-price supplier), subject to their capacity constraints and staying in business. Therefore, if Supplier 1 stays \( (p_1 \geq c_1 - e_1) \), he receives an expected quantity \( q_1(Q, p_2, e_2) = S(Q_1) \), regardless of whether Supplier 2 stays. If Supplier 2 stays \( (p_2 \geq c_2 - e_2) \), then he receives an expected quantity \( S(Q_2) \) if Supplier 1 quits, and \( S(\bar{Q}) - S(Q_1) \) if Supplier 1 stays. This gives the total expected quantity of Supplier 2 when he stays: \( q_2(Q, p_1, e_1) = S(Q_2) - B(Q) \Pr (c_1 \leq p_1 + e_1) \).

Given \( Q \) and \( p \), if suppliers invest efforts \( e = (e_1, e_2) \), the expected profit of Supplier \( i \) is:

\[
\Pi_i^p (e, Q, p) = \mathbb{E} [p_i - c_i + e_i | c_i \leq p_i + e_i] \Pr (c_i \leq p_i + e_i) q_i(Q, p_{-i}, e_{-i}) - \phi(e_i).
\]

The effort profile \( e^p \equiv (e_1^p, e_2^p) \) constitutes an equilibrium if \( e_i^p \) maximizes \( \Pi_i^p (e, Q, p) \) on \( e_i \) for \( e_{-i} = e_{-i}^*, i = 1, 2 \). Such an equilibrium \( e^p \) is characterized in Lemma 3.

**Lemma 3** In the ex ante price commitment mechanism, for given \( Q \) and \( p \), the suppliers’ efforts \( e^p \) are uniquely defined by

\[
e_1^p = \Pr (c_1 \leq p_1 + e_1^p) \frac{S(Q_1)}{a} \quad \text{and} \quad e_2^p = \Pr (c_2 \leq p_2 + e_2^p) \frac{q_2(Q, p_1, e_1^p)}{a}.
\]

It can be shown that \( e_1^p \) increases in \( Q_1 \) and \( p_i, i = 1, 2 \), and \( e_2^p \) decreases in \( Q_1 \) and \( p_1 \). Thus, in the price commitment mechanism, both the price and capacity decisions influence supplier efforts. This is different from the base mechanism, in which only capacity investment influences the suppliers’ efforts.

Based on \( e^p(Q, p) \), the buyer designs \( Q \) and \( p \) to maximize her profit:

\[
\Pi^p (Q, p) = \sum_{i=1}^{2} \Pr (c_i \leq p_i + e_i^p(Q, p)) (r - p_i) q_i(Q, p_{-i}, e_{-i}^p(Q, p)) - k\bar{Q}.
\]
Note that the price $p_i$ committed to Supplier $i$ influences both the supplier’s staying probability, $\Pr\left(c_i \leq p_i + e_i^P (Q, p)\right)$, and the buyer’s profit margin from the supplier if the supplier stays, $r - p_i$. Thus, the buyer’s price decision is a trade-off between the margin and the probability of the supplier staying. It can be shown that, in the optimal solution, the buyer should make the higher price $p_2$ high enough to ensure that Supplier 2 will never quit (i.e., $\Pr\left(c_2 \leq p_2 + e_2^P\right) = 1$), but may design the lower-price $p_1$ to allow a positive probability of Supplier 1 quitting. Thus, the buyer maintains a supply base consisting of a supplier that provides a lower profit margin and will always stay, and another supplier that provides a higher profit margin but may quit (though the supply base reduces to sole sourcing when only one supplier receives positive capacity).

**Lemma 4** In the optimal ex ante price commitment mechanism, the capacities $Q$ and prices $p$ committed to suppliers satisfy $\Pr\left(c_2 \leq p_2 + e_2^P (Q, p)\right) = 1$.

### 5.2 Optimal supply base structure

Let $(Q_1^{P*}, Q_2^{P*})$ be the optimal supplier capacity profile. The supply base structure is characterized in Proposition 3 (for small demand uncertainty $\sigma_d$).

**Proposition 3** i) When demand is certain and equal to $\mu_d$, sD is optimal with $Q_1^{P*} = Q_2^{P*} = \mu_d$ if $\frac{\Delta}{4} \geq \frac{\mu_d}{2a} + k$, otherwise S is optimal with $Q_1^{P*} = 0$ and $Q_2^{P*} = \mu_d$.

ii) When demand uncertainty $\sigma_d$ is positive and small, there exist $k_1^P, k_2^P$ and $\hat{a}^P$ with $k_1^P < k_2^P$ if and only if $a > \hat{a}^P$, such that:

ii-1) when $k \leq k_1^P$, aD is optimal, with $Q_2^{P*} > Q_1^{P*} > 0$, and both $Q_1^{P*}$ and $Q_2^{P*}$ approaching $\mu_d$ as $\sigma_d$ reduces to zero;

ii-2) when $k \in (k_1^P, \max(k_1^P, k_2^P))$, aD is optimal, with $Q_2^{P*} > Q_1^{P*} > 0$, and $Q_1^{P*}$ approaching zero while $Q_2^{P*}$ approaching $\mu_d$ as $\sigma_d$ reduces to zero;

ii-3) when $k \geq \max(k_1^P, k_2^P)$, S is optimal, with $Q_1^{P*} = 0$, and $Q_2^{P*}$ approaching $\mu_d$ as $\sigma_d$ reduces to zero.

