MARKET SEGMENTATION AND PRICING STRATEGIES BY LOGISTIC EFFICIENCY IN TWO-ECHELON SUPPLY CHAIN

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of YU XIA find it satisfactory and recommend that it be accepted.

Chair
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Abstract

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Effective Supply Chain Management (SCM) requires the careful coordination of information, material, and financial flows in the supply chain in a way that supports a competitive cost and service tradeoff profile for the final consumer.

In this dissertation, we study competitive supply marketplaces with multiple suppliers of a single non-differentiated product, and multiple retailers (buyers) who do not competitively interact with each other. We consider two-stage coordinations, coordination via market-based matching at the first stage, and coordination via lot-sizing at the second stage.

The dissertation consists of five chapters. The first chapter introduces the background of this research and presents related literature reviews.

The second chapter focuses on the market-based coordination via matching. It shows that a supplier’s inventory cost structure determines the position as well as the size of her market segment and the magnitude of her inventory cost, relative to her competitors. An efficient algorithm is developed to determine each supplier’s market segment. Market share sensitivity analysis is performed when a supplier’s inventory cost changes or when a new supplier enters the market.
The third chapter studies the supply chain containing two coexisted suppliers and many retailers facing stable demand. Transportation cost is considered via a Hotelling-type model. Two pricing strategies are considered in this chapter: a long term profit maximization strategy (PMS) and a short term sale promotion strategy (SPS). The equilibrium price, the market segment, and the overall profit of each supplier that result from both pricing strategies are obtained and compared. The comparison analysis helps the suppliers to choose their pricing strategies in competitive environment.

The fourth chapter compares the two situations, suppliers do or do not coordinate via lot-sizing, assuming the supply chain is already coordinated via the first stage coordination, matching. The common surface that describes the market segmentation in both situations is found. Then the market segmentations are compared and analyzed.

Finally, the fifth chapter illustrates the algorithms by numerical examples. It also provides examples to support the theories established in the previous chapters. Furthermore, the practical usages and implementations of our models are discussed.
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Chapter 1

INTRODUCTION AND LITERATURE REVIEW

This dissertation focuses on market/order space segmentations and pricing strategies for suppliers in a two echelon supply chain. The supply chain contains multiple suppliers and many retailers. Suppliers compete for retailers’ business by determining their offering prices, which are further determined by their logistic cost structures and competition.

We consider coordinations in two stages, the market-based matching coordination as the first stage, and the traditional lot-sizing coordination as the second stage. This chapter introduce the background for the research and the related literatures in the areas such as logistic costs for supply chain members and the channel, market segmentations, supply chain coordination and supplier competition.
1.1 Introduction

Supply chains are effective networks of independent firms performing from end-to-end disparate set of activities involved in a particular product/service value chain through market mechanisms, contracts and partnership arrangements. Supply Chain Management (SCM) practices offer companies new ways to increase their logistical efficiencies, quickly respond to customer service, and reduce costs in their global facility and supply networks, and improve revenue and working capital usage.

In the tough market economy of today, SCM becomes the cost savior and the competitive differentiator in all industries. Successful retailers are carefully choosing suppliers, beating down supplier pricing through auctions and other open market mechanisms, removing unnecessary costs in internal and supply chain processes, slashing inventories, and placing emphasis on logistical efficiencies. Supply Chain and logistics competencies heavily account for the phenomenal growth of the quarter of a trillion dollar Wal-Mart retailer, while ineffective inventory and logistical management pushed its major competitor K-Mart, a 40 billion retailer, to almost bankruptcy. Lowe’s using the best inventory system in its industry has become the mythical David making significant market share inroads against the Goliath of hardware chains, Home Depot. The competitive success of manufacturers two years ago used to be determined by the extent and depth of their own manufacturing capabilities. But now most of them rely on extensive outsourcing all over the world, and their success is determined by their ability to effectively create and coordinate global supply chains in a fast paced technology and short product life cycle uncertain demand world. It is not just consumer electronics and computers, where always Dell and Cisco competed on their supply chain competencies, but also autos, aerospace, defense and heavy construction equipment industries that
have drastically shifted in the above described way.

Finding the ways to achieve supply chain efficiency and effective coordination is fascinating and challenging, but also elusive in its multiplicity of faces and magnitude of complexity topic for the SCM researcher. The SCM field has developed in many directions at once. The review for this chapter will only focus on the literatures that relate to our research topics. We will briefly introduce the research results in multi-stage supply chain, and then focus on the model comparison and coordination approaches in two-stage supply chain. Furthermore, we discuss the competition among suppliers and the related marketing segmentation issues.

The reminder of this chapter is organized as follows. Section 2 reviews the literatures on supply chain models and compares the different coordination approaches. Section 3 reviews some research results in supplier competition. Section 4 describes the approach of our research, while section 5 focuses on contributions of our research.

1.2 Supply Chain Coordination Approaches and Model Comparison

This section describes several key direction of supply chain research and reviews the related literatures. We summarize the research results and locate our research in the supply chain research literature in term of model, focuses and methodologies.
1.2.1 Multi-Stage Supply Chain

A multi-stage supply chain contains suppliers, manufacturers, wholesalers, retailers and customers, or, more or a subset stages of them as parties linked by flow of goods, information and funds.

Most of the multi-stage supply chain literature presumes central control (see Federgruen (1993) for review). Some recent works have proceeded under the realization that the decentralization in decision-making may be necessary and more realistic for large enterprizes operating in complex environments or for independent supply chain parties. Conflicts in the interests of the different parties may lead to inefficiency. Hence, careful consideration of information and incentives is central to all attempts to improve supply chain performance.

Clark and Scarf (1960) introduce multi-stage inventory theory to model logistics problems encountered by the military. They use a dynamic programming formulation, and derive the optimal ordering and transshipment policy for a single product serial system facing independent, identically distributed demand. The optimal policy is characterized by a critical “order-up-to” stage inventory target for each installation, where stage inventory counts the local stock and the inventory downstream in the system.

Lee and Whang (1997) consider the problem of coordinating a decentralized version of Clark-Scarf serial system. While each site incurs a holding cost, only the site serving the end customer faces a shortage cost. As a result, the upstream parties will carry less buffer inventory than may be best for the system as a whole. Realizing this, the party furthest downstream tends to carry extra inventory, which is inefficient since finished
goods usually are most costly to hold. The authors’ scheme involves a consignment policy for redistributing inventory carrying costs among the parties, an additional backlog penalty paid to an upstream site by its direct customer and a shortage reimbursement paid to a downstream site by its direct supplier. However, implementing this scheme requires common knowledge about the demand distribution. Kumar et al (1996) and Chen (1997) consider the similar problem, but use different set of control mechanisms for coordination.

Munson and Rosenblatt (2001) coordinate a three-level supply chain with quantity discounts. In their model, they consider not only the holding cost, but also the setup cost for each of the three stages of the supply chain. Their results not only contribute to the lot-sizing quantity discount, but also contribute to the lumpy demand coordination. The results will be used in this dissertation.

1.2.2 Two-Stage Supply Chain

A two-stage supply chain could describe the link between any two consecutive parties in a supply chain, and indeed on occasion the tandem may be referred to as suppliers and manufacturers, manufacturers and distributors, or, more generally, suppliers and buyers.

There are three types of supplier-buyer relationships, or three types of supplier-buyer system in term of supplier-buyer relationships, the centralized system, the decentralized coordinated system and the decentralized non-coordinated system.
In an perfect world, total expected supply chain profit would be maximized if all decisions are made by a single decision maker with access to all available information, a central player who controls both supplier and buyer and organize the system to optimality. We refer to this type of supply chain as the centralized supply chain. It is the best case that can happen. It is possible when both buyer and supplier are components of one big company.

However, in reality, suppliers and buyers are independent most of the time. They all want to maximize their individual profits. Besides, neither the suppliers nor the buyers are in the position to access all the information of the supply chain or in the position to control the entire supply chain. We call this type of supply chain as decentralized supply chain. In many cases, suppliers and buyers do have their own incentives and state of information, which make the coordination possible. We thus have decentralized, coordinated and non-coordinate systems. The decentralized non-coordinated system assume that the suppliers and retailers are independent, they make their logistic decisions in favor of themselves alone, and there is no coordination between a supplier and a retailer. In the coordinated system, suppliers and retailers are independent too. But, certain strategies or contracts are used to coordinate the system, for example, matching buyers with the most logistically efficient suppliers accordingly, or lot-sizing to influence buyer’s logistic profile to achieve the system optimization. Suppliers and buyers then share the savings through the coordination.

In most supply chain coordination literature, the investigated supply chain settings in the presence of economies of scale are either two stage linear supply chains (i.e., single supplier to single buyer) or two-stage divergent distribution systems with single
supplier and multiple buyers. The primary coordination mechanisms suggested for the supply chain are carefully structured quantity discounts, and lot-sizing.

The two stage linear supply chains has been studied among others in Abad (1994), Weng (1995), Corbett and DeGroote (2000), and recently in Karabati and Kouvelis (2003). The single supplier divergent distribution system has been studied in the multi-echelon inventory literature (see Graves and Schwartz (1977)). The more interesting recent works on the subject of perfect coordination of such supply chain settings are Roundy (1985) and (1986). Incentive alignment issues for the divergent distribution system have been proposed in Chen, Federguen and Zheng (2001). The vast supply chain coordination literature, with its multiple incentive alignment schemes and types of contracts, is, in a very effective and tutorial way, summarized in Pyke and Peterson (1998), Lariviere(1999), Tsay and Agrawal (2002), and Cachon (2002).

Up to now, most supply chain paper focus on the coordinating system. The conceptual emphasis has been on understanding what incentive alignment schemes will allow independently acting, profit maximizing, economically rational firms to pursue actions that move beyond firm specific objective optimization towards overall supply chain optimizing solutions.

Linear Supply Chain

In an effort to simplify the setting of the models, the SCM literature focuses in its majority on the study of linear supply chains, which assumes a single supplier and a single buyer, and certainly is the most tractable case.
The traditional view in the supply chain coordination can be easily discussed in linear supply chains. For a decentralized, non-coordinated system, the assumed protocol of action involves the buyer choosing order quantity, and corresponding delivery frequency, to meet a constant annual demand in a way that minimizes his holding and setup costs. The supplier, provided with the buyer’s order profile, chooses an appropriate production lot size to optimize her holding and setup costs. For a centralized system, the single decision maker, the “coordinator”, with full information of all parameters of the problem, chooses the supplier and buyer order sizes, under the usual, and rather non-restrictive assumption that the supplier order is an integer multiple of the buyer’s order size, in a way that optimizes the overall supply chain inventory holding and setup costs (see Silver et al (1998)). For a decentralized, coordinated system, the buyer has to be offered appropriate quantity discounts in an effort to align his incentives with the overall supply chain and adjust his order profile according to the coordinated solution (see Weng (1995)). We call this coordinating approach the lot-sizing coordination.

One stream of the research that considers the use of quantity discounting as a coordination mechanism includes Monahan (1984), Rosenblett and Lee (1985), Lee and Rosenblett (1986), and Banerjee (1986).

Monahan (1984) considers the economic implication of offering quantity discounts to the single buyer from the supplier’s point of view. It assumes that the supplier follows a lot for lot policy, then it is shown that a sufficient discount can induce the buyer to order a quantity that increases the supplier’s net profit. This modified quantity is related to the buyer’s original economic order quantity by a factor that depends only
on the ratio of the fixed ordering costs of the supplier and the buyer.

Lee and Rosenblatt (1986) extend Monahan’s model to include the supplier’s lot sizing decision, by considering both the inventory holding cost and a fixed setup cost incurred by the supplier. Instead of the all unit discount schedule featured in both these papers, Rosenblatt and Lee (1985) study a linear discount schedule in the same setting as Rosenblatt and Lee (1986). Different and interestingly, this paper shows that the coordination benefits do not all accrue to the supplier (as in Monahan (1984) and Lee and Rosenblatt (1986)), instead, both supplier and buyer can benefit.

Bannerjee (1986) takes the perspective of a central decision maker who can jointly optimize the total of the channel costs. He then finds out the joint optimal lot-size, quantifies the resulting benefit to both the supplier and the buyer, and thus determines the optimal quantity discount schedule accordingly.

All the above four papers assume the deterministic and price-independent demand, and allow no shortage. Many later research papers follow this track, but relax some of these earlier assumptions.

Another stream of the research begins with Jeuland and Shugan (1983), a market literature. Jeuland and Shugan primarily consider a two-member channel facing market demand, assumed to be a function of the buyer’s selling price and service level, where the latter is measured by a cost. They also assume the production cost is a function of the supplier’s product quantity. Furthermore, by comparing the optimality conditions with and without coordination, they show without coordination, both the supplier and buyer should raise up their price and drop their ordering quantities comparing to the
situation under coordination.

Moorthy (1987) offers different schemes which can coordinate the channel of Jeuland and Shugan (1983) and are easier to implement. In particular, he argues that a two-party tariff is superior to quantity discounting because it is simpler, and it separates the coordination problem from the profit-sharing problem and leads to fewer legal problem. Many subsequent paper in the marketing literature have considered variants of this model. Weng (1995, 1997a, 1997b and 1997c) are excellent examples of those extensions.

Agrawal and Tsay (1998) attempt to generalize the discussion on decision rights by focusing on the effect of intra-organizational goal incongruence on contract efficiency. They consider a single period model of a supply chain consisting of an independent manufacturer and a retailer. The retailer serves a price sensitive stochastic demand, and both supplier and retailer seek to maximize the probability of meeting or exceeding a target profit level specified by the owner. The authors’ analysis evaluates the preferences of the various parties for wholesale and retail prices, inventory levels, and product and customer type. Certain implications for supply chain strategy are suggested: increasing the profitability of a supply chain need not be at the expense of the end customer, and coordination of goals within an organization does not necessarily improve the supply chain coordination.
Divergent Distribution System

The study of the divergent distribution system followed a similar research path to the linear supply chain. Centralized optimal (or equivalently cooperative) strategies have been studied in Graves and Schwarz (1977). Such strategies entail the use of non-stationary replenishment intervals, which are often too complex for practical use.

Roundy (1985, 1986) ingeniously introduced simple coordination strategies for the problem by using the so-called power-of-two policies, in which supplier’s replenish interval is power-of-two multiples of the buyers’ order intervals. It is simpler to implement and can be proved to be within 2% of optimality. However, it is mostly considered in a centralized system since implementation of such cooperative strategies for independent buyers fails in the absence of the right incentives, as the buyer’s cost increase when the coordinating order quantity deviates from the economic order quantity.

For a decentralized divergent system, as suggested in Lee et al (1997), the possibility of rationing by the supplier can induce the competition between buyers and therefore, lead to strategic behavior. In particular, buyers will tend to inflate their orders, which therefore distort the flow of information.

Cachon and Lariviere (1999) model a single-period, single-supplier, two-retailer supply chain in a two period context. The supplier’s production capacity and the whole sale price to the retailers are fixed, but retailers can set their own price. Demand of the second period can be high or low, and is a simple linear function of price. Common information is assumed. In case of shortage, capacity is allocated using a publicly known allocation scheme, of which they consider two stages, “even allocation” and
“turn-and-earn”. The main result of the paper is under turn-and-earn, the supplier’s profit will increase, but the retailers’ profit may not. Retailers end up just selling great volume at a lower price to protect their allocation. The paper does not specify which allocation policy is optimal.

Chen, Federgruen and Zheng (2001) propose an incentive compatible scheme for the implementation of coordinating power-of-two policies in decentralized systems. The scheme involves two components: (a) a common price discount scheme offered to buyers in causing the placement of order in intervals that achieve perfect channel coordination; and (b) each buyer is required to pay the supplier a franchise fee, which allows for redistribution of the coordination benefit in a way that the supplier affords to offer the needed discounts. Near perfect supply chain coordination strategies for this setting are offered by them.

1.3 Competition among Suppliers

Vast majority of existing supply chain research focuses either on linear supply chains or divergent supply since they are the most tractable cases. These do not fall within our scope since retailers have only one resource for product, which is not realistic in modern industries. The most general form of supply chain contains multiple suppliers selling exclusively through multiple independent retailers, which is the case we study for this dissertation.

Competition in supply chain has received a lot of attention in management and operation studies in addition to the market and economic literatures recently. While
many papers emphasize the competition among retailers with one supplier as a leader (Tyer (1998), Cachon (2001), Trivedi (1998), Chen, et al. (1998)), Porter’s (1980) industry analysis distinguishes competition between supplier powers as one of the very important force in business rivalry.

Although we know that market combating exists everywhere, the means to compete vary from area to area. Traditional inventory planning models for supply chains focus on the minimization of the logistical costs.

Although we have not see significant research on the multi-supplier multi-retailer supply chain on which we focus on, the following researches consider the issues of conflict and coordination between suppliers and retailers, which provide insight for the management of the multi-supplier multi-retailer channel.

Building on original work by Artle and Berglund (1959) and Balderston (1958), Baligh and Richartz (1964) consider of designing the optimal distribution system to transfer materials from multiple suppliers to multiple retailers for a single product. They determine the number of levels in the system (with zero levels indicating direct sales) as well as the number of firms within each level to minimize the communication and contact costs in the network. Jaikumar and Rangan (1990) and Rangan and Jaikumar (1991) study on how suppliers’ price rebates offered to different intermediary levels affect the channel choice decision and use this model to determine the optimal pricing and distribution strategy.

