Chapter 8
Tales of a Fashion So(u)rcerer: Optimal Sourcing, Quotation, and In-House Production Decisions

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Abstract Most companies in fashion industry, as well as many other industries, must procure items necessary for their businesses from outside sources, where there are typically a number of competing suppliers with varying cost structures, price schemes, and capacities. This situation poses some interesting research questions from the outlook of different parties in the supply chain. We consider this problem from the perspective of (i) the party that needs to outsource, (ii) the party that is willing to serve as the source, and (iii) the party that has in-house capability to spare. We allow for stochastic demand, capacitated facilities (in-house and suppliers'), and general structures for all relevant cost components. Some simpler versions of this problem are shown to be NP-hard in the literature. We make use of a dynamic programming model with pseudo-polynomial complexity to address all three perspectives by solving the corresponding problems to optimality. Our modeling approach also lets us analyze different aspects of the problem environment such as pricing schemes and channel coordination issues.

Keywords Sourcing · Supplier selection · Inventory · Production · General costs · Capacity · Supply chain · Channel coordination · Fashion industry

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8.1 Introduction and Related Literature

Fashion industry is very challenging in terms of production and inventory planning due to its two main characteristics: (1) the product life cycle is fairly short—especially for fads—because of changing tastes and trends. This typically means that most—if not all—of the production needs to take place before the demand materializes and there is hardly any possibility to adjust the order quantities, considering relatively long production lead times associated with designing the products, sourcing the materials, converting them into final products, and distributing the products to the market. (2) The demand is highly volatile and difficult to predict in advance. This necessitates a careful trade-off between all cost parameters regarding sourcing, manufacturing, underage, and overage in optimizing the production quantities, underage typically being quite costly in the long run. Consequently, an analytical treatment of production and inventory planning for fashion industry incorporating these characteristics is necessary. While the problem can be considered as a basic one in operations management literature characterized by the newsvendor model, the sourcing aspect which is extremely common in today's complex supply chains is mostly overlooked due to the difficulties discussed later in this chapter. In what follows we address this problem from different angles. Since our work does not only apply to fashion industry but also to other industries that are subject to short life cycles and stochastic demand, we follow a generic terminology in the rest of the chapter (i.e., product, component, and manufacturer) instead of one that refers specifically to fashion industry.

Consider a manufacturer or retailer who procures (or, 'sources') a certain product or service, to use directly or indirectly in meeting the stochastic demand that she faces. Considering the manufacturing environment as an example, the product that is to be procured (or, the 'item') can be supplied by a finite number of capacitated external suppliers, and the manufacturer must decide which of the sources to utilize and to what extent. One could prefix the procurement quantity based on inventory- and production-related costs and then find the least costly solution from the available pool of suppliers with corresponding price structures and capacities. However, the optimal sourcing (procurement) decision under stochastic demand requires an integrated approach, using all of the cost parameters and capacity and price information of alternative suppliers simultaneously.

Supplier price and capacity information could be collected by making use of e-business infrastructure or organized industrial associations, or by contacting qualified suppliers, using a request for quotations (RFQ). These sources may have different capacities and price structures, but we consider them to be identical in terms of their function, i.e., the item's characteristics do not depend on the supplier. We do not restrict our analysis to a particular cost function for procurement, and we allow, for example, for a separate fixed cost for initiating the use of each source, for logistics costs that might depend on the geographical location of the suppliers, and for nonlinear unit variable costs. Progressive or all-units quantity discounts are special cases (see Andrade-Pineda et al. 2015, for a particular treatment of a nonlinear quantity discount cost scheme in supplier selection problem). Moreover, the 'cost-of-doing business' with each supplier might incur nonlinear cost factors (Kostamis et al. 2009). The suppliers' capacity utilization might result in re-evaluating the remaining available capacities, inducing quantity-dependent price quotations.

Purchasing is a common operation for all types of businesses. Kaplan and Sawhney (2000) analyze business-to-business e-commerce marketplaces and classify the purchasing market as manufacturing inputs and operating inputs, in terms of what businesses buy and as systematic sourcing and spot sourcing, in terms of how they buy. Our approach applies to any type of manufacturing or operating inputs that face stochastic demand and that are purchased from the spot market: the 'exchanges' and 'yield managers,' respectively (Kaplan and Sawhney 2000). There are numerous Web-based platforms on the market that can materialize the sourcing methodologies prescribed in this study. There are general-purpose B2B e-commerce platforms such as Ariba (2014), Fiatech (2014), and 1 Point Commerce (2014) and specific platforms operated by companies for their operations such as the ones by Ford (2014), Foster Wheeler (2014), and Hilton (2014).

We consider three problems (or sorcerer's tales) in such an environment:

1. Manufacturer's Sourcing Problem: 'How to do the trick?' That is, which sources should be utilized to what extent?
2. Supplier's Problem: 'How to cast a counter-spell?' That is, if a new supplier that intends to bid on the RFQ has information on his competitors' price and capacities, what is the best price he should quote and what is the capacity he should dedicate?
3. Manufacturer's In-House Production Capacity Problem: 'Cast your own spell.' That is, if the manufacturer can allocate some of her resources for in-house manufacturing of the item, how much capacity should she dedicate for this?

We note that our problem environment is extremely general and is not necessarily confined to procurement of goods in fashion industry or even a supply chain context. To name some other environments, consider transportation logistics, manufacturing options, carbon offsetting, and the make-or-buy problem. As for transportation logistics, suppose that the materials ordered by a manufacturer or a retailer are shipped by vehicles with certain capacities. For each vehicle utilized, there may exist a fixed cost as well as a unit variable cost and possibly quantity discounts. The total order may be satisfied with a number of vehicles with varying characteristics. As for the manufacturing options, consider a heating process using industrial ovens. Each oven may have a different capacity and a particular cost of operation, including fixed costs. Similarly, consider a production environment with flexible and dedicated machines, in which each machine incurs different setup and production costs. As for carbon offsetting, consider a socially responsible company that wants to offset its carbon emissions by investing in carbon abatement projects. The company must choose the 'best' (cost minimizing or utility maximizing) way of offsetting, from a number of certified offsetting options with different cost parameters (or utilities) and carbon abatement capacities.

Procurement decisions should consider the cost of materials procured, delivery punctuality, the quality of items procured, creation of effective strategic partnerships, possibly the carbon footprint, and the like. Therefore, one of the key processes of effective supply chain management is the supplier selection process, which consists of determining a supplier base (a set of potential suppliers to operate with), the supplier(s) to procure from, and the procurement quantities. We refer the reader to Elmaghraby (2000) for an overview of research on single- and multiple-sourcing strategies. Aissaouia et al. (2007) present a comprehensive review of literature related to several aspects of the procurement function, including the supplier selection process and in-house versus outsourcing decisions. Firms sometimes employ multiple criteria in selecting their suppliers (Ustun and Demirtas 2008; Hosseininasab and Ahmadi 2015). A survey of multi-criteria approaches for supplier evaluation and selection processes is presented by Ho et al. (2010). More recently, Kumar et al. (2014) introduce a supplier selection approach taking carbon footprint of the suppliers into account. Jia et al. (2015) consider a broader perspective by taking all three aspect of the triple bottom line into account, that is, people, planet, profit in fashion industry. In our work, we do not include the multi-criteria supplier evaluation phase. We assume that the supplier base has already been determined and that the immediate supplier selection decisions are based on the cost criterion.