When demand is certain, Proposition 3 i) shows that the buyer should choose between sole sourcing (S) and symmetric dual sourcing (sD). Specifically, sD is preferred to S when the capacity cost $k$ is low, supplier cost uncertainty $\Delta$ is large, or the effort cost $a$ is high. The parameters drive the supply base design in directions similar to those under the base mechanism. The sD structure requires substantial capacity investment relative to S, and thus is chosen only when $k$ is low. With price commitments, dual sourcing no longer provides the benefit of competitive pricing to reduce information rent; however, it still allows the buyer to mitigate supplier cost uncertainty by providing a backup supplier in case the lower-price
supplier quits. Therefore, sD is preferred for large $\Delta$, when the benefit of mitigating supplier cost uncertainty is significant. The presence of the backup supplier in sD reduces the price committed to the other supplier and thus his effort. Hence, the disadvantage of sD in supplier effort still exists, but this disadvantage is abated when $a$ is high.

When demand is uncertain, Proposition 3 ii) shows that aD may become optimal but sD will never be optimal. The reason for not considering sD can be explained as follows. Recall that the two suppliers are offered different prices, which leads to different probabilities of quitting. This makes the marginal values of capacity investment for the two suppliers different even when their capacities are equal (unless the demand is deterministic). Therefore, investing equal capacities in the two suppliers will not emerge as an optimal solution.

Proposition 3 ii) divides the capacity cost $k$ into three ranges. The high range ($k \geq \max (k_1^p, k_2^p)$) favors S. Although the low ($k < \max (k_1^p, k_2^p)$) and intermediate ($k_1^p \leq k < \max (k_1^p, k_2^p)$) ranges both favor aD, their supply base structures are qualitatively different: As shown in Proposition 3 ii-1) and ii-2), when demand uncertainty reduces to zero, the aD for the low range reduces to sD, while the aD for the intermediate range reduces to S. Thus, we may consider the aD structure for the low range of $k$ qualitatively closer to sD, while that for the intermediate range of $k$ is closer to S. Then Proposition 3 ii) exhibits a pattern of supply base design similar to that revealed in Proposition 1 ii) for the base mechanism. Therefore, the ex ante price commitment mechanism exhibits major features that are qualitatively similar to those in the base mechanism, except that with uncertain demand sD does not arise in this mechanism, and is replaced with aD in which the two suppliers’ capacities are different but relatively close.

6. Ex post capacity investment

Opposite to ex ante price commitment, the ex post capacity investment mechanism postpones both price and capacity decisions until after suppliers’ costs are realized following their efforts. Before suppliers invest effort, the buyer chooses to invite a single supplier or two suppliers to join the supply base; we call the former option sole sourcing and the latter dual sourcing. In §6.1, we analyze the suppliers’ efforts and the buyer’s profit in both sole and dual sourcing. Then, in §6.2, we investigate the buyer’s choice between sole sourcing and dual sourcing.

6.1 Analysis

The analysis of the best-response auction mechanism is similar to that in the base mechanism (see §4.1.1), in the sense that the buyer’s expected profit still takes a supplier’s virtual cost as
his effective cost. However, with the capacity now invested ex post, there are two differences in the result: First, the capacity investment is contingent on a supplier’s cost; a supplier with a different cost will receive different capacity. This is unlike the base mechanism, in which the capacity is invested ex ante and thus is independent of a supplier’s cost. Second, in dual sourcing only the winning supplier (the supplier with a lower cost) will be invested with positive capacity. In other words, although the buyer may invite both suppliers to join the supply base, only the lower-cost supplier will receive capacity investment and will produce for the buyer. This is unlike dual sourcing under the base mechanism, whereby the buyer invests in capacities for both suppliers before knowing the suppliers’ relative cost performance.

The suppliers invest effort based on their expectation of the invested capacity and price resulting from the auction. Lemma 5 summarizes the equilibrium outcome. In the dual sourcing case, since the two suppliers are identical when they make effort decisions, we focus on the symmetric equilibrium of efforts: \( e_1 = e_2 = e \). Define \( Q^* (\rho) \equiv G^{-1} \left( 1 - \frac{k}{r - \rho} \right) \) as the newsvendor solution to \( \max_Q \left( (r - \rho)S(Q) - kQ \right) \); it is the optimal capacity investment for a single supplier with (effective) unit cost \( \rho \).

