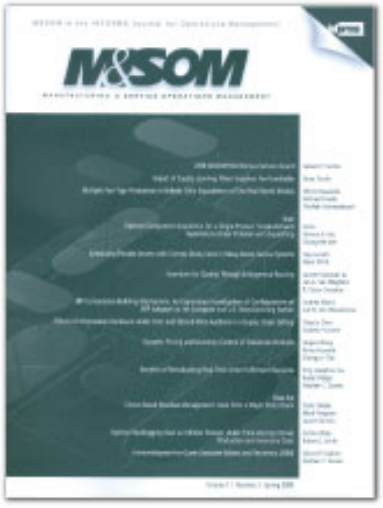

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Supply Contract Competition and Sourcing Policies

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Advances in information technology have opened new venues for companies to create flexible supply chains by offering high-speed communication and tight connectivity. A growing number of companies are taking advantage of new opportunities to outsource portions of their production and other operations. Given the importance of the supplier selection process in the ultimate success of a product, a purchasing manager must understand the different sourcing strategies that she or he can use and the suitability of each sourcing arrangements for her or him. This paper provides an overview of the research that has been done in the fields of operations research and economics on the topic of sourcing strategies. In aggregate, this paper provides a blueprint of what market characteristics can heavily influence a buyer-supplier relationship and, hence, are important to identify and incorporate into the supplier selection process.
(*Auctions; Sole, Dual, Parallel, and Multiple Sourcing; Mechanism Design; Procurement; Outsourcing*)

1. Introduction

Advances in information technology have opened new venues for companies to create flexible supply chains by offering high-speed communication and tight connectivity. A growing number of companies take advantage of new opportunities to outsource portions of their production and other operations. For example, Cisco focuses mainly on the research, development, and marketing of its products, and relies heavily on outside suppliers to manufacture and distribute its products. Today, many companies are moving toward a similar organizational form by focusing on their core competencies and outsourcing significant portions of their business operations.

This increased reliance on outside suppliers for integral inputs into the production process underscores the importance of the supplier selection process. As noted in *The Purchasing Handbook*,

> Supplier selection is the most important milestone in the purchasing process. The ultimate success of a new product, the profitability of a product line, and the timeliness of delivery to the marketplace may depend on this decision. (p. 130)

Given the importance of the supplier selection process in the ultimate success of a product, a purchasing manager must understand the different sourcing strategies she can use and the suitability of each sourcing arrangement. A critical decision a manager must make is whether to partition her order and award business to more than one supplier (referred to as *multiple sourcing*) or award her entire business to a single supplier (i.e., *sole sourcing*). The performance of either sourcing arrangement will critically depend on the particular characteristics of the manager's industry. For example, does the technology necessary for production exist among a large group of suppliers or does the buyer face a limited supplier base? Is the technology necessary for production well defined, or does there exist "learning by doing" in the production process? Does the manager have a predetermined number of units she wishes to purchase, or is the total quantity to be

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procured unknown? A manager must know the answers to these and other market characteristic questions to properly evaluate the suitability of a sourcing strategy.

This article provides an overview of the research that has been done in the fields of operations research and economics on the topic of sourcing strategies. The papers in this review model various market structures and study the performance of (one or more) sourcing strategies within that market. In aggregate, they provide a blueprint of what market characteristics can heavily influence a buyer-supplier relationship; hence, they are important to identify and incorporate into the supplier selection process.

Traditionally, the literature in operations research has been rich with institutional details, building models that try to capture as much detail as possible about an institution's operating characteristics. However, the literature generally has lacked the informational aspects of the institution: The approach most widely adopted is to assume that there is only one decision maker in the model, i.e., a central planner's approach. In sharp contrast to operations researchers, economists have generally sacrificed institutional details and placed a greater emphasis on the information structure of the model; economists study the behavior of individuals operating in a decentralized decision-making framework. The goal of this article is to present the research of both disciplines on the topic of sourcing strategies and to suggest future research directions that fuse the two ideological approaches.

2. Practitioners' Concerns in Procurement and Sourcing Strategies

Managers in charge of procurement operations often face multiple sourcing options, with no comprehensive way to rank them clearly. The nature of the products they wish to procure and the relationship that they are trying to develop with the supplier make it nearly impossible to simply rank different options by a single criterion. Usually there are several criteria of critical importance by which managers judge a procurement arrangement (such as reliability, cost, duration, etc.), and no single sourcing option will always dominate all other options in all dimensions. The best arrangement for a manager depends on market characteristics and the relative importance she places on various dimensions. The lack of a unique optimal sourcing arrangement for all market structures and the need to pinpoint the suitability of certain sourcing strategies to certain market environments motivate the papers in this review and are of great importance to academics and practitioners alike.

Researchers in the marketing literature have tried to understand some of the factors practitioners have reported as relevant when making sourcing decisions. Trevelen and Schweikhart (1988) describe the various types of sourcing arrangements and the risks and benefits of each arrangement with respect to five commonly cited buyer concerns. These concerns are defined as disruption of supply, price escalation, inventory and scheduling, technology access, and quality. The most frequently cited reason behind adopting a particular sourcing strategy is the reduction of uncertainty within one of those dimensions. For example, buyers who employ a single sourcing strategy feel that the chance of a supply disruption is reduced when a buyer develops a strong relationship with a single supplier. In addition, buyers feel that they receive the best price from their single supplier because of the economies of scale achieved from being awarded all of the buyer's business. Conversely, buyers who employ a multiple vendors sourcing strategy feel that the chance of a supply disruption is reduced when a buyer develops relations with *several* suppliers and that competition among the suppliers results in the buyer receiving the lowest competitive price.

In a similar vein, Tullous and Utecht (1992) attempt to understand how risk-reduction concerns would affect the sourcing strategies taken by managers. This is done by interviewing managers from 80 high-technology electronics firms in Texas and California. The question Tullous and Utecht attempt to answer is how the buyer's behavior is affected by the specific uncertainty he encounters. They identify three types of uncertainty in buying-selling situations: need uncertainty (NU), market uncertainty (MU), and transaction uncertainty (TU).[1] NU is high when the product characteristics and/or use cannot be easily specified; MU

[1]*Need uncertainty* refers to how easily the product characteristics and

is high when the buyer is making purchases from an unstable or highly differentiated market (i.e., the potential suppliers are very dissimilar); and TU is high when the buyer's location is far from a supplier and the buyer has no or little previous experience dealing with a supplier. Tullous and Utecht proposed three hypotheses:

(1) Multiple sourcing is more likely to occur when NU is low.

(2) Multiple sourcing is more likely to occur when MU is high.

(3) Multiple sourcing is more likely to occur when TU is high.

None of these hypotheses was supported by the interviews with the managers. The authors conclude that, while it would behoove marketers to understand the rationale behind the adoption of different sourcing strategies, marketers cannot lay the reason behind these choices solely at the feet of the uncertainty buying-selling situations identified in the paper.

Even when restricting the dimensionality of criteria to one, with cost as the primary criterion, it is not possible to establish a hierarchy in "optimality" of sourcing arrangements. Two views have been put forth on the subject of optimal (i.e., minimum cost) procurement arrangements; one by Deming (1986), who focuses on the cost of achieving quality and the other by Porter (1985), who focuses on the acquisition costs. Deming extols the merits of sole sourcing, arguing that sole sourcing minimizes the total transaction costs a buyer incurs when quality (and the cost of achieving quality) is of major importance to the buyer and her customers. By pouring time and energy into establishing one strong and lasting relationship, a buyer is able to cut down on costs by avoiding downtime, rework, and excessive administration and increase quality by establishing a relationship that is responsive to the buyer's needs and demands. High quality levels will avoid loss of goodwill from customers and will augment the buyer's reputation. Porter, on the other hand, claims that total procurement costs will be minimized by introducing and maintaining competition in the process, and that this can only be done if the buyer procures from multiple sources. The threat of losing business to another supplier who already has an established relationship with the buyer will provide suppliers with the incentive to deliver products of high quality at a low cost.

Richardson and Roumasset (1995) compare the performance of sole, competitive, and parallel sourcing arrangements and base the arrangements' performance on total cost. In the models that Richardson and Roumasset analyze, the buyer's objective is to maximize her net value—the value of the product at the realized level of supplier quality less the price paid, the setup costs, and the cost of inspection and coordination.[2] There exist three possible sourcing strategies: sole source all similar products from only one supplier, purchase the same set of similar products from multiple suppliers (multiple source), or sole source each individual product, but have different suppliers for products that are very similar to each other (a form of multiple sourcing known as *parallel sourcing*). The authors conclude that neither sole sourcing nor multiple sourcing is always the best sourcing arrangement, i.e., the superior sourcing arrangement depends upon the individual industry or market in which it will operate. The relative importance and presence of quality concerns, specific investment that must be made with each

product use can be specified, *market uncertainty* relates to the nature of the vendor marketplace, and *transaction uncertainty* relates to the relative location of the supplier with respect to the buyer's facilities and the buyer's experience with the supplier who have bid.