Choi (1991) examines two suppliers whose partially substitutable products are sold through a common retailer, while in Choi (1996) considers that two suppliers use two
common retailers that price-competes with each other. He studies the effect of channel leadership, channel interaction and product differentiation. O’Brien and Shaffer (1993) address the question of whether competing suppliers should sell through a common retailer instead of exclusive retailers. Their research consider both nonlinear pricing and exclusive dealing arrangement when two suppliers contract with a retailer monopolist. Marx and Shaffer (1999, 2001 (a),(b)) examine sequential contracting with two suppliers and the common retailer of them. Focusing on the barging power, Shaffer (2001) investigates how the balance of power between suppliers and retailers influence not only the term of trade, but also the bargaining process used to allocate channel profits. Chiang and Monahan (2002) advise a supplier on how to set inventory levels when distribution occurs through one direct sales channel and one company-owned store, given that each customer has an initial preference for one of the channel types.

The review of the literatures in supply chain models can be summarized by Table 1.1.

INSERT TABLE 1.1 HERE.

1.4 The Approach of This Research

Our research considers a supply chain in which upstream parties (which we refer to as manufacturers or suppliers) provide a single product to downstream parties (which we refer to as buyers or retailers). We study competitive supply marketplaces with multiple suppliers of a single non-differentiated product, multiple retailers (buyers), and where the retailers do not competitively interact with each other. We would like
to clarify that the use of the term “supplier” is interchangeably used to model either a manufacturer of the non-differentiated product or a logistical intermediary (warehousing and distribution company, third-party logistics, etc.), with the appropriate interpretation specific to the application context of our results. Similarly, a “buyer” can be a pure form retailer or simply another logistical and/or production intermediary in a complex value chain that fed by an upstream supplier.

Our model setting can be illustrated by Figure 1.1.

INSERT FIGURE 1.1 HERE.

When supply capacity are sufficient, retailers usually dominate the channel; they have the power to choose one supplier from another. (D. Bowersox, et al. (2002)). If suppliers offer identical product quality and service, price competition among them becomes inevitable. In traditional industries, while suppliers always hold same level of technology, Logistics cost turns to be crucial in deciding suppliers’ contest prices, hence the market share. Based on their logistic parameters, some suppliers benefit from certain retailers and others not. Suppliers coexist because no one can dominate another for the whole market. When certain suppliers fight to get their customers, some may be eliminated while others managed to subsist. Specifically, the competition is a game that determines suppliers’ fate. The survived suppliers share the market in a comparable static situation, Nash equilibria. They eventually get their own market shares; the size and position of each share depend on all involving rivals’ characteristics.

Traditional inventory planning models for supply chains focus on the minimization of the logistic costs. In two-echelon supply chain, for the two stage linear supply chains
(one supplier one retailer channel), EOQ and EOQ with lumpy demand can be found in related results from Munson & Rosenblatt (2001), Lee & Rosenblatt (1986), and Jones et al. (1988). Also, Lal and Staelin (1984) deal with two-stage divergent distribution systems (one supplier, multiple, non-identical retailers), they compute a centralized solution implicitly assuming that each supplier replenishes its stock infrequently.

Our model integrates logistic management and pricing strategies for suppliers under pricing competition. The suppliers need to not only minimize their own logistic costs, but also concentrate on pricing to compete with their peers to attract retailers.

Another major contribution of this research is to consider two stage coordinations instead of one stage lot-sizing coordination considered by most existing research papers in supply chain management. In our research, we consider market-based matching as the first stage coordination, and traditional lot-sizing coordination via discount as the second stage coordination.

Even though the decentralized coordination approach via appropriately determined quantity discounts is appealing in its system optimizing logic, it has practical implementation flaws that could limit its effectiveness, even its feasibility, for certain supply chain environments, and in particular so for the non-differentiated product environment of our study.

The approach starts by assuming the buyer has already picked his supplier, and then works within the confines of the supplier’s logistic cost structure, and via an assumed cooperative partnership, to improve the resulting supply chain. However, the buyer often is the channel leader and exerts his power by picking suppliers for different order
profiles, and might often be resistant to any order profile change. Quite frequently, the order profile of the particular product source is the result of derivative (dependent) demand calculations out of complex production/selling plans of multi-item assembled final goods, with the sourced product just being one of the many required items. This is the case when our “retailer” is either a distributor of systems, with assembly capabilities needed, or a manufacturer herself. Even in a pure retailing context, selling reason and promotional consideration of retailers, often operating in limited retail space stores, with diverse product lines of partially substitutable items make it hard, and potentially infeasible, to change order profiles of any one of the products, without affecting the order profiles of the others which are potentially sourced from other suppliers. Quite frequently for functional, divisional or brand management reasons, the sourcing of different products is a separate decision handled by different purchasing managers, thus making order profile adjustments an organizational nightmare.

These implementation difficulties are easily overcome through our suggested “market-based” supply chain coordination (or coordination by matching) approach. From a conceptual viewpoint, our approach achieves overall supply chain efficiencies by creating a market mechanism that exploits the presence of multiple competitive suppliers with diverse logistical cost structures. The market mechanism leads to the most reasonable match between the buyer’s order with the supplier’s capabilities. In contrast to the quantity discount based coordination (or coordination by lot-sizing), where a predetermined pair of supplier-buyer tries to move from the buyer’s desired order profile towards the profile that the supplier can support, a market-based (or coordination by matching) approach tries to select among a set of bidding suppliers the right supplier for the particular order profile, with the right supplier being defined as the one that
has the logistical cost structure to profitably offer the most competitive price to the buyer. Generally speaking, our approach in improving overall supply chain efficiencies for non-differentiated products, is to create a market mechanism that will lead to the most reasonable match between the retailer’s order with the supplier’s capabilities.

The coordination by matching can be implemented via an appropriate auction mechanism even if the full knowledge of participating suppliers’ cost structures is not available. We will further discuss this issue in Chapter 5.

1.5 Concluding Remarks

Our research distinguishes from others in the following aspects:

First, we consider the supply chain with multiple suppliers and many retailers. This kind of supply chain is close to reality, but has not been sufficiently studied. Most supply chain papers works on linear supply chains (one supplier, one retailer) or divergent system (one supplier, multiple retailers). Tyer(1998), Trivedi(1998), Chen, et al.(1998) and Cachon(2001) emphasize the competition among retailers with one supplier as a leader. In our model, retailers are the channel leaders. They decide which supplier to purchase from; and they purchase from one supplier only. Suppliers compete for retailers’ business.

Second, in term of improving the efficiency of the supply channel, we emphasize matching between supplier and retailer in stead of only lot-sizing coordination. We
propose that the coordination of supply chains consists of two stages. First, retailers choose the most efficiently matching suppliers to work for them, we call this stage market-based matching coordination. Second, suppliers use pricing strategy to further adjust the supply chain lot-size to improve the efficiency, which is the traditional lot-sizing coordination. We argue that matching is the primary coordination stage while lot-sizing is the secondary coordination. As we mentioned above, in reality, lot sizing coordination is difficult or even impossible to reach since it assumes that the retailers have the no-cost flexibility to change its order portfolios. The recent research of Chen (2003) shows that the saving through lot-sizing coordination is limited to 10% of the system cost under certain situation. Matching instead of lot-sizing coordination can be more important in SCM.

Third, our model integrates logistic management and pricing strategies when considering competition and coordination. The suppliers need to not only minimize their own logistic costs, but also determining their offering price to compete with their peers to attract retailers.

Though matching, each retailer uses the supplier offered prices to select the supply partner that best fits his particular order profile, as described by his order size and delivery frequency, of their environment. The supplier offering prices reflect their processing/ logistics costs structure, as captured by relevant economies of scale in a fixed cost nature “setup cost” component, and physical storage, distribution and working capital related variable costs as depicted in a “holding cost per unit” component. In a manufacturer-reseller setting the fixed costs might be beyond just production switch over costs, often amplified to reflect relevant lost revenue considerations of alternative
production uses of the facility in tight capacity situations, to also include fixed trans- 
portation and loading/unloading distribution costs as the product gets moved from a pro-
duction facility to temporary warehousing to finally reaching the re-seller’s distri-
bution, cross-docking or retail location. In a logistical/distribution intermediary - re-
tailer setting (e.g., Li & Fung global distributor - Fashion Manufacturer/Reseller supply 
chains) fixed costs are mostly of logistical nature (inventory accumulation and ware-
housing activities for timing coordination, shipment container - vessel size economies 
of scale etc.). Significant differences in holding costs among suppliers can often exist 
within the broad interpretation of our modeling framework. Long lead-time suppliers 
have often to worry about servicing their working capital needs in their long pipelines. 
Efforts to reduce such needs often imply leasing and operating expensive storage facil-
ities close to their customers, a policy frequently used by their North-American based 
competitors (see Kopczak (1998)).

Traditional inventory planning models for supply chains focus on the minimization 
of the logistic costs. To optimize the channel wide inventory cost, some optimal logistic 
behaviors (order quantity and order frequency) have been found, for example, EOQ 
model, EPQ model, EOQ model with lumpy demand et al. as we mentioned before.

While inventory models focus on optimizing costs, many marketing models focus 
on pricing strategies and their impact on sale volumes and revenues. Jeuland and 
Shugan(1983) consider the marketing strategies in a simple channel with one supplier 
and one retailer. Ingene and Parry (1995) extends the simple channel into multi-
retailer settings. However, their models emphasize neither on logistic behavior, nor on 
logistic parameters such as setup and holding cost. Integrating inventory control and
pricing strategies was first advocated by Whirin(1955). Kohli and Park(1987). They concern minimizing the logistic cost by a pricing strategy in a one supplier and one retailer channel. Their decision variable includes both the order quantity from retailer and price a supplier offers. Recently, to minimize channel wide inventory cost, discount strategies have been widely discussed to lure the retailers to order the right quantity that benefit both retailers and suppliers. (Chakravarty (1989), Rosenblatt(1985)) . Chen, Federgruen and Zheng (2001) further combined the pricing and replenishment strategies in their one supplier, multiple retailers model to optimize the supply chain system. In their paper, the leading supplier actually offers discount based on three retailer logistic behaving characters, order size, annual sale volume and order frequency.

Our research combines logistic efficiency with pricing strategy. Interesting enough, the single variable we use to separate market is a simple function of Chen, et al.’s (2001) three retailer logistic behaving characters.

Fourth, to solve the competition problem among suppliers, we use game theory. Game theory has been broadly used in supply chain optimization model. Cachon and Zipkin (1999) show in a one supplier, multiple retailer two-echelon supply chain, system optimal solution can be achieved as a Nash equilibrium using simple linear transfer payments. In our model, system optimal is achieved by Nash equilibrium pricing strategy based on logistic efficiency.

Our research not only studies the competitions among suppliers, but also finds out the market shares of them based on the competition results. Determining market shares has always been an important task for marketing. Traditionally, market components are characterized, listed and then grouped by gender, age, sensitivity et al. Market
shares then contain components holding certain characteristics. Liu (1992) discusses the market share for transportation industry and divide the market by a single parameter, freight value. His model separates the transportation market into six segments based on the freight value line.

In conclusion, this research tries to relate suppliers’ logistic efficiency with their competition power, hence the market segmentation. It considers two-levels coordination within a multi-supplier, multi-retailer supply channel. Matching suppliers with retailers is considered as the primary coordination while traditional lot-sizing coordination is considered as secondary.

It also further considers the transportation cost through a hoteling model and compares two different pricing strategies and how they influence the market segmentation of the channel. Moreover, both matching and lot-sizing coordination are considered together. The market segmentations are compared. Implementation and numerical examples for the coordinations are introduced at the end of this dissertation.
Bibliography


Chapter 2

MARKET-BASED SUPPLY CHAIN COORDINATION BY MATCHING SUPPLIERS’ COST STRUCTURE WITH BUYERS’ ORDER PROFILE

We study competitive market places with multiple suppliers and multiple buyers dealing with a single non-differentiated product. A buyer chooses the supplier that offers the best price for his order profile, as described by his order size and delivery frequency. A supplier’s offering price reflects her logistic cost structure, as captured by relevant economies of scale in a “setup cost” component, and storage, and distribution related costs in a “holding cost per unit”. We argue that the matching of buyers order profiles
to suppliers cost structures is the main source of supply chain coordination benefits in this many-to-many supply chain. Such cost-effective matching can be achieved naturally through price competition among suppliers. We identify the segment of the buyers order space each supplier could win and perform market share sensitivity analysis when a supplier’s cost structure changes or when a new supplier enters the market. The winning supplier, at the equilibrium of price competition, offers the lowest price of her closest competitor instead of the lowest price she can offer.

2.1 Introduction

In the paper, we study competitive supply marketplaces with multiple suppliers of a single non-differentiated product, multiple retailers (buyers), and where the retailers do not competitively interact with each other. We argue rigorously through stylized modeling that for this perfectly competitive non-differentiated product supply setting, with common knowledge of all competing supplier’s logistic cost structures (i.e. setup and holding costs), each supplier’s market share and market “sweet spots” (i.e., order profiles that the supplier can effectively serve vis–vis her competitors) are fully determined by her logistic cost structure.

We are going to interestingly observe that suppliers with relatively low setup costs and high inventory holding costs effectively serve retail orders that are large in quantity but infrequent. On the other hand, suppliers with high setup costs and low inventory holding costs are the most effective in retail settings with small but frequent orders. Furthermore, for a given supplier set and any retail order profile (i.e., order size and
delivery frequency) we are going to explicitly describe the prices offered to the retailer. At the equilibrium, the winning supplier does not offer the lowest price she can offer, but instead she offers the lowest price of her closest competitors. In addition, to avoid any further modeling complexity on the supply side, we assume that all suppliers order their needed inputs from common, or similar in nature, sources in all relevant dimensions (price, quality, lead-time, etc.). This further upstream supply tier is assumed to have ample supply.

We would like to clarify that the use of the term “supplier” is interchangeably used to model either a manufacturer of the non-differentiated product or a logistical intermediary (warehousing and distribution company, third-party logistics, etc.), with the appropriate interpretation specific to the application context of our results. Similarly, a “buyer” can be a pure form retailer or simply another logistical and/or production intermediary in a complex value chain that fed by an upstream supplier.

Within this multi-supplier, multi-retailer marketplace, retailers use the supplier offered prices to select the supply partner that best fits the particular order profile, as described by order size and delivery frequency, of their environment. The supplier prices reflect their processing/logistics costs structure, as captured by relevant economies of scale in a fixed cost nature “setup cost” component, and physical storage, distribution and working capital related variable costs as depicted in a “holding cost per unit” component. In a manufacturer-reseller setting the fixed costs might be beyond just production switchover costs, often amplified to reflect relevant lost revenue considerations of alternative production uses of the facility in tight capacity situations, to also include fixed transportation and loading/unloading distribution costs as the product
gets moved from a production facility to temporary warehousing to finally reaching the reseller’s distribution, cross-docking or retail location. In a logistical/distribution intermediary - retailer setting (e.g., Li & Fung global distributor - Fashion Manufacturer/Reseller supply chains) fixed costs are mostly of logistical nature (inventory accumulation and warehousing activities for timing coordination, shipment container - vessel size economies of scale etc.). Significant differences in holding costs among suppliers can often exist within the broad interpretation of our modeling framework. Long lead-time foreign suppliers have often to worry about servicing their working capital needs in their long pipelines. Efforts to reduce such needs often imply leasing and operating expensive storage facilities close to their customers, a policy frequently used by their North-American based competitors (see Kopczak (1998)).

In the Supply Chain Coordination literature, the investigated supply chain settings in the presence of economies of scale are either two stage linear supply chains (i.e., single supplier setting to single manufacturer) or two-stage divergent distribution systems with single supplier and multiple retailers.

The primary coordination mechanisms suggested for the supply chain are carefully structured quantity discounts. The single supplier-single retailer setting has been studied among others in Abad (1994), Corbett and DeGroote (2000), Weng (1995), and recently in Karabati and Kouvelis (2003). The single supplier divergent distribution system has been studied in the multi-echelon inventory literature (see Graves and Schwartz (1977)). The more interesting recent work on the subject of perfect coordination of such supply chain settings is Roundy (1985), (1986), and incentive alignment issues for the divergent distribution system have been proposed in Chen, Federguen

The traditional viewpoint in the supply chain coordination via discounts literature can be easily discussed in the single supplier-single retailer setting. For a decentralized, non-coordinated system, the assumed protocol of action involves the supplier choosing order quantity, and corresponding delivery frequency to meet a constant annual demand in a way that minimizes her holding and setup costs. The supplier, provided with the retailer’s order profile, chooses an appropriate production lot size to optimize his holding and setup costs. Within a centralized decision making (frequently referred to as cooperative strategy) setting, the single decision maker, the “coordinator”, with full information of all parameters of the problem, chooses the supplier and retailer order sizes, under the usual, and rather non-restrictive, assumption that the supplier order is an integer multiple of the retailer order size, in a way that optimizes the overall supply chain inventory holding and setup costs (see Silver et al (1998)). In the coordinated solution, although the overall cost of the supply chain is lower, the retailer’s total cost increases. Thus, in order to achieve implementation of the coordinated solution in an independent decentralized decision making setting, the retailer has to be offered appropriate quantity discounts in an effort to align her incentives with the overall supply chain and adjust her order profile according to the coordinated solution (see Weng (1995)).

Even though this decentralized coordination via appropriately determined quantity discounts approach is appealing in its system optimizing logic, it has practical
implementation flaws that could limit its effectiveness, potentially even its feasibility, and in particular so in the non-differentiated product environment of our study. The approach starts by assuming the retailer has already picked her supplier, and then works within the confines of the supplier’s logistic cost structure and via an assumed cooperative partnership to improve the resulting supply chain. But this cooperative solution requires the retailer to change his order profile, which might not be desirable and/or even practically feasible to do.

Quite frequently, the order profile of the particular product sourced is the result of derivative (dependent) demand calculations out of complex production/selling plans of multi-item assembled final goods, with the sourced product just being one of the many required items. This is the case when our “retailer” is either a distributor of systems, with assembly capabilities needed, or a manufacturer herself. Even in a pure retailing context, selling reason and promotional consideration of retailers, often operating in limited retail space stores, with diverse product lines of partially substitutable items make it hard, and potentially infeasible, to change order profiles of any one of the products, without affecting the order profiles of the others which are potentially sourced from other suppliers. Quite frequently for functional, divisional or brand management reasons, the sourcing of different products is a separate decision handled by different purchasing managers, thus making order profile adjustments an organizational nightmare.