**Lemma 5**

i) In sole sourcing, the supplier’s effort \( e^{C,S} \) is the unique solution to \( ae = E_c [S (Q^* (J (c, e)))] \) on \( e \), and the capacity investment is \( Q^* (J (\gamma + e^{C,S}, e^{C,S})) \) for realized cost \( \gamma \). The total expected profit of the buyer is

\[
\Pi^{C,S} = E_c \left[ \max_Q \left( (r - J (c, e^{C,S})) S(Q) - kQ \right) \right].
\] (11)

ii) In dual sourcing, each supplier invests effort \( e^{C,D} \) that is the unique solution to \( ae = E_{c(1)} [S (Q^* (J (c_{(1)}, e)))] / 2 \) on \( e \), where \( c_{(1)} = \min (c_1, c_2) \) is the lower statistic of the two suppliers’ types. Given cost realizations \( \gamma_1 \) and \( \gamma_2 \), \( \gamma_i \leq \gamma_{-i} \), the capacity investment for Supplier \( i \) is \( Q^* (J (\gamma_i + e^{C,D}, e^{C,D})) \) and for Supplier \( -i \) is zero. The total expected profit of the buyer is

\[
\Pi^{C,D} = E_{c(1)} \left[ \max_Q \left( (r - J (c_{(1)}, e^{C,D})) S(Q) - kQ \right) \right].
\] (12)

Lemma 5 i) shows the outcome of sole sourcing. The supplier invests effort \( e \) based on his expectation of the sourcing quantity \( E_c [S (Q^* (J (c, e)))] \); the greater the expected quantity, the greater the invested effort. As shown in Equ. (11), the buyer’s profit takes into consideration the supplier’s virtual cost \( J(c, e^{C,S}) \) as the ex ante unit cost.

Lemma 5 ii) shows the outcome of dual sourcing. Since a supplier has only a 50 percent chance of winning, his total expected quantity is equal to 50 percent of the quantity expected by the winner, \( E [S (Q^* (J (c_{(1)}, e^{C,D})))] / 2 \). The buyer’s profit, as characterized in Equ.
(12), takes a form similar to that in sole sourcing, except that the supplier effort is different and the supplier type is based on the lower statistic \(c_{(1)}\).

Unlike sole sourcing, dual sourcing allows the buyer to take advantage of supplier competition, investing only in the lower-cost supplier and negotiating a competitive price. However, the supplier effort in dual sourcing, \(e^{C,D}\), may be smaller than that in sole sourcing, \(e^{C,S}\). Thus, the buyer’s choice between the two strategies is a trade-off between supplier effort and supplier-competition benefits.

6.2 Optimal supply base structure

We analyze when the buyer should invite only one supplier (sole sourcing) or two suppliers (dual sourcing) to join her supply base.

**Proposition 4** When demand is certain and equal to \(\mu_d\), dual sourcing is optimal if \(\Delta \geq \mu_d^2 / a\), otherwise sole sourcing is optimal.

Proposition 4 suggests that dual sourcing is preferred over sole sourcing when supplier cost uncertainty \(\Delta\) is high or effort cost \(a\) is large. Although this result is proven for certain demand, it continues to hold even with significant demand uncertainty in our numerical study. Thus, the impact of \(\Delta\) and \(a\) on the choice between sole and dual sourcing is similar to that under the base mechanism.

A difference, however, is that the capacity cost \(k\) does not have a major impact on supply base design as under the base mechanism. As shown in Proposition 4, the capacity cost is irrelevant when demand is certain. This occurs because both sole and dual sourcing result in capacity investment for a single supplier. Thus, the difference between the two structures in capacity investment is not as substantial as under ex ante capacity investment, where redundant capacity is invested in dual sourcing to maintain supplier competition. For this reason, the supply base structure is less sensitive to the capacity cost \(k\). Concerning the direction of the impact, our numerical study shows that increasing \(k\) (while \(\sigma_d > 0\)) leads to the supply base shifting away from sole sourcing toward dual sourcing. This effect may be explained by the influence of capacity cost on supplier effort: Increasing \(k\) reduces the expected quantity provided by the (winning) supplier. Expecting a lower quantity, the supplier(s) will reduce the effort investment. Such a negative effect on supplier effort is more significant in sole sourcing than in dual sourcing, because the quantity reduction is shouldered by a single supplier in the former structure, but shared by two suppliers in the latter.
7. **Buyer’s optimal sourcing strategy**

Having analyzed the supply base design under each contracting mechanism, in this section we compare the three mechanisms in order to study the buyer’s optimal sourcing strategy. The sourcing strategy is defined on two dimensions: the supply base and the contracting mechanism. The supply base design determines the level of supplier competition by choosing between sole and dual sourcing (and further specifying the capacity profile of the supply base when the capacity is invested ex ante). The contracting mechanism determines the level of decision delays in the sourcing contract, by choosing among ex ante price commitment, the base mechanism, and ex post capacity investment. As shown in the analysis, the supply base design trades off the benefits of supplier competition and supplier effort: A more competitive supply base provides greater benefit in pricing and mitigating supplier cost uncertainty, while a less competitive supply base motivates suppliers to invest more cost-reduction effort. The effect of supplier competition and the incentive of supplier effort are further influenced by the contracting mechanism. A contracting mechanism with more decision delays enhances the benefit of supplier competition, as more contract terms are determined in response to suppliers’ cost realizations. But meanwhile it may compromise the incentive of supplier effort, since more decisions are postponed until after supplier effort investment, leaving the buyer fewer leverages to proactively motivate effort. Considering these effects, how should the supply base design and contracting mechanism be combined in the buyer’s sourcing strategy? We first examine the benchmark situation under certain demand $\mu_d$ in §7.1, then we present the results with uncertain demand in §7.2.

