JOINT PRICING AND INVENTORY/PRODUCTION DECISIONS IN A SUPPLY CHAIN: A STATE-OF-THE-ART SURVEY

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ABSTRACT

Joint pricing and inventory/production decision problem in a supply chain is an emerging research area with great academic and practical importance. This line of research lies in the interface between marketing and production/inventory planning, and focuses mainly on the coordination mechanism among chain members and characteristics of optimal decisions. Price-sensitive demand and production/inventory issues are two of the main features in this domain. This paper surveys the leading research in this area. We summarize important efforts and categorize the research based on considerations about supply chain structure, demand pattern, and interaction among chain members. Future research directions are suggested.

INTRODUCTION

There is a considerable amount of literature that describes advances in research and management practices in the area of joint pricing and inventory/production decisions (from now on, joint decisions) in a single firm. These papers deal with the interface between marketing and manufacturing decisions, specifically the simultaneous determination of pricing and inventory/production planning decisions. Research on joint decisions in a single firm has spanned over 50 years, and over 100 articles have been published. [4] and [18] provide a broad review on this topic.

The idea of joint decisions can be extended to multi-firm supply chains. The main objective of supply chain management is to minimize the chain-wide costs, while satisfying service requirements and focusing on how to coordinate supply chain members in an efficient manner. [2] and [3] provide intensive reviews on supply chain coordination. It is intuitive to think that supply chain members could leverage chain-wide profits if their pricing and inventory/production decisions are made jointly. There is an emerging body of literature that deals with joint decisions in a multi-firm supply chain setting. The first papers were published over 20 years ago, and there is a growing interest in the area. Although the time span of this body of literature is still relatively modest compared to some other areas in supply chain management, we feel that the academic and practical importance of the topic merits a survey paper.

This paper surveys the current status of research as well as directions for future research in the area of joint decisions in a supply chain. We discuss joint decisions, summarize modeling assumptions in related research, and categorize existing models into four categories. Our findings and directions for future research are also provided. The detailed survey of relevant research based on the categories

identified in this paper can be found in the full length paper on http://blake.webster.edu/~runniu68/research.

JOINT DECISIONS

In practice, pricing and inventory/production decisions have traditionally been determined sequentially. Even in a single firm with multiple functional departments, the marketing department determines prices to maximize the firm's profit, based on the demand forecast and estimated average product costs. In a supply chain with multiple firms, prices, production plans, and purchase plans have to be determined by each firm member. For example, on the supplier's side, wholesale prices, production plans, and raw material purchase plans have to be determined. The retailer's prices and replenishment decisions according to the contract arrangements between chain members also have to be determined. In a decentralized supply chain, each member is an independent interest entity and makes its decisions only to maximize its own profits. Since each independent interest entity considers only its own profits in its decision making, double marginalization exists in a decentralized supply chain. Thus, a vertically integrated supply chain is more efficient than a decentralized supply chain [15].

Both practical and theoretical efforts have focused on the development of coordination mechanisms that can help achieve integrated performance without real vertical integration. In recent years, mechanisms such as quantity discounts, buy-back contracts, and two-part tariff contracts have been applied in many industries as well as research to improve coordination in decentralized supply chains. Reviews on supply chain coordination and contracting can be found in [2] and [17]. If a decentralized supply chain performs as efficiently as a centralized supply chain, perfect coordination is achieved. Thus, the optimal solution of a centralized supply chain provides a benchmark to evaluate the performance of these coordination mechanisms. In addition to the development of coordination mechanisms, many practitioners have realized that sequential pricing and inventory/production decisions are problematic and have made efforts to improve efficiencies by making joint decisions both in single firms and among chain members. In a single firm, teams across multiple functional departments are formed to make better decisions. Similarly, firms forming a supply chain have been establishing strategic relationships to improve the performance of the supply chain to enhance their competitive advantages.