From a conceptual viewpoint, our approach in improving overall supply chain efficiencies for non-differentiated products, in the presence of diverse in terms of logistical cost structures and competitive pricing suppliers, is to create a market mechanism
that will lead to the most reasonable match between the retailer’s order with the supplier’s capabilities. In contrast to the quantity discount based coordination, where a pre-determined pair of supplier-retailer tries to move from the retailer’s desired order profile towards the profile that the supplier can support, our approach tries to select the right supplier for the particular order profile, with the right supplier being defined as the one that has the logistical cost structure to profitably offer the most competitive price to the retailer.

The study of the single-supplier multi-retailer divergent distribution system followed a similar research path to the two party(stages) linear supply chain one. Centralized optimal (or equivalently cooperative) strategies have been studied in Graves and Schwarz (1977). Such strategies entail the use of non-stationary replenishment intervals, which are often too complex for practical use. Roundy (1985, 1986) ingeniously introduced simple coordination strategies for the problem by using the so-called power-of-two policies. Such intervals that are power-of-two multiples of the supplier’s replenishment interval, are simpler to implement and can be proved to be within 2% of optimality. Implementation of such cooperative strategies for independent retailers fails in the absence of the right incentives, as the retailer’s cost increases when the coordinating order quantity deviates from the economic order one. Chen, Federgruen and Zheng (2001) propose an incentive compatible scheme for the implementation of coordinating power-of-two policies in decentralized settings. The scheme involves two components: (a) a common price discount scheme offered to retailers in causing the placement of order in intervals that achieve perfect channel coordination; and (b) each retailer is required to pay the supplier a franchise fee, which allows for redistribution of the coordination benefit in a way that the retailer affords to offer the needed discounts.
Near perfect supply chain coordination strategies for this setting are offered by Wang (2001) using order timing coordination as derived via a Stackelberg game in which the supplier acts as the leader and retailers act as followers. For all these type of decentralized coordination via quantity discounts or order timing coordination, we have the same reservations as for their equivalent ones in linear supply chains. The predetermined matching of supplier-and-retailer, and the imposed requirement for cooperative improvement via substantial adjustment in the retailer’s order profile, either through order quantity or delivery timing, limits their applicability and effectiveness for many realistic settings. Again, our price directed mechanisms for matching the retailer’s order profile-to-supplier, in logistically diverse and competitive supply networks, will lead to a natural equilibrium for the overall system rather easily.

The remainder of the paper is organized as follows. Section 2 describes the two-echelon supply chain model under consideration. Section 3 focuses on the market share analysis for two suppliers. The results are generalized to multiple suppliers in Section 4. In particular, we characterize the equilibrium market share obtained by each supplier and the equilibrium price offered to each retailer. An efficient algorithm is developed to determine the market shares for all coexisting suppliers. Section 5 performs market share sensitivity analysis as a supplier’s inventory cost changes or as a new supplier enters the market.
2.2 Model Description

The two-stage supply chain under consideration consists of \( N \) suppliers and many buyers. A single product type with uniform quality is involved in the exchange between suppliers and buyers. The buyer’s order profile is characterized by his order quantity \( q \) and order frequency \( \mu \), both assumed to be fixed for each buyer. In reality, a buyer might have multiple orders with different profiles. In our exposition, we treat each order as a separate buyer. This modeling artifice has no implication for the results other than our expository convenience. In later sections of the paper, we use the ratio \( \rho = \mu/q \) (we refer to it as the order profile ratio) as an alternative characterization for a buyer. In either case, the buyer’s market can be described by a two dimensional space with parameters \( q \) and \( \mu \) or parameters \( \rho \) and \( \mu \). In the \( q-\mu \) space, a point \((q, \mu)\) represents a buyer that orders \( q \) units each time and \( \mu \) times a year with an annual demand of \( d = \mu q \). In the \( \rho-\mu \) space, a point \((\rho, \mu)\) represents a buyer that orders \( \mu/\rho \) units each time and \( \mu \) times a year with an annual demand of \( d = \mu^2/\rho \). All the parameters we introduce here shall be nonnegative.

To fulfill buyers’ orders, all suppliers order from a common source with ample supply and they pay the same unit cost \( C_0 \). We assume that suppliers do not combine orders from different buyers in our model. The suppliers differ from each other in terms of their inventory holding costs \( H_i, i = 1, \ldots, N \), and setup costs \( S_i, i = 1, \ldots, N \). Without loss of generality, the indices of the suppliers are ordered according to their setup costs: \( S_i < S_{i+1}, i = 1, \ldots, N - 1 \). We assume

\[
S_i \neq S_j \quad \text{and} \quad S_i/H_i \neq S_j/H_j \quad \forall i, j = 1, \ldots, N, i \neq j. \tag{2.1}
\]
Indeed, if $S_i = S_j$ then either these two suppliers are identical (when their inventory holding costs are the same) or the supplier with a lower inventory holding cost dominates the other supplier. If $S_i/H_i = S_j/H_j$ then the supplier with a lower setup cost (and thus inventory holding cost) dominates the other supplier. The information about $H_i$ and $S_i$ for all suppliers is assumed to be common knowledge among the suppliers. In Section 8, we will discuss how our results can be extended and effectively implemented when the “common knowledge” assumption is not valid.

We assume that there is no cooperation between any supplier and any buyer in this paper. A buyer chooses his supplier based on the price offered. The suppliers compete for buyer’s market by determining their inventory replenishment policy and pricing strategy. More specifically, we assume that all suppliers have the flexibility of offering different prices to different buyers based on buyers’ order profile, i.e., their order quantities and order frequencies. Notice that this pricing strategy, when suppliers know each others logistics cost structure, can be implemented through a price menu approach to avoid antitrust litigation under the Robinson-Patman Act. In the absence of full cost knowledge of competing suppliers, implementation of this pricing equilibrium will require a second-price sealed bid auction to be executed for every buyer’s order (see Section 8 for detailed discussion).

Clearly, the lowest price a supplier can offer to a buyer depends on the supplier’s setup and inventory holding cost. To minimize her inventory cost, it is optimal for each supplier to follow the “EOQ model with lumpy demand” for her inventory policy (Munson and Rosenblatt(2001)). More specifically, let us suppose buyer $(q, \mu)$ (or $(\rho, \mu)$) orders from supplier $i$. Then the supplier should order $nq$ units each time and
\( \mu/n \) times a year. The optimal multiple \( n \) is given by

\[
n^* = \left\lfloor \frac{1}{2} \left( 1 + \sqrt{1 + \frac{8 S_i d}{H_i q^2}} \right) \right\rfloor = \left\lfloor \frac{1}{2} (1 + \sqrt{1 + 8 \rho S_i / H_i}) \right\rfloor,
\]

where \( \lfloor x \rfloor \) represents the largest integer less than or equal to \( x \). The minimum annual inventory cost per product incurred to supplier \( i \) is given by:

\[
C^*_i = \frac{S_i}{n^* q} + \frac{(n^* - 1) H_i}{2 \mu} = \frac{H_i}{\mu} \left( \frac{\rho S_i / H_i}{(1 + \sqrt{1 + 8 \rho S_i / H_i}) / 2} + \frac{1}{2} \left\lfloor \frac{4 \rho S_i / H_i}{(1 + \sqrt{1 + 8 \rho S_i / H_i})} \right\rfloor \right).
\]

(2.2)

It is well known that the inventory cost of most EOQ models are insensitive to the order quantity variations near the optimal order quantity. In the remaining paper, we approximate the inventory cost \( C^*_i \) by ignoring the integer operation in (3.1). After some algebraic simplifications, we have:

\[
C^*_i \approx \frac{4 S_i \rho}{(1 + \sqrt{1 + 8 \rho S_i / H_i}) \mu}.
\]

Define relative inventory cost

\[
C_i(\rho) = \frac{4 S_i \rho}{1 + \sqrt{1 + 8 \rho S_i / H_i}}.
\]

It follows that the lowest price supplier \( i \) can offer to buyer \((\rho, \mu)\), while maintaining profitability, is given by: \( P_i(\rho, \mu) = C_0 + C_i(\rho)/\mu \).
2.3 Order Space Segmentation and Pricing for Two Suppliers

To better understand how $N$ suppliers compete for buyers’ order space segment, we start by analyzing a special case where only two suppliers exist in the supply chain. Without loss of generality, let supplier 1 and supplier 2 (with $S_1 < S_2$) be the two suppliers. Since the buyers are price-takers by assumption, both suppliers will compete on the unit offering price to gain buyer’s order space. Therefore, for buyer $(q, \mu)$, the supplier with the smaller $P_i(\rho, \mu)$ will eventually win the price war. Define

$$R_{ij}(\rho) = \frac{C_i(\rho)}{C_j(\rho)} = \frac{S_i(1 + \sqrt{1 + 8\rho S_j/H_j})}{S_j(1 + \sqrt{1 + 8\rho S_i/H_i})}, \quad i = 1, j = 2.$$ 

Since the purchasing price $C_0$ is the same for both suppliers, $R_{12}(\rho) < 1$, or $C_1(\rho) < C_2(\rho)$, if and only if $P_1(\rho, \mu) < P_2(\rho, \mu)$. Notice that $R_{12}$ is a function of a single parameter $\rho = \mu/q$, the order profile ratio. This implies that the order profile ratio $\rho$ alone, instead of a pair of parameters $(q, \mu)$ or $(\rho, \mu)$, is sufficient to characterize supplier 1 and supplier 2’s order space segments. The boundary of the order space segments between supplier 1 and supplier 2 can be determined by simply solving a nonlinear equation: $R_{12}(\rho) = 1$. To characterize the order space segment boundary, we need the following property about this equation.

**Proposition 1** Equation $R_{12}(\rho) = 1$ has at most one positive solution.

The proof of the proposition is provided in the appendix. With this result, we are
able to provide a necessary and sufficient condition for supplier 1 and supplier 2 to share the market.

**Theorem 1** Suppose supplier 1 and supplier 2 (with \( S_1 < S_2 \)) compete for buyer’s order space through pricing. Both suppliers have positive order space segments (coexist) if and only if

\[
S_1H_1 > S_2H_2. \tag{2.3}
\]

Otherwise, supplier 1 dominates supplier 2 by taking away all buyer’s order space.

**Proof:**

Both Supplier 1 and supplier 2 will have positive order space segments if and only if equation \( R_{12}(\rho) = 1 \) has a positive solution. By definition, \( \lim_{\rho \to 0} R_{12}(\rho) = \frac{S_1}{S_2} < 1 \).

From Proposition 1, equation \( R_{12}(\rho) = 1 \) has at most one positive solution. It follows that a positive solution exists if and only if \( \lim_{\rho \to \infty} R_{12}(\rho) = \sqrt{\frac{S_1H_1}{S_2H_2}} > 1 \). Clearly, this condition is equivalent to \( S_1H_1 > S_2H_2 \). On the other hand, if this condition is not satisfied, then \( R_{12}(\rho) < 1 \) for all \( \rho > 0 \) since equation \( R_{12}(\rho) = 1 \) has at most one solution. This implies that supplier 1 dominates supplier 2.

We call condition (2.3) the pairwise coexisting condition. The condition has the following implications. For a supplier to acquire a positive order space segment, she has to be competitive in either setup cost or inventory holding cost relative to her competitors. Furthermore, the setup cost plays a more critical role than the holding cost.
The pairwise coexisting condition is not transitional in general. I.e., even if two suppliers are able to coexist with a common supplier in their respective competitions, these two suppliers may not coexist when they compete directly. Consider the following three suppliers with $S_1 = 30$, $H_1 = 9$, $S_2 = 45$, $H_2 = 2$, and $S_3 = 60$, $H_3 = 3$. Clearly, $S_1 < S_2 < S_3$ and $S_1H_1 > S_3H_3 > S_2H_2$. By Theorem 1, both supplier 2 and supplier 3 coexist with supplier 1. However, supplier 2 dominates supplier 3 when they compete.

Suppose now supplier 1 and supplier 2 are able to coexist. Let $M_1$ and $M_2$ be their respective equilibrium order space segments as a result of their price competition. The next result determines the boundary of their order space segments.

**Theorem 2** Suppose supplier 1 and supplier 2 satisfy the pairwise coexisting condition (2.3) and they compete for buyer’s order space segment through pricing. Let

$$\rho_{12} = \frac{H_1H_2(H_1 - H_2)(S_2 - S_1)}{2(S_1H_1 - S_2H_2)^2}.$$  \hspace{1cm} (2.4)

Then the equilibrium order space segments of supplier 1 and supplier 2 are given by

$$M_1 = \{\rho < \rho_{12}\} \quad \text{and} \quad M_2 = \{\rho > \rho_{12}\},$$

respectively.

**Proof:** Under condition (2.3), it is easy to verify that $\rho_{12} > 0$ is a positive solution of equation $R_{12}(\rho) = 1$. By Proposition 1, the solution is unique. From the proof of Theorem 1, $\lim_{\rho \to 0} R_{12}(\rho) < 1$. It follows that $R_{12}(\rho) < 1$, $C_1(\rho) < C_2(\rho)$, and
$P_1(\rho, \mu) < P_2(\rho, \mu)$ for all $\rho < \rho_{12}$. Therefore, all buyers with $\rho < \rho_{12}$ order from supplier 1 and $M_1$ describes supplier 1’s order space segment correctly. By a similar argument, $M_2$ correctly describes supplier 2’s order space segment. \hfill \blacksquare

Figure 2.1 shows the order space segmentation in both $q$-$\mu$ and $\rho$-$\mu$ spaces. While the space of buyers is characterized by two parameters, $(q, \mu)$ or $(\rho, \mu)$, a supplier’s order space segment depends on only one parameter $\rho = \mu / q$.

**INSERT FIGURE 2.1 HERE**

The supplier with the lower inventory cost wins a buyer’s order, to maximizes her own profit, she does not have to offer the lowest price she can offer. Indeed, at the equilibrium of the price competition, she offers the buyer with the lowest price her competitor can offer. The result is formally stated in the following theorem.

**Theorem 3** Under the assumption of Theorem 2, the equilibrium price $P(\rho, \mu)$ offered to buyer $(\rho, \mu)$ is given by

$$P(\rho, \mu) = \max\{P_1(\rho, \mu), P_2(\rho, \mu)\} = C_0 + \begin{cases} 
C_2(\rho) / \mu & \text{if } (\rho, \mu) \in M_1 \\
C_1(\rho) / \mu & \text{if } (\rho, \mu) \in M_2 
\end{cases}$$

**Proof:** Consider a buyer $(\rho, \mu) \in M_1$. Based on the proof of Theorem 2,

$$P_1(\rho, \mu) = C_0 + C_1(\rho) / \mu < C_0 + C_2(\rho) / \mu = P_2(\rho, \mu).$$
As long as supplier 1’s offering price to buyer \((\rho, \mu)\) is under \(P_2(q, \mu)\), supplier 1 will win the buyer’s order. On the other hand, if supplier 1’s offering price is strictly higher than \(P_2(\rho, \mu)\), supplier 2 will be able to offer the buyer a price that is slightly below supplier 1’s price to win the buyer, but higher than \(P_2(q, \mu)\) to make a profit. Since the objective of both suppliers is to gain buyer’s order space and maintain profitability, at the equilibrium of the price competition, supplier 1’s offering price to the buyer \((\rho, \mu)\) has to be \(P_2(q, \mu)\). The same argument also holds for a buyer \((\rho, \mu) \in M_2\).

2.4 Order Space Segmentation and Pricing for \(N\) Suppliers

We extend the order space segmentation analysis for 2 suppliers to \(N\) suppliers in this section. Clearly, among the \(N\) suppliers, if one of the suppliers is dominated by another, this supplier will not have any order space segment after the competition. Such dominated suppliers can be easily identified by checking the pairwise coexisting condition (2.3) developed in the previous section. In this section, we assume all \(N\) suppliers satisfy the pairwise coexisting condition and they are arranged according to the following sequence:

\[
S_i < S_{i+1} \text{ and } S_i H_i > S_{i+1} H_{i+1} \quad \forall i = 1, \ldots, N - 1.
\]  

(2.5)

In view of Theorem 1, condition (2.5) ensures that the \(N\) suppliers do not dominate
each other pairwisely. This condition, however, does not guarantee that all $N$ suppliers will end up with positive order space segments when they compete together. This is demonstrated by the following example. Consider three suppliers 1, 2, and 3 with $S_1 = 400$, $H_1 = 16$, $S_2 = 420$, $H_2 = 15$, and $S_3 = 440$, $H_3 = 14$. Clearly, $S_1 < S_2 < S_3$ and $S_1 H_1 > S_2 H_2 > S_3 H_3$. The three suppliers satisfy pairwise coexisting condition (2.5) and will coexist when they compete pairwise. However, applying (2.4) to calculate the boundaries of three suppliers’ order space segments, we have $\rho_{12} = 0.24$, $\rho_{13} = 0.156$, and $\rho_{23} = 0.107$. By definition,

$$C_2(\rho) > C_1(\rho) \quad \forall 0 < \rho < 0.24 \quad \text{and} \quad C_2(\rho) > C_3(\rho) \quad \forall \rho > 0.107.$$ 

Therefore, when these three suppliers compete, supplier 2’s relative inventory cost can not be the lowest, thus she is dominated by the presence of supplier 1 and supplier 3 together and will end up with winning no buyer’s order. The final price competition result is that supplier 1 and supplier 3 coexist with their order space segment boundary set at $\rho_{13} = 0.156$.