[2]The buyer-supplier(s) relationship is established as follows: The buyer proposes a contract that specifies the quantity, level of quality expected, and the price. Suppliers that accept this contract are expected to oblige the buyer in all three dimensions. If a supplier provides a quality that is less than stated in the contract, the buyer can consider switching to another supplier. Whether or not she does so depends on the associated costs of switching. It is assumed to be costly for a supplier to provide high levels of quality, i.e., the cost of providing a product of quality q is increasing in q. In addition, the value the buyer actually obtains from her purchases is dependent on the quality of the suppliers' service. They assume complete information, i.e., each player knows each other's objectives, costs, and actions. The buyer chooses the supplier performance level, the level of inspection and coordination to maximize profits each period, subject to the constraint that (under multiple or parallel sourcing) the suppliers earn an acceptable profit or (under sole sourcing) the supplier will subsequently choose a performance level that maximizes his profits while still preventing the buyer from switching to another supplier.

supplier, coordination costs, and purchasing costs will decide which sourcing arrangement minimizes the buyer's transaction costs.

Richardson and Roumasset do their analysis by adopting the transaction cost theory of organizations first proposed by Coase (1937) and later espoused and more richly developed by Williamson (1979). In transaction cost theory, a firm wishing to procure a product from a group of suppliers will structure its relationship with the suppliers so as to minimize total transaction costs, which include the actual cost of acquisition as well as the cost of monitoring performance and the cost of establishing and maintaining a relationship. What Richardson and Roussamet's study illustrates is the different incentives (to suppliers) emanating from each sourcing strategy. Under multiple or parallel sourcing, the buyer is assumed to have established relations with more than one supplier, and can costlessly switch from one supplier to another. It is the threat of losing business to other suppliers currently employed by the buyer that will dissuade suppliers from providing a lower level of quality than dictated by their contract with the buyer. If a supplier were to shirk and provide a poorer quality, the buyer could costlessly switch to another supplier. Therefore, in multiple and parallel sourcing, as long as each supplier is provided with a reasonable profit by the buyer's proposed contract, he will find no incentive to shirk from the quality requested by the buyer. Under sole sourcing, the buyer chooses to establish a relation with only one supplier. If there are no sunk investment costs in building such a relationship, a buyer could easily leave a current supplier and replace him with a new one. However, if there are switching costs in the form of sunk firm-specific investment costs, the buyer cannot credibly threaten to switch to another supplier for any deviations in quality. If the switching costs exceed the cost of low supplier quality, the buyer will not find it in her best interest to switch suppliers. Therefore, for a given contract, there is an inverse relationship between the level of quality the supplier will find optimal to deliver and switching costs. In designing the optimal contract, the buyer must take into account the supplier's cost of quality and hence his incentive to deviate below the buyer's requested quality level. The performance of each sourcing alternative depends on the specific nature of the market structure, and therefore no clear dominance among sourcing strategies can be established.

It should be emphasized that choosing among several outsourcing strategies (sole source, dual source, etc.) is only one of the issues that a procurement manager must address. Initially, the manager must decide whether or not to outsource at all; a company may find it beneficial to internally produce or provide a product or service. (There is a rich literature on vertically integrated firms and the various concerns that are encountered within; see Laffont and Tirole 1993 and Tirole 1989 for excellent overviews. If the decision to outsource is made, other issues arise that must be dealt with; for example, how to select the future suppliers (via an auction or an alternative mechanism),[3] how to structure the bidding process, how to monitor the supplier(s), how much of the buyer's private information should be shared with the supplier(s), and how to create an environment of trust to make the relationship as beneficial as possible (see Kramer and Tyler 1996 for a review of current issues in the study of trust in organizations). Each of these is an equally important and interesting question; however, they will not be addressed in this review.

The focus of this literature review is the type of supplier incentives created when different sourcing strategies are employed. Whereas traditionally the operations research literature has analyzed the buyer's optimal purchasing decisions *given* a fixed set of suppliers that has deterministic costs and time to delivery, the emphasis in economics has been on the incentives created for supplier performance under various sourcing strategies. Section 3 contains a useful approach for grouping the literature based on sourcing strategy and model assumptions. Sections 4 through 7 review the literature based on these groupings. Section 8 addresses applicability of the papers' results for the emerging management issues in business to business e-commerce, and §9 concludes with a brief commentary on the papers' results and suggestions for future directions of research.

[3]Manelli and Vincent (1995) examine a model where a buyer wishes to procure a single object from a single supplier. The buyer can select a supplier via an auction or via successive take-it-or-leave-it offers.

3. Categorization of the Literature

As discussed in §2, no one sourcing arrangement is optimal for all market structures. Depending on the nature of the buyer-supplier relationship, i.e., the industry's technology and size, whether this is a one time only purchase or to be done on a regular basis, etc., a buyer will find different procurement arrangements best suited for her situation. To better understand the sourcing arrangement and market structure a paper is analyzing, I have partitioned the papers into distinct categories based on the following two questions:

How many opportunities are there for the buyer to select a supplier? Often a buyer is not required to purchase all of her goods in a single auction but, instead, will make purchases over time. A buyer may find it advantageous to introduce multiple opportunities for supplier selection to infuse competition at several points. The advantage of additional competition must be weighed against the possible introduction of inefficiencies into the procurement process when "learning by doing" is present and suppliers' investment in production is costly.

Given that the buyer needs to select suppliers, from how many will she procure goods? Is there to be a single supplier or multiple suppliers selected? Has the buyer predetermined from how many suppliers she will source, or is that endogenously determined through auction?

The following two questions are equally important for understanding the nature of the procurement arrangement and market structure:

What type of contract is awarded to the winner supplier(s), fixed or incentive? A buyer either awards a supplier (or a group of suppliers) a contract of fixed size and quantity or an incentive (payment) contract. In an incentive contract, the supplier is specified a target quantity or price that he will be paid and how much of any costs overruns he will have to bear if the target level is not met. A fixed contract awards a supplier a fixed price, making the supplier the residual claimant for all of his cost savings.

Can the supplier(s) influence his production costs in any way (via investment, effort, or learning by doing)? In equivalent terms, is a supplier's production cost dependent or independent of his actions?

The papers reviewed in §§4–7 have been grouped according to the first two dimensions (single or multiple supplier selection periods, single or multiple sourcing). Papers where the number of suppliers is endogenously determined via the selection process are grouped under multiple sourcing.

4. Single Selection Period, Single Supplier

The single-selection-period, single-supplier model is the most developed and well understood in the area of procurement arrangements. There are several excellent surveys that chronicle the significant contributions in this area of research and serve as great complements to the papers found in this review. McAfee and McMillan (1987) and Milgrom and Weber (1982) provide an excellent overview of general auction literature, with particular emphasis on the performance of commonly used auctions formats (English, Dutch, first and second price sealed-bid auctions) in the sale of one indivisible unit to symmetric bidders within this model. The most recent and comprehensive survey of the auction literature is by Klemperer (1999).[4] Myerson (1981), although not a review paper, is pathbreaking in its contribution to the optimal auction literature, that is, the identification of an auction structure that enables the auction maker to attain the optimal of some criterion (e.g., maximizes the seller's revenue, minimize a buyer's purchasing cost, maximize social welfare, etc.). Rogerson (1995) provides a sweeping overview of the defense-related procurement literature. Rogerson focuses his review on single-supplier, single-selection period models and analyzes several strands of defense procurement research: issues of moral hazard, adverse selection, economies of scale in production, and research and development.

Most of the literature in these reviews assumes asymmetric information exists between the seller (buyer) and bidders, that is, the bidder's types are unknown to the seller (buyer). A critical issue under asymmetric information is whether a particular auction structure induces bidders to reveal their true capabilities (types), i.e., whether the auction is incentive

[4]A small number of the papers included in Klemperer (1999) study multiperiod auctions and multisourcing.

compatible. Typically in a situation with asymmetric information, the auction designer must allow the bidders to accrue some positive rent from their private cost information in order to induce them to reveal their true types.

In addition to the topics covered in the aforementioned papers, another important and active area of single-selection period, single-supplier models that should be highlighted is franchise bidding. The franchise bidding literature is concerned with situations where the buyer finds it in her best interest to select a single supplier (via a single-selection stage), usually because of the presence of large economies of scale in production. Riordan and Sappington (1987) and Bushnell and Oren (1993) are representative of the literature that examines the awarding of a monopoly franchise to one of a fixed number of potential suppliers.

In their model, Riordan and Sappington consider the task of a risk-neutral buyer (a regulator) selecting a single supplier to provide a good that is produced under increasing returns to scale. The regulator is interested in maximizing expected consumers' welfare. Riordan and Sappington examine a framework where the demand for the franchise is assumed to be common knowledge, whereas each individual supplier's cost is private information. In addition, each potential supplier only learns his marginal cost of production after being awarded the franchise and incurring the fixed costs of production. In exchange for the franchise award and a production subsidy, the supplier must pay a franchise fee upfront. The determination of the franchise winner, the unit price the producer is allowed to charge, the fee paid to the regulator, and the subsidy the producer receives from the regulator is a two-stage process. In the first stage, the buyer collects bids from suppliers who do not know their true cost of production, but who have some information on their valuation of the monopoly, i.e., each supplier observes a private (independent and identically distributed) signal about his prospective valuation of the franchise award. Based on these bids, a single supplier is chosen as the winner. Upon being chosen, the winner must pay the regulator a franchise fee, based on his winning bid. After being chosen, the winner incurs a fixed cost, learns his marginal cost, and submits a second bid (which serves as an estimate of its marginal cost) to the buyer. The buyer uses the winner's initial bid to determine his franchise fee and uses the bid-cost pair to determine the optimal production subsidy and franchise price for the winner.