In our analysis, we consider a single-period, single-item make-to-stock setting. The procurement problem has received much attention, mostly under the deterministic demand assumption (which results in a preset total procurement quantity). When the demand is deterministic, the problem becomes either (i) to determine the set of suppliers to purchase a given quantity, or (ii) to determine the suppliers and the purchasing frequency for a given demand rate. Chauhan and Proth (2003) consider a version of the problem, in which there is a lower and an upper bound for the capacity of each supplier, and the supply costs are concave. They propose heuristic algorithms. Chauhan et al. (2005) show that the problem considered by Chauhan and Proth (2003) is NP-hard. Burke et al. (2008a) consider this problem under different quantity discount schemes and capacitated suppliers. They propose heuristic algorithms to solve the problem. Burke et al. (2008b) discuss that this particular problem is a version of the 'continuous knapsack problem,' in which the objective is to minimize the sum of separable concave functions, and show that this problem is NP-hard. Romeijn et al. (2007) analyze the continuous knapsack problem with nonseparable concave functions and propose a polynomial time algorithm. We note that the supplier selection problem with stochastic demand results in a nonseparable cost function; it is actually not a knapsack problem, because the size of the knapsack (the amount allocated to the suppliers) is itself a decision variable. We provide an exact pseudo-polynomial algorithm to solve the stochastic version of this problem, while not imposing restrictions on the supply cost. We refer the interested reader to Burke et al. (2008b) for a further review of the related literature and to Qi (2007), Kawtummachai and Hop (2005), and Mansini et al. (2012) for different aspects of the problem under deterministic demand. In this study, we contribute to the literature by considering stochastic demand and by including general cost structures.

The stochastic demand version of the procurement problem under capacitated suppliers has also received attention to a certain extent in the literature. Alp and Tan (2008) and Tan and Alp (2009) analyze the problem with two supply options, in a multi-period setting under fixed costs of procurement. Alp et al. (2014) consider an infinite horizon version of this problem with identical suppliers and a linear cost function with a fixed component, which is a special case of ours. Awasthi et al. (2009) consider multiple suppliers that have minimum order quantity requirements and/or a maximum supply capacity, but no fixed cost is associated with procurement. They show that this problem is NP-hard, even when the suppliers quote the same unit price to the manufacturer and propose a heuristic algorithm for the general version. Hazra and Mahadevan (2009) analyze an environment in which the buyer reserves capacity from a set of suppliers through a contracting mechanism. The capacity is reserved before the random demand is observed and allocated uniformly to the selected suppliers. If the capacity is short upon demand realization, the shortage is fulfilled from a spot market at a higher unit price. Our work differs from these articles, because we consider multiple suppliers and general cost functions, and we do not impose a particular structure on the allocation of purchased quantity to the suppliers.

Zhang and Zhang (2011) consider a similar environment to ours. A single item that faces stochastic demand is procured from potential suppliers that have minimum and maximum order sizes, and a fixed procurement cost is considered. They propose a nonlinear mixed-integer programming formulation and a branch-and-bound algorithm. Our problem is more general than this, as we do not impose restrictions on the supply cost structures, a situation that cannot be handled by the methodology proposed by the aforementioned authors. Finally, we note that Zhang and Ma (2009) also consider a similar problem for multiple items. They assume that suppliers are capacitated and offer quantity discounts. A mixed-integer nonlinear programming formulation that determines the optimal production quantities of each product, purchasing quantities of the raw materials, and the corresponding suppliers to make the purchases is proposed. Ayhan and Kilic (2015) propose a two-stage approach to select suppliers under quantity discounts where the first stage is used to find the relative weights of the selection criteria and the second stage selects best suppliers via a MILP model. Another work that is related to our problem environment, particularly considering the problem from the suppliers' point of view, is by Li and Debo (2009). The authors consider an existing and an entrant supplier that compete for the business of the manufacturer. Using a unit variable cost structure and considering a two-period setting where the demand in the second period is stochastic, the authors derive several managerial insights regarding the capacity investment and price quotation decisions of both suppliers.

Our study also elaborates on the value of coordinating the business channel between a supplier and the manufacturer. Several mechanisms such as contracting, quantity discounts, return options have been proposed in the literature in order to coordinate the channel and create a win–win situation. Li and Wang (2007) present a comprehensive review of the channel coordination literature. Toptal and Cetinkaya (2008) quantify the value of channel coordination between a supplier and a buyer under a certain cost structure. Kheljani et al. (2009) consider a buyer's sourcing decisions by focusing on optimizing the channel's profit. Both of these studies consider deterministic demand. Xia et al. (2008) consider the channel coordination problem for a multiple supplier and multiple buyer setting. The order quantity and frequency of the buyers are exogenous parameters. The authors present models that can be used to coordinate the channel by matching the suppliers' cost functions and the buyers' purchasing behaviors.

In the third subproblem, we show how our main methodology can be used to find the optimal in-house production versus outsourcing decision (considering the cost aspect of the problem in isolation), as in-house production can be considered one of the available sourcing options. In such situations, it is likely that the total cost of allocating some or all in-house capacity for producing the item would have a nonlinear nature, stemming from cost components such as fixed costs, incremental capacity usage costs, and concave or convex capacity allocation (opportunity) costs. The complexity of in-house capacity costs is also illustrated by a Darden School of Business case on Emerson Electric Company (Davis and Page 1991). The flexibility of our proposed methodology in its ability to handle all kinds of cost functions is one of our major contributions to literature.

The major contributions of our paper can be summarized as follows:

- We build a novel dynamic programming model that we use for finding the optimal solution to the NP-hard sourcing problem under a fairly general setting consisting of stochastic demand, general cost structures and capacitated suppliers in one shot. The computational complexity of the solution that we propose is pseudo-polynomial.
- We evaluate the performance of decoupling sourcing and production decisions.
- We develop a methodology to find the optimal pricing decision of a supplier who competes with other suppliers.
- We develop a methodology to find the optimal capacity allocation decision of the manufacturer for in-house manufacturing under the existence of alternative production sources.
- Finally, we make observations and build managerial insights, some of which are contrary to the collective intuition that traditional inventory/production models generate.

The rest of the paper is organized as follows: We present the manufacturer's sourcing problem in Sect. 8.2. The supplier's problem is analyzed in Sect. 8.3 and the manufacturer's in-house production capacity problem is analyzed in Sect. 8.4. We conclude the paper in Sect. 8.5.

8.2 Manufacturer's Sourcing Problem: How to Do the Trick?

In this section, we analyze the procurement problem in a single-period setting, under a given set of alternative capacitated suppliers, with corresponding general procurement cost functions. The procured quantity also dictates the stock quantity, subject to stochastic demand. There are two decisions in such an environment: Which sources should be utilized and in what quantities? The relevant parameters in determining those quantities are not only procurement costs and supplier capacities, but also the inventory-related cost parameters in the system. Nevertheless, one could either prefix the total order quantity and then decide on the allocation of this to the supplier base in a sequential manner, or make those decisions in an integrated fashion. The former could be a result of factors such as (i) the perception that procurement-related (external) parameters and production/inventory-related (internal) parameters need to be treated separately; (ii) the time lag between those decisions, e.g., the production department determines required quantities and relays this information to the purchasing department, who makes the purchase with the least cost; (iii) lack of sufficient coordination between separate departments within the organization, e.g., making their uncoordinated decisions based on sales targets and forecasts of the company or their separate performance incentives; (iv) the conventional market and/or company practice of tendering for bids based on a prefixed quantity; (v) lack of sufficient information on the supplier base; and (vi) managerial overlook on the potential savings of integration. In the absence of such factors, solving the problem by considering all problem parameters in an integrated way constitutes the basic research question that we address.

In what follows, we first highlight a major drawback of the sequential approach. Then, we present a dynamic programming model to formulate the problem under consideration and show how the optimal solution can be found in an integrated manner. Finally, we present the results of the numerical study we conducted to investigate (i) the effect of problem parameters on the optimal solution, and (ii) the performance of the sequential approach.