It is evident to us that research on pricing is separate from research on inventory/production decisions. On the one hand, there is plenty of research on inventory management and on supply chain management that almost invariably assumes that the demand processes are determined exogenously; thus, they are uncontrollable. This line of research mainly focuses on capturing the inventory holding and stock out penalty costs at different stages of a supply chain. Thus, in this exogenous demand setting, the main objective is to minimize either the firm's or the chain-wide total inventory and production costs. In reality, however, demand processes can often be controlled by varying the price structure. For example, in a supply chain, the inventory decisions of each member can be affected by changes in retail prices. On the other hand, in the marketing and economics research on pricing and channel coordination, price, which is determined by considering marginal costs while ignoring inventory/production issues, is the main instrument available to coordinate a channel.

To summarize, we can see that marketing and economics researchers have been concerned, for the most part, with the effect of price changes on demand without much regard to inventory and production problems; whereas, operations management researchers have started with the assumption that retail prices are given and attempted to minimize total inventory and production costs subject to some

exogenous demand pattern. The artificial separation of marketing and operational decisions reduces efficiency for both single firms and multiple-firm supply chains.

There is a growing body of literature that studies joint decision making problems in decentralized supply chains. In this paper, we review articles that focus on joint decision making in these types of supply chains and identify future key research topics within this area. The main feature of these reviewed articles is that they address both retail price-sensitive demand processes that are seldom considered in inventory control research and inventory issues that most marketing and economic researchers have ignored. We now turn our attention to the modeling considerations and categories that will provide structure to our survey.

MODEL CATEGORIES

As discussed in the previous section, the main motivation behind joint decision making is the price-sensitive nature of demand that creates an interface between pricing and production. While all the literature surveyed in this paper shares the paradigm of joint decision making, there are other aspects in which the approaches differ. In this section, we discuss the role of supply chain structure, demand pattern, and some other aspects in choosing and developing joint decision making models. Furthermore, we categorize the research in joint decision making in multi-firm supply chains into four categories based on supply chain structures, demand patterns, and interaction among chain members.

Supply Chain Structures

Most reviewed articles consider two-level supply chains in which the suppliers can be referred to as the upstream firms, the manufacturers, or the distributors; and the buyers as the downstream firms, the distributors, or the retailers. The supply chain structure with a single supplier and a single buyer has been the most widely studied structure in research on joint decision problems. We use 1-to-1 to denote this structure. Some articles consider supply chains with a single supplier and multiple buyers. We use 1-to-M to denote supply chains with one single supplier and multiple non-identical buyers. When there is more than one buyer in a supply chain, the mechanism used to coordinate firms can be different. In particular, competition among buyers can affect the coordination mechanisms. We use 1-to-M/w to denote supply chains with a single supplier and multiple competitive buyers. We use 1-to-M/n to denote supply chains with a single supplier and multiple non-competitive buyers.

Demand Patterns

This survey considers research with price-sensitive demand that can be modeled as either deterministic or stochastic processes. Most articles have addressed demand as a deterministic demand (Dd) function of a retail price when there is a single buyer, or of a retail price vector in cases of multiple buyers that charge different prices. Deterministic price-sensitive demand is generally formulated as a downward sloping curve of retail prices.

Joint decision problems with stochastic demand (Sd) are usually seen as price-sensitive newsvendor problems with an addition or a multiplication of a deterministic component and a random component. [14] points out that different demand forms cause significantly different conclusions for joint decision problems in [13] and [9]. A fundamental difference between these two different demand forms is the role that price plays in demand uncertainty. With additive demand, the variance of demand is independent of price, while the demand coefficient of variation increases with price. With multiplicative

demand, the variance of demand decreases with price, while the demand coefficient of variation is independent of price. Although pricing provides an opportunity to reduce the risk of overstocking or understocking, it cannot ideally decrease both demand variance and coefficient of variation (two most commonly used measure of variation) for either additive or multiplicative demand. Thus, different pricing decisions are reached for different demand forms.

