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Price and Service Competition in an Outsourced Supply Chain

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Abstract

We study the dual-sourcing problem faced by a buyer who outsources the manufacturing of a given product to multiple symmetric suppliers who compete on both price and service level. The buyer allocates demand to the suppliers using a two-dimensional score function with an exponential form, which specifies the relative importance of price vs. service level, in order to minimize his own costs, while the suppliers choose their prices and service levels to maximize their own profits. We characterize the optimal allocation policy for the buyer, considering the impact of the buyer's decisions on the suppliers and considering how the suppliers compete against each other to earn a larger portion of the buyer's demand. We prove the existence of a unique equilibrium and characterize the equilibrium behavior of the system. We show that the equilibrium prices and service levels, as well as the buyer's equilibrium cost, are increasing in the number of suppliers. We conclude that the increase in operational costs caused by the splitting of demands among a large number of suppliers outweighs any competitive benefits that would be achieved from sourcing from a large number of suppliers.

1 Introduction and Motivation

The past two decades have seen a sharp increase in the use of outsourcing and contract manufacturing in a variety of industries, including telecommunications manufacturing, with the primary goal of reducing costs and obtaining operational efficiencies (McIvor, 2003). As a result of this increased reliance on outsourcing, global manufacturers of complex telecommunications equipment such as Alcatel-Lucent must now make strategic decisions regarding the design of their sourcing processes, including how to qualify suppliers, whether to single- or multi-source and, in case of the latter, the number of suppliers from which to source.

In recent years, manufacturing firms has come to recognize many benefits from multi-sourcing the procurement of key inputs. Within these organizations, multi-sourcing is considered one of the most powerful ways to achieve the best results in terms of pricing, payment terms, delivery, quality, etc., in the negotiation with suppliers. Multi-sourcing also provides enhanced security-of-supply. However, while there have been advocates within these organizations for increasing the number of inputs that are multi-sourced, with a focus on dual-sourcing, the adoption of multi-sourcing is not without hurdles. The cost and time involved in the current practices associated with multi-sourcing often turns time-pressed product designers towards single-sourcing. Therefore, swift and effective decision-making is key for the successful application of multi-sourcing. Thus, there is a clear need for innovative methodologies and systems that cover a wide range of related decisions, such as which products are suitable for multi-sourcing, how many suppliers to qualify and how to qualify them, the specific supplier(s) to select, and how to allocate orders across competing suppliers.

The above discussion demonstrates that a critical issue faced by manufacturers who have made the decision to outsource the production of key inputs is the design of the sourcing process. In practice, a typical sourcing process consists of two distinct stages: the qualification stage and the supplier selection and allocation stage. In the qualification stage, potential suppliers may be screened for a variety of different capabilities, including quality, reliability, financial viability, etc. As Wan and Beil (2009) note, the qualification stage is primarily "meant to mitigate the risk of supplier nonperformance" on some critical dimension.

The second stage of the sourcing process is the supplier selection and allocation stage, in which those suppliers that are "qualified" are invited to compete for a portion of the buyer's business. A key question at this stage is whether the buyer should single- or multi-source. Given the complexity and increasing globalization of modern supply chains, and despite the trend toward long-term supplier partnerships, it is becoming common for manufacturers to acquire identical goods from multiple sources; see, e.g., McMillan (1990), Richardson (1993) and Latour (2001). Manufacturers choose to multi-source in order to protect against supplier failure, to gain access to a wider set of supplier capabilities and expertise, and to better cope with fluctuations in demand (Slack *et al.* 2007). Multi-sourcing also enables the manufacturer to encourage competition between its suppliers, on both price and a variety of quality- and service-related dimensions.

If the manufacturer chooses to multi-source, then she must perform both supplier selection and order allocation, i.e., she must determine which portion of her orders to allocate to each supplier. A key goal of the supplier selection and allocation stage, regardless of whether the buyer has chosen to single- or multi-source, is to induce competition between the qualified suppliers, perhaps by implementing a mechanism for competitive supplier bidding. This bidding process may depend on a single supplier attribute, such as price, or may be a function of multiple attributes, such as price, service or quality. In the latter case, the attributes may be combined using a score function, which uses the suppliers' performance on the various attributes to calculate a single numerical score for each supplier (Burke *et al.*, 2006). This score function, either implicitly or explicitly, captures the relative importance of the various attributes to the buyer by assigning a different weight to each of the different attributes.