The relevant costs in our environment are the costs of procuring from suppliers and underage and overage costs, all of which are exogenously determined and nonnegative. We do not impose any conditions on the costs of procuring from suppliers, and, hence, these costs might assume any form, including fixed costs for procurement, stepwise costs for shipments, costs that imply minimum order quantities, and different forms of quantity discounts. Our approach allows for the underage and overage costs of the remaining inventory level after demand materialization to also assume any form, via the corresponding loss function. We consider capacitated suppliers with fixed and known capacities. We assume full availability of the ordered quantities, and we also assume that the differences between procurement lead times from alternative suppliers can be neglected. In case the latter assumption is significantly violated, different lead times can be approximately incorporated into the model, by considering appropriate costs associated

Table 8.1 Summary of notation

N	Number of alternative suppliers
Q	Total procurement quantity
U_n	Capacity of supplier $n, n = 1, 2, \ldots, N$
q_n	Quantity procured from supplier n
$C_n(q_n)$	Cost of procuring q_n units from supplier $n, n = 1, 2, \ldots, N$
h	Overage cost per unit unsold
b	Underage cost per unit of unmet demand
W	Random variable denoting the demand
$G(w)$	Distribution function of W

with purchasing from each supplier, reflecting the cost effect of corresponding procurement lead times. Similarly, other non-biddable price factors, such as delivery punctuality, the quality of items procured, and strategic partnership concerns, are also valuated by the manufacturer and reflected in the procurement costs. Naturally, the more differences in non-biddable price factors, the less accurate the cost-based methods (like ours). For a discussion on the valuation of non-biddable price factors, see Kostamis et al. (2009). We summarize our major notation in Table 8.1.

If q_n units are procured from supplier $n, n = 1, 2, \ldots, N$, with a corresponding cost of $C_n(q_n)$, then the total cost of procuring $Q = \sum_n q_n$ units is $PC(Q) = \sum_n C_n(q_n)$, and the resulting average unit procurement cost is $c = PC(Q)/Q$. The problem is to minimize expected total costs $ETC(Q) = PC(Q) + \mathcal{L}(Q)$, where $\mathcal{L}(Q)$ denotes the total expected overage and underage costs, the standard loss function $\mathcal{L}(Q) = h\int_0^Q (Q - w)dG(w) + b\int_0^\infty (w - Q)dG(w)$ being a special case. In the sequential approach, the total order quantity Q^o is decided without knowing the total cost of procurement. This is because it is unknown, a priori, what the exact allocation of the total order quantity to the supplier base is, or whether the supplier base has the total capacity to meet this order. Once the total order quantity is determined, the allocation is optimized by solving the following problem (P), based on the sales prices and capacities quoted by various suppliers:

$$\begin{aligned} \text{Min.} \quad & \sum_n C_n(q_n) \\ \text{st} \quad & \sum_n q_n = \min\left\{Q^o, \sum_n U_n\right\} \\ & q_n \le U_n \quad \text{for all } n. \end{aligned}$$

Note that Q^o is not necessarily equal to the optimal procurement quantity, $\widehat{Q} = \sum_n q_n$. As to the determination of the total order quantity Q^o, if only the inventory-related costs are considered, then the optimal order quantity is $\widehat{Q}^o = \arg, \min_Q\{\mathcal{L}(Q)\}$. But this approach results in overestimation of the required quantity, as it neglects procurement costs. If one prefers to incorporate a linear unit procurement cost of c, the resulting optimal order quantity would be $\widehat{Q}^o(c) = \arg, \min_Q\{cQ + \mathcal{L}(Q)\}$ (in case of standard loss function $\mathcal{L}(Q)$, the solution would then be $\widehat{Q}^o(c) = G^{-1}\left(\frac{b-c}{b+h}\right)\Big)$. However, in general, there is no way of knowing what the actual procurement cost will be, until the required quantity is known. One could prepare a list of all possible quantities, but each entry in the list requires solving problem P, which is a knapsack problem with a general objective function. A special case is the fixed-charge continuous knapsack problem (see Haberl 1999), which is NP-hard with some known pseudo-polynomial algorithms.

A simple approach is to incorporate an estimate of the purchasing cost, $\tilde{c} = \frac{\sum_n C_n(U_n)}{\sum_n U_n}$, and decide on $\widehat{Q}^o(\tilde{c})$ accordingly, after which $\widehat{Q} = \min\left\{\widehat{Q}^o(\tilde{c}) \sum_n U_n\right\}$ units are procured by solving problem P. Nevertheless, this approach can be improved: Once the optimal cost of procuring $\widehat{Q}$ and the corresponding average unit procurement cost $c = PC(\widehat{Q})/\widehat{Q}$ are known, $\widehat{Q}^o$ can be updated by making use of this information, and so forth. Exploiting this idea, one can come up with the following algorithm (where Step 0 makes use of the computations stated above as the simple approach):

Step 0. Set i = 1, $\widehat{Q}_i = \min\left\{\widehat{Q}^o(\tilde{c}), \sum_n U_n\right\}, c_{i+1} = PC(\widehat{Q}_i)/\widehat{Q}_i$.

Step 1. Set $i = i + 1$. Find $\widehat{Q}_i^o(c_i) = \arg, \min_Q\{c_iQ + \mathcal{L}(Q)\}$.

Step 2. Solve problem P with $Q^o = \widehat{Q}_i^o(c_i)$ to decide on the optimal allocation of $\widehat{Q}_i = \min\left\{\widehat{Q}_i^o(c_i), \sum_n U_n\right\}$ to the supplier base.

Step 3. Compute the average unit cost associated with purchasing $\widehat{Q}_i$ units, $c_{i+1} = PC(\widehat{Q}_i)/\widehat{Q}_i$.

Step 4. If the solution converges (i.e., if $\left|\widehat{Q}_i - \widehat{Q}_{i-1}\right| < \epsilon$, where ϵ is a small enough constant) or the algorithm is run for a sufficiently long time, quit with $Q = \widehat{Q}_i$. Otherwise, go to Step 1.

Naturally, the sequential approach described above does not necessarily find the optimal solution. Any approach (such as dynamic programming, DP) that considers the allocation of an additional unit will not guarantee optimality either, as the solution may change drastically by this additional unit. Furthermore, the problem cannot be seen as a special case of a knapsack problem with a non-separable objective function, because the 'knapsack size' (i.e., the total amount to be purchased and allocated to the suppliers) is also a decision variable. Consequently, the problem requires a different solution approach.

Nevertheless, the following DP formulation can be used to solve the integrated problem of finding optimal procurement decisions, including the procurement quantity, with $f_n(x)$ defined as the minimum total cost of

(i) procuring from the partial supplier base $\{n, n+1, \ldots, N\}$ and
(ii) the expected overage and underage of the total quantity purchased from the full supplier base $\{1, \ldots, N\}$,

when x units are already procured from the partial supplier base $\{1, 2, \ldots, n-1\}$.

The manufacturer's problem (MP):

$$\text{for } 0 \le x \le \sum_{i=1}^{N} U_i: \quad f_{N+1}(x) = \mathcal{L}(x),$$
$$\text{for } 0 \le x \le \sum_{i=1}^{N} U_i: \quad f_n(x) = \min_{y: x \le y \le x+U_n} \{C_n(y-x) + f_{n+1}(y)\} \quad \text{for} \quad 2 \le n \le N,$$
$$f_1 = \min_{y: 0 \le y \le U_1} \{C_1(y) + f_2(y)\}.$$

Theorem 1 *The minimum cost attained by the optimal solution of MP is given by f_1 for any arbitrary order of suppliers numbered from 1 to N.*