Other Modeling Assumptions

The decisions are either static or dynamic. Static decisions refer to pricing and production/inventory decisions that remain constant along the planning horizon. If decisions can be changed during the planning horizon, they are referred to as dynamic decisions. Dynamic decisions are becoming more and more widely applied both in the research world and in practice. Costs associated with changing decisions over time have to be factored in when making and applying dynamic decisions. For traditional industries with mature products and stable markets, a static decision strategy is generally a good choice that is easy to manage. In some industries or new business models, such as e-commerce, dynamic decisions are more common because sellers can change pricing quickly; thus, it is less costly to obtain more profits than with static decisions. Although there is a rich body of research on dynamic pricing and inventory control in a single firm (see [6] for a review), we found only a few papers considering dynamic pricing and inventory control in a supply chain setting.

The basic and well-known economic order quantity (EOQ) model seeks the optimal order quantity under consideration of ordering costs, purchasing costs, and inventory holding costs. Research that considers setup costs or fixed ordering costs usually models joint decision problems using extended price-sensitive EOQ models, where total costs are convex in quantity at any given price. Regarding replenishment policies, the chain members replenish their inventory by ordering from their suppliers. In the surveyed articles, constant replenishment lead times are generally assumed. The lead times are scaled to zero for simplicity since the time horizon can always be shifted to accommodate non-zero lead times.

Most research considers a single product that is manufactured or purchased by the supplier and then distributed to the buyers. In the last section, we discuss articles that consider multiple products that are partially substitutable or complementary. Game theory is a powerful tool for analyzing problems with entities that interact. Supply chain management that considers interaction among members is a field where game theory can make a substantial contribution. In the reviewed papers, we notice that game theory concepts such as Stackelberg, Nash, and Pareto solutions are usually employed. Readers are referred, for example, to [8] for an introduction of various game theory concepts.

Next, we categorize the related articles into four categories based on supply chain structures, demand patterns, and interaction among chain members.

Categorization of Research

The bulk of the existing research can be partitioned into four categories based on supply chain structures, demand patterns, and interaction among chain members that we have just discussed:
1) 1-to-1-Dd settings in which supply chains with a single supplier and a single buyer face a deterministic demand; 2) 1-to M/w-Dd settings in which supply chains with a single supplier and multiple competitive buyers face deterministic demand; 3) 1-to-M/n-Dd settings in which supply chains with a single supplier and multiple non-competitive buyers face deterministic demand; 4) Sd settings in which supply chains face stochastic demand. We consider research on stochastic demand under different chain structures in one category because of the limited number of publications focusing on stochastic

demand. We refer the reader to our full length paper for the detailed survey of research in each category on http://blake.webster.edu/~runniu68/research.

DISCUSSION AND DIRECTIONS FOR FUTURE RESEARCH

Joint decision problems in real world settings can be very complicated. A supply chain usually has multiple levels, multiple suppliers and multiple buyers at each level, and multiple product types. The production capacity and inventory capacity are limited. A supply chain is also a dynamic system, in which participating members and available resources change continuously. Uncertainty exists in every aspect of a supply chain. Business relationships between suppliers and buyers are dynamic. Although this survey shows that the body of literature, although not vast, is very diverse and has great academic and practical relevance, the surveyed research simplifies joint decision problems in the real world with various (sometimes restrictive) assumptions. There are important gaps between what has been done in research and the problems that arise in industrial settings.

Most research on joint decision problems in supply chains focuses on a single product. In the real world, supply chains seldom involve only a single product. In the case of multiple products, the pricing decisions of one product can affect the demand of others when the products are (partially) substitutable or complementary. Furthermore, interaction exists in the manufacturing of products such as sharing production resources and setups. Production capacity becomes an important issue when multiple products in a supply chain share the same resources. Thus, it is interesting to incorporate capacity constraints and to see their effect on joint decisions and how buyers react to the product capacity limit of suppliers. Incorporating the interaction of multiple products in joint decision models in supply chains is an important but challenging direction for future research.