1.1 Literature Review

We next review the relevant literature and discuss our contributions relative to this literature. Since we consider a single buyer who procures goods from two suppliers, we start by briefly reviewing the literature on inventory management for a buyer who procures inventory from multiple supply sources. See Minner (2003) for a review. This research generally considers a buyer who procures inventory from two or more suppliers, who may differ on one or more critical characteristics, such as price, lead time, reliability or service level, and takes the characteristics of the suppliers as fixed. Thus, the focus of this research is on the optimal procurement decision for the buyer, and competition between the suppliers is not an issue.

Since we are interested in how the buyer can use the sourcing process to encourage competition between potential suppliers, with the goal of improving supply chain perfomance and decreasing costs, a more relevant stream of literature considers competition between suppliers when the buyer chooses among them based on a number of criteria, e.g., price, lead time, service level. A key issue is how the buyer should design his allocation method, i.e., how the buyer's demand should be divided between the suppliers, given their characteristics. Several recent papers have considered this issue, including Ha *et al.* (2003), Benjaafar *et al.* (2007), and Cachon and Zhang (2007).

Ha *et al.* (2003) use an EOQ-like model to consider two suppliers who compete on price and delivery frequency (time between shipments). Given the suppliers' announced prices and delivery frequencies, the buyer determines the fraction of demand to allocate to each supplier in order to minimize his long run average ordering and holding costs. The authors study the equilibrium behavior of the system under various assumptions regarding decision rights, i.e., which player has responsibility for which decisions (price and logistics).

Benjaafar *et al.* (2007) consider a buyer who allocates demand for his product to competing suppliers. They study two types of allocation methods: one in which each supplier is allocated a proportion of demand based on her service offering (SA) and another in which one supplier is randomly selected to fill all demand, with the probability of selection increasing in the service offered (SS). In each case, the allocation decision is based only on service, not price. The authors study how competition can improve the service offered by the suppliers. The model considered in the current paper is similar to the make-to-stock model considered in Benjaafar *et al.* (2007), but with some key differences. First, we consider suppliers who choose both price and service level (fill rate). Second, while we focus on an allocation function based on an exponential score function, we incorporate the buyer's decision problem of choosing the parameters of the allocation function in order to minimize her own costs. In contrast, Benjaafar *et al.* (2007) consider more general allocation functions, but assume the buyer's goal is to achieve the maximum service quality given fixed prices.

Cachon and Zhang (2007) consider a buyer who procures a service from two competing suppliers. The buyer allocates service jobs between the two suppliers with the goal of minimizing the average time to complete a job. The price paid by the buyer per job is assumed to be fixed. The suppliers choose their capacities with the goal of maximizing their average profits. The authors model the competition between the suppliers and study how the buyer's allocation method affects the equilibrium capacities chosen by the suppliers. They consider two types of allocation methods: state-dependent (-independent) methods in which the decision regarding how to allocate an arriving job is (is not) a function of the state of the system. The current paper differs in that we assume the suppliers choose their service levels and prices, and that the buyer seeks to minimize his total cost. In addition, we focus only on state-independent allocation policies in which, given the characteristics of the suppliers, a fixed fraction of demand is allocated to each supplier. Cachon and Zhang (2003) extend Cachon and Zhang (2007) to also consider the buyer's pricing decision. In contrast, in the current paper we assume it is the suppliers who set the price.

While the above papers consider suppliers who compete for orders placed by a single buyer, a related stream of literature considers suppliers (retailers) who complete for a portion of the market demand. For our purposes, the most relevant paper from this stream of research is Bernstein and Federgruen (2004), who consider the equilibrium behavior of a supply chain in which multiple retailers compete for market demand on the basis of price and fill rate.