Before presenting a condition for $N$ suppliers to coexist, we first study some order relationship among the order space segment boundaries when three suppliers compete for buyer’s order space.

**Proposition 2** Let 1, 2, and 3 be three suppliers competing for buyer’s order space through pricing. Suppose they satisfy the pairwise coexisting condition (2.5). Then either

$$\rho_{12} < \rho_{13} < \rho_{23},$$
in which case the three suppliers share the order space with

\[ M_1 = \{ \rho < \rho_{12} \}, \quad M_2 = \{ \rho_{12} < \rho < \rho_{23} \}, \quad M_3 = \{ \rho > \rho_{23} \}, \]

or

\[ \rho_{23} \leq \rho_{13} \leq \rho_{12}, \]

in which case supplier 2 is dominated by suppliers 1 and 3 and their order space segments are given by

\[ M_1 = \{ \rho < \rho_{13} \}, \quad M_2 = \emptyset, \quad M_3 = \{ (\rho > \rho_{13} \}. \]

\textbf{Proof:}

For three suppliers, we have either \( \rho_{12} < \rho_{13} \), or \( \rho_{12} > \rho_{13} \), or \( \rho_{12} = \rho_{13} \).

If \( \rho_{12} < \rho_{13} \), we show that \( \rho_{13} < \rho_{23} \). Suppose this is not true. Then there exists a buyer \((\rho, \mu)\) with \( \max\{\rho_{12}, \rho_{23}\} < \rho < \rho_{13} \). By definition of \( \rho_{ij} \) and the coexisting condition (2.5), we have the following inequalities:

\[ C_2(\rho) < C_1(\rho), \quad C_1(\rho) < C_3(\rho), \quad \text{and} \quad C_3(\rho) < C_2(\rho). \]

However, these inequalities cannot hold simultaneously and this leads to a contradiction. Therefore, \( \rho_{12} < \rho_{13} < \rho_{23} \). To determine the order space segmentation for the suppliers, first consider any buyer \((\rho, \mu)\) such that \( 0 < \rho < \rho_{12} \). Since \( \rho_{12} < \rho_{23} \), by
definition of \( \rho_{ij} \) and condition (2.5), we have

\[
C_1(\rho) < C_2(\rho) < C_3(\rho)
\]

and supplier 1’s order space segment follows immediately. Supplier 3’s order space segment can be determined in a similar manner. For supplier 2, consider any buyer with \( \rho_{12} < \rho < \rho_{23} \). We have

\[
C_2(\rho) < C_1(\rho) \quad \text{and} \quad C_2(\rho) < C_3(\rho)
\]

and thus supplier 2’s order space segment.

In case \( \rho_{12} > \rho_{13} \), that \( \rho_{23} < \rho_{13} \) can be shown in a similar manner. Suppose this is not true, then there is a buyer whose \( \rho \) satisfies \( \rho_{13} < \rho < \min\{\rho_{12}, \rho_{23}\} \). Again, we have the following inequalities:

\[
C_3(\rho) < C_1(\rho), \quad C_1(\rho) < C_2(\rho), \quad \text{and} \quad C_2(\rho) < C_3(\rho).
\]

These inequalities cannot hold simultaneously and this leads to a contradiction. Therefore, \( \rho_{23} < \rho_{13} < \rho_{12} \). Since

\[
C_1(\rho) < C_2(\rho) \quad \forall \rho < \rho_{12}, \quad C_3(\rho) < C_2(\rho) \quad \forall \rho > \rho_{23}
\]

and \( \rho_{23} < \rho_{12} \), supplier 2 is dominated by the existence of supplier 1 and supplier 3 together. It follows that the market will be shared by only supplier 1 and supplier 3 with the boundary set at \( \rho_{13} \).
If \( \rho_{12} = \rho_{13} \), the problem is degenerate. We have \( \rho_{12} = \rho_{23} = \rho_{13} \) and supplier 2 is dominated.

We now generalize the order space segmentation analysis to the case of \( N \) suppliers. The following result provides a necessary and sufficient condition for \( N \) suppliers to share buyers’ market when they compete together.

**Theorem 4** Suppose condition (2.5) holds for the \( N \) suppliers competing for buyer’s order space through pricing. All suppliers coexist if and only if

\[
\rho_{i-1,i} < \rho_{i,i+1} \quad \forall i = 2, \ldots, N - 1.
\] (2.6)

In addition, under condition (2.6), supplier \( i \)'s order space segment is given by

\[
M_i = \begin{cases} 
\{ \rho < \rho_{12} \} & \text{if } i = 1, \\
\{ \rho_{i-1,i} < \rho < \rho_{i,i+1} \} & \text{if } i = 2, \ldots, N - 1, \\
\{ \rho > \rho_{N-1,N} \} & \text{if } i = N.
\end{cases}
\]

**Proof:** To show that condition (2.6) is necessary, suppose \( \rho_{i-1,i} \geq \rho_{i,i+1} \) for some \( i = 2, \ldots, N - 1 \). Consider three suppliers \( i-1, i, \) and \( i+1 \). By Proposition 2, supplier \( i \) is dominated by supplier \( i-1 \) and supplier \( i+1 \) together. Thus, condition (2.6) is a necessary condition for \( N \) suppliers to coexist. We next show that condition (2.6) is also sufficient. For supplier 1, consider any buyer \((\rho, \mu)\) with \( \rho < \rho_{12} \). Under conditions
(2.5) and (2.6), we have

\[ C_1(\rho) < C_2(\rho) < \ldots < C_N(\rho) \quad (2.7) \]

by definition of \( \rho_{ij} \). It follows that supplier 1 has a positive order space segment, which is given by \( M_1 \) in the theorem. The proof for supplier \( N \)'s order space segment is essentially the same. For supplier \( i \), consider any buyer \((\rho, \mu)\) with \( \rho_{i-1,i} < \rho < \rho_{i,i+1} \).

Again by definition of \( \rho_{ij} \), we have

\[ C_1(\rho) > \ldots > C_{i-1}(\rho) > C_i(\rho) \quad \text{and} \quad C_i(\rho) < C_{i+1}(\rho) < \ldots < C_N(\rho). \quad (2.8) \]

Therefore, supplier \( i \) has a positive order space segment, which is given by \( M_i \) in the theorem.

Figure 2.2 shows the order space segmentation of \( N \) suppliers in both \( q-\mu \) and \( \rho-\mu \) spaces when they compete together.

We have the following observations about the order space segmentation for \( N \) suppliers:

- A supplier will have a positive order space segment as long as she is not dominated by her closest competitors. In our model, the closest competitors of a supplier are those suppliers that have a common order space segment boundary. We call
these suppliers “neighbor suppliers”.

- For supplier 1 and supplier \( N \) to have a positive order space segment, condition (2.6) is not necessary. Condition (2.5) alone would be sufficient. Indeed, for supplier 1, if she coexists pairwisely with all other suppliers, i.e., \( \rho_{1,i} > 0 \) for all \( i = 2, \ldots, N \), her order space segment is given by \( M_1 = \{ \rho < \min_{i=2,\ldots,N} \rho_{1i} \} \). Similar result also holds for supplier \( N \). The coexisting condition is weaker for suppliers 1 and \( N \) because they have only one neighbor supplier. Hence, the competition comes from only one side.

- When several suppliers compete for buyers through pricing, each supplier captures the market of buyers who they can serve most cost effectively. A supplier with a relatively low setup cost and a high inventory holding cost usually matches buyers that order in large quantities but infrequently. On the other hand, a supplier with a relatively low inventory holding cost and a high setup cost usually attracts buyers that order in small quantities but frequently.

Even though the last observation seems paradoxical, it is actually not if we carefully examine the properties of \( R_{ij}(\rho) \) (see Section 4). For a buyer order profile with large order quality and small frequency, the best any supplier can do is to match this frequency with her production schedule. In a setup cost dominated environment, this implies that the lowest setup cost supplier has the per unit cost advantage. On the other hand, for an order profile with small order quantities delivered frequently, the supplier with high setup cost and lower holding costs will produce large batch sizes and hold them longer. In doing so, she will allocate her setup cost disadvantage via a large lot size relative to the low setup cost supplier. Due to her higher inventory
holding costs, the low setup cost supplier uses her flexibility in producing smaller lots as an effort to avoid large holding costs, but that results in setup costs accumulated over smaller batches, thus finally resulting in a per unit cost disadvantage relative to the high setup cost supplier. In other words, for highly repetitive small order quantity buyer profiles, the ability to effectively aggregate orders in the production environments proved beneficial relative to the flexibility of frequently small lot switch overs.

We now present an algorithm to determine the order space segments for all coexisting suppliers. Again we assume that all $N$ suppliers satisfy the pairwise coexisting condition (2.5) but not necessarily condition (2.6). The algorithm represents a built-on process. It determines the order space segment of supplier 1 by finding her “neighbor” supplier and locating the corresponding boundary. The dominated suppliers are eliminated in the mean time. Then the algorithm labels the neighbor supplier as the current supplier and continues to find the next neighbor supplier and the order space segment boundary. The process stops when the order space segment of supplier $N$ is determined. In the following description of the algorithm, $N'$ is the total number of coexisting suppliers, $k(j)$ is the original index of the $j$th coexisting supplier, $j = 1, \ldots, N'$, and $M_{k(j)}$ is her order space segment.

Algorithm to Determine Order Space Segmentation for Multiple Suppliers

**Step 0** Set $k(1) = 1$, $j = 1$.

**Step 1** Find

$$l = \arg \min_{\ell = k(j) + 1, \ldots, N'} \rho_{k(j), \ell}.$$
Step 2 Set
\[ M_{k(j)} = \begin{cases} 
\{ \rho < \rho_{k(j),l} \} & \text{if } j = 1, \\
\{ \rho > \rho_{k(j),j} \} & \text{if } l = N, \\
\{ \rho_{k(j-1),k(j)} < \rho < \rho_{k(j),j} \} & \text{otherwise.}
\end{cases} \]

Step 3 Set \( j = j + 1 \), \( k(j) = l \). If \( l = N \), set \( N' = j \) and stop; otherwise, go to Step 1.

Theorem 5 The above algorithm correctly determines the order space segment for each supplier.

Proof: Let \( \{ k(1), \ldots, k(j), \ldots k(N') \} \) be the coexisting suppliers identified by the above algorithm. Notice that \( k(1) = 1 \) and \( k(N') = N \). The algorithm divides the buyer’s order space, in terms of parameter \( \rho \), into the following segment:

\( (0, \rho_{1,k(2)}), \ldots, (\rho_{k(j-1),k(j)}, \rho_{k(j),k(j+1)}), \ldots, (\rho_{k(N'-1),N}, \infty) \).

To prove Theorem 5, it suffices to show

\( \rho_{k(j-1),k(j)} < \rho_{k(j),k(j+1)} \) for all \( j = 2, \ldots, N' - 1 \) \hspace{1cm} (2.9)

and

\[ C_i(\rho) \geq \begin{cases} 
C_1(\rho) & \forall 0 < \rho < \rho_{1,k(2)}, \\
C_{k(j)}(\rho) & \forall \rho_{k(j-1),k(j)} < \rho < \rho_{k(j),k(j+1)}, \ j = 2, \ldots, N' - 1, \\
C_N(\rho) & \forall \rho > \rho_{k(N'-1),N}.
\end{cases} \] \hspace{1cm} (2.10)

holds for all \( i = 1, \ldots, N \). From Step 1 and Step 3 of the algorithm, we have

\( \rho_{k(j-1),k(j)} < \rho_{k(j-1),k(j+1)} \) for all \( j = 2, \ldots, N' - 1 \).
By Proposition 2, we have

\[ \rho_{k(j-1),k(j)} < \rho_{k(j-1),k(j+1)} < \rho_{k(j),k(j+1)} \]

and hence inequality (2.9). To prove (2.10), first observe that (2.10) is true for all suppliers \( k(j), j = 1, \ldots, N' \). This follows from (2.9), condition (2.5), and Theorem 4. It remains to show that the other suppliers are dominated by suppliers \( k(j), j = 1, \ldots, N' \). Indeed, consider any supplier \( i \) such that \( k(j) < i < k(j + 1) \) for some \( j = 1, \ldots, N' - 1 \). From Step 1 and Step 3 of the algorithm, we have \( \rho_{k(j),i} > \rho_{k(j),k(j+1)} \). By Proposition 2, supplier \( i \) is dominated by suppliers \( k(i) \) and \( k(i + 1) \) together.

Next, we study the equilibrium price offered to each buyer \((\rho, \mu)\). Similar to the two supplier situation studied in the previous section, for a given buyer, the supplier who is capable of offering the lowest price will win the buyer’s order as the result of price competition. However, at the equilibrium, the winner does not offer the lowest price she can offer. Instead, she offers the lowest price of her closest competitors, her “neighbor” suppliers in this case. The result is formally stated in the following theorem.

**Theorem 6** Suppose conditions (2.5) and (2.6) hold for the \( N \) suppliers competing for buyer’s order space through pricing. The equilibrium price offered to buyer \((\rho, \mu)\) is given by

\[
P(\rho, \mu) = \begin{cases} 
  P_2(\rho, \mu) & \text{if } (\rho, \mu) \in M_1, \\
  P_{i-1}(\rho, \mu) & \text{if } (\rho, \mu) \in M_i \text{ and } \rho < \rho_{i-1,i+1}, \\
  P_{i+1}(\rho, \mu) & \text{if } (\rho, \mu) \in M_i \text{ and } \rho \geq \rho_{i-1,i+1}, \\
  P_{N-1}(\rho, \mu) & \text{if } (\rho, \mu) \in M_N,
\end{cases}
\]

(2.11)

where \( P_i(\rho, \mu) = C_0 + C_i(\rho) / \mu \).
**Proof:** In view of the proof for Theorem 3, it suffices to show that \( P(\rho, \mu) \) is the second lowest price offered to buyer \((\rho, \mu)\). If \((\rho, \mu) \in M_1\), the result follows from (2.7). The same argument also holds for \((\rho, \mu) \in M_N\). If \((\rho, \mu) \in M_1\), by Proposition 2 and Theorem 4, we have \( \rho_{i-1,i} < \rho_{i-1,i+1} < \rho_{i,i+1} \). From (2.8), either \( P_{i-1}(\rho, \mu) = C_0 + C_{i-1}(\rho)/\mu \) or \( P_{i+1}(\rho, \mu) = C_0 + C_{i+1}(\rho)/\mu \) will be the second lowest price offered to buyer \((\rho, \mu)\). If \( \rho_{i-1,i} < \rho < \rho_{i-1,i+1} \), \( C_{i-1}(\rho) < C_{i+1}(\rho) \) and \( P_{i-1}(\rho, \mu) \) is the second lowest price. Otherwise, \( P_{i+1}(\rho, \mu) \) is the second lowest price. This completes the proof. \(\Box\)

The equilibrium pricing strategy for multiple coexisting suppliers are illustrated in 2.3 below.

**2.5 Order Space Segmentation Sensitivity Analysis**

This section answers the following questions:

- If a supplier’s logistic cost structure (setup cost or inventory holding cost) changes, how will her order space segment and other suppliers’ order space segments be affected?

- If a new supplier enters the market, will she acquire a positive order space segment? If so, how will other supplier’s order space segments be affected? Will any existing supplier be eliminated because of the competition from the new entrant?
2.5.1 Sensitivity Analysis for Coexisting Suppliers

Let us consider the two supplier situation first. Notice that the order space segment boundary $\rho_{12}$, given by expression (2.4), is a function of the two suppliers’ inventory costs: $H_1$, $H_2$, $S_1$, and $S_2$. We have the following result based on expression (2.4).

**Proposition 3** Suppose supplier 1 and 2 satisfy the pairwise coexisting condition (2.5) with $S_1 < S_2$. Then $\rho_{12}$ is a decreasing function of $H_1$ and $S_1$ and an increasing function of $H_2$ and $S_2$.

**Proof:** Since the two suppliers satisfy the pairwise coexisting condition, we have

$$S_1 < S_2, \quad \text{and} \quad H_1 S_1 > H_2 S_2.$$

In view of expression (2.4), it is quite obvious that $\rho_{12}$ is a decreasing function of $S_1$ and an increasing function of $S_2$. To see that $\rho_{12}$ is a decreasing function of $H_1$, we rewrite the function as follows:

$$\rho_{12}(H_1, H_2, S_1, S_2) = \frac{1}{1 - \frac{1}{S_1 H_1}} \frac{1}{1 - \frac{1}{S_2 H_2}} \frac{H_2 (S_2 - S_1)}{2 S_1^2}.$$

In the above expression, the third fraction is independent of $H_1$. The first fraction is a decreasing function of $H_1$ as long as $H_1 S_1 > H_2 S_2$. The second fraction is also a decreasing function of $H_1$ as long as $H_1 S_1 > H_2 S_2$ and $S_2 / S_1 > 1$. This is because $(1 - x)/(1 - \alpha x)$ is an increasing function of $x$ if $\alpha > 1$ and $1 - \alpha x > 0$. Therefore, the whole function is a decreasing function of $H_1$. Following a similar approach, we can
also show that $\rho_{12}$ is an increasing function of $H_2$. 

Now consider the situation when $N$ suppliers share the buyer’s order space. Let us apply Proposition 3 to supplier $i$ whose order space segment is given by

$$M_i = \{\rho_{i-1,i} < \rho < \rho_{i,i+1}\}.$$ 

We have the following observations based on Proposition 3:

- While the position of supplier $i$’s order space segment depends on the relative scales of $S_i$ and $H_i$ in comparison to her competing suppliers, the size of her order space segment, depends on the magnitude of her relevant inventory costs.