### 7.1 Certain demand

Recall from the previous analysis that, without demand uncertainty, either sole sourcing or symmetric dual sourcing is optimal in the base mechanism and the ex ante price commitment mechanism. Under these two mechanisms, the buyer invests in capacity $\mu_d$ for only one supplier in sole sourcing, and for each supplier in dual sourcing. Under ex post capacity investment, the buyer always invests $\mu_d$ for a single supplier, under both sole and dual sourcing. In each contracting mechanism, the average unit price can be decomposed into the purchasing price under zero supplier effort, and the price reduction brought from supplier effort; denote these two components by $p_0$ and $e$, respectively (then the unit price is $p_0 - e$). Table 1 summarizes the supplier effort ($e$), purchasing price with no effort ($p_0$), and the buyer’s profit ($\Pi$) achieved under each mechanism in either sole sourcing (with superscript $S$) or dual sourcing (with superscript $D$). The last row of the table lists the condition for dual sourcing preferred to sole sourcing ($\Pi^D \geq \Pi^S$) under each mechanism.
In each contracting mechanism, dual sourcing is preferred to sole sourcing when the supplier cost uncertainty $\Delta$ or the cost of effort $a$ is relatively high. In addition, the condition for dual sourcing under ex post capacity investment is weaker than the condition under the base mechanism, which is again weaker than the condition under ex ante price commitment. In other words, dual sourcing is increasingly preferred to sole sourcing as the contracting mechanism imposes more decision delays. The explanation is as follows. Compared to the case under the base mechanism, dual sourcing is less favored under ex ante price commitment because it no longer provides the benefit of competitive pricing (though it still allows the buyer to mitigate supplier cost uncertainty by resorting to the higher-price supplier if the lower-price supplier quits). Also, dual sourcing is more favored under ex post capacity investment because it no longer suffers from the disadvantage of redundant capacity investment over sole sourcing as in the base mechanism.

To compare the buyer’s profits under different contracting mechanisms, we first examine the supplier effort $e$ and the purchasing price with no effort $p_0$ resulting from the mechanisms. As we can see from Table 1, with certain demand, all three sourcing mechanisms result in the same supplier effort in either sole sourcing ($e^S$) or dual sourcing ($e^D$). In other words, the timing of capacity investment and price decisions does not affect supplier effort when demand is certain. This result occurs because a supplier expects the same quantity regardless of the contracting mechanism; the expected quantity is equal to $\mu_d$ in sole sourcing and $\mu_d/2$ in dual sourcing. Therefore, without demand uncertainty, precommitments lose the advantage of motivating supplier effort.

The effect of supplier competition is reflected in the price with no effort, $p_0$. As shown in Table 1, under sole sourcing, this price is same ($p^S_0$) in all three contracting mechanisms: Without supplier competition, the purchasing price is set based on the highest possible supplier type $\bar{c}$, whether the contract decisions are made ex ante or ex post. However, the contracting mechanism matters for the price in dual sourcing, $p^D_0$: The ex ante price commitment leads to a higher price ($\bar{c} - \frac{\Delta}{4}$) than the other two mechanisms, which result in

<table>
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<th>Ex ante price commitment</th>
<th>Base mechanism</th>
<th>Ex post capacity investment</th>
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<tbody>
<tr>
<td>$e^S, p^S_0$</td>
<td>$\frac{\mu_d}{a}, \bar{c}$</td>
<td>$\frac{\mu_d}{a}, \bar{c}$</td>
<td>$\frac{\mu_d}{a}, \bar{c}$</td>
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<tr>
<td>$e^D, p^D_0$</td>
<td>$\frac{\mu_d}{2a}, \bar{c} - \frac{\Delta}{4}$</td>
<td>$\frac{\mu_d}{2a}, \bar{c} - \frac{\Delta}{4}$</td>
<td>$\frac{\mu_d}{2a}, \bar{c} - \frac{\Delta}{4}$</td>
</tr>
<tr>
<td>$\Pi^S$</td>
<td>$\mu_d \left( r - \bar{c} + \frac{\mu_d}{4} \right)$</td>
<td>$\mu_d \left( r - \bar{c} + \frac{\mu_d}{4} \right)$</td>
<td>$\mu_d \left( r - \bar{c} + \frac{\mu_d}{4} \right)$</td>
</tr>
<tr>
<td>$\Pi^D$</td>
<td>$\mu_d \left( r - \bar{c} + \frac{\Delta}{4} + \frac{\mu_d}{2a} \right)$</td>
<td>$\mu_d \left( r - \bar{c} + \frac{\Delta}{4} + \frac{\mu_d}{2a} \right)$</td>
<td>$\mu_d \left( r - \bar{c} + \frac{\Delta}{4} + \frac{\mu_d}{2a} \right)$</td>
</tr>
<tr>
<td>$\Pi^D \geq \Pi^S$</td>
<td>$\frac{\Delta}{3} \geq \frac{\mu_d}{2a} + k$</td>
<td>$\frac{\Delta}{3} \geq \frac{\mu_d}{2a} + k$</td>
<td>$\frac{\Delta}{3} \geq \frac{\mu_d}{2a} + k$</td>
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Table 1: Comparison of the buyer’s profits under sole sourcing ($\Pi^S$) and dual sourcing ($\Pi^D$) in three contracting mechanisms with certain demand
the same purchasing price ($\bar{c} - \frac{\Delta}{3}$). The difference between the two prices characterizes the benefit of competitive pricing, which is lost under price commitment.