They assume that the fraction of demand, i.e., market share, seen by each retailer can be modeled using an attraction model, such as the multinomial logit model, in which the the attraction value of a given firm is a function of the price and fill rate offered by that firm. Our allocation function is similar to the multinomial logit attraction model considered in Bernstein and Federgruen (2004). Several other papers have considered a similar problem in which retailers (suppliers) compete on service and/or price for market share, e.g., Hall and Porteus (2000), Gans (2002), Cachon and Harker (2002), Allon and Federgruen (2007), Tsay and Agrawal (2000) and Boyaci and Gallego (2004). Similarly, numerous papers have considered a problem in which retailers (suppliers) compete on quality and price, e.g., Banker *et al.* (1998), Matsubayashi (2007) and Moorthy (1988). In all of these papers, the manner in which the market is allocated to the retailers as a function of their price and / or service / quality decisions is taken as exogenous, i.e., the allocation function is taken as fixed and given, not as a decision variable. In contrast, in the current paper, the parameters of the allocation function are chosen by the buyer in order to encourage an optimal level / type of competition between the suppliers.

In summary, we extend the existing literature by considering a supply chain which captures horizontal competition between the suppliers as well as vertical competition between the buyer and the suppliers. We do so under the assumption that the suppliers may choose both their service levels and their prices, i.e., *the suppliers have a two dimensional strategy space*, which significantly complicates the analysis. We note that few papers in the supply chain literature have considered such multi-dimensional strategy spaces (Zhao *et al.* 2005, is one exception). Using a two dimensional strategy space enables us to study how the suppliers trade-off the benefits of offering a lower price vs. higher service level and to consider how the buyer can choose her allocation function to obtain the price-service level trade-off that will minimize her own costs.

2 Problem Description and Model Analysis

A single buyer outsources the manufacturing of a given product to N competing suppliers. Initially, we assume symmetric suppliers. The buyer faces Poisson(λ) demand for her product. Each demand must be satisfied by one of the suppliers. The buyer chooses an allocation policy, i.e., a method for splitting demands between the N suppliers, in order to minimize her long run average cost. Specifically, the buyer determines the allocation using an exponential score function, $a(s_i, p_i) = e^{s_i - \alpha p_i}$, which depends on both the price charged by supplier i, p_i, and the service level provided by supplier i, s_i. The parameter α indicates the relative importance of price vs. service. See Jin and Ryan (2009) and Benjaafar *et al.* (2007) for a justification for using a score function of this form. Then, each arriving demand at the buyer is immediately allocated to one of N competing suppliers according to a given probability, $\beta_i, i = 1, 2$, where $\beta_i = \frac{a(p_i, s_i)}{\sum_{j=1}^{N} a(p_j, s_j)}$ for $i = 1, \ldots, N$. Thus the total demand seen by supplier i is Poisson with arrival rate $\beta_i \lambda$. Given the allocation policy, which the buyer announces to the suppliers, supplier i chooses her selling price, p_i, and service level, s_i, in order to maximize her long run average profits, under competition with the other suppliers.

In analyzing this problem, we are interested in understanding the equilibrium behavior of the suppliers, i.e., the equilibrium prices and service levels, as well as the impact of the choice of allocation method on the performance of the buyer, i.e., how the buyer can use the allocation method to improve her costs and the performance of the supply chain as a whole.

We start by formulating the problems faced by the suppliers and by the buyer. We then analyze the equilibrium behavior of the system.