- If supplier $i$ seeks to increase the size of her order space segment, she has two options. She may continuously reduce her setup cost or holding cost and expand her order space segment in both directions at the expenses of her neighbor suppliers $i - 1$ and $i + 1$. In this case, the relative position of the supplier’s order space segment does not change and her expansion will not affect other suppliers until one of her “neighbor” suppliers is eliminated, which happens when $\rho_{i-1,i}$ reduces to $\rho_{i-2,i-1}$ or $\rho_{i,i+1}$ increases to $\rho_{i+1,i+2}$, whichever happens first. Alternatively, the supplier may change her logistic cost structure dramatically and position herself at a different segment of buyer’s order space. This might require substantial re-engineering of supplier’s operation process. The strategy will work if the competitors in the new order space segment are less efficient in terms of their inventory costs.
2.5.2 New Entrant Analysis

We consider the situation when a new supplier $k$ enters the buyer’s market. Clearly, if supplier $k$ is dominated by any of the current suppliers, it will not have any order space segment. This happens when supplier $k$ fails to satisfy the pairwise coexisting condition (2.3) with the current $N$ suppliers. In the remaining section, we assume that supplier $k$ satisfies the following pairwise coexisting condition

$$S_i < S_k < S_{i+1}, \quad S_iH_i > S_kH_k > S_{i+1}H_{i+1}$$

(2.12)

for some $i = 1, \ldots, N$. As we discussed before, the above pairwise coexisting condition is necessary, but not sufficient, for supplier $k$ to coexist with the current $N$ suppliers. For supplier $k$ to have positive order space segment, she has to gain order space segments from at least one of her neighbor suppliers $i$ or $i+1$. Indeed, by applying Theorem 4 to the $N$ existing suppliers and the new supplier, we have the following results:

**Corollary 1** Let $1, 2, \ldots, i, \ldots, N$ be $N$ coexisting suppliers. The new supplier $k$ satisfying condition (2.12) will have a positive order space segment if and only if

$$\rho_{i,k} < \rho_{k,i+1}.$$ 

Furthermore, it will coexist with all $N$ current suppliers if and only if

$$\rho_{i-1,i} < \rho_{i,k} < \rho_{k,i+1} < \rho_{i+1,i+2}.$$
One the other hand, if \( \rho_{i,k} < \rho_{i-1,i} \), or \( \rho_{k,i+1} > \rho_{i+1,i+2} \), or both inequalities hold, then by Proposition 2, supplier \( k \) takes away all order space segments from her “neighbor” supplier \( i \), or \( i+1 \), or both. Once one of supplier \( k \)’s immediate “neighbor” suppliers is driven out of market, she will compete with her next “neighbor” suppliers and may take part or all of their order space segments. More precisely, supplier \( k \)’s order space segment can be determined by the following algorithm:

Algorithm to Determine the Market Segment for a New Supplier

Step 0 Set \( l_\ = i \), \( l_+ = i + 1 \).

Step 1 Repeat \( l_\ = l_\ - 1 \) until \( \rho_{l_\ - 1,l_\} < \rho_{l_\ - k} \). Repeat \( l_+ = l_+ + 1 \) until \( \rho_{k,l_\} > \rho_{l_\ + 1,l_\ + 1} \).

Step 2 The order space segment of supplier \( k \) is given by \( M_k = \{ (\rho, \mu) > 0 | \rho_{l_\ - k} < \rho < \rho_{k,l_\} \} \).

The next theorem assures the validity of the above algorithm.

Theorem 7 The above algorithm correctly determines the order space segment for the new entrant supplier \( k \).

Proof: Since \( \rho_{l_\ - 1,l_\} < \rho_{l_\ - k} \), by Proposition 2, supplier \( k \) coexists with supplier \( l_\) and all suppliers \( l < l_\). In case \( l_\ < i \), we show that all suppliers with \( l_\ < l \leq i \) are dominated by suppliers \( l_\) and \( k \). Indeed, by the construction of the algorithm, we have \( \rho_{l_\ - l_\ + 1} \geq \rho_{l_\ - k} \). On the other hand, since suppliers \( l_\), \( l_\ + 1 \), and \( l \) coexist before \( k \) enters the market, we have \( \rho_{l_\ - l} \geq \rho_{l_\ - l_\ + 1} \). Therefore, \( \rho_{l_\ - l} > \rho_{l_\ - k} \).
Proposition 2, supplier \( l \) is dominated by suppliers \( l_- \) and \( k \). Similarly, we can also show that \( k \) coexists with supplier \( l_+ \) and all suppliers \( l > l_+ \). In case \( l_+ > i + 1 \), all suppliers with \( i + 1 \leq l < i + 1 \) are dominated by suppliers \( l_+ \) and \( k \). Putting the above arguments together, the order space segment of supplier \( k \), is described by \( M_k \) in the above algorithm and all suppliers with \( l_- < l < l_+ \), if any, are by suppliers \( l_- \), \( k \), and \( l_+ \).

In summary, when a new supplier enters the market, she may be dominated by one of the existing suppliers or two of the existing suppliers together. In both cases, the new supplier will not survive. The new supplier may also share market with all \( N \) current suppliers. In this case, she takes away some order space segment from one or two of her closest competitors (“neighbor” suppliers). Finally, if the new supplier is very competitive in inventory costs, she may eliminate her closest competitors that share the similar logistic cost structure. Our paper provides conditions for each cases and an algorithm to determine the order space segment for the new supplier.

### 2.6 Concluding Remarks

This chapter studies the first stage coordination, market-based matching, in a competitive market places with multiple suppliers and multiple buyers dealing with a single non-differentiated product. We not only find out that a buyer chooses the supplier that offers the best price for his order profile, as described by his order size and delivery frequency, but also calculate out a supplier’s offering price reflecting her logistic cost structure, as captured by relevant economies of scale in a “setup cost” component, and
storage, and distribution related costs in a “holding cost per unit”. We argue that the matching of buyers order profiles to suppliers cost structures is the main source of supply chain coordination benefits in this many-to-many supply chain. Such cost-effective matching can be achieved naturally through price competition among suppliers. We identify the segment of the buyers order space each supplier could win and perform market share sensitivity analysis when a supplier’s cost structure changes or when a new supplier enters the market. The winning supplier, at the equilibrium of price competition, offers the lowest price of her closest competitor instead of the lowest price she can offer. Based on this observation, we will suggest implementing the cost-effective matching between suppliers and buyers through the use of either reverse auctions or series of global logistic intermediaries in Chapter 5.

Appendix

Proof of Proposition 1

Proof:

Suppose on the contrary that equation $R_{12}(\rho) = 1$ has two distinct solutions $\rho_1 > 0$ and $\rho_2 > 0$. For simplicity, denote

$$a = 8\rho_1 S_1 / H_1, \quad b = 8\rho_1 S_2 / H_2, \quad c = 8\rho_2 S_1 / H_1, \quad d = 8\rho_2 S_2 / H_2.$$ 

By definition, we have $ad = bc$ and $a \neq b, c \neq d$ since $S_1 / H_1 \neq S_2 / H_2$ by assumption.
Since $\rho_1$ and $\rho_2$ are both solutions of equation $R_{12}(\rho) = 1$, we have

\[
\frac{1 + \sqrt{1 + a}}{1 + \sqrt{1 + b}} = \frac{1 + \sqrt{1 + c}}{1 + \sqrt{1 + d}}.
\]

Using the fact that $ad = bc$, we can rewrite the above equality as

\[
\sqrt{1 + a} + \sqrt{1 + d} = \sqrt{1 + b} + \sqrt{1 + c} + \sqrt{1 + b + c + bc}.
\] (2.13)

We next lead to contradictions by considering the following three cases:

• If $a + d > b + c$, then

\[
(\sqrt{1 + a} + \sqrt{1 + d})^2 = 2 + a + d + 2\sqrt{1 + a + d + ad} > 2 + b + c + 2\sqrt{1 + b + c + bc} = (\sqrt{1 + b} + \sqrt{1 + c})^2.
\]

Since $ad = bc$, we have

\[
\sqrt{1 + a} + \sqrt{1 + d} + \sqrt{1 + a + d + ad} > \sqrt{1 + b} + \sqrt{1 + c} + \sqrt{1 + b + c + bc}.
\]

However, the above inequality contradicts (2.13).

• If $a + d < b + c$, the similar argument also applies.

• If $a + d = b + c$, we have

\[
(a - c)(a - b) = a^2 + bc - a(b + c) = a^2 + ad - a(b + c) = a(a + d - b - c) = 0.
\]

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The second equality is true because $ad = bc$. Since $a \neq b$, $a = c$. This implies $\rho_1 = \rho_2$, which contradicts to our assumption that $\rho_1$ and $\rho_2$ are two distinct solutions to equation $R_{12}(\rho) = 1$. 
Bibliography


Chapter 3

SUPPLIER COMPETITION AND MARKET SEGMENTATION UNDER TWO PRICING STRATEGIES

This chapter studies the competitive behavior and market segmentation of suppliers in a two-echelon supply chain. The supply chain contains two coexisted suppliers and many retailers facing stable demand. Transportation cost is considered via a Hotelling-type model. Retailers are uniformly distributed along a line segment with the two suppliers located at both ends. All retailers face stable customer demands of one common product. They are distinguished by their logistics behaviors (order quantity and frequency) and their location. Each retailer places his order from one of the suppliers based on the price offered and the transportation cost he has to pay. The
two suppliers differ in terms of their inventory cost structures (holding cost and setup cost). They compete for retail market through pricing. Two pricing strategies are considered in this paper: a long term profit maximization strategy (PMS) and a short term sale promotion strategy (SPS). The equilibrium price, the market segment, and the overall profit of each supplier that result from both pricing strategies are obtained and compared. The comparison analysis helps the suppliers to choose their pricing strategies in the competitive environment.

3.1 Introduction

Supply chain management has been a popular research topic in the past decade. From operations management perspective, research has focused on the optimization and coordination of the supply chain. Most supply chain models consist of either one supplier one retailer (e.g. Lee and Rosenblatt(1986), Munson and Rosenblatt(2001)) or one supplier multiple retailers (e.g. Trivedi(1998), Cachon and Zipkin (1999), Cachon(2001)).

In the marketing literature, many models focus on pricing strategies and their impact on sale volumes and revenues. Jeuland and Shugan (1983) consider the marketing strategies in a simple channel with one supplier and one retailer. Ingene and Parry (1995) extends the simple channel into multi-retailer settings. However, most marketing models do not include logistic issues in their price decision.

Integrating inventory control and pricing strategies was first advocated by Whirin(1955). Kohli and Park(1989) concern minimizing the logistic cost by a pricing strategy in a
one supplier and one retailer channel. Their decision variable includes both the order quantity from the retailer and the price that the supplier offers. More recently, many papers focus on designing discount strategies and contracts to coordinate the logistic operations of supply chains so that both retailers and suppliers will benefit (Rosenblatt and Lee (1985), Chakravarty (1988), Chen, Federgruen and Zheng (2001)). Most of the above papers, however, assume one supplier in their supply chains.

In reality, supplier’s market is not given and stable. Indeed, when supply capacity is sufficient, retailers usually dominate the channel. They have the power to choose one supplier from another (Bowersox, Closs and Cooper(2002)). Porter’s (1980) industry analysis identifies competition between supply powers as one of the very important forces in business rivalry.

Our paper studies the competition between two suppliers via constructing the transportation cost though a Hotelling type model. Retailers of different order profiles are uniformly distributed along a line segment with the two suppliers located at the both ends. All retailers face stable customer demands of one common product. They choose to order from one of the suppliers based on the price offered and the transportation costs they have to pay. The two suppliers have different inventory cost structures. They determine their offering prices based on their pricing strategies and retailers’ order profiles (order quantity and frequency).

In modeling the problem, we integrate both the inventory control and pricing strategies. We would like to clarify that the use of the term “supplier” is interchangeably used to model either a manufacturer of the non-differentiated product or a logistical intermediary (warehousing and distribution company, third-party logistics, etc.),
with the appropriate interpretation specific to the application context of our results. Similarly, a “retailer” can be a pure form retailer or simply another logistical and/or production intermediary in a complex value chain that gets feed by an upstream supplier. To avoid any further modeling complexity on the supply side, we assume that all suppliers order their needed inputs from common, or similar in nature, sources in all relevant dimensions (price, quality, lead-time, etc.). This further upstream supply tier is assumed to have ample supply.

Our model differs from the classical Hotelling model in the following aspects. First, most Hotelling type models study the retailer-customer market and the competition between retailers, while our paper focuses on the supplier-retailer market and the supplier competition. Second, the pricing and competition in our model are not only based on the transportation cost, but also the inventory cost of the suppliers.

The paper is also an extension to the resent paper by Xia, Chen and Kovelis (2003), which studies the retailer’s market segmentation based on retailer’s order profile and suppliers’ inventory efficiency. Our paper shows that transportation cost, in addition to suppliers’ inventory cost, plays an important role in determining a supplier’s market segment.

Moreover, our paper considers two pricing strategies for the suppliers to determine their offering prices: a long term profit maximization strategy (PMS) and a short term sale promotion strategy (SPM). There is no doubt that a supplier’s long term target is to maximize its profit. On the other hand, sale promotion strategy is nowadays more and more often used by suppliers to uphold their sale, expand their market segment, puncture competitor’s market segment, gain reputation from customers, and sometime
clean their inventory. In general, sale promotion strategies include advertising and price promotion. The changing power patterns between retailers and suppliers has shifted market promotion strategies more towards price promotions (Arcelus, Pakkala and Srinivasan (2001)). We consider the latter aspect of the sale promotion strategy in this paper.

Although sale promotion strategy might benefit a supplier in a short term, it usually decreases the supplier’s profit margin and should not be a long term action. Whether a supplier should conduct the market promotion strategy, when and how should she carry out the promotion strategy have always been a delicate decisions. Our paper compares the equilibrium price, the market segment, and the overall profit for each supplier resulting from both strategies. The comparison analysis helps the suppliers to choose their pricing strategies in the competitive environment.

In summary, this paper seeks to address to the following issues through a stylized model:

- How do inventory costs and transportation cost affect the suppliers’ competition and how are these factors relate to the suppliers’ market shares?

- How do pricing strategies change a supplier’s market segment and resulting profit. Under what condition, a supplier may want to choose the SPS instead of PMS?

The remainder of the paper is organized as follows. Section 2 introduces the basic model. Section 3 and 4 find the Nash equilibrium and corresponding market shares for PMS and SPS respectively. Section 5 compares and analyzes the two strategies. Section 6 concludes the paper with a some final remarks.
3.2 Model Description

Two suppliers, indexed by \( i = l, k \) are located at the two ends of a segment. Without loss of generality, we assume the length of the segment equals to 1, and retailers holding the same logistics behavior (order frequency \( \mu \) and order quantity \( q \)) uniformly distributed along the line between the two suppliers. Both suppliers offer same product quality and service. However, they hold different logistic parameters (holding cost \( H_i \) and setup cost \( S_i \)). The two suppliers compete on unit price offering to retailers. There are two strategies that suppliers may choose in their rivalry: one is to maximize their profit (profit maximization strategy), the other is to maximize their market shares without deficiency (sale promotion strategy). Our model can be illustrated by the following Figure 3.1.

In our model, we assume each retailer chooses a supplier base on his unit cost incurred. First of all, although other issues exist, cost is still the primary reason for a retailer to choose a supplier, wether he considers coordination or not. For the market with steady demand, like the raw resource products and daily necessities markets, the retailers’ unit cost is even more important.

Retailers are distinguished by their logistic behavior (order frequency \( \mu \) and order quantity \( q \)) and location, which is described by the distance between a retailer and the supplier \( l, x \). Retailers serve for stable customer demand. For a retailer, its annual demand is denoted as \( d, d = \mu \ast q \). In later sections of the paper, we use the ratio \( \rho = \mu / q \) as an alternative characterization for a retailer. We will show that the retailer’s
market can be described by a two dimensional space with parameters $\rho$ and $x$.

We assume that there is no channel coordination or cooperation between any supplier and any retailer in this paper. The information of suppliers’ logistic parameters and retailers’ logistic behavior is common knowledge in the channel. Retailers are independent with each other and with suppliers. Retailers are the leaders of the channel, they have the power to choose one supplier from another; however, they have to choose one of the suppliers to work with.

To fulfill retailers’ orders, all suppliers order from a common source with ample supply and they pay the same unit cost $C_0$. We assume that suppliers do not combine orders from different retailers.

The suppliers compete for retailer’s market by determining their offering price to retailers $p(\mu, q)$. The price a supplier offers should be higher than the sum of her product and inventory cost to generate profit and to avoid being sued “dumping”. More specifically, we assume that all suppliers have the flexibility of offering different prices to different retailers based on retailers’ order profile, i.e., their order quantities and order frequencies. Notice that this pricing scheduling can be implemented through a price menu approach to avoid antitrust litigation under the Robinson-Patman Act.

Clearly, the lowest price a supplier can offer to a retailer depends on the supplier’s product cost and inventory cost. To minimize her inventory cost, it is optimal for each supplier to follow the “EOQ model with lumpy demand” for her inventory policy (Munson and Rosenblatt(2001)). More specifically, suppose retailer $(q, \mu)$ (or $(\rho, \mu)$) orders from supplier $i$, the supplier should order $nq$ products each time and $\mu/n$ times
a year. The optimal multiple $n$ is given by

\[ n^* = \left\lfloor \frac{1}{2} \left( 1 + \sqrt{1 + \frac{8S_i d}{H_i q^2}} \right) \right\rfloor = \left\lfloor \frac{1}{2} \left( 1 + \sqrt{1 + 8\rho S_i / H_i} \right) \right\rfloor, \]

where $\lfloor y \rfloor$ represents the largest integer less than or equal to $y$. The minimum annual inventory cost per product incurred to supplier $i$ is given by:

\[ C_{i}^* = \frac{S_i}{n^* q} + \frac{(n^* - 1)H_i}{2\mu} = \frac{H_i}{\mu} \left( \frac{\rho S_i / H_i}{\lfloor (1 + \sqrt{1 + 8\rho S_i / H_i})/2 \rfloor} + \frac{1}{2} \left( \frac{4\rho S_i / H_i}{(1 + \sqrt{1 + 8\rho S_i / H_i})} \right) \right). \quad (3.1) \]

It is well known that the inventory cost of most EOQ models are insensitive to the order quantity variations near the optimal order quantity. In the remaining paper, we approximate the inventory cost $C_{i}^*$ by ignoring the integer operation in (3.1). After some algebraic simplifications, we have:

\[ C_{i}^* \approx \frac{4S_i \rho}{(1 + \sqrt{1 + 8\rho S_i / H_i})\mu}. \]

Define

\[ C_i(\rho, \mu) = C_0 + \frac{4S_i \rho}{(1 + \sqrt{1 + 8\rho S_i / H_i})/\mu}. \]

It follows that the lowest price supplier $i$ can offer to retailer $(\rho, \mu)$, while maintaining profitability is $C_i(\rho, \mu)$.