Proof Let us number the suppliers from 1 to N. Any order can be used. The Procurement Problem is to find the optimal procurement quantities q_n^* for $n \in \{1, \ldots, N\}$ that minimize the total cost of procuring from the supplier base $\{1, 2, \ldots, N\}$ and the expected overage and underage cost, i.e.,

$$\begin{aligned}
& C_1(q_1^*) + C_2(q_2^*) + \cdots + C_N(q_N^*) + \mathcal{L}(q_1^* + q_2^* + \cdots + q_N^*) \\
&= \min_{\substack{0 \le q_1 \le U_1, \\ \ldots, \\ 0 \le q_N \le U_N}} \{C_1(q_1) + C_2(q_2) + \cdots + C_N(q_N) + \mathcal{L}(q_1 + q_2 + \cdots + q_N)\} \\
&= \min_{0 \le q_1 \le U_1, \ldots, 0 \le q_N \le U_N} \{C_1(q_1) + C_2(q_2) + \cdots + C_N(q_N) + f_{N+1}(q_1 + q_2 + \cdots + q_N)\} \\
&= \min_{0 \le q_1 \le U_1, \ldots, 0 \le q_{N-1} \le U_{N-1}} \Big\{C_1(q_1) + \cdots + C_{N-1}(q_{N-1}) \\
&\quad + \min_{0 \le q_N \le U_N} \{C_N(q_N) + f_{N+1}(q_1 + q_2 + \cdots + q_N)\}\Big\} \\
&= \min_{0 \le q_1 \le U_1, \ldots, 0 \le q_{N-2} \le U_{N-2}} \{C_1(q_1) + \cdots + C_{N-1}(q_{N-1}) + f_N(q_1 + \cdots + q_{N-1})\} \\
&= \min_{0 \le q_1 \le U_1, \ldots, 0 \le q_{N-2} \le U_{N-2}} \Big\{C_1(q_1) + \cdots + C_{N-2}(q_{N-2}) \\
&\quad + \min_{0 \le q_{N-1} \le U_{N-1}} \{C_{N-1}(q_{N-1}) + f_N(q_1 + q_2 + \cdots + q_{N-1})\}\Big\} \\
&= \min_{0 \le q_1 \le U_1, \ldots, 0 \le q_{N-2} \le U_{N-2}} \{C_1(q_1) + \cdots + C_{N-2}(q_{N-2}) + f_{N-1}(q_1 + \cdots + q_{N-2})\} \\
& \ldots \\
&= \min_{0 \le q_1 \le U_1} \{C_1(q_1) + f_2(q_1)\} = f_1.
\end{aligned}$$

Note that the above result does not depend on the ordering of the suppliers due to the commutative property of the addition operator; hence, it does not depend on the initial choice of ordering, and, therefore, the theorem holds for any arbitrary order of suppliers. □

Let $q_n^*(x)$ be such that $x \le q_n^*(x) \le x + u_n$ and

$$C_n\big(q_n^*(x)\big) + f_{n+1}\big(x + q_n^*(x)\big) \le C_n(y - x) + f_{n+1}(y) \quad \forall y : x \le y \le x + u_n,$$

for any given value of x. Then, the optimal quantity procured from supplier n, τ_n, is given by

$$\tau_1 = q_1^*(0), \tau_n = q_n^*\left(\sum_{i=1}^{n} \tau_i\right) \text{ for } 2 \le n \le N.$$

The total optimal procurement quantity is given by $Q^* = \sum_{i=1}^{N} \tau_i$. The computational complexity of this DP is $O\big(N\big(\sum_n U_n\big)\max_n(U_n)\big)$.

We conducted a numerical study to investigate (i) the effect of problem parameters on the optimal solution (Sects. 8.2.1 and 8.2.2) and (ii) the performance of the sequential approach (Sect. 8.2.3). We considered the following setting: The demand has a Gamma distribution with coefficient of variation (CV) values of 0.5, 1, 1.5, and with expected values, *E[W]*, of 20, 40, 50, and 60. Demand is assumed to be discrete in this section for ease of exposition. The cost parameters are $h = 1$, $b = 2, 5, 10, 50$, and 200. We consider three sets of suppliers. In the first set (Supplier Base 1), there are $N = 5$ alternative suppliers $(n = 1, 2, \ldots, 5)$ with capacities U_n = 40, 20, 20, 10, and 10, respectively. There exists a fixed-cost component of ordering from supplier n, with $K_n = 40, 20, 20, 10$, and 10, respectively, and a linear unit variable cost component of c_n, in which $c_1 \in \{1.5, 2, 2.5\}$, c_2 and $c_3 \in \{2, 2.5, 3\}$, c_4 and $c_5 \in \{2.5, 3, 3.5\}$. This set resembles a situation in which the supplier base consists of a variety of suppliers, in terms of cost and capacity. In the second set (Supplier Base 2), there are also $N = 5$ alternative suppliers, but their capacities are $U_n = 60, 10, 10, 10$, and 10, respectively. We set the fixed cost of ordering from supplier n as $K_n = 60, 10, 10, 10$, and 10, respectively, and we set a linear unit variable cost component of c_n, as $c_1 \in \{1.0, 1.5, 2.0\}$, and c_2 to $c_5 \in \{2.5, 3, 3.5\}$. This set resembles a situation in which there is one dominant supplier in the supply base, and the rest are relatively smaller suppliers. The third set (Supplier Base 3) also consists of $N = 5$ alternative suppliers, but their capacities are $U_n = 24, 22, 20, 18$, and 16, respectively. We set the fixed cost of ordering from supplier n as $K_n = 24, 22, 20, 18$, and 16, respectively, and a linear unit variable cost component of c_n, as $c_1 \in \{1.8, 2.3, 2.8\}$, $c_2 \in \{1.9, 2.6, 2.9\}$, $c_3 \in \{2.0, 2.5, 3.0\}$, $c_4 \in \{2.1, 2.6, 3.1\}$, and $c_5 \in \{2.2, 2.7, 3.2\}$. This set resembles a situation in which there is no dominant supplier, and all suppliers are comparable in capacity.

Table 8.2 The optimal procurement decision at different coefficients of demand variation and underage costs

	$b = 2$	$b = 5$	$b = 10$	$b = 50$	$b = 200$
CV = 0.5	$(0, 0, 0, 0, 0)$	$(40, 0, 0, 0, 0)$	$(40, 0, 0, 0, 0)$	$(40, 20, 17, 0, 0)$	$(40, 20, 20, 10, 0)$
CV = 1.0	$(0, 0, 0, 0, 0)$	$(0, 20, 0, 0, 0)$	$(40, 0, 0, 0, 0)$	$(40, 20, 20, 10, 0)$	$(40, 20, 20, 10, 10)$
CV = 1.5	$(0, 0, 0, 0, 0)$	$(0, 0, 0, 0, 0)$	$(40, 0, 0, 0, 0)$	$(40, 20, 20, 10, 10)$	$(40, 20, 20, 10, 10)$

Supplier Base 1; $E[W] = 40$; and $c_n = 1.5, 2, 2, 3$, and 3, for $n = 1, \ldots, 5$

8.2.1 *Effects of Demand Variability and Cost Parameters*

The following insight that simple inventory/production models generate holds for the procurement problem to some extent: As the unit underage cost increases (while keeping all other problem parameters constant), the total quantity procured from the suppliers and the total expected costs of the operation increase. As any cost component of a supplier increases, the supplier is preferred less by the buyer, and the total procurement quantity, if any, from that supplier decreases. The optimal total procurement quantity does not necessarily increase as the variability of demand increases (see Table 8.2), because the risk of being left with unsold goods (as in obsolescence) outweighs the risk of goodwill loss, due to relatively high procurement and overage costs.

We also observe that the optimal solution might be extremely sensitive to cost parameters. For example, when $\mathrm{CV} = 1.0$, $b = 5$, $N = 3$, $U_n = 40, 20, 10$, $K_n = 40, 20, 10$, and $c_n = 1.5, 2.5, 2.5$, for $n = 1, 2, 3$, respectively, the optimal solution is $(37, 0, 0)$. When we keep all parameters the same, except for $c_1 = 2$, instead of 1.5, the optimal solution becomes $(0, 0, 10)$, which represents not only a 73 % decrease in total procurement quantity, but also a completely different supplier selection. This example shows that the optimal solution of a particular situation could significantly change, even when a single parameter changes, indicating a lack of robustness, which emphasizes the importance of having a methodology appropriate for finding the optimal solution.