Riordan and Sappington find that it is optimal to create links between initial bidding (where the monopoly provider is chosen) and the setting of the production subsidy (which is set after the winner submits his second bid) in the second stage. While the auction yields productive efficiency, i.e., the contract is awarded to the supplier with the lowest expected costs, the final franchise prices are set above realized marginal costs; therefore, the auction does not achieve allocative efficiency. Although these production distortions (away from the first best when the buyer knows the winner's costs with certainty) are created by this link, the buyer is able to offset this loss in consumer surplus by increasing the franchise fee; this is done by introducing competition in the initial selection process. A surprising result of Riordan and Sappington's analysis is that increased competition influences the optimal scheme only through the franchise fee, i.e., the number of suppliers competing for the monopoly franchise affects the optimal franchise fee schedule, but has no effect on the optimal production distortions for any bid-cost pair.

Bushnell and Oren (1993) model the selection of a single power producer via an auction. The buyer (a regulator) wishes to award an exclusive supply contract to a single power producer (possibly because of significant economies of scale in generation). In contrast to Riordan and Sappington, the regulator here is interested in maximizing total social welfare (both productive and allocative efficiency), not only consumer surplus. The regulator employs an auction to award the contract.

In Riordan and Sappington, the regulator employed a unidimensional bid in the first auction and asked the winning supplier to reveal only his marginal cost in the second stage. In contrast to this, Bushnell and Oren study and auction where the suppliers submit bids on both dimensions of their costs, both fixed and marginal. That is, suppliers will submit a pair of fixed, F_i, and variable, v_i, prices. The variable price indicates the supplier's per unit selling price; if the supplier should

win, he is obligated to satisfy all of the demand at that variable price (as in Riordan and Sappington, they assume that the demand function is known and deterministic). The regulator then scores each bid using a publicly known scoring rule that converts the two-dimensional bid into a single number. Based on the final scores, the contract is awarded to the supplier with the lowest score. The goal of the regulator is to choose a scoring rule, $S(.,.)$ that maximizes social welfare.

In search of an auction that attains both productive and allocative efficiency, Bushnell and Oren study both a first and second price auction. In a first price auction, given bidder i bids F_i and p_i, and wins, his profit is given by

$$\pi_i^1(F_i, p_i) = F_i + p_i D(p_i) - C_i(D(p_i)),$$

where $D(p_i)$ is the demand at price p_i and $C_i(.)$ is the cost to bidder i of meeting the demand at price p_i. In a second price auction, given bidder i bids F_i and p_i, and wins, his profit is given by

$$\pi_i^2(F_i, p_i) = \hat{F}_i + p_i D(p_i) - C_i(D(p_i)),$$
$$\text{where } S(\hat{F}_i, p_i) = S(F_j, p_j),$$

where $S(F_j, p_j)$ is the lowest losing score. Therefore, $\hat{F}_i$ equates bidder i's score with that of the lowest losing score.

Bushnell and Oren find that a scoring rule that maximizes both consumer and producer surplus can be found for the second price auction. The optimal scoring rule is the negative of consumer surplus resulting from a fixed payment F and a price p for the good. Under this scoring rule, it is a dominant strategy for a supplier to bid the variable price that maximizes total surplus under his cost function.

5. Single Selection Period, Multiple Sourcing

By definition, when a buyer uses multiple sourcing and is facing a set of diverse suppliers, the buyer will increase the actual costs of production since she awards production to at least two suppliers, one of which is not least cost. Therefore, when a buyer chooses to multiple source, she may introduce production inefficiencies into the procurement process. To counter this effect and potentially reduce overall procurement costs, the buyer hopes that the competition induced by awarding production to more than one supplier will decrease the supplier's information rents and hence decrease their submitted bids.

On Two-Source Factor Purchasing

Horowitz (1986) explains why it is rational for a buyer to purchase a portion of her demand for a product from a higher priced supplier. Horowitz considers a model with two possible suppliers; one supplier's price is known with certainty (there is no uncertainty in his production costs) and, hence, is able to guarantee the buyer a price, whereas the second's price is uncertain and hence is unable to guarantee the buyer a price. Both suppliers' prices are dependent on the amount the buyer purchases from them. When presented with a choice of these two suppliers, a risk-averse buyer may find it beneficial to purchase more from the certain supplier than a risk-neutral buyer would have done. In addition, the risk-averse buyer is willing to pay the certain supplier a premium above the expected cost from the uncertain supplier, whereas a risk-neutral supplier would not do so.

Split Awards, Procurement, and Innovation

Anton and Yao (1989) analyze a complete information game where a buyer will award a divisible contract for the provision of a public service. The buyer wishes to award the contract in a low-price sealed-bid auction. There are two potential suppliers who will bid for the contract. The buyer can choose to award either a sole source contract or a dual source (or split award) contract. Anton and Yao illustrate how under a split award procurement, the two suppliers implicitly collude to extract the highest payment from the buyer in equilibrium.

Suppliers are allowed to submit a supply curve indicating, for each fraction of the total contract size, the price the supplier wishes to be paid to provide that fraction of the contract. The suppliers' costs are assumed to be publicly known. Anton and Yao demonstrate that sole sourcing is the unique equilibrium whenever sole-source production is efficient. They also find that a dual sourcing outcome is an equilibrium outcome only when it is efficient to do so. In a split award equilibrium, the suppliers are able to extract all

of the gains from dual sourcing (the reduction in costs from single sourcing from the lowest cost provider) by submitting bids that result in the highest price to the buyer. Therefore, while it is efficient to dual source, the buyer is made worse off by the sellers' implicit collusion at higher bid prices. Anton and Yao find that, given the choice between offering a traditional single source only award or a split award, the buyer strictly prefers a single source only award auction, whereas the sellers strictly prefer a split award auction.

Coordination and Split Award Auctions

In their second paper, Anton and Yao (1992) again consider bidder's behavior in an auction for a contract, but this time under asymmetric cost information. The buyer will either award the entire contract to one supplier or divide the contract between the two suppliers equally.[5] Each supplier submits two bids indicating his price to provide the entire contract and only half of the contract. Each supplier's type, its cost to provide either all or half of the contract, is private information.

Although there are potentially three classes of equilibria, (1) sole sourcing for all realizations of suppliers' types, (2) sole and dual sourcing depending on the realization of suppliers' types, and (3) dual sourcing for all realization of suppliers' types (labeled a σ-equilibria), the authors focus only on σ-equilibria. In a σ-equilibria, the suppliers' bids lead the buyer to select dual sourcing as the cost-minimizing award for all realizations of suppliers' types. Anton and Yao find that a necessary condition for a σ-equilibrium is that dual sourcing is efficient (this is similar to their result under complete information). They find that a σ-equilibrium involves the pooling of bidder types, i.e., different types of suppliers submit the same bid. In addition, whereas under complete information, the buyer (winning seller) was made strictly worse off under a split (single source) award as opposed to a single source (split) award, the same is not true under incomplete information. Under incomplete information, all parties can benefit from a split award over a single source auction.

[5]The authors note that the assumption of equal division is not necessary to their results. What is necessary is that the form of the split be known to the suppliers before bidding, i.e., the split of the contract between the suppliers is not endogenously determined.

Managing Procurement Auctions

Dasgupta and Spulber (1989/90) determine a buyer's optimal mechanism under three different procurement scenarios. Building on previous analysis of procurement auctions where the buyer selects one winning firm and awards it a predetermined quantity, they examine sole sourcing of a fixed (predetermined) quantity when the buyer's demand curve is downward sloping. They then turn their attention to a sole sourcing arrangement when the quantity awarded to the winner is determined endogenously by the submitted bids. Finally they examine a multiple sourcing arrangement where the amount awarded to the suppliers is determined endogenously through the submitted bids. Dasgupta and Spulber find that a multiple sourcing arrangement dominates (in terms of the buyer's expected profit) sole sourcing with an endogenously determined award quantity, which in turn dominates sole sourcing with an exogenously determined award quantity.

Dasgupta and Spulber analyze a model where there are a fixed number of suppliers participating in the market. Each supplier has a cost function of the form

$$C_i(Q) = C(q, \theta_i) = K + \int_0^Q c(q, \theta_i)dq,$$

where θ_i represents a supplier's private information about its production costs, K is the supplier's fixed costs, and Q is the quantity produced. The buyer knows the form of the suppliers' cost function, does not know their type θ_i, but does know the common cumulative distribution function, $F(.)$, from which all types are independently and identically distributed.