We also assume that retailers pay for the product and the transportation cost. We suppose the transportation cost is linearly related to the distance and the order.
frequency of the retailer with a common ratio K. Thus, the unit cost for a retailer to buy from supplier \( l \) is:

\[
P_l(\mu, q) + K \times x \times \mu / d = P_l(\mu, q) + K \times x / q,
\]

to buy from supplier \( k \) is:

\[
P_k(\mu, q) + K \times (1 - x) \times \mu / d = P_k(\mu, q) + K \times (1 - x) / q.
\]

Therefore, the market shares of the two suppliers is geographically separated at a location, \( x_o(\mu, q) \) on the demand segment, where

\[
P_l(\mu, q) + K \times x_o / q = P_k(\mu, q) + K \times (1 - x_o) / q,
\]

and,

\[
x_o(\mu, q) = \frac{P_k - P_l + K / q}{2K / q}.
\]  

(3.2)

Any retailers with \( x < x_o \) will buy from supplier \( l \)’s, while other retailers will buy from supplier \( k \)’s.

In this paper, we discuss two pricing strategies that the suppliers may choose. One strategy aims to maximize the profit, we call it profit maximization strategy (PMS); another strategy aims to maximize the market shares, we call it sale promotion strategy (SPS). \( x_p \) and \( x_s \) will be used to denote the market separating location for PMS and SPS respectively.
3.3 Profit Maximization Strategy

This section describes the competition between the two suppliers and finds the exact market shares and the corresponding equilibrium price when they both choose profit maximization strategy.

For the convenience of demonstration, we denote

$$\delta(\rho) = 2\mu(C_k(\rho, \mu) - C_l(\rho, \mu)) = H_k \sqrt{1 + 8S_k/ H_k \rho} - H_l \sqrt{1 + 8S_l/ H_l \rho} + H_l - H_k.$$  

Note that $\delta$ is a function of $\rho$ only. We have the following results:

**Theorem 8** For PMS strategy, the equilibrium prices and corresponding market separating location are:

1. If $|\delta| < 6K\rho$
   
   $$P_l^*(\mu, q) = \frac{K}{q} + \frac{2}{3}C_l + \frac{1}{3}C_k,$$  
   $$P_k^*(\mu, q) = \frac{K}{q} + \frac{2}{3}C_k + \frac{1}{3}C_l;$$  
   $$x_p(\rho) = \delta/12K\rho + 0.5.$$  

2. If $\delta \geq 6K\rho$,  
   
   $$P_l^*(\mu, q) = C_k - K/q, P_k^*(\mu, q) = C_l; \quad x_p = 1.$$  

3. If $\delta \leq -6K\rho$,  
   
   $$P_l^*(\mu, q) = C_l, P_k^*(\mu, q) = C_l - K/q; \quad x_p = 0.$$  

**Proof:**
\( r_i(P_{-i}) \) be the reaction function of supplier \( i \), \( r_i(P_{-i}) = r_i(P_k) = P_i \); \( r_k(P_{-k}) = r_k(P_l) = P_k \). Since the market’s demand is uniformly distributed, define

\[
U_l = (r_l(P_k) - C_l) x_p = (P_l - C_l) \frac{P_k - P_l + K/q}{2K/q}
\]

\[
U_k = (r_k(P_l) - C_k)(1 - x_p) = (P_k - C_k) \frac{P_l - P_k + K/q}{2K/q}
\]
as the profit functions for supplier \( l \) and supplier \( k \) respectively when \( P_l \geq C_l \) and \( P_k \geq C_k \).

By the definition of Nash equilibrium, let \( \frac{\partial U_l}{\partial P_l} = 0 \) and \( \frac{\partial U_k}{\partial P_k} = 0 \), then we have

\[-2P_l + P_k + C_l + K/q = 0 \quad \text{and} \quad P_l - 2P_k + C_k + K/q = 0.\]

These equations lead to (3.3) and (3.4). The corresponding separating location (3.5) can then be calculated out using equation (3.2). Note that we assume \( P_l \geq C_l \) and \( P_k \geq C_k \).

When \( \delta \geq 6K\rho \), \( \frac{\partial U_l}{\partial P_l} = 0 \) and \( \frac{\partial U_k}{\partial P_k} = 0 \) cannot be satisfied if \( P_k \geq C_k \), supplier \( k \) is not able to get any profit under profit maximization strategy. However, to minimize its rival’s profit, it offers the lowest price it can offer, \( P_k = C_k \); supplier \( l \) is forced to offer a price equal to \( C_k - K/q \) to maximize its profit. In addition, we have \( x_p = 1 \). When \( \delta \leq -6K\rho \), the similar proof applies.

We notice that the equilibrium price for a supplier not only relates to its own cost, but also relates to its rival’s cost; furthermore, the rival’s cost weighs half as much \((1/3)\) as the supplier’s own cost \((2/3)\) in the supplier’s price decision when \(|\delta| < 6K\rho \). Moreover, the function of cost difference, \( \delta \) determines the different segments of the
price function and the market separating location function. If $|\delta| < 6K\rho$, the two suppliers share the market; otherwise one supplier dominates the market. When $C_l$ and $C_k$ are equal, the two suppliers share the market evenly with the same pricing strategy.

Most importantly, the market separation location $x_p$ is the function with only one variable of the retailer $\rho$. Therefore, we are able to describe the market segmentation on a two dimensional space $(x, \rho)$.

Moreover, we have the following additional characterizations on PMS equilibrium pricing:

**Corollary 2** For PMS strategy, both suppliers’ equilibrium prices are always in between $\min(C_l, C_k) + K/q$ and $\max(C_l, C_k) + K/q$.

**Proof:**

If $|\delta| < 6K\rho$, the result is obvious.

If $|\delta| \geq 6K\rho$, the higher price equals to $\max(C_l, C_k)$,

$$\max(C_l, C_k) < K/q + \max(C_l, C_k);$$

the lower price equals to $\max(C_l, C_k) - K/q$,

$$\max(C_l, C_k) - K/q \geq \min(C_l, C_k) + 2K/q > \min(C_l, C_k) + K/q,$$

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since $|\delta| = 2\mu|C_k - C_l| \geq 6K\rho$, therefore

$$\max(C_l, C_k) - \min(C_l, C_k) = |C_k - C_l| \geq 6K\rho/(2\mu) = 3K/q.$$ 

\[ \square \]

**Corollary 3** For the PMS strategy, the difference between suppliers’ Nash equilibrium prices $P_l^*$ and $P_k^*$ is bound by $K/q$.

**Proof:** Consider two situations, $|\delta| < 6K\rho$ and $|\delta| \geq 6K\rho$.

If $|\delta| < 6K\rho$, from Theorem 8 (I), we have

$$|P_l^* - P_k^*| = |C_k - C_l|/3 = |\delta|/(2\mu)/3 < 6K\rho/(6\mu) = K/q;$$

If $|\delta| \geq 6K\rho$, from Theorem 8(II) and (III), we have

$$|P_l^* - P_k^*| = K/q.$$

\[ \square \]

**Corollary 4** For PMS strategy, the difference between the suppliers’ unit profit at equilibrium is bounded by $2K/q$ when $|\delta| < 6K\rho$; bigger than $2K/q$ otherwise.

**Proof:** The unit profits for suppliers $l$ and $k$ are $P_l^* - C_l$, $P_k^* - C_k$ respectively.

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If $|\delta| < 6K\rho$, from Theorem 8 (I), we have

$$||(P^*_l - C_l) - (P^*_k - C_k)|| = 2/3|C_k - C_l| < 2K/q;$$

If $|\delta| \geq 6K\rho$, from Theorem 8(II) and (III), we have

$$||(P^*_l - C_l) - (P^*_k - C_k)|| = |C_k - C_l| - K/q = |\delta|/(2\mu) - K/q \geq 3K/q - K/q = 2K/q$$

Notice that the bounds in Corollary 2 to 4 do not depend on the suppliers logistics parameters, $s$ and $h$. They are functions of only the transportation cost $K$ and retailer’s order quantity $q$.

There are also other characteristics of the Nash equilibrium price and the market segmentation situation for PMS. Since those characteristics are shared by or can be compared with those of SPS, we will discuss them in Section 5 together.

### 3.4 Sale Promotion Strategy

Although suppliers’ long term target is always to maximize their profit, in short term, they may aim to expand their market shares. This section describes the sale promotion pricing strategy and the corresponding market shares when suppliers both aim to maximize their market shares.
Theorem 9 For sale promotion strategy (SPS) strategy, the equilibrium prices and corresponding market separating locations are:

(I) if \( |\delta| < 2K\rho \), \( P^*_i(\mu, q) = C_i(\mu, q), \) \( i = l, k; \) \( x_s(\rho) = \frac{\delta}{4K\rho} + 0.5. \)

(II) if \( \delta \geq 2K\rho \), \( P^*_i(\mu, q) = C_k - K/q, P^*_k(\mu, q) = C_k; \) \( x_s = 1. \)

(III) if \( \delta \leq -2K\rho \), \( P^*_i(\mu, q) = C_l, P^*_k(\mu, q) = C_l - K/q; \) \( x_s = 0. \)

Proof:

From equation (3.2), we know that \( x_s(\mu, q) = \frac{P_k - P_l + K/q}{2K/q}. \)

Since the suppliers’ target is to maximize the market segment, we check \( \frac{\partial x_s}{\partial P_l} \) and \( \frac{\partial (1 - x_s)}{\partial P_k} \) and find out that

\[
\frac{\partial x_s}{\partial P_l} = -\frac{q}{2K} < 0, \quad \frac{\partial (1 - x_s)}{\partial P_k} = -\frac{q}{2K} < 0.
\]

Since we also assume that \( P_i > C_i \) for \( i = l, k, P^*_i(\mu, q) = C_i(\mu, q), \) \( i = l, k \) \( (0 < x_s < 1). \) From equation (3.2,) we then can obtain the condition for the two suppliers to share the market \((0 < x_s < 1)\) is \( |\delta| < 2K\rho. \)

If \( \delta \geq 2K\rho, \) \( x_s = 1, \) \( \frac{\partial x_s}{\partial P_i} = 0, \) \( \frac{\partial x_s}{\partial P_k} = 0, \) supplier k is not able to get any market segment without deficiency. However, to minimize its rival’s profit, it keeps offer the lowest price it can offer, \( C_k; \) supplier l is then forced to offer a price no higher than \( C_k - K/q \) to keep supplier k out of the market.

If \( \delta \leq -2K\rho \) the proof is similar.
Since suppliers’ strategy is to maximize their market shares, they want any business as long as it does not lead to a deficit. By the result of competition, the supplier who minimizes a retailer’s unit cost wins its business. Therefore, for certain retailer, if
\[ C_l(\mu, q) + Kx\mu/d < C_k(\mu, q) + K(1 - x)\mu/d, \]
then supplier \( l \) wins the business after competition; otherwise, supplier \( k \) wins the business.

**Corollary 5** If both suppliers follow SPS strategy, The supplier with lower logistic cost can earn profit only if \(|\delta| > 2K\rho\)

When \(|\delta| < 2K\rho\), which is equivalent to \(|C_l - C_k| < K/q\), the two suppliers’ logistic costs are close to each other, hence the market competition is more fierce, no profit left for both suppliers. Only if \(|\delta| \geq 2K\rho\), the supplier will lower logistic cost can generate profit. Therefore, unless there is a significant difference between the logistic efficiency of the two suppliers, sale promotion strategy can only be used temporarily.

This result is different from the result of Xia, Chen and Kouvelis(2003), which does not consider the transportation cost associated with the retailers. When the transportation cost is not considered, Xia, Chen and Kouvelis (2003) shows that the Nash equilibrium pricing strategy for the two suppliers is \(\max(C_l, C_k)\). Suppliers always can earn profit by the costs difference. However, after considering the transportation cost, the logistic cost difference must be large enough for the supplier with lower cost to generate profit if both suppliers follow SPS. The equilibrium price drops to her own cost if the costs difference is small (\(|\delta| < 2K\rho\)) since suppliers want to attract the retailers geographically away from them. The distance between a supplier and her retailer implies her market segment size, therefore she has to decrease the price to
allure the retailers as far away as possible. Note the price only relates to the logistic
cost for suppliers to serve retailers, it has no relationship with the location of the
retailers. This is also the requirement of the Robinson-Patman Act. Retailers shall
not be discriminated by their location.

3.5 Strategies Comparison and Analysis

This section compares the two pricing strategies (PMS and SPS) for the suppliers by
their coexisting condition, market segmentation situation, equilibrium price and profit.
It analyzes the common features and difference between the two strategies and then
suggests when to use each strategy.

3.5.1 Coexisting Condition Comparison

This subsection compares the coexisting conditions for the suppliers when PMS and
SPS strategies are adapted.

**Corollary 6** If $|\delta| < 2K\rho$, the two suppliers coexist for both strategies; if $2K\rho \leq |\delta| < 6K\rho$, the two suppliers can coexist by PMS, but cannot coexist by SPS; if $|\delta| \geq 6K\rho$, the two suppliers cannot coexist by both strategies.

Obviously, SPS has a tighter coexisting condition than PMS. Therefore, if $2K\rho \leq |\delta| < 6K\rho$, one supplier actually has the choice to coexist with another supplier and
earn higher profit or eliminate the other supplier. If she decides to eliminate the other supplier, she will earn a lower profit for a while, however later enjoy the result from sale promotion, i.e., new customers, bigger customer base, and famous brand name.

Specifically, when $2K\rho \leq \delta < 6K\rho$, supplier $l$ has the power to choose SPS. If supplier $l$ chooses the SPS, it earns lower profit, but will get all customer in the market to purchase from it at least for a while. If supplier $l$ chooses the PMS, then supplier $k$ can coexist with profit up to $2K/9q$ (at $\delta = 2K\rho$) and supplier $l$ earns a profit higher than choosing SPS (a profit of $8K/9q$ instead of $0$ at $\delta = 2K\rho$; the difference of the profits from PMS and SPS decreases as $\delta$ increases, it drop to $0$ at $\delta = 6K\rho$). When $-6K\rho < \delta \leq -2K\rho$, same situation happens vice verse for supplier $k$.

### 3.5.2 Market Segmentation Situations

Similar to coexisting conditions, market segmentation situations relate with the logistic efficiency of the suppliers.

It is obvious that if the two suppliers have same logistic parameters, they always share the market evenly under both PMS and SPS. Each of them gets half retailers close to them. When the logistic parameters of the suppliers are different, two major market segmentation situations happen. Interesting enough, instead of $\mu$ and $q$, the market separating locations $x_p$ and $x_s$ only relate to $\rho = \mu/q$. Therefore, we can describe the market segmentation situation on the $(x, \rho)$ surface.

**Theorem 10** Assuming $S_l < S_k$, $S_l/H_l \neq S_k/H_k$, two situations happen for the mar-
ket segmentation for both PMS and SPS.

(I) If $S_lH_l < S_kH_k$, \[ x_p(\rho) > 0.5, \quad x_s(\rho) > 0.5 \quad \text{for} \quad 0 < \rho < \infty. \]

(II) If $S_lH_l > S_kH_k$, let $\rho_o = \frac{H_lH_k(H_k-H_l)(S_l-S_k)}{2(S_lH_l-S_kH_k)^2}$,

\[ x_p(\rho_o) = 0.5 \quad x_s(\rho_o) = 0.5; \]

\[ x_p(\rho) > 0.5, \quad x_s(\rho) > 0.5 \quad \text{for} \quad 0 < \rho < \rho_o; \]

\[ x_p(\rho) < 0.5, \quad x_s(\rho) < 0.5 \quad \text{for} \quad \rho_o < \rho < \infty. \]

**Proof:** From theorem 8 and 9, if $\delta > 0$, $x_p(\rho) > 0.5$, $x_s(\rho) > 0.5$; if $\delta < 0$, $x_p(\rho) < 0.5$, $x_s(\rho) < 0.5$; if $\delta = 0$, $x_p(\rho) = 0.5$, $x_s(\rho) = 0.5$.

From definition, we know that

\[ \delta = 2\mu(C_k - C_l) = 2\mu\left((C_k - C_0) - (C_l - C_0)\right) \]

Define

\[ R_{lk} = \frac{C_l - C_0}{C_k - C_0} = \frac{S_l(1 + \sqrt{1 + 8\rho S_l/H_l})}{S_k(1 + \sqrt{1 + 8\rho S_l/H_l})} \]

$R_{lk} < 1 \leftrightarrow \delta > 0$, $R_{lk} > 1 \leftrightarrow \delta < 0$, $R_{lk} = 1 \leftrightarrow \delta = 0$.