The above results on the supplier effort and purchasing price suggest that the three mechanisms are equal in sole sourcing, and more decision delays benefit the buyer in dual sourcing. Indeed, as shown in Table 1, the buyer’s sole-sourcing profits are equal in all three mechanisms, and the dual-sourcing profit under ex post capacity investment is higher than that under the base mechanism, which is again higher than that under ex ante price commitment. Therefore, without demand uncertainty, the ex post capacity investment mechanism dominates the base mechanism, which in turn dominates the ex ante price commitment mechanism.

7.2 Uncertain demand
With uncertain demand, we find ex ante price commitment is still (weakly) dominated by the base mechanism. Particularly, we prove that they result in same supplier effort and generate equal profits for the buyer under sole sourcing (Proposition 5 i). Therefore, ex ante price commitment is equal to the base mechanism when $\Delta$ or $a$ is low (which leads to sole sourcing in both mechanisms), and it becomes worse than the base mechanism as $\Delta$ or $a$ increases; this is formalized in Proposition 5 ii-1) for small demand uncertainty. This result suggests that postponing the price decision alone does not discourage supplier effort. This is attributable to unobservability of supplier effort: With supplier effort unobservable, even ex post price negotiation is based on a pre-determined auction mechanism, anticipating but not responding to supplier effort; hence, it does not hold-up a supplier’s effort as a cost-contingent mechanism would do for observable effort. Bernstein and Kök (2009) compare target-price contracts and cost-contingent contracts, assuming observable effort and deterministic cost with no supplier competition. They show that target-price contracts lead to greater effort of a supplier and higher profits of the buyer than cost-contingent contracts. Although based on different model settings, we complement their result by showing that, with unobservable supplier effort and uncertain cost, ex post price negotiation does not necessarily sacrifice supplier effort, and it is superior to price commitment in the presence of supplier competition.

Postponing the capacity decision, however, is not necessarily better for the buyer when demand is uncertain. In this case, a supplier’s expected delivery quantity is no longer fixed but depends on the capacity invested by the buyer. With ex ante capacity investment, the buyer is able to induce greater supplier effort by committing a larger capacity, which implies higher expected quantity sourced from the supplier. In other words, demand uncertainty introduces the advantage of ex ante capacity investment in motivating supplier effort. As a result, we find that the base mechanism is more favorable than ex post capacity investment
if the supplier cost uncertainty $\Delta$ or the effort cost $a$ is sufficiently low, although increasing $\Delta$ or $a$ improves the favorability of the latter. This is formalized in Proposition 5 ii-2) for small demand uncertainty.

**Proposition 5**  
i) The base mechanism and ex ante price commitment are equivalent in sole sourcing.

ii) When demand uncertainty $\sigma_d$ is positive and small,

ii-1) the ex ante price commitment mechanism is equal to the base mechanism if $\Delta$ or $a$ is sufficiently low, and the former becomes worse than the latter as $\Delta$ or $a$ increases;

ii-2) the base mechanism is better than ex post capacity investment if $\Delta$ or $a$ is sufficiently low, and the former becomes worse than the latter as $\Delta$ or $a$ increases.

Based on Proposition 5 ii), as $\Delta$ or $a$ increases, the buyer favors the base mechanism over ex ante price commitment, and ex post capacity investment over the base mechanism. From the previous analysis of each contracting mechanism, increasing $\Delta$ or $a$ enhances the superiority of dual sourcing to sole sourcing. Thus, the buyer favors increasing supplier competition in supply base design and more decision delays in the contracting mechanism, as $\Delta$ or $a$ increases. We supplement Proposition 5 with numerical study of the buyer’s optimal sourcing strategy in general situations where demand uncertainty can be large.

A representative example is illustrated in Figure 3. The left plot compares ex ante price commitment and the base mechanism, and the right plot compares the base mechanism and ex post capacity investment, both in the space of $\Delta$ and $a$. The texts mark the choice of the contracting mechanism (“B” for the base mechanism, “P” for ex ante price commitment, and “C” for ex post capacity investment) and the supply base structure (“S” for sole sourcing, “D” for dual sourcing, which may further divide into “aD” for asymmetric dual sourcing and “sD” for symmetric dual sourcing).