2.1 The Supplier's Problem

Supplier i faces exponential production times and operates on a make-to-stock basis with base-stock level, B_i. The symmetric suppliers each incur a unit production cost, w, a cost per unit of capacity, c, and a unit holding cost h. All suppliers scale their capacity to maintain a fixed utilization, ρ. Given B_i, supplier i's expected inventory is just $E[I_i] = B_i - \frac{\rho}{1-\rho}\left(1-\rho^{B_i}\right)$, while her fill rate is $s_i = P(I_i > 0) = 1 - \rho^{B_i}$. As in Benjaafar *et al.* (2007), we can reformulate the problem so that the supplier's decision variables are s_i, the service level, and p_i, the unit selling price, where the former determines the appropriate base-stock level, B_i. After doing so, we find that $E[I_i] = \frac{\ln(1-s_i)}{\ln\rho} - \frac{\rho}{1-\rho}s_i$. We can then write the expected profit for supplier i as:

$$\Pi_i(p_i, s_i) = \beta_i\lambda\left(p_i - w - c/\rho\right) - h\left(\frac{\ln(1-s_i)}{\ln\rho} - \frac{\rho}{1-\rho}\ s_i\right), \tag{1}$$

where β_i is the fraction of the buyer's demand allocated to supplier i.

2.2 The Buyer's Problem

Since the suppliers follow base-stock policies, when a demand arrives from the buyer, that demand may or may not be filled immediately. Any demands that cannot be filled immediately are backordered with the backorder cost, b, incurred by the buyer. Assuming the buyer eventually fills all demands and sells the product at a fixed price, total revenue will be fixed.

Therefore, we formulate the buyer's problem as cost minimization, where her cost function is:

$$C = \sum_{i=1}^{N} (\beta_i \lambda) p_i + b \sum_{i=1}^{N} \frac{\rho}{1-\rho}(1 - s_i), \tag{2}$$

where $\frac{\rho}{1-\rho}(1 - s_i)$ is the expected backorders incurred by supplier i. Recall that the buyer's allocation, β_i, depends on α, the score function parameter.

The buyer's problem is to choose the score function parameter, α, to minimize her long run average cost, C. Note that α is a measure of the importance of price relative to service level, i.e., higher α implies that the buyer places greater weight on price when making the allocation decision.

2.3 Equilibrium Analysis

Our analysis of the system equilibrium consists of two stages. First, we assume a fixed value of α and consider the competition between the suppliers to determine the equilibrium prices and service levels. Then, given these prices and service levels, we determine the buyer's optimal α. We are interested in understanding the impact of the number of suppliers on the buyer's equilibrium cost and whether increased competition, obtained by qualifying more suppliers, can improve the performance of the buyer. The following theorem (Jin and Ryan 2009) summarizes our results.

Theorem 1 *If* $\frac{N}{N-1}\frac{h}{b} < \left(\frac{1-\rho}{\rho}\right)\left(\frac{-1}{\ln \rho}\right) < \frac{N-1}{N}\frac{b}{h}$, *there exists one and only one symmetric equilibrium and the equilibrium prices and service levels can be written as:*

$$s^* = 1 - \sqrt{\left(\frac{N}{N-1}\right)\left(\frac{h}{b}\right)\left(\frac{1-\rho}{\rho}\right)\left(\frac{-1}{\ln \rho}\right)},$$

and

$$p^* \;=\; \left(\frac{N^2}{N-1}\right)\left(\frac{h}{\lambda}\right)\left[\left(\frac{-1}{\ln\rho}\right)\left(\frac{1}{1-s^*}\right)-\frac{\rho}{1-\rho}\right]+w+c/\rho.$$

The buyer's equilibrium score function parameter and cost can be written as:

$$\alpha^* \;=\; \frac{\lambda}{Nhg(N,b,h,\rho)}, \qquad \textit{where} \quad g(N,b,h,\rho)=\sqrt{\left(\frac{N-1}{N}\right)\left(\frac{b}{h}\right)\left(\frac{\rho}{1-\rho}\right)\left(\frac{-1}{\ln\rho}\right)}-\frac{\rho}{1-\rho}$$

and

$$C^* \;=\; \lambda p^* + \sqrt{b\ h\ \left(\frac{N^3}{N-1}\right)\left(\frac{\rho}{1-\rho}\right)\left(\frac{-1}{\ln\rho}\right)}.$$

Finally, the equilibrium prices, the equilibrium service levels and the buyer's equilibrium cost are all increasing in the number of suppliers, N, while the optimal score function parameter, α^*, is decreasing in the number of suppliers, N.