We prove that $R_{lk} = 1$ has at most one positive solution (See Appendix)

By definition,

\[ \lim_{\rho \to 0} R_{lk}(\rho) = \frac{S_l}{S_k}. \]

\[ \lim_{\rho \to \infty} R_{lk}(\rho) = \sqrt{\frac{S_lH_l}{S_kH_k}}. \]
Since equation $R_{lk}(\rho) = 1$ has at most one positive solution and we assume $S_l < S_k$, it follows that if $\frac{S_lH_l}{S_kH_k} < 1$, then $R_{lk}(\rho) < 1$ for $0 < \rho < \infty$, which is situation (I).

If $\frac{S_lH_l}{S_kH_k} > 1$, then $R_{lk}(\rho) = 1$ has positive solution $\rho_o$, which is situation (II).

If we assume $S_l > S_k$, the result is symmetric for two suppliers. If $S_l > S_k$, then the supplier with lower holding cost $H_l$ always has bigger market segment; if $S_l/H_l = S_k/H_k$, then the supplier with lower setup cost $S_l$ always has bigger market segment.

The two market segmentation situations for both PMS and SPS are illustrated by Figures 3.1 and 3.2.

We denote the market into four regions as Figure 2 shows. Region I always belongs to supplier $k$ while region III always belongs to supplier $l$. Without considering the transportation cost, the two suppliers separate the market only by $\rho_o$ (Xia, Chen and Kouvelis 2003); after considering the transportation cost, the retailers with $\rho < \rho_o$ and closer to supplier $l$ still belongs to supplier $l$ while the retailers with $\rho > \rho_o$ and closer to supplier $k$ still belongs to supplier $k$. Suppliers separate the market in region II and IV by the separating locations as described by Theorem 8 and Theorem 9, while the saving in the logistics saving is covered by the loss from extra transportation cost or vice verse.

We also have the following observation about the market segmentation situation of both PMS and SPS.
**Corollary 7** \( \lim_{\rho \to \infty} x_p(\rho) = 0.5 \quad \lim_{\rho \to \infty} x_s(\rho) = 0.5 \)

**Proof:** When \( \rho \to \infty \), \( \delta/K\rho \to 0 \) and \( |\delta| < 2K\rho \) are always satisfied. From the result in Theorem 8(I) equation 3.5, for \( |\delta| < 6K\rho \), \( x_p(\rho) = \delta/12K\rho + 0.5 \), we have \( \lim_{\rho \to \infty} x_p(\rho) = 0.5 \).

From 9(I), we know that for \( |\delta| < 2K\rho \), \( x_s(\rho) = \delta/4K\rho + 0.5 \). Therefore, \( \lim_{\rho \to \infty} x_s(\rho) = 0.5 \).

The corollary is approved. \( \blacksquare \)

No matter which strategy the two suppliers choose, when \( \rho \to \infty \) (retailers order small quantity each time and order many times each year), suppliers share the market evenly by the location. Intuitively, when \( \rho \to \infty \), the logistic cost difference between two suppliers can be ignored comparing to the transportation cost difference of buying from the two suppliers. Notice that when \( \rho \to \infty \), retailer’s demand can be viewed as continuous and the suppliers use the EOQ model to serve for the retailer’s demand.

### 3.5.3 Equilibrium Price and Profit Comparison

This subsection uncovers the common features and difference of the equilibrium price and profit of the two strategies. The results are generated in the following Corollary.

**Corollary 8** Define \( m = \frac{C_h - C_s}{K/q} = \delta/2k\rho \).

(I) When \( |\delta| < 2K\rho \),
if the two suppliers conduct PMS, their profits are

\[ U_t = (1 + m/3)(0.5 + m/6) \frac{K}{q}, \quad U_k = (1 - m/3)(0.5 - m/6) \frac{K}{q}; \]

if the two suppliers conduct SPS, their profits are

\[ U_t = 0, U_k = 0. \]

(II) When \(2K \rho \leq |\delta| \leq 6K \rho\),

if the two suppliers conduct PMS, their profits are

\[ U_t = (1 + m/3)(0.5 + m/6) \frac{K}{q}, \quad U_k = (1 + m/3)(0.5 + m/6) \frac{K}{q}; \]

if the two suppliers conduct SPS, their profits are

\[ U_t = \max(m - 1, 0) \frac{K}{q}, U_k = \max(-(m + 1), 0) \frac{K}{q}. \]

(III) When \(|\delta| > 6K \rho\),

for both PMS and SPS,

\[ U_t = \max(m - 1, 0)K/q, U_k = \max(-(m + 1), 0)K/q. \]

The above corollary can be easily generated from Theorem 8 and 9. When \(|\delta| < 2K \rho\), following PMS can generate profit for both suppliers, but following SPS cannot.
When \(2K\rho \leq |\delta| \leq 6K\rho\), following PMS, both suppliers can generate profit, following SPS, only the supplier with lower logistic cost can generate profit. When \(|\delta| > 6K\rho\), no matter which strategy to follow, suppliers with lower logistic cost always can generate profit, while the supplier with higher logistic cost always cannot.

In conclusion, the comparison of the two strategies is summarized in Table 1 as below.

INSERT TABLE 3.1 HERE

### 3.5.4 Strategy Suitability Analysis

From the former results, we know that no matter which strategy the two suppliers choose, equilibrium price, the corresponding market separating location functions and the profits of the suppliers change according to \(\delta\), which can also be expressed as a function of the cost difference between the two suppliers \((C_k - C_l)\), since \(\delta = 2\mu(C_k - C_l)\). In this subsection, we will discuss the suitability of the two strategies relating the range of \(\delta\).

**Corollary 9** The supplier with lower cost can use SPS to increase its market segment if \(|\delta| < 6K/q\); SPS and MPS are the same if \(|\delta| \geq 6K/q\). The market segment difference is maximized to \(1/3\) at \(\delta = 2K/q\).

**Proof:** Assume \(\delta \geq 0\), following the result of Theorem 8 and 9,
if $\delta < 2K\rho$, $x_s - x_p = \delta/6K\rho > 0$;

if $2K\rho < \delta < 6K\rho$, $x_s - x_p = 0.5 - \delta/12K\rho > 0$;

if $\delta > 6K\rho$, $x_s = x_p$.

Besides, $\max(x_s - x_p) = 1/3$ at $\delta = 2K\rho$

the result is symmetric when $\delta \leq 0$ ($C_k < C_l$).

**Corollary 10** If $2K\rho < |\delta| < 6K\rho$, when SPS is chosen, the supplier with lower logistic cost is able to reach all the retailers on the market.

From the result of Corollary 9, only if $|\delta| < 6K\rho$, will it benefit certain suppliers in term of market segment if she follows SPS.

If suppliers choose SPS when $|\delta| < 2K\rho$, both of them cannot earn any profit. No one can dominate the other; they will coexist. Beside, only the supplier with lower cost can earn market segment by choosing SPS. The market segment a supplier gets by losing all its profit is $|\delta|/6$, which is to say that the market segment can be punctuated by SPS is limit to $|\delta|/6$, and one supplier is not able to dominate the whole market.

If $2K\rho < |\delta| < 6K\rho$, the supplier with lower cost is able to dominate the other supplier by choosing SPS. If it decides to choose the PMS, it will get higher profit, but it will share market with the other supplier. The supplier has the power to decide which strategy to choose basing on whether the additional profit or the market coverage is
more important to her. The supplier with higher cost will have to accept the decision made by the lower cost supplier.

3.6 Concluding Remarks

The contribution of this paper lies in three major aspects.

First, instead of the one supplier-one retailer and one supplier-multiple retailers setup, this paper extends the system into two suppliers and many retailers’ situation. The competition of the suppliers are considered and equilibriums are found for pricing strategy and market segmentation.

Second, this paper integrates the supply chain logistic efficiency with the transportation cost and successfully describes the market segmentation situation on the two dimensional space \((x, \rho)\). In considering the transportation cost, Hotelling model is used in the level of supplier-retailer relationship.

Finally, this paper compares and analyzes two pricing strategies, profit maximization strategy (PMS) and sale promotion strategy (SPS). Based on suppliers’ logistic efficiency difference and the retailers that they focus to serve (relationship between \(\delta\) and \(\rho\)), different strategies then are recommended.

This paper has other contributions, such as combining inventory management with market segmentation and finding characteristics of the two strategies, PMS and SPS.
However, this paper also has its limitations and can be further extended. The uniformly distributed and steady retailers’ demand assumption is reasonable for raw resource and daily necessities, but need to be further justified for other products. The two suppliers system can be extended into multiple suppliers system. The Hotelling model can be extended to the circle model in considering the transportation cost for multiple suppliers.
Bibliography


Chapter 4

MARKET SEGMENTATION COMPARISON FOR SUPPLIERS WITH OR WITHOUT LOT-SIZING COORDINATION

Our research assumes that the coordination in supply chain includes two stages, market-based matching and lot-sizing coordination. Our research also shows that the benefit from the second stage coordination (lot-sizing coordination) is limited. This chapter tries to show how significantly the market segmentation will be affected by lot-sizing coordination.

We find the common space to describe the supplier market segmentation in one stage and in two stages (without or with lot-sizing coordination). We also illustrate
the market segmentation on the new common space. We then compare the suppliers’ market segments in supply chain that coordinated in the first stage (market-based matching) only and in both stages (matching and lot-sizing coordination). We are able to predict how the second stage lot-sizing coordination changes the suppliers’ market segments. The results can help suppliers to forecast the real market shares.

4.1 Introduction

Chapter 2 and Chapter 3 study the first stage supply chain coordination, matching suppliers’ logistic efficiency with retailers’ order profile. In this chapter, we further suppose that suppliers may conduct the second stage coordination, lot-sizing coordination, that is to use pricing strategy, for example, pricing menu and so on, to coordinate the channel and make the retailers to order the right quantity and at right frequency to minimize the cost of the channel. We further assume that a retailer chooses a supplier basing on the his own total cost (inventory cost and purchasing cost). The market shares after the second stage coordination can be decided accordingly. Furthermore, we find a common space which can describe the supply market segmentation with or without lot-sizing coordination, which allow us to compare the suppliers’ market segmentation in two situations.

Our research distinguishes from others in the following aspects: First, we consider the supply chain with multiple suppliers and many retailers. This kind of supply chain is close to real cases, but is rarely studied. Most supply chain papers works on one supplier, one retailer or one supplier, multiple retailers situations. Tyer(1998),

Second, in our model, retailers are the channel leaders. They decide which supplier to purchase from; and they purchase from one supplier only. Suppliers compete for retailers’ business. Porter’s (1980) industry analysis distinguishes competition between supplier powers as one of the very important force in business rivalry. In fact, when supply capacity are sufficient, retailers usually dominate the channel; they have the power to choose one supplier from another. (D. Bowersox, et al.(2002))

Third, our model integrates logistic management and pricing strategies when considering competition. The suppliers need to not only minimize their own logistic costs, but also concentrate on pricing to compete with their peers to attract retailers. Traditional inventory planning models for supply chains focus on the minimization of the inventory cost. To optimize the channel wide inventory cost, some optimal logistic behaviors (order quantity and order frequency) have been found. For the one supplier one retailer channel, EOQ model, EPQ model, EOQ model with lumpy demand et al. (Munson & Rosenblatt(2001), Lee & Rosenblatt(1986), Jones et al. (1988) ) have been thoroughly studied. More complex supply chain, as the supply chain with one supplier and multiple, non-identical retailers, has also been studied by Lal and Staelin (1984). They compute a centralized solution implicitly assuming the supplier replenishes its stock infrequently.

While inventory models focus on optimizing costs, many marketing models focus on pricing strategies and their impact on sale volumes and revenues. Jeuland and Shugan(1983) consider the marketing strategies in a simple channel with one supplier
and one retailer. Ingene and Parrry (1995) extends the simple channel into multi-retailer settings. However, their models emphasize neither on logistic behavior, nor on logistic parameters such as setup and holding cost. Integrating inventory control and pricing strategies was first advocated by Whirin (1955). Kohli and Park (1987) concern minimizing the logistic cost by a pricing strategy in a one supplier and one retailer channel. Their decision variable includes both the order quantity from retailer and the price a supplier offers. Recently, to minimize channel wide inventory cost, discount strategies have been widely discussed to lure the retailers to order the right quantity that benefit both retailers and suppliers. (Chakravarty (1989), Rosenblatt (1985)). Chen, Federgruen and Zheng (2001) further combined the pricing and replenishment strategies in their one supplier, multiple retailers model to optimize the supply chain system. In their paper, the leading supplier actually offers discount based on three retailer logistic behaving characters, order size, annual sale volume and order frequency. Cachon and Zipkin (1999) show in a one supplier, multiple retailer two-echelon supply chain, system optimal solution can be achieved as a Nash equilibrium using simple linear transfer payments. In our model, system optimal is achieved by Nash equilibrium pricing strategy based on logistic efficiency.

Finally, our research considers two-stage coordination instead of only the lot-sizing coordination. It not only studies the competitions among suppliers, but also finds out the market segments of them at one stage coordination and at two stages coordination. Determining market segmentation situation has always been an important task for marketing. Traditionally, market components are characterized, listed and then grouped by gender, age, sensitivity et al. Market shares then contain components holding certain characteristics. Liu (1992) discusses the market segment for transporta-
tion industry and divide the market by a single parameter, freight value. His model separates the transportation market into 6 segments on the freight value line. We successfully described the coexisting suppliers’ market segment by retailers’ logistics behavior.

The reminder of the paper is organized as follows. Section 2 introduces the model. Section 3 maps the market segments without coordination into the same space that the market segments with lot-sizing coordination will be described on. Section 4 finds the market segments of the suppliers with lot-sizing coordination. Section 5 compares the market segmentation with and without lot-sizing coordination.

4.2 Model Description

The two-stage supply chain under consideration consists of $N$ suppliers and many retailers. A single product type with uniform quality is involved in the exchange between suppliers and retailers. The retailer’s order profile is characterized by his order quantity $q$ and order frequency $\mu$, both assumed to be fixed for each retailer. In reality, a retailer might have multiple orders with different profiles. In our exposition, we treat each order as a separate retailer. This modeling artifice has no implication for the results other than our expository convenience.

In Chapter 2 of this dissertation, we use the ratio $\rho = \mu/q$ (we refer to it as the order profile ratio) as an alternative characterization for a retailer in a supply chain only conduct first stage coordination, matching. The retailer’s market can be described by a two dimensional space with parameters $q$ and $\mu$ or parameters $\rho$ and $\mu$. In the
$q$-$\mu$ space, a point $(q, \mu)$ represents a retailer that orders $q$ units each time and $\mu$ times a year with an annual demand of $d = \mu q$. In the $\rho$-$\mu$ space, a point $(\rho, \mu)$ represents a retailer that orders $\mu/\rho$ units each time and $\mu$ times a year with an annual demand of $d = \mu^2/\rho$.

To fulfill retailers’ orders, all suppliers order from a common source with ample supply and they pay the same unit cost $C_0$. We assume that suppliers do not combine orders from different retailers in our model. The suppliers differ from each other in terms of their inventory holding costs $H_i, i = 1, \ldots, N$, and setup costs $S_i, i = 1, \ldots, N$. Without loss of generality, the indices of the suppliers are ordered according to their setup costs: $S_i < S_{i+1}, i = 1, \ldots, N-1$. We assume

$$S_i \neq S_j \quad \text{and} \quad S_i/H_i \neq S_j/H_j \quad \forall i, j = 1, \ldots, N, i \neq j.$$  \hspace{1cm} (4.1)

Indeed, if $S_i = S_j$ then either these two suppliers are identical (when their inventory holding costs are the same) or the supplier with a lower inventory holding cost dominates the other supplier. If $S_i/H_i = S_j/H_j$ then the supplier with a lower setup cost (and thus inventory holding cost) dominates the other supplier. The information about $H_i$ and $S_i$ for all suppliers is assumed to be common knowledge among the suppliers.

We assume that there is no central coordinator in this system. A retailer chooses his supplier based on his total cost to work with the supplier. The suppliers compete for retailer’s market by determining their inventory replenishment policy and pricing strategy. More specifically, we assume that all suppliers have the flexibility of offering different prices to different retailers based on retailers’ order profile, i.e., their order
quantities and order frequencies. Notice that this pricing strategy, when suppliers know each others logistics cost structure, can be implemented through a price menu approach to avoid antitrust litigation under the Robinson-Patman Act. In the absence of full cost knowledge of competing suppliers, implementation of this pricing equilibrium will require a second-price sealed bid auction to be executed for every retailer’s order (see Chapter 5 for detailed discussion).