The numerical results are consistent with Proposition 5, and reveal additional properties. We find that the base mechanism can only be better than ex post capacity investment when it is adopted with sole sourcing. In other words, the base mechanism under dual sourcing never outperforms ex post capacity investment; as seen in Figure 3, in the area where the base mechanism leads to dual sourcing (shown in the left plot), ex post capacity investment is superior to the base mechanism (shown in the right plot). This result may be interpreted by the reason that ex post capacity investment enhances the benefit of supplier competition. Thus, when introducing supplier competition is beneficial in the base mechanism, it is even better to adopt dual sourcing with ex post capacity investment. In addition, as seen in the right plot of Figure 3, the area is negligible where ex post capacity investment under sole sourcing outperforms the base mechanism. In other words, ex post capacity investment gains its strength under dual sourcing.
Figure 3: The buyer’s choice of the contracting mechanism and the supply base structure. The left plot is between ex ante price commitment and the base mechanism, and the right plot is between the base mechanism and ex post capacity investment. \( r = 6.0, k = 0.6, (c + \bar{c})/2 = 1.0 \), demand is drawn from a uniform distribution on \([0, 4]\).

Based on our results above, the sourcing strategy may reduce to the choice between ex ante price commitment (which is equal to the base mechanism under sole sourcing) and ex post capacity investment. When \( \Delta \) or \( a \) is low, the buyer prefers to commit both the capacity and price with a single supplier; this strategy represents a long-term relationship. When \( \Delta \) or \( a \) is high, the buyer is inclined to invite both suppliers to join the supply base, but invest in capacity for only one supplier and determine the price based on the result of supplier cost competition; this strategy represents an arms-length relationship. In practice, there may be situations where ex post capacity investment cannot be implemented. This can be the case when a supplier’s cost-reduction effort pertains to improving the efficiency of operating the assets invested by the buyer, and thus requires the capacity in place. It can also be interpreted as the case when suppliers exert continuous efforts and produce for the buyer over multiple periods after they receive capacity investment from the buyer (though we present a single-period abstraction of this situation). Then, the base mechanism should be taken into consideration. For \( \Delta \) or \( a \) relatively high, the buyer may choose to invest capacity in both suppliers, and then determine price and demand allocation through supplier competition; this represents a performance-based partnership.

Figure 4 illustrates the buyer’s sourcing strategy in a two-dimensional space, with the supplier base design as the vertical dimension and contracting mechanism as the horizontal dimension. Our results suggest that the buyer’s optimal sourcing strategy should be located on the diagonal line. The strategy shifts towards a long-term relationship when sourcing products that are less complex in structure (smaller \( \Delta \)) or produced with newer technology.
(lower $a$), and towards an arms-length relationship when the product is more complex (larger $\Delta$) or the production technology matures (higher $a$); the performance-based partnership may not need to be considered, unless capacity investment must precede supplier effort. In reality, the supplier cost uncertainty $\Delta$ and marginal cost of effort $a$ may be inversely related; a product with a more complex structure is often associated with more opportunities to improve the design or production process to reduce costs. Then the choice of the sourcing strategy depends on the relative strength of both effects of higher $\Delta$ and lower $a$, which drive the decision in opposite directions. The automotive industry has observed the trend of supply base consolidation as OEMs outsource more complex subassembly systems (Maurer et al., 2004). This phenomenon may be explained by the reason that the effect of lower $a$ from increasing product complexity dominates that of greater $\Delta$, thus driving the sourcing strategy towards a long-term relationship.

![Figure 4: The buyer’s sourcing strategy](image)

8. Discussion and extensions

In this section, we consider several extensions to the model and summarize the results. The detailed analysis is presented in Appendix B.
8.1 Fractional cost reduction

We have assumed that a supplier’s cost reduction takes an additive form and thus is independent of the supplier’s type (the original cost). In this extension we consider the case in which the cost reduction is a fraction of the type: For a supplier with type $c_i$, the cost reduction effort $e_i \in [0, 1]$ reduces the cost by $c_i e_i$, resulting in a final cost $\gamma_i = c_i (1 - e_i)$. The rest of the model remains the same.

Under the assumption $a \geq \mu_d \left( \frac{\sigma^2}{\Delta} + \mu_e \right)$, a unique pure-strategy equilibrium of supplier efforts can be identified for the base mechanism for any given capacity profile. Unlike the additive cost-reduction model, the average supplier effort is no longer a constant for a given total capacity; instead, it increases with the capacity difference between suppliers. Nevertheless, it remains true that the larger-capacity supplier always invests more effort than the smaller-capacity supplier, and the effort difference increases with the capacity difference. We find that the major results regarding the supply base structure and contracting mechanism still hold qualitatively with this fractional cost-reduction model.