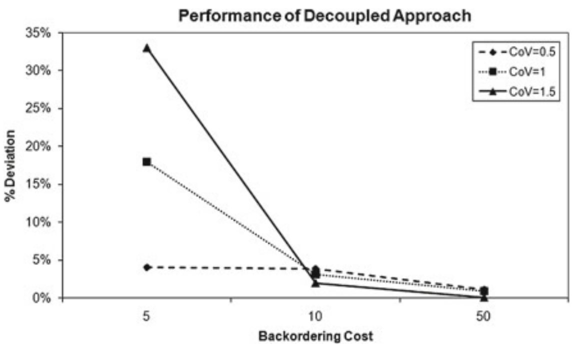
8.2.2 *Effects of Flexibility*

In this section, we analyze the impact of flexibility on optimal procurement decisions. We call one problem environment ‘more flexible’ than another when there is at least one more procurement option to choose from. In our numerical tests, we frequently observe that the total procurement quantity does not decrease as the problem environment becomes more flexible. Nevertheless, our numerical experiments reveal that a more flexible environment may also lead to lower procurement quantities. Such a situation is observed when a more appealing (e.g., cheaper per unit, when the order size is sufficiently high) procurement alternative is introduced to the supplier base, and it is not necessary to place a high order size, to benefit from economies of scale in the former situation, by utilizing this new supplier. An example of this situation can be illustrated by the following instance: Supplier Base 1, $E[W] = 40$, $\mathrm{CV} = 0.5$, $b = 5$, $c_n = 2.5, 3, 3, 2.5$, and 2.5, for $n = 1, \ldots, 5$, respectively. Let us first set $U_3 = U_5 = 0$, i.e., only suppliers 1, 2, and 4 are available with $U_1 = 40, U_2 = 20$, and $U_4 = 10$. In this case, the optimal solution is $(34, 0, 0, 0, 0)$. When we make this system more flexible by letting $U_3 = 20$, and $U_5 = 10$, the optimal solution becomes $(0, 0, 0, 10, 10)$, decreasing the total procurement by 41 %. In the former situation, the buyer does not prefer to procure 20 units (as in the latter case), because Supplier 1 is short in capacity, and Supplier 2 is a more expensive option. The fixed cost of Supplier 1 leads to the procurement of a larger quantity in the optimal solution. In the latter situation, the introduction of Supplier 5, a cheaper option, makes it unnecessary to utilize Supplier 1 with its high fixed cost; 20 units turn out to be optimal when the trade-off between the underage and fixed costs are resolved. This phenomenon is observed in several more problem instances with similar conditions, also for Supplier Base 2 and 3. On the other hand, this is attributed to the existence of suppliers with diverse cost and capacity structures, e.g., when there is a dominant supplier. When we decreased this diversity in our numerical tests by trimming the cost differences among the suppliers in any particular supplier base, we consistently observed a decrease in the number of cases in which this phenomenon is observed. Obviously, in the limit when all suppliers are identical, increasing flexibility does not lead to a decrease in total procurement quantity.

8.2.3 Value of the Integrated Approach

Finally, we compare the optimal solution of the integrated approach with the solution found by the sequential approach as presented in Sect. 8.2. The average cost deviation percentages relative to the optimal solution over all the problems in our test bed are presented in Fig. 8.1.

Fig. 8.1 Percent of cost deviation due to sequential approach



The sequential approach performs well, when the underage cost is either extremely low or is the dominating cost factor: the sequential approach yields the optimal solution when $b = 2$ and the average cost deviation is 0.34 % for $b = 200$, in our test bed. This is because when b is as low as 2 in our test bed, the optimal policy is trivially to always backorder; when b is high, procurement takes place in large quantities, sometimes consuming the full available capacity, which is the other extreme trivial solution. Nevertheless, when the underage cost is neither dominating nor insignificant, the value of the integrated approach over the sequential approach appears to be significant. The average cost deviation over all cases considered is 12.18 and 4.67 % when $b = 5$ and 10, respectively; the maximum is 85.81 %, which also demonstrates the importance and non-triviality of finding the optimal solution.

8.3 Supplier's Problem: How to Cast a Counterspell?

In this section, we take the suppliers' point of view into consideration. Consider a particular supplier (referred to as 'the supplier' from now on) who intends to earn the manufacturer's business, preferably by forming a channel between himself and the manufacturer. The supplier—who might be a new entrant to the market—intends to respond to the RFQ announced by the manufacturer. He either needs to install new capacity or spare a portion of his existing capacity for the manufacture of the item. What the supplier must determine are the optimal capacity to dedicate and the optimal price to quote to the manufacturer, under the existence of other suppliers (referred to as the 'alternative suppliers' in the rest of the text). After receiving all quotations, the manufacturer will determine her optimal course of action by using the methodology explained in Sect. 8.2.

The supplier would benefit from the price and capacity information of the alternative suppliers in order to make a better decision about the capacity to dedicate and the price to quote to the manufacturer, should the information be collected one way or another. Such information might be available to the supplier if (i) the supplier has enough experience in the market, e.g., through the subcontractors that he has been collaborating with, (ii) the majority of the alternative suppliers are members of organized industrial associations or zones, where their association puts additional marketing effort by disclosing relevant information to interested parties, (iii) there exists a business-to-business establishment, e.g., an e-business portal with suppliers' posted price and capacity information (see, e.g., Agrali et al. 2008, for the case of an auction-based logistics market), or an online auction (see, e.g., Chen et al. 2005) where the information is made available to the other bidders, and the like. Note that in some cases such as sourcing from overseas suppliers, transportation cost might constitute an important portion of the procurement cost, which facilitates collecting necessary information on the cost structure. If the supplier has information on the manufacturer's demand distribution or he can anticipate it, he could use the methodology presented in Sect. 8.2 to predict how the manufacturer would operate. The question that we address in this section is how the supplier can make use of this information to form a list of price quotations at various quantities that will result in the manufacturer procuring the quantity that maximizes the supplier's profit. If the supplier could find such a price and capacity pair, then he would eliminate the uncertainty as to the capacity he should dedicate to this manufacturer.

Prior to the quotation of the supplier, the manufacturer has a certain course of action. However, any capacity and price quotation offered by the supplier might change the manufacturer's decision considerably. As noted in Sect. 8.2.1, this problem is very sensitive to the problem parameters; the effect of a change in even one of the parameters or an increase in the number of available suppliers cannot be easily anticipated without solving the problem under the new settings to optimality. Therefore, even if the supplier has all the necessary information, it is not straightforward to derive insights and to set a price and capacity pair without a methodology to find the optimal solution. The supplier needs to solve the following optimization problem, where we index the supplier as 1, and the alternative suppliers from 2 to N without loss of generality.

The supplier's problem (SP):

$$\begin{array}{lll} \max\limits_{p(Q^s) \geq 0, 0 < Q^s \leq U_1} & Z(p(Q^s), Q^s) = C_1(Q^s) - K_1(Q^s) - A(Q^s) & \\ \text{s.t.} & C_1(Q^s) + f_2(Q^s) \leq C_1(y) + f_2(y) \quad \forall y \leq U_1 & \\ & Q^s, y : \text{integer} & \end{array} \tag{8.1}$$

where

Q^s	Quantity quoted by the supplier
$p(Q^s)$	Average price per unit corresponding to selling Q^s units
$K_1(Q^s)$	Costs associated with purchasing Q^s units from the supplier that are not accrued by the supplier
$Z(p(Q^s), Q^s)$	Total profit of the supplier
$A(Q^s)$	Total cost of dedicating Q^s units of capacity to the manufacturer
$C_1(Q^s)$	$Q^s p(Q^s) + K_1(Q^s)$
$f_2(Q^s)$	The minimum cost of purchasing from alternative suppliers. If Q^s units are purchased from the supplier

Recall that $f_2(Q^s)$—which is the minimum cost of purchasing from all of the alternative suppliers—does not depend on the ordering of the suppliers, due to Theorem 1. Hence, the alternative suppliers may be ordered arbitrarily from 2 to N, where the solution does not depend on which supplier is indexed as number 2.