Under all three scenarios, the buyer determines an allocation mechanism that maximizes her expected gain, subject to the mechanism being incentive compatible (each supplier finds it optimal to bid truthfully) and individually rational (the supplier cannot be made worse off if he participates in the auction). Dasgupta and Spulber are able to characterize the optimal mechanism under all three procurement scenarios and outline implementation mechanisms for each. In the two cases of sole sourcing, the optimal mechanism is found for any cost function satisfying $c_Q \geq 0$, $c_\theta \geq 0$, $c_{\theta\theta} \geq 0$, and $c_{Q\theta} \geq 0$. However, in the case of multiple

sourcing, they are only able to characterize the optimal mechanism when fixed costs are assumed to be zero, i.e., $K = 0$, and firm cost functions are strictly convex. Under these assumptions for multiple sourcing, *all* suppliers are awarded a positive quantity in equilibrium. The optimal mechanism is implemented by having the buyer initially post a schedule of incentive contracts of the form

$$R_i = B_i(\theta) + S(\theta_i, \theta_{(i)})(q_i - Z(\theta_i)),$$

where B_i is a supplier's bid, $S(.,.)$ is a sharing rule dependent on the supplier's type θ_i and all other suppliers' types, $\theta_{(i)}$, the quantity actually produced q_i, and a target output level $Z(\theta_i)$. After suppliers have submitted their bids, the buyer can infer the suppliers' types and give each supplier a personalized payment schedule. The suppliers then choose the optimal output to produce. The authors' results for multiple sourcing do not extend, however, to the case where suppliers have a positive fixed cost.

Multiple Source Procurement Competitions

Seshadri et al. (1991) develop a model that illustrates the strategic interplay between an industry's propensity to compete (e.g., its capacity utilization rate), the number of suppliers from whom a buyer will multiple source, and the equilibrium bidding behavior of those sellers who decide to submit bids. They use their model to describe under what circumstances multiple sourcing may reduce a buyer's acquisition costs. Their paper builds on an empirical analysis done by Greer and Liao (1986) of the U.S. government's purchasing strategies for its defense sector.

The authors consider a model where a buyer wishes to procure a divisible object from a subset of risk-neutral suppliers via an auction conducted only once. All winners in the auction will be awarded equal-sized contracts at the highest accepted bid price. The buyer must decide from how many suppliers she wishes to procure. All potential suppliers have an opportunity cost associated with submitting a bid, i.e., the supplier must dedicate some of his resources while preparing for a bid submission and therefore cannot allocate those resources to other profit-generating purposes. Each supplier knows his opportunity cost as well as the number of suppliers from whom the buyer will multiple source. However, suppliers do not know how many other suppliers will submit bids, their own cost of production, and their opponents' cost of production.

A supplier must decide whether or not to enter into bidding competition based on his opportunity cost of doing so. A supplier's opportunity cost reflects the resources that must be spent and capacity that must be temporarily committed during the bidding process at a cost to the supplier. All potential suppliers must decide whether or not to submit a bid simultaneously and, hence, will now know for certain how many competitors he will face in the auction. Once a supplier decides to submit a bid, he learns his actual cost of production. Production costs are assumed to be variable only, i.e., there do not exist economies of scale. All suppliers' costs are independently and identically distributed, with each supplier's cost of production remaining private information throughout the bidding process. The common distribution function is common knowledge. In summary, a supplier's opportunity cost affects his decision to enter into the bidding competition, while a supplier's actual production costs determine its bidding strategy. The authors are able to characterize the buyer's expected payment as

$$E_N[T] = E_N[E[T \mid n{:}K < n] + T_{\max} \Pr\{n \leq K\},$$

where T is the buyer's total procurement costs, N, is the number of potential bidders who actually submit bids, K is the number of suppliers to be selected, and $T_{\max}$ is the buyer's reservation price (if the number of suppliers participating in the auction is not more than K, i.e., $n < K$, then each supplier receives $T_{\max}/n$). The probability that a supplier chooses to participate in the auction depends on whether his expected profit when there are K suppliers bidding, π_K, is greater than or equal to his opportunity cost of doing so, i.e., r. Since all potential suppliers are assumed to be identical except for their opportunity costs (which are independently and identically distributed) and cost estimates, i.e., suppliers have identical beliefs over their opponent's opportunity cost distribution $G(r)$, suppliers view the number of competitors who bid as a Bernoulli trial.

Seshadri et al. (1991) identifies two aspects of an auction that are usually overlooked: the industry's propensity to compete and the industry's potential to compete (i.e., the number of firms (*potential* bidders) in the

industry). Greer and Liao's (1986) empirical analysis of the government's purchasing strategies from the aerospace industry indicate that when the industry had a capacity utilization rate above 80%, procurement auctions yielded noncompetitive results. Seshadri et al.'s model explains this phenomenon as a result of the industry's propensity to compete. They claim that an industry's propensity to compete can be loosely measured by its capacity utilization. As capacity utilization increases, the distribution of opportunity costs, $G(r)$, shifts to the right (and hence the industry's propensity to compete decreases). A shift to the right of $G(r)$ increases the probability of fewer bidders and leads to higher expected procurement costs.

Greer and Liao also find that winner-take-all awards result in lower contract prices than do dual source awards, all other variables held constant. This also might be explained using the industry's propensity to compete. As the number of winners increases, the portion each winner is awarded decreases, and hence each bidder's opportunity cost decreases (all else held equal), i.e., $G(r)$ shifts to the left. But it might be that the shift, and subsequent increase in the number of bidders, was not enough to offset the actual increased cost in production due to the inclusion of a less efficient supplier in addition to the lowest bidder.

Designing a Private Industry

A buyer (the government) considers auctioning production rights to either a single supplier (thereby creating a monopoly), two suppliers (thereby creating a duopoly), or producing the goods itself.[6] The model assumes that there are only two potential suppliers bidding in the auction. The value to each supplier of winning production rights depends on whether or not he will be the sole supplier. A supplier's type, defined by his constant marginal cost of production, and hence profit under monopoly production and duopoly production is private information. Each supplier's type is assumed to be independently distributed, although not identically. It is assumed that suppliers' types are the sole determinant of their production costs, and hence profits, under different market structure.

The government proposes a mechanism that specifies who will produce and how much each supplier must pay for the right to produce as a function of submitted bids. The government is unable to monitor the eventual production of the winner(s) and charge them accordingly and therefore must demand a transfer payment upfront for the right to produce. The government is concerned with constructing a binding contract that, *ex ante*, maximizes social welfare.

Dana and Spier (1994) find that, when compared to the most efficient outcome (when there is complete information), the optimal mechanism under incomplete information increases the likelihood that the government does not award production to either supplier and decreases the likelihood of awarding a duopoly. This is a result of the government's ability to extract more of the supplier's information rent when they are competing for the right to a monopoly. By increasing the portion of time a monopoly is awarded, the government is able to increase social welfare. In addition, by increasing the probability that neither supplier will be awarded production, the government is able to reproduce the effect of a reserve price in an auction: The fear of bidding too high and causing the government to choose neither supplier causes suppliers to decrease their bids.

Bidding for Contests

As opposed to the other papers discussed, Seshadri (1995) (and the last paper in this section) assumes that a supplier can influence his production costs by undertaking costly effort. Seshadri compares the performance of a two procurement scenarios: (1) The buyer procures from a single supplier who is awarded an incentive contract, and (2) the buyer procures from two suppliers, where each supplier is paid his actual (observable) costs plus a fixed portion of a pooled fee (this procurement scheme is referred to as a *cost plus contest arrangement*). Seshadri finds that sometimes the buyer will find it optimal to dual source with a cost plus contract in place of a single source with an incentive contract, because associated with each procurement arrangement will be a different optimal level of supplier

[6]Most of the literature that deals with an endogenously determined number of suppliers focuses on governments procuring services (e.g., a medical clinic) for its constituents. The issue is whether the government should award monopoly or duopoly rights. The papers in this area are less relevant and their results less applicable to supply chain management.

effort and different costs of inducing that effort. While under dual sourcing, by definition, two suppliers must be paid instead of one, the presence of competition and a contest lessens the cost of effort. At times, the presence of competition and associated reduction in cost is greater than the increase in having two suppliers, and a dual source arrangement is optimal.

Under dual sourcing, several suppliers bid to be one of two suppliers chosen to produce a fixed (equal) quantity. After suppliers bid and the two lowest bidders are chosen for production, the suppliers can chose to exert effort to reduce their total cost of production. However, these activities are costly to the suppliers. To give the suppliers an incentive to reduce their production costs, Seshadri suggests that the buyer create a pooled fee, which is then awarded unequally to the suppliers, with the lower cost supplier being awarded the larger share of the pooled fee. Hence, *after production,* the suppliers will be paid their actual cost plus the profits from a contest. Seshadri argues that this cost plus contest arrangement may be advantageous to the buyer over a single source with an incentive contract arrangement.

Each potential supplier i has an opportunity cost, τ_i, associated with winning in the auction, i.e., there exists an opportunity cost associated with dedicating resources to production that is privately known and is independently and identically distributed among all the suppliers. Bidding is costless, and there exists a fixed number of bidders participating in the market. In a departure from most other papers reviewed here, each supplier is assumed to be risk averse and have a constant absolute risk aversion. The total cost for supplier i to produce Q_i, comprises three parts: a common cost that is uncertain at the time of bidding, a cost reduction term that directly reflects the effort a supplier exerts at a cost to himself and is private information, and a random term that is privately known. After bidding, the common cost component is made known to both suppliers but is unknown to the buyer. The suppliers engage in cost-reducing activities, realize their individual random cost component, and complete production. After production is completed, the suppliers' total costs are made known to the buyer, but not their individual cost components. Each supplier i is reimbursed Q_i plus a portion of the pooled fee c. If $Q_i = \min[Q_i, Q_j]$, then supplier i wins the contest and is awarded fc, where $f > 1/2$ and c is the size of the pooled fee; otherwise, supplier is awarded $(1 - f)c$.