8.2 Suppliers invest in capacity

Our model assumes the buyer investing in the capacity for a supplier. In this extension, we consider the case when suppliers make their capacity investment. The buyer can determine the price before or after suppliers’ investment of their capacity and effort, giving rise to the ex ante and ex post mechanisms. In the ex ante mechanism, the buyer specifies the price with each supplier before suppliers make their investments. In the ex post mechanism, the buyer first invites one or two suppliers to join the supply base, then the suppliers invest in capacity and effort, after which an auction is conducted to determine the price and quantity of each supplier. In order to obtain analytical insights, our analysis focuses on the situation with certain demand.

We find the supplier cost uncertainty $\Delta$ and effort cost $a$ drive the buyer’s sourcing strategy in directions similar to when the buyer invests capacity. However, shifting the capacity responsibility to suppliers makes the ex post mechanism less attractive, as this mechanism may hold up not only suppliers’ cost-reduction effort, but also their capacity investment. (In fact, the ex post mechanism may fail to induce any capacity investment at all.) Since such weakness in motivating supplier capacity investment is aggravated by supplier competition, dual sourcing is considered less favorably in the ex post mechanism compared to the case under the buyer’s capacity investment. In contrast, dual sourcing becomes more favorable in the ex ante mechanism, as the buyer no longer necessarily shares all capacity cost.
8.3 No contract breaching

In the ex ante price commitment mechanism, we allow a supplier to quit the relationship with the buyer when his realized production cost becomes higher than the price. In this model, there is no remedy for contract breaching. Generally, there are two common types of breach remedies: damages and specific performance. Under the damages remedy, unilateral breach is allowed as long as the defaulting firm pays the other firm a certain amount of money to compensate for the damages. Different damage measures can be used. The no damages measure, by which the defaulting firm pays nothing, is a special one and may be employed when the cost of seeking damages is prohibitively high (Shavell, 1980). Our model can be regarded as such a case under the no damages measure: In our model, breaching the contract leaves the supplier zero profit (which is better than producing at a cost higher than the price). Considering that seeking damages beyond a firm’s profit is difficult (e.g., the firm can be protected by bankruptcy), no damage can be sought from the defaulting supplier.

Under the specific performance remedy, either firm can insist that the contract be performed by the enforcement of the court and thus unilateral breach is not possible. In this extension, we consider such a situation when a supplier is not allowed to breach. (The buyer will never initiate the breach because the price is always lower than her revenue.) Then, in the ex ante price commitment mechanism, a supplier will accept a price offer as long as the price brings a positive expected profit, and will always stay to deliver upon accepting the price. From the buyer’s perspective, there is no risk from suppliers’ cost uncertainty, thus dual sourcing provides no benefit at all. As a result, with no contract breaching, the ex ante price commitment mechanism always leads to sole sourcing.

With no contract breaching, the buyer is able to offer a price that leaves the supplier zero expected profit in the ex ante price commitment mechanism. This gives ex ante price commitment substantial advantage, as ex post price negotiations concede information rent to suppliers. Indeed, we find that the ex ante price commitment mechanism becomes superior to both the base and ex post capacity investment mechanisms.

8.4 Observable supplier costs

We assume that a supplier’s production cost is both uncertain and unobservable. In order to separate the effects of uncertainty and information asymmetry, in this extension we consider the case in which the supplier cost is observable although stochastic. In other words, the supplier cost is still drawn from a random distribution depending on the supplier effort, but the realized cost is observable to the buyer. In this case, a supplier will not invest any effort under ex post price negotiation (in the base or ex post capacity investment mechanism). This
is because the buyer would demand a price equal to the actual cost, leaving the supplier zero return from his effort. Then, with no influence on supplier effort, the base mechanism is always dominated by ex post capacity investment, and the latter mechanism always leads to dual sourcing. Finally, in the ex post capacity investment mechanism, since the contract is determined based on suppliers’ true costs without concerning information rent, the buyer benefits from greater supplier cost uncertainty $\Delta$, which stochastically reduces the lower-cost of the suppliers. (Higher $\Delta$ only hurts the buyer’s profit when the supplier cost is unobservable because it increases information rent.) Supplier costs becoming observable does not influence the ex ante price commitment mechanism.

Therefore, unobservability of supplier costs affects only ex post price negotiation mechanisms, and its role can be summarized as follows: It encourages suppliers to invest effort even under ex post price negotiations, which in turn makes the base mechanism relevant and the sole sourcing structure possible under ex post capacity investment. It also introduces information rent, decreasing the buyer’s profit in supplier cost uncertainty.

### 8.5 Supply chain profits

In our model, the suppliers obtain profits based on the contract price and delivery quantity; there is no side payment between the buyer and the suppliers. If the buyer can impose ex ante a fixed payment on a supplier besides the sourcing contract, then the buyer is able to extract all profit of the supplier, obtaining profits of the whole supply chain. In this case, the supply base and contracting mechanism are designed to maximize the total profits of the supply chain (although given the sourcing strategy, each supplier and the buyer still determine the effort and the auction mechanism to optimize their own ongoing profits).