The objective function of SP is to maximize the profit generated by the supplier when the manufacturer purchases Q^s units with a cost of $C_1(Q^s)$, resulting is an average price of $p(Q^s)$ per unit, accrued by the supplier (possibly as a result of a nonlinear cost scheme quoted by the supplier). The cost $C_1(Q^s)$ also includes all costs associated with purchasing Q^s units from the supplier that are not accrued by the supplier, such as the shipping costs charged by a logistics service provider. In the constraint set, the expression on the left-hand side is the total cost of the manufacturer's optimal purchasing strategy when the supplier quotes Q^s units at an average price of $p(Q^s)$ per unit, whereas the right-hand side is the manufacturer's total cost associated with procuring any quantity less than U_1 from the supplier and the rest from the alternative suppliers. This constraint set ensures that the price quoted for each Q^s value makes it economical for the manufacturer to procure Q^s units in full from the supplier with a cost of $C_1(Q^s)$. Note that SP is a nonlinear programming model as the functions $A(Q^s)$, $C_1(Q^s)$, and $f_2(Q^s)$ can have any functional form. Nevertheless, we devise an algorithm to find the optimal solution by inspection.

For a given value of Q^s, $p(Q^s)$ attains the largest possible value, since we have a maximization problem. We first note that the constraint (8.1) at $y = 0$ provides an upper bound on $p(Q^s)$ because the manufacturer would procure only from the alternative suppliers for any price quotation above $p(Q^s)$. Since $C_1(0) = 0$, this upper bound turns out to be $p(Q^s) \leq \frac{f_2(0)-f_2(Q^s)}{Q^s}$. Repeating this for all $0 < Q^s \leq U_1$ generates a list of price quotations at each possible Q^s such that the manufacturer is indifferent between procuring Q^s units at a price of $p(Q^s)$ from the supplier and procuring Q^s units elsewhere. This means that the constraint set (8.1) is equivalent to $C_1(Q^s) + f_2(Q^s) \leq f_2(0) \quad \forall 0 < Q^s \leq U_1$, which decreases the complexity of the problem.

While SP generates a list of price quotations for all $0 < Q^s \leq U_1$, the supplier would not be interested in $(Q^s, p(Q^s))$ pairs with $Z(p(Q^s), Q^s) \leq 0$. Hence, the list consists of the $(Q^s, p(Q^s))$ pairs with positive profit. The supplier needs to give an incentive to the manufacturer to make sure that $Q^{s*} = Q^s$ that maximizes $Z(p(Q^s), Q^s)$ is procured by quoting a price of $p^*(Q^{s*}) = p(Q^{s*}) - \varepsilon$ for Q^{s*}, with $\varepsilon > 0$. We note that $Z(p^*(Q^{s*}), Q^{s*})$ is the maximum benefit that can be generated by the business channel between the supplier and the manufacturer. The supplier enjoys all of this benefit but the incentive, where the incentive ensures that the manufacturer is also better off compared to the situation without this business channel, resulting in channel coordination.

Property 2 *A list is optimal if it includes* $(Q^{s*}, p^*(Q^{s*}))$ *and* $(\bar{Q}^s, p(\bar{Q}^s))$ *such that* $p(\bar{Q}^s) \geq p(Q^s)$ *for all* $Q^s \neq Q^{s*}$.

In what follows, we provide an algorithm that can be used to generate a profitable quotation list, based on SP.

Step 0. Number the alternative suppliers starting from 2 and find $f_2(Q^s)$ by solving MP for all $0 \leq Q^s \leq U_1$.

Step 1. For each value of Q^s such that $0 \leq Q^s \leq U_1$, $p(Q^s) = (f_2(0) - f_2(Q^s))/Q^s$.

Step 2. Let $Q^{s*} = \arg\max_{Q^s} Z(p(Q^s), Q^s)$ and $p^*(Q^{s*}) = p(Q^{s*}) - \varepsilon$, such that $p^*(Q^{s*}) > 0$ and $Z(p^*(Q^{s*}), Q^{s*}) > 0$. If no such $(p^*(Q^{s*}), Q^{s*})$ exists, quit the algorithm as there is no profitable quotation list.

Step 3. An optimal quotation list consists of $(Q^{s*}, p^*(Q^{s*}))$ and $(Q^s, p(Q^s))$ for all $0 < Q^s \leq U_1$ such that $Q^s \neq Q^{s*}$, $p(Q^s) > 0$ and $Z(p(Q^s), Q^s) > 0$.

Step 0 and Step 1 take $O\left(N\left(\sum_n U_n\right)\max_n(U_n)\right)$ and $O(U_1)$ computational time, respectively, and Step 2 can already be computed within the effort required in Step 1. Therefore, the computational complexity of this algorithm is $O\left(N\left(\sum_n U_n\right)\right.$ $\left.\max_n(U_n)\right)$, i.e., it does not add to the complexity of MP.

Although for any non-speculative cost structure $f_2(Q^s)$ is non-increasing in Q^s, we note that $p(Q^s)$ is not necessarily monotonic in Q^s. Figure 8.2 depicts an example under the parameter setting introduced in Sect. 8.2 with $b = 10$, $\mathrm{CV} = 1.5$, and $c_n = 1.5, 2, 2, 2.5, 2.5$ for $n = 1, \ldots, 5$, respectively (the dotted line on the figure). The optimal $(Q^{s*}, p^*(Q^{s*}))$ is also encircled in Fig. 8.2, which is not even a local optima of the Q^s versus $p(Q^s)$ graph. While the Q^s versus $p(Q^s)$ graph may yield any form, it would be unconventional and complicated to quote such a non-monotone pricing scheme. To that end, the supplier can adopt a more practical scheme, such as quantity discounts, as long as it is in line with Property 2. Note that such a scheme would require the supplier to apply artificial mark-ups to optimal prices. We also depict an example pricing scheme with quantity discounts after the artificial mark-up in Fig. 8.2 (the solid line). A possible disadvantage of quoting elevated prices in practice is the prospective loss of goodwill of the manufacturer. Therefore, a remedy would be to apply a constant unit-price scheme (or, 'linear' scheme), which is observed frequently in practice. Furthermore, the manufacturer might specifically require a linear scheme. Nevertheless, which constant unit price must be quoted is not a trivial decision and requires further analysis. Quoting $p^*(Q^{s*})$ is not necessarily optimal, and moreover, it violates Property 2 unless $p^*(Q^{s*}) = \max_{Q^s} p(Q^s)$. Therefore, in the remainder of this section, we consider the 'special case' of linear price quotations between the supplier and the manufacturer.

If the manufacturer requires a linear pricing scheme from the supplier, then the supplier's problem becomes the following:

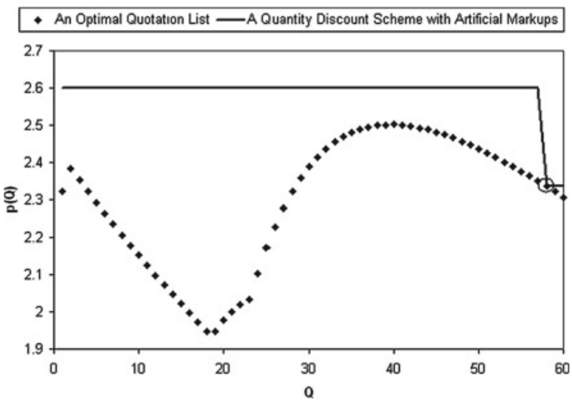


Fig. 8.2 An optimal pricing scheme example

$$
\begin{array}{lll}
(\mathrm{SP}^{\mathrm{L}}): & \max\limits_{p \geq 0, 0 < Q^s \leq U_1} & Z(p, Q^s) = pQ^s - A(Q^s) \\
\text{s.t.} & & pQ^s + K_1(Q^s) + f_2(Q^s) \leq py + K_1(y) + f_2(y) \quad \forall y \leq U_1 \\
& & Q^s, y : \text{integer}
\end{array}
$$