The condition required for Theorem 1 will generally hold as long as $\rho \geq 0.3$ and $b \geq 4h$, and is needed to ensure that the equilibrium α^* is finite and that the equilibrium service level is positive. We will discuss the results in Theorem 1 in detail in the next section.

Finally, we have performed some sensitivity analysis on the equilibrium behavior of the system. Our results are summarized in the following theorem.

Theorem 2 *If $b \geq 4h$, the following results hold:*

- *α^* is decreasing in h and b, increasing in λ, and constant in c.*
- *$p(\alpha^*)$ is increasing in h, b and c, and decreasing in λ.*

- *$s(\alpha^*)$ is increasing in b and ρ, decreasing in h, and constant in c and λ.*

The results indicate that as the backorder and holding costs increase, the buyer will place less weight on price in the score function, i.e., as these costs increase, service becomes a more important criterion for the buyer, and the price charged by the suppliers will increase. As expected, the service level seen by the buyer will increase as the backorder cost increases and decrease as the holding cost increases. In addition, the service level will be increasing in the utilization. Notice that we are not able to say anything about the behavior of α^* and $p(\alpha^*)$ as a function of the utilization, ρ. This is because the function $g(N, b, h, \rho)$ is not strictly increasing or decreasing in ρ. However, our computational results indicate that both α^* and $p(\alpha^*)$ will generally, although not always, be decreasing in ρ.

3 Managerial Insights

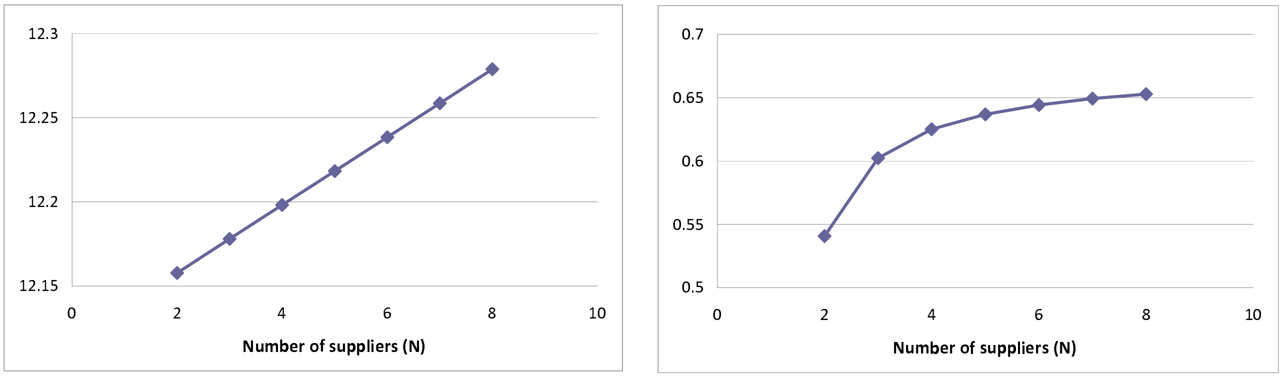
Since we are particularly interested in the impact of the number of qualified suppliers, N, on the results, we will focus our discussion of Theorem 1 on this issue. We can explain the results in Theorem 1 as follows. The buyer allocates the orders to the N suppliers in a static manner, i.e., independently of the current status of the suppliers. Thus, as the number of suppliers increases, the orders are allocated to more and more separate queues and are served by slower machines (since the utilization rate is fixed). Thus, for given p and s, the buyer sees increased backorders as the number of suppliers increases. This can be easily seen by considering equation (2), the cost function for the buyer, as a function of N, the number of suppliers. Since we consider only the symmetric equilibrium, the prices and service levels are the same for all suppliers, and the buyer's cost function can be written as

$$C = \sum_{i=1}^{N} (\beta_i \lambda) p_i + b \sum_{i=1}^{N} \frac{\rho}{1-\rho}(1 - s_i) = \lambda p + N \frac{\rho}{1-\rho}(1 - s).$$

Thus, if price and service are fixed, the buyer's backorder cost increases linearly in the number of suppliers, N.