When measured by the supply chain profits, the benefit of supplier effort becomes smaller as it has to deduct the suppliers’ costs for the efforts from the total cost reduction achieved in the efforts. In addition, the benefit of supplier competition also becomes smaller because the reduction of information rent is not considered as a gain in the supply chain profits. Therefore, using the supply chain profits as the measurement decreases both benefits of supplier effort and competition, although the tradeoff between these two benefits still governs the sourcing strategy design. Compared to the original case based on the buyer’s profit, we find that the sourcing strategy is less sensitive to such parameters as the supplier cost uncertainty and cost of effort.
9. Conclusion

A buying firm relying on suppliers for critical production activities must make strategic decisions concerning the supply base and the mechanism of contracting with suppliers. A buyer has two levers to reduce supply-related costs: involving suppliers in competition, and motivating suppliers to invest cost-reduction effort. Both the supply base design and contracting mechanism affect supplier competition and the incentive for supplier effort.

The supply base design is concerned with the number of suppliers and capacity investment for each. While a sole-supplier base (sole sourcing) provides great incentive for a supplier to invest effort, a dual-supplier base with equal-capacity suppliers (symmetric dual sourcing) maximizes supplier competition. We find that a buyer without demand uncertainty should choose only between sole sourcing and symmetric dual sourcing. With demand uncertainty, however, the buyer may trade off the benefits of supplier competition and effort investment by creating an unbalanced supply base—equipping both suppliers, but with unequal capacities. In other words, even if suppliers are ex ante identical, asymmetric dual sourcing may be optimal. In addition, we find that increasing demand uncertainty may prompt the buyer to switch from dual sourcing to sole sourcing, while at the same time reducing total capacity investment.

Our results suggest that a buyer facing uncertain demand should not only focus on the total capacity and the total number of suppliers needed in the supply base, but should also carefully decide how the capacity should be allocated between suppliers—some imbalance in capacity between suppliers may be created intentionally. Furthermore, when designing the supply base capacity, the buyer should not only be concerned with operational capacity (the capacity to meet uncertain demand), but also consider strategic capacity (the redundant capacity needed to stimulate supplier competition). While greater demand uncertainty typically calls for a greater buffer of operational capacity, it reduces the value of the strategic capacity. Thus, the total capacity, along with the number of suppliers, may decrease with demand uncertainty.

The contracting mechanism, in terms of the timing of the price and capacity investment decisions, further influences the benefit of supplier competition and the incentive of supplier effort. While ex post decisions, made after supplier efforts and contingent on the realization of supplier costs, enhance the supplier competition effect, ex ante commitments on the price or capacity may provide greater motivation for supplier effort. Because of such joint effects, the contracting mechanism should be considered simultaneously with supply base design. We find that increasing supplier cost uncertainty \( \Delta \) (measure of product complexity) or marginal cost of effort \( a \) (measure of technology maturity) drives for greater supplier competition in
the supply base and more decision delays in the contracting mechanism. Specifically, ex ante commitment on both the price and capacity should be used with a sole-supplier base, forming a long-term relationship, when $\Delta$ or $a$ is low, while ex post price and capacity decisions should be adopted with a dual-supplier base, forming an arms-length relationship, when $\Delta$ or $a$ is high. The base mechanism, by which ex ante capacity investment is followed by ex post price negotiations, may not need to be considered. However, if supplier effort can only be invested after capacity, then for relatively high $\Delta$ or $a$, the buyer may adopt the base mechanism for a dual-supplier base, forming a performance-based partnership.

Our results are consistent with empirical observations. Japanese automakers typically form close relationships with their suppliers by sharing knowledge and providing engineering support (Dyer 2000). A close supplier relationship reduces supplier cost uncertainty, as it allows the buyer to gain information about a supplier’s cost structure and keep a supplier’s performance variation under control. It also lowers the cost of supplier improvement, due to the support provided by the buyer. Along with establishing close relationships with suppliers, Japanese automakers often source from a single supplier (or a small number of suppliers) and commit target prices. Compared to their Japanese peers, U.S. automakers do not work as closely with their suppliers, thus reasonably facing suppliers with higher cost uncertainty and greater cost of effort. Meanwhile, they are more inclined to engage suppliers in competition by forming a larger supply base, and often renegotiate prices based on suppliers’ achieved costs. (McMillan, 1990; Liker and Choi, 2004)

We hope this research leads to future work on sourcing considering buyer-supplier collaboration along with supplier competition, both important strategies of supply base development. On one hand, under the trend of building deeper supplier relationships in practice, the idea of closer buyer-supplier collaboration, in which both parties invest resources to improve performance, has been increasingly embraced by practitioners and receives growing attention from researchers. On the other hand, the value of supplier competition has long been recognized in the practice and research of procurement. While supplier competition has been generally considered as an adversarial force for collaboration, it provides some benefits and is not necessarily exclusive to collaboration. How can or should these two strategies be effectively combined? When may one replace the other? Answers to these questions depend on the nature of collaboration and competition. Complementing our theoretical work, it will also be interesting to develop empirical work to further investigate how a buyer’s sourcing strategy varies in different environments.
References