For any $0 < Q^s \leq U_1$, we have the following relations from the constraint set:

$$
p \quad \leq \quad (f_2(y) - f_2(Q^s) + K_1(y) - K_1(Q^s))/(Q^s - y) \quad \text{for all } y \leq U_1 \tag{8.2}
$$

Let the optimal price to quote that would result in ordering Q^s units from the supplier be $\bar{p}(Q^s)$. The maximum unit price that will not violate (8.2) is given by $\bar{p}(Q^s) = \min_y (f_2(y) - f_2(Q^s) + K_1(y) - K_1(Q^s))/(Q^s - y)$. In what follows we provide an algorithm that can be used to generate a profitable quotation list, based on SP^{L}:

Step 0. Number the alternative suppliers starting from 2 and find $f_2(Q^s)$ by solving MP for all $0 \leq Q^s \leq U_1$.
Step 1. For each value of Q^s such that $0 \leq Q^s \leq U_1$, $\bar{p}(Q^s) = \min_{y:0 \leq y \leq U_1} (f_2(y) - f_2(Q^s) + K_1(y) - K_1(Q^s))/(Q^s - y)$.
Step 2. Let $Q^{s*} = \arg\max_{Q^s} Z(\bar{p}(Q^s), Q^s)$ and $p^* = \bar{p}(Q^{s*})$ such that $p^* > 0$ and $Z(p^*, Q^{s*}) > 0$. If no such (p^*, Q^{s*}) exists, quit the algorithm as there is no profitable quotation.
Step 3. The optimal unit price is to quote available capacity U_1 at a unit price of p^*.

By solving SP^{L}, the supplier finds the optimal quantity Q^{s*} that will be ordered by the manufacturer from the quoted capacity of U_1, and the corresponding unit price p^* that will maximize his profit. If the algorithm generates a non-empty quotation list, then the supplier will be in business. In this case, the manufacturer is also better off and benefits due to the presence of the supplier.

In the following discussion, we examine the impact of problem parameters on operating characteristics. As a numerical test bed, we use the parameter set introduced above, and in addition we let $A(Q^s) = 1.5Q^s$ and include $b = 100$. For this discussion, let Π^s denote the benefit (i.e., the profit) of the supplier, Π^m the benefit of the manufacturer, and $\Pi = \Pi^s + \Pi^m$ the total benefit of the system due to the presence of the supplier. If the supplier decides not to engage in business due to a non-positive profit, then the benefits are zero. We first investigate the impact of the demand variability on the supplier's and manufacturer's benefits under different backordering costs (see Fig. 8.3).

For low values of the backordering cost ($b = 5$ or 10 in Fig. 8.3), we observe that the benefit to the supplier decreases as the demand variability increases. This is because the manufacturer prefers to decrease[1] the total procurement amount from the market (see Table 8.3), cf. Section 8.2.1. For larger values of b, the

[1]In this discussion, we use the term 'decreasing' ('increasing') in the weak sense, to mean 'non-increasing' ('non-decreasing').

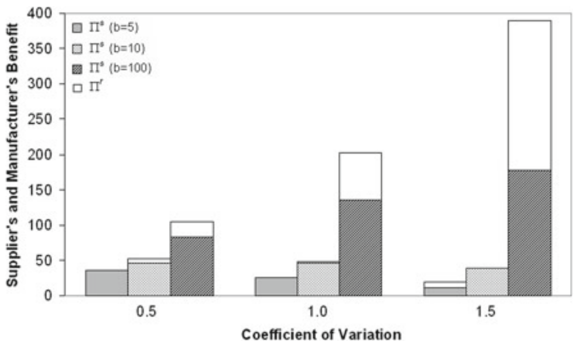


Fig. 8.3 Impact of demand variability on the benefits to the supplier and the manufacturer

Table 8.3 Optimal procurement quantities and the unit price

	Q^{s*}			Q_m			p^*		
CV	$b = 5$	$b = 10$	$b = 100$	$b = 5$	$b = 10$	$b = 100$	$b = 5$	$b = 10$	$b = 100$
0.5	33	47	84	33	47	84	2.59	2.5	2.49
1	17	47	90	17	47	130	3.02	2.48	3
1.5	10	39	89	10	39	169	2.64	2.5	3.5

Q_m : Capacity procured by the manufacturer from all suppliers

manufacturer's total procurement quantity increases in demand variability, which leads to an increase in the benefit to the supplier.

The optimal prices quoted by the supplier under different demand variations and backordering costs are also shown in Table 8.3. The behavior of the optimal price strongly depends on the problem parameters and, in general, there is no monotonicity. When $b = 100$, we observe that p^* increases as CV increases, even though Q^{s*} remains about the same. Recall that as CV increases, the manufacturer is willing to procure more capacity under high backordering costs. This makes the supplier's capacity more valuable and gives him an opportunity to elevate his prices. To be more specific, we explain the rationale behind this opportunistic behavior as follows: In this problem instance, a total of 100 units of capacity are available from alternative suppliers, and the maximum capacity that the supplier can quote is also 100 units. When CV = 0.5, the supplier competes with all alternative suppliers for the existing range of capacity that would be procured by the manufacturer and quotes a price of 2.49, which beats all alternative suppliers. When CV = 1, the manufacturer is willing to procure more than 100 units in total. As 40 units are procured from the 'cheapest' alternative supplier, the supplier now competes with the remaining 'relatively more expensive' ones that have a total capacity of 60 and hence is able to increase his quoted price while achieving higher sales (90 units rather than 84). When CV = 1.5, the supplier competes with even more expensive suppliers and hence increases the quoted price.

A similar but reverse effect is observed for $b = 5$. When CV is increased from 1 to 1.5, the manufacturer prefers to procure less this time, since the backordering

Fig. 8.4 Quantity procured from the supplier's quoted capacity versus unit price, when CV = 0.5

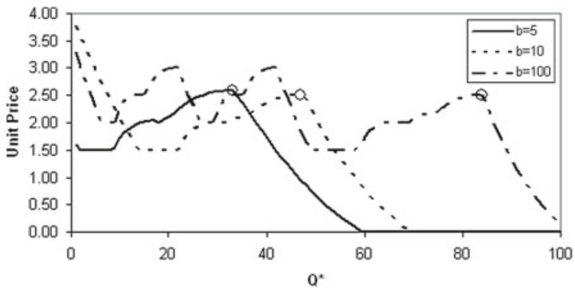
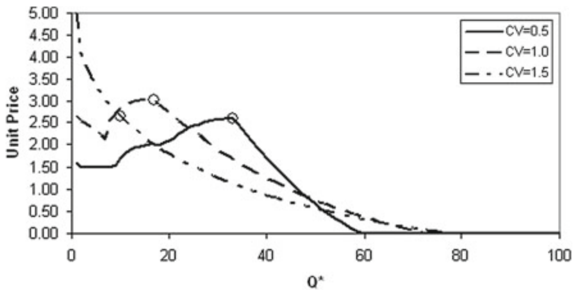


Fig. 8.5 The supplier's quoted capacity versus unit price



cost is relatively low. Hence, the supplier needs to compete for a smaller market size with 'relatively cheaper' suppliers, which forces him to decrease the quoted prices.

When $b = 10$, the manufacturer normally prefers to procure less as CV increases from 0.5 to 1 (all other parameters are kept constant). However in this case, the supplier slightly decreases his price (from 2.5 to 2.48) by forcing the manufacturer to procure the same quantity (47). Had the manufacturer procured 46 units at a price of 2.5, the supplier's profit would have been 115, which is less than the profit he makes (116.56) by selling 47 units at a price of 2.48.

As illustrated above, the optimal prices are determined according to the particular interactions of the problem parameters and there is no monotonic behavior. Figure 8.4 (Fig. 8.5) depicts the optimal quantity procured from the supplier versus the unit price quoted, for different backordering costs when CV = 0.5 (coefficient of variation values when $b = 5$). The optimal procurement quantity and unit-price pair are shown with a circle. In both figures, we plot the graphs for all unit prices in the feasible range, irrespective of profitability. As the unit cost for the supplier is 1.5, quoting any price less than 1.5 would not be rational in the short run; nevertheless, the supplier might prefer to operate with negative profits in return for capturing a large portion of the market and garnering a strategic benefit in the long run.