Most of the surveyed articles assume that complete information is shared between the members in a supply chain. However, it is sometimes difficult or even impossible to get private information about other parties. It can even be in one party's interest to mislead others about its private information. [19] demonstrates that a buyer is better off to keep its reservation profit a secret or even to mislead its supplier to believe that it has a higher reservation profit. More work needs to be done to examine joint decision models in an asymmetric information setting.

Accurate estimation of demand input of a supply chain system is very important to the success of a joint decision model. Characterizing and justifying joint decision models and conclusions from real data is an important future research direction. Most earlier work assumes either additive or multiplicative demand with little justification [10]. Empirical work is needed to justify the use of additive or multiplicative demand. Furthermore, one critical assumption about the demand processes in current research is that they are independent among different periods in periodic review models. Time-independent demand does exist for most non-durable goods such as milk and bread or for situations where the selling season is normally too short to give buyers enough information to affect future purchases. However, it is expected that customers can delay their purchase of durable goods if they estimate a lower price in the future; thus demand in one period is correlated with demand in other periods. [18] indicates that the effect of price changes on customers' behavior of durable goods consumption over a time horizon has attracted little attention in research. In recent years, more researchers have started to examine the impact of strategic customers on demand and on optimal pricing decisions [1] [16] [11] [5]. Joint decision problems in a supply chain facing time-dependent demand caused by strategic customer behaviors need more attention.

Inducing coordination among supply chain members is currently one of the major managerial concerns among practitioners. It is also an intensive research area because of the belief that coordination can improve the efficiency of the whole chain. One intriguing issue about supply chain coordination is the ways in which the members in a supply chain can benefit from the improved chain performance due to coordination. In a fair commercial relationship, each party should be better off in order to be willing to take part in the coordination. Even if one party is dominant in the chain and uses certain instruments to induce its partners to coordinate for its own benefits, the other participating parties should at least be no worse off. A number of articles focus on how to achieve coordination while ignoring the issue of benefit sharing in designing a coordination scheme. Nonetheless, not all sharing schemes are easy to monitor or to implement in practice. Most articles that we surveyed assume risk-neutral chain members. However, attitudes toward risk should probably be taken into account when designing coordination mechanisms, especially when demand is stochastic, because the risk-taking attitude of the members can affect their decisions and their profit sharing. The design of various benefits sharing schemes and their impact on joint decisions need to be investigated.

A line of work in supply chain management has focused on multiple sourcing problems from multiple suppliers. Having multiple suppliers can reduce the risk of production or sales being disrupted from any problems in one supplier. However, Most of the research considers only two-level supply chains with one supplier. Supply chains in practical problems usually include more than two levels and more members in each level, which increases the complexity of the problems. Examining whether some conclusions in existing two-level supply chain models will still hold in supply chains with more than two levels would be worthwhile. Joint decisions problems in a multiple supplier supply chain needs attention. Several articles study joint decision problems in supply chains with one supplier and multiple buyers. The buyers usually are modeled as the follower in the game except in the buyer-driven model in [7]. [12] believes that the bargaining power in grocery channels has shifted to powerful buyers such as Wal-Mart. A future research topic would be joint decision problems in a buyer-driven supply chain: What are the characteristics of the pricing and replenishment decisions? How does the supply chain perform when multiple manufacturers supply a large retailer?

We realize that subtle changes in modeling assumptions or the focus of analysis can often lead to dramatically different mathematical structures because joint decision problems in supply chains are complex. In addition to the aspects that we suggested for future work, we believe there can be other new research streams in joint decision problems.

This survey not only considered the state of the art of research in joint decision making but also classified the research into categories based on the approach and assumptions used. The survey also identified the main trends in the current literature and promising areas for future research. We strongly believe that joint pricing and inventory/production decisions can result in substantially increased profits for supply chains. Research in this area has the potential to bring together concepts from operations management, economics, and marketing. Significant pioneering work has been done, and it provides motivation and suggests promising directions for future research.

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