The determination of the optimal pooled fee size, c, is a difficult problem for the buyer. She must be careful not to set c too low so as to not induce enough cost-reducing effort and not too high and overcompensate the suppliers. Seshadri suggests setting c equal to the buyer's opportunity cost of using the two lowest bidders, i.e., to set c equal to the bid of the third lowest bidder. This scheme allows him to take advantage of Vickrey's result that it is then optimal for suppliers to bid their true reservation values for the job. The decision problem for the buyer is then to choose the optimal level of f that minimized the buyer's total outlays.

Incomplete Information and Optimal Market Structure, Public Purchases from Private Providers

McGuire and Riordan (1995) examine a similar problem to Dana and Spier (1994), in that they examine a setting where the market structure, i.e., the sourcing strategy, is endogenously determined. In their model, a buyer (the government) wishes to provide a service for the public so as to maximize social welfare; the service can be provided by one of two risk-neutral providers (creating a monopoly provider) or by both in a dual sourcing arrangement. In a dual sourcing arrangement, providers equally divide the market. The potential suppliers' cost of providing service comprises three parts: a common fixed cost, a privately known (unobservable) variable cost, and a (unobservable) cost-reducing effort. Any effort induces a reduction in cost, but at the expense of the supplier's total profit. A supplier's actual total cost, if chosen as a provider, is observable. The government proposes a mechanism that specifies who will produce and an incentive contract, indicating how much each supplier will be reimbursed for the provision of services, as a function of submitted bids. Each chosen provider is reimbursed directly only for submitted, targeted costs and shares with the buyer any overrun costs.

Generally, in principal agent problems, the principal must design the contract so as to counter the incentive of an efficient provider to mask himself as an inefficient one. This is even more of a problem when there is the possibility of dual sourcing, since dual sourcing

by definition awards production to more than the most efficient provider. To counter this fundamental problem in contract design, an optimal contract must make a sole award more probable than it would be if the principal had complete information about providers' costs. McGuire and Riordan point out, "Essentially, the regulator uses sole sourcing with the most efficient provider as a threat that discourages each provider from misrepresenting its costs" (p. 136).

McGuire and Riordan find that when there is no social cost of providers' profit, the government is able to provide a mechanism to induce providers to exert the optimal level of effort. When economies of scale are not too large, the government proposes a mechanism that will award a monopoly contract if a single supplier's cost is sufficiently small in comparison to his competitor's or will award a dual sourcing contract when the providers have similar costs. In addition, the optimal market structure, given the providers' types, is the same as under complete information.

6. Multiple Selection Periods, Single Supplier

When a buyer's supply base is initially limited, then the presence of entry costs and/or "learning by doing" can only further exacerbate the limited competition present. One way that has been employed to balance a (small) incumbent/knowledgable supplier base with limited competition and supplier market power is to infuse competition into the procurement process in more than one time period. Another method has been to transfer an incumbent's technology over to a second supplier source. Either method has its advantages and disadvantages, which are discussed in the following papers.

The Design of Procurement Contracts

When a buyer wishes to procure a well-defined good and the technology for its production exists among several (noncolluding) suppliers, then a simple price-based auction can be conducted to promote competitive bidding. If, however, the technology for a good's production does not exist in full or the buyer's supply base is initially limited, then typically "educational buys" are used; a single supplier is chosen to research and develop the technology necessary to produce the good. The technology developed from the education buy becomes the property of the buyer, who may choose to transfer it to another supplier at a later date. Usually a supplier's technology is not completely transferable, i.e., there are efficiency losses in using a second source. Rob (1986) is interested in the use of sequential procurement auctions to help reduce procurement costs when there are relatively few potential suppliers. Rob studies the use of educational buys, assuming that learning can occur *and* that the learning advantage can be transferred, at a cost, to a competing supplier. Rob's procurement environment is as follows: The buyer conducts two auctions in sequence. In the first auction, n suppliers competitively bid to supply a fixed portion of a project, y units. A single winner emerges from the auction; the winner is committed to supplying y units of the good and will be paid his asking price for each unit. At the time of bidding, suppliers do not know their actual production costs. Following the initial auction, the winner engages in research and development to achieve a low production cost. The cost of research and development is modeled as a search cost: The winning supplier must decide how many draws to take from some cost distribution function while each draw costs supplier i s_i. Therefore, at the start of the initial auction a supplier does not know his actual production costs, but he does (privately) know his search cost and hence the value, z_i, at which is it is no longer beneficial to draw.[7] In addition, z_i is the lowest price at which the supplier is willing to undertake the project.

The winning supplier will supply y units at his bid price and a per unit cost of $c_m \equiv Min(c_1, \ldots, c_n)$.[8] The technology associated with the cost c_m is assumed to be transferable to other potential suppliers, but not without efficiency losses. Using the same technology, it costs an alternative supplier αc_m to produce one unit, where $\alpha > 1$. Both α and c_m are assumed to be common knowledge. After the initial auction and the R&D

[7]The value of z_i, which leaves supplier i (who has won in the initial auction at his bid price and must supply y units) indifferent between producing at the lowest cost found from n searches, i.e., $c_m \equiv Min(c_1, \ldots, c_n)$, and searching once further, can be computed using a dynamic programming formulation.

[8]Where n is the number of samples taken by the supplier.

stage, the buyer holds a second auction to procure the remainder of her units. Since the cost to produce the units is the same for all potential suppliers, save the incumbent, and is greater than the incumbent's cost of doing so, the remaining units will be awarded to the incumbent at a per unit price of αc_m. While the structure of Rob's model is such that the same supplier emerges as the winner in both auctions, the threat of competition disciplines the incumbent. Rob shows that by injecting competition at two different points in time, instead of only at one initial auction, the buyer is able to further lower her total procurement costs.

The decision the buyer must make is (1) how many units to offer in the initial round of auctions and (2) how low to set her reserve price, i.e., the price at which she will not award production to a supplier competing in the auction but procure it from elsewhere. The author considers the buyer's optimal choice when the total number of units to be purchased is fixed and when the amount procured in the first auction is fixed but the amount procured in the second auction is a decision variable (it will be dependent on c_m).

Rob finds that, in both scenarios, the buyer will find it optimal to procure fewer than the total number of units desired in the first auction if the cost of transferring the technology to alternative suppliers is not too severe. If the costs of transferring are too high, then the incumbent supplier receives high profits in the second auction, and the buyer is made worse off by holding two auctions. If the costs of transferring are low, then the low ceiling on the incumbent's profits in the second auction makes it advantageous to procure less than the total amount in the first auction.

Rob also finds that partitioning the procurement process into two segments is beneficial if the number of bidders is small. If the number of bidders is large, then there are no benefits to be had from delaying the procurement of any of the goods until after the R&D stage. This is because when there are many bidders, there will be perfect competition, and suppliers will bid away any profit in the initial auction. If, however, the number of bidders is small, the winner in the first auction will accrue positive profit. The buyer can capture some of the winning supplier's rent by delaying the auctioning of some units the second auction—where the price mark-up over true cost is α. However, the buyer must be certain to award a sufficient number of units in the first auction to induce the winner to increase its search and reduce its production costs.

Information Expropriation and Moral Hazard in Optimal Second-Source Auctions

Stole (1994) analyzes a model with one risk-neutral buyer and two risk-neutral suppliers (a developer and a second source). The buyer wishes to procure a single object at the lowest possible expected price. The buyer values the object highly and therefore will always choose to purchase the object. She can procure the object from the developer or the second source; if she chooses the second source, she can transfer (license) the developer's technology to the second source or allow the second source to produce using his own technology. The question this paper addresses is when, if ever, should the buyer introduce a second source when she is trying to minimize expected procurement costs? Moreover, should the buyer license the developer's technology to the second source or allow the second source to produce using his own (possibly more expensive) technology?

By introducing a second source, the buyer may introduce productive inefficiencies. There may be efficiency losses in licensing the technology, i.e., if c_1 is the developer's cost of production, $l(c_1, c_2)$ is the cost of production via licensing, then $l(c_1, c_2) > c_1$. The buyer does not know the suppliers' costs, only their cost distributions and licensing costs as a function of supplier costs, i.e., $l(.,.)$. However, the threat of losing business to a second source may allow the buyer to secure a lower price than otherwise from the developer. The buyer's goal is to balance the introduction of inefficiencies with the reduction of information rents so as to procure the object at the lowest possible expected price.

Stole considers two scenarios: (1) The developer's investment decision in technology is exogenously determined, and (2) the developer's unobservable investment decision is endogenously determined, i.e., the developer can affect the cost of producing the object through its investment decision. An increase in investment levels decreases the expected cost of production; however, cost-reducing investment is costly to the developer. Underlying this second scenario, there is a

moral hazard problem. If the buyer is unable to monitor and compensate a developer directly for the effort it exerts during an educational buy, how should the buyer promote and compensate effort? The threat of transferring the technology, and hence future production requests, to an alternative supplier may have the effect of reducing the effort by the developer.

Under both scenarios, the buyer announces a set of allocation rules for the subsequent auction. These rules state, conditional on the submitted bids, who will win production and whether or not the developer's technology is licensed in the case the second source is chosen. In addition, these rules determine payments to each firm. The buyer is constrained to offer only *ex post* profitable allocation rules, i.e., neither firm can incur a loss by choosing to participate in the auction for any cost realization. Both suppliers have a choice to reject the buyer's allocation rules and hence not participate in the auction. However, they must decide without knowing either their own costs or their opponent's costs with certainty.