Finally, we elaborate on the benefit of channel coordination under the linear pricing scheme as modeled by SP^L, making use of a numerical example with a Poisson demand and $b = 100$. In this case, the optimal course of action for the supplier is to quote a unit price of 2.5, which results in a procurement quantity of 52 units with $\Pi^s = 52$, $\Pi^m = 20.84$, and $\Pi = 72.84$. This is the only operational point that would be materialized without any further coordination effort. However, the manufacturer's benefit would have been maximized if she had requested 39 units from the supplier, which would dictate the supplier to quote a unit price of 2 according to SP^L. In this case, $\Pi^s = 19.50$, $\Pi^m = 68.15$, and $\Pi = 87.65$. Nevertheless, neither of these two operating points coordinate the channel. The maximum benefit of the channel is attained when the supplier quotes a unit price of 2.14, resulting in a procurement quantity of 41 units, with $\Pi^s = 26.28$, $\Pi^m = 62.24$, and $\Pi = 88.52$. A particular mechanism in the form of a tailored contract is necessary to ensure that both parties are better off and this channel-coordinating point is attained. Hence, the maximum channel profit of 88.52, which stands for an additional benefit of 15.68 compared to the situation without coordination, could be shared between the parties in such a way that the supplier's profit exceeds 52 and the manufacturer's benefit exceeds 20.84.

8.4 Manufacturer's in-House Production Capacity Problem: Cast Your Own Spell

In this section, we switch back to the manufacturer's point of view, with the consideration that she might allocate some in-house production capacity to produce the item if she has (the ability to acquire) the technology to do so. This might be desirable for the manufacturer not only because of cost advantages, but also due to the strategic decision of being less dependent on suppliers. Moreover, the solution to MP is highly sensitive to relatively small changes in problem parameters, as discussed in Sect. 8.2.1, and the manufacturer might need to build or allocate some in-house capacity as a remedy. Assuming that such concerns can be translated into financial terms (i.e., updating the quotations accordingly to incorporate them), we take the cost perspective into account in what follows.

As the quotations of prospective suppliers are available to the manufacturer, she may be better off manufacturing (part of) the items in-house, depending on the quotations and the cost of allocating her own manufacturing capability or acquiring this capability. Therefore, the manufacturer makes the in-house production versus outsourcing decision, where combining the two is also an option. The methodology we introduced in Sect. 8.2 can be used as the key facilitator to that end. We note that it does not suffice to simply use 'in-house production option' as an alternative supplier in that methodology, because the capacity to allocate is also a decision variable now. Nevertheless, the manufacturer can determine her optimal course of action in terms of best in-house capacity allocation versus outsourcing strategy as follows:

Let the cost of acquiring/allocating in-house production capability for manufacturing Q^{ih} items be $A(Q^{ih})$, which may assume any form. Then, the manufacturer's in-house production capacity problem (MCP) can be modeled as follows:

$$\min_{0 \leq Q^{ih} \leq U_0} A(Q^{ih}) + f_2(Q^{ih})$$

where U_0 is the maximum in-house capacity that can be allocated. Note that this model considers all possible outsourcing options in combination with in-house production in one shot. The solution complexity is the same as that of MP, i.e., $O\left(N\left(\sum_n U_n\right)\max_n(U_n)\right)$. That is, once the cost structure of allocating in-house capability is known, there is no additional complexity required for solving MCP.

MCP shows a similarity to SP, as the capacity to be quoted is also a decision variable in SP. Nevertheless, the objective of the supplier is to maximize his profit, whereas that of the manufacturer is to minimize her costs. The maximum benefit that can be generated by introducing a 'new source' of capacity (i.e., the supplier's capacity in Sect. 8.3 and the in-house option here) to the system is the same in both models. Hence, if $A(\cdot)$ is the same in those two models and the quotation list of the supplier is determined by the solution of SP as proposed with the algorithm provided in Sect. 8.3 with $\varepsilon = 0$, the difference between those two cases rests on who collects the benefit, and the total production remains the same. Nevertheless, the total benefit generated with different quotation structures (as in SP^{L}) might be less than that with MCP, which might encourage the manufacturer to produce in-house and eventually avoid double marginalization. Similarly, the total production quantities with MCP and with different quotation structures (as in SP^{L}) are also not necessarily the same.

8.5 Conclusions

In this paper, we consider the sourcing decisions of a manufacturer in fashion industry from three perspectives: (i) Supplier selection problem of the manufacturer where she determines which supplier(s) to utilize and to what extent, (ii) Capacity and price quotation problem of a supplier, (iii) In-house versus outsourcing decision of the manufacturer. We allow for stochastic demand and capacitated production facilities. Our modeling approach is capable of handling sourcing problems in a wide range of environments, as we do not impose restrictions on the relevant cost components. The procurement problem and its several variations are proven to be NP-hard in literature; however, we develop a dynamic programming model with a state definition, which makes the solution algorithm pseudo-polynomial. We achieve this by proving that the order of the sources is irrelevant for the optimal solution. Our main model is the basis for solving all three subproblems posed.

We derive the following managerial insights through numerical studies:

- An increase in the availability of sourcing options (a more flexible system) may lead to a decrease in the total quantity procured, when there are suppliers with diverse cost and capacity structures, e.g., when there is a dominant supplier.

- The optimal solution to the sourcing problem is not necessarily robust, as a change in even a mere cost parameter might completely change the optimal course of action. In case robustness is sought (for reasons such as ensuring product uniformity or decreasing administrative costs of procurement), strategic partnership, vertical integration, or making instead of buying are some possible means of eliminating or reducing such parameter dependence.
- As it is also common to newsvendor models, the total quantity procured by the manufacturer does not necessarily increase as variability of demand increases. For relatively low service level requirements, the total quantity procured decreases as the variability of the demand increases; whereas a reverse effect is observed otherwise.
- There is significant value in integrating the decisions as to the supplier selection and the procurement quantity, particularly for moderate service level requirements.
- The entrance of a new supplier to the market can form a business channel between the supplier and the manufacturer, which brings a nonnegative benefit to both parties (in terms of decreased sourcing costs for the manufacturer and profit for the supplier). The party that reaps the maximum benefit that can be generated is the supplier, as long as he has the liberty of setting a quotation list in any form, such as non-monotonically quoted prices. As such a quotation list might be impractical, the supplier may be forced to adopt a particular pricing scheme such as a constant unit price. However, in that case, the generated channel benefit might be limited and is shared by the supplier and the manufacturer. Consequently, the supplier and the manufacturer need to collaborate and tailor a contract in order to ensure that the channel is coordinated and both parties are better off. Traditional policies proposed for channel coordination such as quantity discounts, buy back policies do not necessarily 'do the trick' for coordinating the channel.

We also note that the methodology that we propose can be used repeatedly by relevant decision makers. For example, once the supplier solves SP and offers a quotation list, the manufacturer solves MP (or MCP if there is in-house manufacturing capability and desire) and contacts (some of the) suppliers if necessary for a reverse auction with the motivation of driving the prices down. In that case, if the quotations are disclosed (possibly the supplier identities being censored), any supplier might (re-) solve SP with updated information and offers a new quotation list, provided that it is profitable to do so. Note that multiple suppliers cannot approach this problem in a game theoretical framework, as the *cost* structures of the suppliers—unlike the price–would not be available to each other.

Our work can be extended to include some other relevant elements such as multiple-period decision making or supply disruptions. Furthermore, other possible extensions include explicit treatment of the non-biddable price factors such as delivery punctuality, the quality of items procured, and strategic partnership concerns that we assumed to have been implicitly reflected on the procurement costs.

Multiple criteria analysis taking these factors into account could be another interesting extension.

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