Because of this result, as the number of suppliers increases, improving service level becomes more critical. Thus, with more suppliers, the buyer would decrease α in order to incent the suppliers to provide a higher level of service. In other words, the buyer would be willing to accept a higher price from the suppliers in exchange for a higher service level. Such an adjustment helps the buyer to offset the increase in backorders that would occur as a result of the increasing number of independent queues. However, overall, the buyer's total cost still increases. In other words, the increase in operational costs caused by the splitting of demands among a large number of suppliers outweighs any competitive benefits that would be achieved from sourcing from a large number of suppliers. Therefore, it is preferable for the buyer to use only two suppliers or, alternatively, to allocate the orders to the suppliers in a state-dependent manner.

Figure 3 shows the behavior of the equilibrium price and service levels for the suppliers as a function of the number of suppliers, N. As can be seen from the figure, the equilibrium service level is increasing and concave in N, while the equilibrium price increases approximately linearly in N. Thus, while the marginal benefit, in terms of improved service level, of having an additional supplier is decreasing, the marginal cost, in terms of increased price, of having an additional supplier appears to be constant. In other words, as the number of



a) $p(\alpha^*)$ b) $s(\alpha^*)$

Figure 1: Equilibrium price and service level as a function of the number of suppliers, N

suppliers increases, the additional benefit to the buyer from improved service diminishes, while the additional cost to the buyer from increased price remains constant.

Finally, Theorem 1 indicates that a smaller number of suppliers is better for the buyer. However, the theorem only applies for $N \geq 2$. It is difficult to compare the results of our model to the single supplier ($N = 1$) case because in the latter case it is not clear how price would be set. When there are multiple suppliers, we can determine the equilibrium prices that result from competition between suppliers. In contrast, under a single sourcing arrangement it is not clear who (the buyer or the supplier) would set the purchase price, or how that would be done, i.e., additional model development and assumptions would be required. However, we note that a premise of our paper is that the buyer has made a strategic decision to multi-source. Given that decision, the questions that remain are how many suppliers to use and how to allocate demand between them. These questions are addressed in Theorem 1.

4 Conclusions and Future Research

The above model of the supplier allocation process, while making a number of simplifying assumptions, enables us to derive some understanding of how a price- and service-sensitive buyer should allocate uncertain demands across a set of symmetric suppliers. In particular, this model allows us to capture the key trade-off between the competitive benefit of sourcing from a large number of suppliers and the operational costs caused by the splitting of demands among a large number of qualified suppliers. Understanding this fundamental trade-off is critical for a buyer who, in addition to designing a supplier allocation process, is also deciding how to design the supplier qualification process, i.e., is determining how stringent that process should be. Notice that the number of suppliers, N, in the above model would be an output of the supplier qualification process. Thus, a more stringent qualification process would result in a smaller N. Incorporating this qualification process into the buyer's decision model is a key step in our future work.

Finally, we note that our results rely on the assumption of an exponential form for the score function used to allocated demands between the suppliers. Unfortunately, generalizing our results to other score function forms is difficult. Specifically, while it is possible to extend the results to score functions of the form $a(s, p) = (e^{s-\alpha p})^{\gamma}$, which allows the buyer to set two parameters, α and γ, and thus provides additional flexibility, we have not been able to obtain results for non-exponential score functions. In order to obtain more general results, we have considered the case of fixed service levels. In this case, we still consider a buyer who allocates demand on the basis of both price and service level, but under the assumption that the supplier's service levels are fixed, due perhaps to budget or space limitations. Notice that, if the fixed service levels at the suppliers differ, then their score functions will differ, i.e., supplier i's score function will be $a_i(p) = a(p, s_i)$. For this problem, for general score function forms, we can show that the supplier game is supermodular, and thus that an equilibrium exists. In addition, if the service levels are not equal, i.e., if $s_1 \neq s_2$, then the equilibrium prices and allocations will not be symmetric. These results can be considered an extension of the results in Bernstein and Federgruen (2004).

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