Once a supplier decides to participate in the auction, he discovers his true production costs. In the case of endogenously determined investment levels, the developer must first choose an investment level, and then observe his true costs. Whether investment is exogenously or endogenously determined, in the optimal truth-telling mechanism, the buyer may find it optimal to commit to a technology transfer for certain bids (i.e., realization of costs), when it would not be optimal under complete information. This is because by committing to use a technology transfer for some cost reports, the buyer reduces the developer's *ex ante* information rent. The gains in information rent reduction are greater than the costs of inefficient licensing, and hence the buyer finds it advantageous to do so.

A Theory of Incentives in Procurement and Regulation

Laffont and Tirole (1993) consider a situation similar to Stole (1994): A buyer wishes to procure a service from one of two suppliers over two time periods. In period one, the buyer randomly chooses one of the suppliers (to be called the incumbent) to produce. In the second period, the buyer has the option of switching procurement to the second supplier (to be called the entrant). In the second period, the buyer holds an auction and chooses to award production based upon the suppliers' announced costs. The buyer wishes to design an optimal break-out rule (a rule by which the buyer switches from the incumbent to the entrant in period two) and optimal incentives contracts (one for each period for each supplier) so as to maximize social welfare. However, Laffont and Tirole do not confine their search over optimal mechanisms that are *ex post* profitable for the suppliers (as did Stole).

The chosen supplier in each stage is awarded an (possibly distinct) incentive contract. Under an incentive contract, the winning supplier is paid his announced costs plus a share of the difference between his announced and actual costs, i.e., the buyer uses an incentive contract whereby the buyer and supplier share costs. Before period one, each supplier has a cost that is independently and identically distributed and is the supplier's private knowledge. In each period, the chosen supplier can engage in cost-reducing effort, but at a cost to his own utility. The suppliers are assumed to have the same disutility of effort. In addition, in period one, the incumbent can choose to invest in cost-reducing technologies. Any investments made in the first period increase an incumbent's first period production costs and produce cost savings only in the second period. The buyer can observe the supplier's actual total cost but not the investment and effort levels. Depending on the transferability of the cost-reducing investments by the incumbent in period one, the entrant may benefit from the incumbent's investments in period one. However, each supplier is the sole receiver of any cost reductions due to his own effort, i.e., cost-reducing effort is not transferable.

If the incumbent's investment is (at least partially) transferable and the incumbent cannot be directly rewarded for his level of investment, then he has the incentive to underinvest relative to the optimum. Laffonte and Tirole find that the buyer's optimal break-out rule favors the incumbent[9] and her optimal sharing rule increases the incumbent's incentive to invest. This

[9]A supplier's type is a direct reflection of his production costs. A break-out rule is said to favor the incumbent, of type β, over the second source, of type β^*, when, for $\beta > \beta^* + \Delta$, $\Delta > 0$, the incumbent is chosen to produce.

optimal incentive contract for the incumbent is time variant: The incumbent shares a smaller portion of costs in the first period and a higher portion in the second period. Structured as such, the incumbent bears a small fraction of its first period costs and therefore perceives investment as cheap. However, if he were to win in the second period, he would bear a high fraction of his second period costs. These two incentives, combined, increase an incumbent's incentive to invest.

If, however, the incumbent's (unobservable) investment is not transferable, the optimal break-out rule should be biased in favor of the entrant. This is because the incumbent has, on average, a cost advantage over the entrant in the second period. To further promote competition and reduce the incumbent's information rent, the optimal break-out rule favors the entrant. In addition, since there are no longer any externalities due to investment, the optimal incentive contracts for the incumbent are time invariant, i.e., the share of costs borne by the incumbent is the same, if he should produce in both periods.

Second Sourcing

Riordan and Sappington (1989) stress the importance of linking up the development stage with the production stage in the procurement process. They consider whether it is advantageous for a buyer to commit herself to sole sourcing or retain the option to second source, when the technology for production must first be developed. In their model, the buyer wishes to procure a fixed quantity of goods and initially faces a fixed number of identical suppliers. The buyer must choose a supplier to initially develop the technology for production. The buyer is assumed to be the owner of the technology and, after the development stage, can opt to award the production of the good to an alternative supplier and incur a transfer cost. The buyer would like to develop and procure the goods so as to maximize her benefit (valuations for the goods minus acquisition costs); however, there exists the possibility of terminating without production if the cost of production is too high. Riordan and Sappington argue that, to minimize acquisition costs, it is optimal for the buyer to decide *before* the development stage whether or not she may use a second source for production.

In the first period, the buyer will select (via an auction) a supplier who will develop the technology for the eventual production of the good. The developer is awarded a fixed price contract that is paid upfront after the first auction. The selected developer chooses his effort level, which in turn determines the length of the development stage. It is personally costly to the developer to undertake research and development effort, and his chosen effort is unobservable by the buyer. However, the buyer can observe the final development date t. The results of the developer's efforts are stochastic, i.e., for any given effort level there exists a range of possible production cost functions that might be realized. The development lag affects the value of production via obsolescence (imagine the U.S. government entrusting a supplier with the development of a particular weapon—the value of the weapon may decrease with time if the technology becomes obsolete); therefore, the longer it takes to complete development, the less the value of the final good to the buyer.

After the development stage, the buyer offers a fixed price for production to a supplier; what this price is and to whom production is offered depend on whether the buyer can commit to only sole sourcing or retains the right to second source. When the buyer can commit to only sole source, she maximizes her benefit by setting a price, p, equal to $p = v - H(p)$, where v is the buyer's valuation for the goods and $H(.)$ is the (incentive compatibility) information rent for a supplier with an actual production cost of p. When the buyer does not (or cannot) commit to sole sourcing, then the buyer maximizes her benefit by offering a take-it-or-leave-it price of p_2 to the developer, where p_2 satisfies $H(p_2) = \min[v - p_2, \Delta]$, where Δ is the cost to transfer the technology to a second source (i.e., if the developer can produce at cost c, then the second source can produce at cost $c + \Delta$). If the developer rejects this price, he must make public his cost of production, c, and the buyer awards the contract to a second source at price of $r_2 = c + \Delta$, if $r_2 \leq v$.

Riordan and Sappington argue that it may be optimal for the buyer to commit to sole sourcing before the selection of a developer (this could be done by vesting proprietary rights to the technology with the developer), that is, the supplier chosen to develop the production technology will also be awarded final production of the goods. In this case, the suppliers will

compete away all rents at the initial developer selection stage, and the buyer's procurement costs are minimized. If the buyer does not commit to sole sourcing and retains ownership of the developed technology, then she has the option to use a second source in the production stage. In this case, the development and production contracts will be negotiated separately. Given this knowledge, suppliers will anticipate lower rents for production and hence will bid less aggressively for the development contract. This implies that the buyer may face very high development costs.

Riordan and Sappington illustrate that the option to second source may decrease the buyer's expected benefit. Whether or not it does so depends on the of the following factors: (1) the production diversion effect, (2) production enhancement effect, (3) the technology transfer cost Δ, and (4) the value of the goods v. The production diversion effect refers to the increase in production costs if a second source is chosen. The production enhancement effect refers to the possibility that the buyer awards production to the second source when it otherwise would not have awarded production at all. Finally, the value of the goods v critically affects the action a buyer takes; if v is too high, then the buyer would never terminate without production, and if it is too low, then the transfer cost Δ is (relatively) prohibitively high; in either case, the presence of a second source is of no consequence.

7. Multiple Selection Periods, Multiple Suppliers

Dual Sourcing in Repeated Procurement Competitions

It is often an objective of buyers to maintain a potential supply base that is balanced with its current supplier in terms of technical expertise and, hence, costs. One of the methods employed for maintaining a balanced supply base is an educational buy. Klotz and Chatterjee (1995) study educational buys but from a different perspective from Rob (1986); Klotz and Chatterjee assume that learning can occur but that the learning advantage *cannot* be transferred. The objective of the paper by Klotz and Chatterjee is not to establish the optimality of dual sourcing as a procurement mechanism, but instead to illustrate its beneficial cost-reducing properties. Dual sourcing in their paper defines a procurement environment where a fixed portion of production is evenly divided between the two suppliers, with the remainder auctioned and awarded to the lowest bidder (and hence is competitive).

The paper examines a model where there are two suppliers. The buyer wishes to procure one divisible good in two consecutive periods. A supplier's cost to produce in period two is dependent on his production level in period one, i.e., production learning occurs. In each period that a supplier decides to enter into the bidding competition, he must incur a fixed cost k. The fixed cost is time-invariant and can be interpreted as the fixed costs associated with preparing a bid submission. A supplier does not know his cost when he decides to enter into the bidding competition; he only knows the distribution of his possible costs. In reward for deciding to enter into the bidding competition, a supplier is guaranteed half of a fixed portion of production at a fixed unit price M. M is also the per unit price at which the buyer can procure the entire project from an alternative source. Once the supplier chooses to enter into bidding competition, he learns its constant marginal production cost. The assumed cost structure implies that there are no (dis-)economies of scale in production.

It is not unheard of to guarantee a supplier a fixed production quantity in exchange for his bidding for the remainder of the project. Burnett and Kovacic (1989) point out in their analysis of the Department of Defense's dual sourcing procurement policy that "DOD may need to guarantee each contractor a minimum annual share of production—for example, a minimum of twenty-five percent—to convince it to incur program-specific costs" (p. 288).

Define z_t to be the portion of production that is auctioned to the lowest bidder in period t. The winning price is determined by the losing bid, i.e., it is a second price auction. The buyer must decide how much of production the suppliers should compete for and, hence, how much the suppliers should be guaranteed once they decide to enter into bidding competition. The structure of the procurement process is such that only one supplier will win in the competitive auction.

Since there exist fixed entry costs to enter into bidding competition, the possibility of losing and the negative profit associated with it will make it such that some suppliers may be better off if they do not enter at all. The absence of competition in the auction will cause the buyer to pay the maximum price M to the one supplier present. To avoid having all of its rent transferred to the winning supplier, the buyer would be better off compensating both suppliers for entry to promote competition when bidding. Dual sourcing, as defined by Klotz and Chatterjee, is one mechanism by which to transfer wealth to supplier to cover their entry costs.

In addition to entry costs, suppliers are assumed to experience learning from production in the first period. If the entire production in period one were awarded to a single supplier and suppliers *can* buy-in their future gains from period two,[10] then suppliers will compete away all of their profits in the first period, and the buyer has no need to ensure competition in period two. However, if a supplier *cannot* buy-in his future gains in period one, then suppliers cannot compete it away, and the buyer will be facing severely asymmetric potential suppliers in period two. The suppliers' costs will be asymmetric because of the downward effect learning has on the winner's cost function. The greater the difference between the two costs, the greater the price and profit the buyer must pay to the winner in the second period. To minimize this difference, it would be beneficial to the buyer to keep the supplier's costs fairly close. Dual sourcing provides a means by which the buyer can control the rate at which suppliers move along their learning curve and, hence, can control the difference between the suppliers' costs.

Klotz and Chatterjee consider two cost frameworks: (1) the suppliers' costs, once revealed, are identical and learning is deterministically determined by the function $c(x)$, where x is the quantity produced in period one; and (2) the suppliers' costs are *i.i.d.* and uniformly distributed between 0 and 1 in period one, whereas in period two, the producer with more production experience draws his estimate from $U(0, a_s)$ and the producer with less experience from $U(0, a_w)$, where $a_s < a_w < 1$.[11]

Klotz and Chatterjee's results in the case of initial common costs are,

Result 1. *When suppliers can buy-in future gains, a positive entry cost is necessary and sufficient for dual sourcing to be optimal in both periods, i.e., $z_t < 1$ for $t = 1, 2$.*

Result 2. *When suppliers can buy-in future gains, a buyer may sometime find it optimal to dual source more than is required to guarantee entry of both suppliers.*

Result 3. *When suppliers cannot buy-in future gains, a positive entry cost is no longer necessary for dual sourcing to be optimal.*

Result 1 speaks to the ability of suppliers to bid away or buy-in all of their potential profits in the first period. If positive entry costs do not exist, then suppliers lose nothing by entering into bidding competition in both periods. A supplier is able to compute its potential profits in the second period if he should win in the first (and hence the second) auction and is willing to reduce his bid until his expected profits are zero. The result of zero profits rests on the fact that the suppliers have initially identical costs and are in fierce competition in the first auction. With this extreme supplier competition, a buyer cannot increase the competition further and, therefore, should avoid the costs of dual sourcing. Result 2 speaks to the case when, for some learning cost curves, keeping suppliers' costs symmetric in the second period outweighs the cost of doing so (dual sourcing). The costs for dual sourcing are the higher unit price, M, paid for the guaranteed portion in period one and the higher bids in period one by the winner.[12]

When a supplier cannot buy-in future gains, the gains from learning can only be realized by the buyer in a second period auction. As stated earlier, the closer the two suppliers' costs are to each other in the second

[10]When a supplier is able to buy-in his future gains, he can pass on his cost reduction in the second period from learning into his bid in the first period and, hence, submits bids in the first period that are below his production costs.

[11]The authors also assume that a_s and a_w are a decreasing function of first period production.

[12]The winner submits a higher price under dual sourcing than under sole sourcing due to its reduced production in period one and, hence, smaller decrease in production costs in period two.

period, the stronger the competition in the auction. In such cases, Result 3 tells us that it is sometimes optimal for the buyer to dual source a fair share portion of production in the first period in order to reap the benefits of competition in period two's auction, whether or not entry costs exist.

8. Growth of Procurement Over the Internet

Most of the papers reviewed thus far have assumed that there are only a handful of eligible suppliers from whom to choose. However, the ability to quickly and cheaply locate suppliers over the Internet is making this assumption less reasonable. The Internet provides buyers with a medium for trade that is characterized by connectivity, convenience, speed, and low cost. The ability to create markets on the Web and access potential suppliers around the world has serious ramifications for buyer-supplier relationships (e.g., the duration of the contracts and the willingness of suppliers to exert buyer-specific costly effort) and how these relationships are established. In this section, I will briefly describe the growing presence of procurement markets over the Internet and the potential effects of these new markets on the number of suppliers with whom a buyer does business.

In an effort to understand the effect of electronic commerce on the economy and particularly on business-to-business transactions, the Clinton Administration and the U.S. Department of Commerce issued the report, "The Emerging Digital Economy" (Department of Commerce, 4/98). The report contains case studies that illustrate the importance of electronic commerce on procurement practices of businesses.

> Estimated at more than $8 billion in 1997, the value of goods and services traded between businesses over the Internet (excluding transfer of funds or financial securities purchased) far exceeds on-line transactions between businesses and consumers. . . . It opens the door to doing business electronically with new suppliers and with small and medium-sized suppliers who formerly communicated only via fax or phone. Its global reach and real-time communication capabilities are driving the creation of new on-line marketplaces for production and on-production materials. (p. A3-1)

Forecasting the future size of the business-to-business e-commerce market, Forrester Research estimates revenues in year 2003 to be in the amount of $1.3 trillion, while Goldman Sachs estimates revenues in the year 2004 to be in the about of $1.5 trillion.[13] Researchers and practitioners alike are excited by the seemingly endless possibilities offered by the Internet, and curious as to the implications of using this new and powerful tool on procurement practices. The literature dealing with procurement practices over the Internet is still in its formative years, most of it emanating from researchers in information systems. An emerging debate in this field focuses on whether the Internet will increase or decrease the number of suppliers with whom a buyer does business. The main argument in support of the number of suppliers increasing is based on the reduction of coordination costs. Malone, Yates, and Benjamin (1987) reason that the main impetus behind vertical integration of companies is the reduction of transaction/coordination costs. The Internet reduces the cost of locating a supplier and gathering, processing, and communicating information with that supplier; therefore, we may witness an increase in the number of suppliers with whom a buyer establishes a relationship.

The fact that businesses are quick to realize the cost-savings potential of securing suppliers via the Internet is evidenced by the number of different companies that have made *this* their business. Several different types of procurement markets are appearing on the Internet today; a few of the pioneers in this area have been General Electric's Trading Post Network (TPN), MRO.com Inc., auto-parts exchange, and FreeMarkets. The ability to procure complicated components over the Internet is the catalyst behind Ford, Chrysler, and GM coming together to create a platform over the Internet for trades between buyers and suppliers in the automobile industry. In 1995, GE's Information Services division aided GE's Lighting Division in the construction and implementation of an on-line protocol for the announcement and processing of bid proposals. What came out of this endeavor was GE's TPN, an Internet-based support system that streamlines the sourcing process. GE TPN Post puts buyers in touch with a list of diverse prequalified suppliers, located all over the world, from whom they can solicit bids

[13] *Source:* 10/25/99 www.briefing.com, Greg Jones.

electronically. GE is currently purchasing over $1 billion worth of goods from its suppliers on-line each year.[14]

GE uses the TPN Post not only for procurement requests from within GE, but also offers outside buyers access to TPN. GE's role is the intermediary, connecting a buyer with an interested and prequalified list of suppliers; its list of customers currently includes Hewlett Packard, 3M, and Textron Automotive. While GE internally created its procurement support system, many other companies see an opportunity for selling "Internet Procurement" packages to buyers and sellers who do not have GE's expertise and manpower. MRO.com, Inc., a wholly owned subsidiary of Project Software and Development, Inc., is one such business-software company that has realized the significant potential in creating support systems that can be used to manage the entire Maintenance, Repair, and Operating supply system.[15] The concept behind their product is similar to that of GE; the creation of a marketplace where buyers can periodically go and search a list of prequalified suppliers for one that best matches their interests.

While the services offered by GE's TPN Post and MRO.com, Inc., include an established list of suppliers to whom Requests for Proposals are sent, FreeMarkets specializes in finding qualified suppliers tailored to the purchasing requirements and concerns of the buyer. That is, FreeMarkets creates customized business-to-business on-line auctions to the specific needs of the buyer. This is done by an extensive gathering of information regarding the supplier market, understanding the underlying cost characteristics of potential suppliers, and optimally designing an auction to secure a low price for the buyer.[16] In addition to locating suitable suppliers and securing their commitment to participate in the auction, FreeMarkets must design the structure of the auction (that is, how to bundle the objects together, how many separate auctions to create, the sequencing of the auctions, etc.).[17]

The implications of being a member of GE's TPN lists (or similar lists) are still not well understood. As Rogerson (1995) notes,

> An extremely important feature of the procurement process is that firms' behavior is interconnected across the three stages of procurement: design, sole source selection and production. This means that models of the procurement process which focus on only one of the stages may fail to capture important aspects of the problem. (p. 318)[18]

On the one hand, having cheap access to and being a member of such a list would potentially increase cost-saving and sales opportunities, but it can also have the detrimental effect of promoting cut-throat competition that causes more damage than good to a buyer's long-term interests. To build a well-orchestrated supply chain, the willingness of suppliers to exert buyer-specific costly effort must be secured. Industry tendencies toward lean manufacturing require trust and a cooperative environment between buyers and sellers. If Malone, Yates, and Benjamin's (1987) prediction that buyers will utilize the Internet to successively locate cheaper suppliers is true, then the cooperative environment necessary for just-in-time manufacturing will suffer. Surprisingly, Bakos and Brynjolfsson (1997) find anecdotal evidence of an overall *reduction* in the number of suppliers used by a buyer. Their reasoning is similar in nature to that set forth by Seshadri et al. (1991)[19]; the larger the expected future rewards, the

[14]"For This Supplier, The Sum of Its Parts Adds Up To Success," *The Economist,* 9/14/97

[15]Other such companies include Commerce Once and Ariba. When Commerce One, which created an Internet marketplace for business buyers and suppliers, went public in July, its shares soared to $62 from $21 on the first day of trading. A few weeks earlier, its rival Ariba did even better, with its shares quickly jumping to $90 from $23 (source for this information is *New York Times on the Web,* September 22, 1999).

[16]It is important to note that the lowest bidder is not always chosen as a result of the auction. Often, the buyer is evaluating the supplier on several dimensions, one of which is cost. FreeMarkets identifies a qualified list of suppliers who are willing to sell their services at the prices determined through the bidding process. The buyer is not required to select the lowest bidder.

[17]An extremely important sector of the economy that has dramatically changed recently and is taking advantage of the ability to procure services on-line is the electricity industry. See Elmaghraby (1998) for an analysis of designing an efficient multisupplier electricity auction.

[18]While Rogerson specifically notes sole sourcing selection, his statement equally holds for multiple source selection.

[19]Recall that in Seshadri et al. (1991) a supplier decided on whether or not to compete for the buyer's business based on his expected

more likely a supplier is to invest in maintaining a high quality relationship (that is, responsiveness to the concerns of the buyer, investment in buyer-specific technology, etc.). As the number of suppliers with whom the buyer does business increases, the less likely it becomes that a particular supplier will receive the buyer's business; his expected future rewards decrease, and hence the quality of his relationship with the buyer suffers. Bakos and Brynjolfsson argue that it is the incontractible elements of a buyer-supplier relationship, e.g., effort, responsiveness, and trust, that determine how advantageous the relationship is and eventually have the greatest impact on the buyer's "bottom line."

Rogerson's (1994) observation concerning the interdependence among the various procurement stages implies that the ability to locate distant suppliers quickly and cheaply over the Internet will not only affect the number of suppliers with whom a buyer does business but the very nature of the buyer-supplier relationship. It remains to be seen how buyers will exploit the potential of the Internet and how (what) kind of procurement arrangements will be found to be optimal.

9. Future Research Directions

One of the most important steps in a successful supplier-selection process is to identify critical market and supplier characteristics that can influence the buyer-supplier relationship. Through the papers in this review, we have learned that a manager must be able to answer the following questions to make an informed decision and properly evaluate the suitability of different sourcing strategy:

1. Does "learning by doing" exist in production?
2. Is there a limited supplier base?
3. Does the manager have the ability (right) to transfer technology across suppliers?
4. Can a supplier directly influence its costs by investing or undertaking other costly actions?
5. Can the manager observe the supplier(s) costs and directly compensate a supplier for any investments?
6. Is the supply market balanced or do great differences exist in the suppliers' production capabilities and costs?
7. Are the total number of units to be purchased predetermined or unknown at the time of the auction?
8. Will the manager need to make a similar purchase at some point in the future, or is this a one-time purchase?

The papers reviewed here have seriously contributed to our understanding of procurement mechanisms, but there is much room for bridging models between the various papers and expanding their results. Listed below are some suggestions for extending the current body of literature to better understand the interplay among various market/supplier characteristics and their effect on sourcing strategies.

• A nice extension would be to link the frameworks of Richardson and Roumasset (1995) and Dasgupta and Spulber (1989/90). Both papers are concerned with ranking the performance of multiple and sole sourcing. However, the results from Richardson and Roumasset are limited since they assume complete information, whereas Dasgupta and Spulber assume that the only cost present in a buyer-supplier relationship, and hence the only factor to influence a buyer's optimal sourcing strategy, is the supplier's (unchangeable) production costs. A richer model would incorporate the presence of supplier quality, setup costs, cost of inspection, and coordination (in addition to purchasing costs) in the face of incomplete information.

• One important bridge to build is between the Seshadri et al. (1991) model (which attempts to understand the trade-offs between increasing a buyer's supply base and increases in acquisition costs) and the multiperiod models by Klotz and Chatterjee (1995) and Seshadri (1995). By expanding Seshadri et al.'s (1991) model into a multiperiod setting, we no longer limit the buyer's objective function to minimizing immediate acquisition costs but instead allow the buyer's objective function to reflect the repeated nature of most procurement transactions and the benefits and shortcomings of a diversified supply base. That is, the buyer's objective function should incorporate the risk-reduction benefits of multiple sourcing, which are addressed in repeated auctions models. In addition, the

profit of doing so. His expected profit of deciding to compete was crucial dependent on the number of other suppliers who also decided to compete.

benefits of multiple sourcing critically rely on the underlying cost structures of production. Several papers reviewed do not consider the effect of learning in their model precisely because they look only at a one-shot game. However, one of the main reasons for employing multiple sources in procurement is to maintain a broader supply source and avoid the pitfalls of "capture" associated with single sourcing. Therefore, we would ideally like to employ a more holistic approach to modeling the various costs and benefits of sourcing strategies.

• Many times a supplier is not only the manufacturer, but is also instrumental in the development stage of a product. While Riordan and Sappington (1989) address the importance of linking up the development stage with the production stage, they assume that the buyer *randomly* selects a *single* supplier from among *n identical* suppliers and entrusts him with the development stage. After the development stage, the buyer is assumed to purchase a *prespecified* quantity from the supplier awarded production. These four assumptions (i.e., random, single, identical, and prespecified) are strong, and this paper would benefit greatly from their relaxation. For example, an interesting extension would be to endogenize the final quantity purchased, as done in Rob (1986). Additionally, an important and more realistic model would be to assume that the suppliers are diverse and that their costs are private information. In such a scenario, a buyer may want to explore auctioning off the development stage to more than one supplier and awarding production to a single supplier as a form of prize (similar to what was done in Seshadri 1995). These forms of "tournaments" are found in practice (e.g., the defense industry); however, very little research has been done on their application in procurement process.

Many important market/supplier characteristics were not discussed in any of the papers and must be addressed to better our understanding of procurement auctions in practical and relevant ways. Listed below are suggested directions for future research:

• Economies of Scale in Production. A serious omission from all of the papers (save Dasgupta and Spulber 1989/90) is the presence of economies of scale. Almost all supplier-buyer relationships are characterized by economies of scale in the production and/or transportation of goods. Not only can the size of an order influence any economies of scales, but it may also effect the quality of the product produced. Therefore, it is imperative to understand the effect of economies of scale on various sourcing strategies.

• Volume Discounts. When a supplier knows that he will experience economies of scale as his order size grows, he often will reflect his cost synergies by presenting buyers with volume discounts. All of the papers here, with the exception of Anton and Yao (1989), assume that a supplier submits only a single bid to the buyer, and is not allowed to submit a supply curve. If suppliers submit supply curves that reflect volume discounts, then solving for the least-cost (set of) suppliers given the submitted curves is not guaranteed to be a simple task. In addition, understanding how different sourcing arrangements (i.e., how many suppliers will be awarded business, and if more than one supplier is chosen, how much of the buyer's order he will receive based on his bids) will effect the bidding behavior of a supplier will prove to be a difficult but important problem to solve.

• Multiple Supplier Criteria. Only in rare cases is a buyer wise to judge a supplier on the basis of price alone (this is only a smart strategy if the supplier base is very competitive and the product has a commodity status). Typically, many other criteria are important in the supplier-selection process; for example, a supplier's quality, reliability, size, degree of vertical integration, and available capacity, to name a few. Once a buyer has identified which supplier characteristics are of utmost importance to her, she must decide on an appropriate way to judge the suppliers on the multiple attributes.

• Supply Disruption and Long-Term Availability. As cited in Trevelen and Schweikhart (1988), one of the benefits of sourcing from more than one supplier is that it minimizes the risk of supply disruption. Price considerations may become secondary if a buyer is susceptible to supply disruptions. The type of supplier from whom a buyer procures may influence the chance of a supply disruption. For example, larger suppliers may be more stable (or vertically integrated) and therefore possess less of a threat for supply disruptions than smaller suppliers. However, purchases concentrated at

a few large suppliers may reduce the supplier base. A buyer must weigh the risk of a supply disruption against the threat of reducing her future supply base.

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