Clearly, the lowest price a supplier can offer to a retailer depends on the supplier’s setup and inventory holding cost. To minimize her inventory cost, it is optimal for each supplier to follow the “EOQ model with lumpy demand” for her inventory policy (Munson and Rosenblatt(2001)). More specifically, let us suppose retailer \((q, \mu)\) (or \((\rho, \mu)\)) orders from supplier \(i\). Then the supplier should order \(nq\) units each time and \(\mu/n\) times a year. The optimal multiple \(n\) is given by

\[
n^* = \left\lfloor \frac{1}{2} \left( 1 + \sqrt{1 + \frac{8S_i d}{H_i q^2}} \right) \right\rfloor = \left\lfloor \frac{1}{2} \left( 1 + \sqrt{1 + \frac{8\rho S_i}{H_i}} \right) \right\rfloor,
\]

where \(\lfloor x \rfloor\) represents the largest integer less than or equal to \(x\). The minimum annual inventory cost per product incurred to supplier \(i\) is given by:

\[
C_i^* = \frac{S_i}{n^*q} + \frac{(n^* - 1)H_i}{2\mu} = \frac{H_i}{\mu} \left( \frac{\rho S_i/H_i}{(1 + \sqrt{1 + 8\rho S_i/H_i})/2} + \frac{1}{2} \left[ \frac{4\rho S_i/H_i}{(1 + \sqrt{1 + 8\rho S_i/H_i})} \right] \right). \tag{4.2}
\]

It is well known that the inventory cost of most EOQ models are insensitive to the
order quantity variations near the optimal order quantity. In the remaining paper, we approximate the inventory cost $C_i^*$ by ignoring the integer operation in (3.1). After some algebraic simplifications, we have:

$$C_i^* \approx \frac{4S_i\rho}{(1 + \sqrt{1 + 8\rho S_i/H_i})\mu}.$$  

Define relative inventory cost

$$C_i(\rho) = \frac{4S_i\rho}{1 + \sqrt{1 + 8\rho S_i/H_i}}.$$  

It follows that the lowest price supplier $i$ can offer to retailer $(\rho, \mu)$, while maintaining profitability, is given by: \(P_i(\rho, \mu) = C_0 + C_i(\rho)/\mu.\)

For market-based matching coordination, the retailers choose the EOQ model to minimize its own logistic cost. Therefore, for a given retailer, their order quantity and order frequency as well as their own logistic costs are fixed. Therefore, in case of choosing suppliers, a retailer always chooses the supplier who can offer the lowest price to it. Our research result in Chapter 2 shows that any two suppliers (with $S_1 < S_2$) satisfying

$$S_1 H_1 > S_2 H_2 \quad (4.3)$$

can coexisting with border

$$\rho_{12} = \frac{H_1 H_2 (H_1 - H_2)(S_2 - S_1)}{2(S_1 H_1 - S_2 H_2)^2}. \quad (4.4)$$
With lot-sizing coordination, the suppliers may choose all kinds of pricing strategy to make a retailer to order certain quantity and at certain frequency to minimize the system cost, which includes the supplier’s logistic cost and the retailer’s logistic cost. Therefore, a retailer chooses different order quantities and order frequencies for different suppliers. A retailer chooses a supplier based on his total cost, including his own logistic cost and purchasing cost. There are no transfer payments between the suppliers and retailers in both models with or without lot-sizing coordination. For notational convenience, we assume there is no lead-time; all orders are received instantaneously upon order placement. Positive but deterministic lead-times can be handled by a simple shift in time of all desired replenishment epochs and shall not influence our result.

4.3 Market Segmentation without Lot-Sizing Coordination

In chapter 2, we describe the market segmentation with only market-based matching coordination on the space of retailers’ order quantity and order frequency. However, after the second stage lot-sizing coordination, a retailer’s logistic behavior is different when it works with different suppliers. Therefore, we are no longer able to describe the market sharing situation on suppliers’ order quantity and frequency space. We need to find a space where the suppliers’ market segmentation can be described with or without lot-sizing coordination. This space is the \( h - s \) space. In the former research, the order quantity and order frequency of retailers are denoted as \( \mu \) and \( q \). The market is segmented by the ratio of \( \rho = \mu / q \) as shown by Figure 2.2.
Since retailers are assumed to choose the EOQ model when they decide their logistic behavior, the following results hold for all retailers:

\[ \mu = \sqrt{\frac{dh}{2s}}, \quad q = \sqrt{\frac{2ds}{h}}, \]

therefore, \( \mu/q = 0.5h/s \).

We further denote \( r = h/s \), then have,

\[ \rho = 0.5r \quad (4.5) \]

Since the market was segmented by \( \rho \) in chapter 2, it then can be transferred to be segmented by \( r \), the ratio of holding cost and setup cost of retailers. The change of the market segmentation description is shown in Figure 4.1:

INSERT FIGURE 4.1 HERE

### 4.4 Market Segmentation with Two-Stage Coordination

We assume that a retailer choose suppliers base on its own total cost, the sum of purchasing cost and logistic cost; and the supplier can use its pricing strategy to coordinate the supply chain through lot-sizing. In a supplier-retailer channel, since the supplier’s profit is nonnegative, the retailer’s purchase cost is equal to or greater than the sum of the suppliers’ logistic cost and purchase cost. In another word, the
retailer pays at least the sum of the logistic and purchase costs of the channel (the logistic cost of the supplier, the logistic cost of the retailer and the purchase cost of the supplier).

We suppose the unit purchasing cost is the same for all suppliers, then the retailers actually choose the suppliers basing on the system’s logistic cost. For a system that contains supplier $i$ and retailer $j$, the optimal logistic cost, denoted as $C_{ij}$, is as below:

$$C_{ij} = \sqrt{2S_iH_j/d_j}$$ (4.6)

Where

$$S_i = S_i/n_{ij} + s, \quad H_j = (n_{ij} - 1)H_i + h_j,$$

$$n_{ij} = \left[0.5 \left(1 + \sqrt{1 + \frac{4S_i(h - H_i)}{sH_i}}\right)\right]$$

We now consider market segments for two suppliers, supplier 1 and supplier 2, both coordinate with retailers through lot-sizing. There must exist a border between the market segment of supplier 1 and 2. The retailers on the border have same the optimal system logistic cost whether they cooperate with supplier 1 or 2. Therefore, the order profile of the retailers on the border between suppliers 1’s market and supplier 2’s market satisfy the following equation:

$$C_1 = 2\sqrt{2S_1/\left(1 + \sqrt{1 + \frac{4S_1(h - H_1)}{sH_1}}\right) + s}\left[\left(\sqrt{1 + \frac{4S_1(h - H_1)}{sH_1}} - 1\right)H_1 + h\right]/2d$$
\[
C_2 = \frac{2 \left[ 2S_2 / \left( 1 + \sqrt{1 + \frac{4S_2(h - H_2)}{sH_2}} \right) + s \right] \left[ \left( \sqrt{1 + \frac{4S_2(h - H_2)}{sH_2}} - 1 \right) H_2 + h \right]}{2d}
\]

After some algebraic manipulation, the above equation can be simplified as:

\[
S_1H_1 + sH_1 \left( \sqrt{1 + \frac{4S_1(h - H_1)}{sH_1}} - 1 \right) = S_2H_2 + sH_2 \left( \sqrt{1 + \frac{4S_2(h - H_2)}{sH_2}} - 1 \right)
\]

Clearly, market segment border between supplier 1 and supplier 2 is a function of retailer’s holding cost \(h\) and set up cost \(s\), it is not a function of the retailer’s demand \(d\). Therefore, we can describe both suppliers’ market segments on the \(h - s\) space. Moreover, the border after coordination is a curve that satisfy (4.7) instead a straight line. Furthermore, we can extend the market sharing situation of two suppliers to multiple suppliers. For multiple suppliers, all the retailers on borders must satisfy function (4.7).

4.5 Market Segmentation Comparison and Conclusion

It is obviously that the market segmentation situation of the suppliers with or without lot-sizing coordination are different. However, we can describe both situations on the \(h - s\) space. The borders of the suppliers’ market shares without lot-sizing coordination
are straight lines while with lot-sizing coordination are curves described by equation (4.7).

Managerially speaking, after coordination, suppliers market segment will be changed. Some retailers belong to certain supplier’s market will now belong to other suppliers’ market. Suppliers can use the formula provided in this paper to predict which part of the market segment they are going to gain and which part of the market segment they are going to lose after conduct coordination. They can then use the information to predict demand or decide other strategies to promote their market shares.

Since we can describe the market segmentation without lot-sizing coordination, the question now is to find the characteristics for the border curves after coordination.

Although it is difficult to observe, we did generate some results about the characteristics of the border curve with coordination.

**Theorem 11** Suppose supplier 1 and supplier 2 (satisfy the coexisting condition as in Theorem 1) compete for retailer’s market, and they both conduct lot-sizing coordination with their retailers respectively, the curve border between their market segments approaches to a straight line as retailer’s setup cost increases, and this line is parallel to the border line without lot-sizing coordination with a positive intercept.

**Proof:**

We know that the curve border satisfies equation (4.7). Reorganize equation (4.7),
we then have
\[
s[H_1(\sqrt{1 + 4 \frac{S_1(h - H_1)}{H_1 s}} - 1) - H_2(\sqrt{1 + 4 \frac{S_2(h - H_2)}{H_2 s}} - 1)] = S_1H_1 - S_2H_2
\]

As \( s \to \infty \)
\[
s[H_1(\sqrt{1 + 4 \frac{S_1}{H_1 s}}h - 1) - H_2(\sqrt{1 + 4 \frac{S_2}{H_2 s}}h - 1)] = S_1H_1 - S_2H_2.
\]

Derive the equation in respect with \( s \).

\[
\frac{2S_1(\partial h/\partial s - h/s)}{s\sqrt{1 + 4 \frac{S_1}{H_1 s}}} - \frac{2S_2(\partial h/\partial s - h/s)}{s\sqrt{1 + 4 \frac{S_2}{H_2 s}}} = H_2(\sqrt{1 + 4 \frac{S_2}{H_2 s}}h - 1) - H_1(\sqrt{1 + 4 \frac{S_1}{H_1 s}}h - 1)
\]

If \( h = o(s) \) or \( s = o(h) \), it is obviously that the above equation or equation (4.7) cannot hold. Therefore, \( h \) and \( s \) should be linearly related. When \( s \to \infty \), set \( \partial h/\partial s = h/s = k_1 \),

\[
H_2(\sqrt{1 + 4 \frac{S_2}{H_2}k_1 - 1}) - H_1(\sqrt{1 + 4 \frac{S_1}{H_1}k_1 - 1}).
\]

Solve the equation, \( k_1 = \frac{H_1H_2(h_1 - H_2)(s_2 - s_1)}{(s_1H_1 - s_2H_2)^2} \). Compare \( k_1 \) with the equation (2.4) and (4.5), \( k_1 = 2\rho_{12} = r_{12} \).

We then define \( k_2 = h - k_1s \). We can show that \( k_2 > 0 \) since the curve border equation is concave and with the slope approach to \( k_1 \).
Figure 4.2 shows the market segmentation before and after lot-sizing coordination.

After lot-sizing coordination, the border shifts up. Therefore, some retailers with higher holding up cost switch to supplier 1. This is the result of lot-sizing, which decreases the total system cost by increasing retailer’s order quantity. Therefore, the holding cost influence is comparably lower.

If we extend the result to multiple suppliers, we have the following observation.

**Corollary 11** For multiple coexisting suppliers, the market segment for supplier with lowest setup cost will increase, while the market segment for supplier with highest setup cost will decrease after lot-sizing coordination.

For a group of coexisting suppliers as indexed before, supplier 1 always benefit from lot-sizing while supplier N always be hurt. For supplier with smallest set-up cost and biggest holding cost, there is driven power for lot-sizing coordination. For supplier with biggest set-up cost and smallest holding cost, who intending to produce or order in large lots, lot-sizing is not a good choice in market competition.

Even though the last observation seems paradoxical, it is actually not. Our research result in Chapter 2 shows that for a buyer order profile with large order quality and small frequency, the best any supplier can do is to match this frequency with her production schedule. In a setup cost dominated environment, this implies that the lowest setup cost supplier has the per unit cost advantage. On the other hand, for an order profile with small order quantities delivered frequently, the supplier with high
setup cost and lower holding costs will produce large batch sizes and hold them longer. In doing so, she will allocate her setup cost disadvantage via a large lot size relative to the low setup cost supplier. Due to her higher inventory holding costs, the low setup cost supplier uses her flexibility in producing smaller lots as an effort to avoid large holding costs, but that results in setup costs accumulated over smaller batches, thus finally resulting in a per unit cost disadvantage relative to the high setup cost supplier. In other words, for highly repetitive small order quantity buyer profiles, the ability to effectively aggregate orders in the production environments proved beneficial relative to the flexibility of frequently small lot switch overs. That explains why lot-sizing coordination is more beneficial for suppliers with smaller setup cost, higher holding cost logistic structure.
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Chapter 5

NUMERICAL EXAMPLES AND IMPLEMENTATIONS

This chapter uses numerical examples to illustrate the algorithms and support the theories and ideas we developed in the first four chapters. Furthermore, the practical usages and implementations of our models are discussed.

5.1 Numerical Examples

In this section, we provide four examples to illustrate the market-based matching between suppliers and buyers proposed before.

The first example describes the matching processes and the resulting order space segments for all suppliers in the supply chain with first stage coordination, market-
based matching. We consider 8 suppliers with certain logistic parameters competing in the market, and then follow “Algorithm to Determine Order Space Of Multiple Suppliers” step by step to decide the order spaces of the subsisting suppliers. We then further suppose the retailer’s demand follow special distribution to determine the market segments of the suppliers. Furthermore, we suppose the parameter for the retail demand changes, the market segments change are then discussed.

The second example continues on the base of the first example. It describes the order space segmentation changes when a new supplier enters the market. ‘Algorithm to Determine Order Space Of a New Supplier” is illustrated by this example.

The third example demonstrates the benefit of using the market-based matching vs. the traditional lot-sizing coordination. Two suppliers are chosen and their order space segments are decided. Retailers with different order profiles are then assigned to replenish from the two suppliers with or without lot-sizing coordination. Since we know the retailers’ order profile, we can decide whether there is a first stage market-based matching coordination between the supplier and the retailer or not. Four different situations, matching and lot-sizing, matching and no lot-sizing, no matching and lot-sizing, and no match and no lot-sizing are compared in respect with the system costs. The examples shows that matching as a primary cost-saving coordination stage while lot-sizing as the secondary.

The fourth example compares the market segmentation with and without lot-sizing coordination. We first consider two suppliers, and compare their market segments before and after lot-sizing coordination. We then shows how market segmentation situation change for multiple suppliers. The numerical example supports the result we
generated from Chapter 4, that is the market borders shift upward and approach a parallel line of the borders before lot-sizing coordination.

In the four examples, we choose the parameters for suppliers and retailers based on the existing research. The holding costs range from 9 to 20. The setup costs range from 400 to 700. Munson and Rosenblatt (2001) set the parameters of suppliers based on the realistic situations. This research follows the idea from their numerical examples in choosing parameters for suppliers.

### 5.1.1 Example One

Consider a two-stage supply chain with 8 suppliers. Their inventory costs are described in the following Table 5.1.

<table>
<thead>
<tr>
<th>Supplier</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_i$</td>
<td>400</td>
<td>420</td>
<td>440</td>
<td>470</td>
<td>500</td>
<td>540</td>
<td>590</td>
<td>670</td>
</tr>
<tr>
<td>$H_i$</td>
<td>16</td>
<td>15</td>
<td>14</td>
<td>13</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>$S_iH_i$</td>
<td>6400</td>
<td>6300</td>
<td>6160</td>
<td>6110</td>
<td>6000</td>
<td>5940</td>
<td>5900</td>
<td>6030</td>
</tr>
</tbody>
</table>

By the pairwise coexisting condition (2.5), all suppliers, except supplier 8, coexist pairwisely. Supplier 8 is dominated by suppliers 5, 6, and 7, respectively. However, when these remaining 7 suppliers compete together, all suppliers, except supplier 1 and supplier 7, are not guaranteed to have positive order space segments. To determine the order space segments for each supplier, we apply the algorithm developed in Section 4.
Starting from supplier 1, we find

$$\rho_{12} = 0.24, \quad \rho_{13} = 0.16, \quad \rho_{14} = 0.26, \quad \rho_{15} = 0.24, \quad \rho_{16} = 0.29, \quad \rho_{17} = 0.36.$$ 

Since the value of $\rho_{13}$ is the smallest, supplier 3 will be supplier 1’s neighbor supplier with their order space segments separated at $\rho_{13}$. Supplier 2 is dominated by the existence of supplier 1 and supplier 3 together. The algorithm then repeats with the following calculations starting from supplier 3

$$\rho_{34} = 1.09, \quad \rho_{35} = 0.39, \quad \rho_{36} = 0.48, \quad \rho_{37} = 0.62.$$ 

Since $\rho_{35}$ is the smallest, supplier 5 will coexist with supplier 1, 3, and 7. Supplier 4 is dominated by supplier 3 and 5. Continuing this process, the algorithm finally determines that supplier 1, 3, 5, 6, and 7 will coexist, and their order space segment are separated by

$$\rho_{13} = 0.16, \quad \rho_{35} = 0.39, \quad \rho_{56} = 0.73, \quad \rho_{67} = 1.72.$$ 

Figure 4 describes the order space segmentation of the coexisting suppliers in the $q$-$\mu$ space.

Our paper determines the order space segment of a supplier by matching her logistic cost structure with buyers’ order profiles. In practice, the size of a supplier’s market share is often measured by a fraction of the total buyer demand she acquires. To make such transformation, we need the information on how the demand from all buyers is distributed across their order profiles (measured by $\rho$ here). Suppose the total
demand, after scaling, is equal to 1 and the demand follows a probability distribution $f(\rho)$. Let suppliers $1, \ldots, N$ be the coexisting suppliers based on our order space segmentation analysis in Section 4 and their order space segments are separated by $\rho_{i,i+1}$, $i = 1, \ldots, N - 1$. Then supplier $i$’s market share $V_i$, measured in terms of the fraction of the total demand she acquires, is given by

$$V_i = \begin{cases} \int_0^{\rho_{12}} f(\rho)d\rho & \text{if } i = 1, \\ \int_{\rho_i}^{\rho_{i+1}} f(\rho)d\rho & \text{if } i = 2, \ldots, N - 1, \\ \int_{\rho_N}^{\infty} f(\rho)d\rho & \text{if } i = N. \end{cases}$$

For numerical demonstration, let us assume that the demand follows a Gamma distribution $GAM(\theta, 2)$, as shown in Figure 5.2, which has a mean of $2\theta$. Figure 5.3 shows the market share of suppliers 1, 3, 5, 6 and 7, as a fraction of total demand, under various values of $\theta$. Clearly, as $\theta$ increases, more demand is generated from buyers with larger $\rho$. Those suppliers with larger setup costs and smaller holding costs will gain market share due to their order space segment positions.

5.1.2 Example Two

The second example describes the order space segmentation changes when a new supplier enters the market. Suppose new supplier $k$ ($S_k = 466, H_k = 13$) enters the market consisting of coexisting suppliers 1, 3, 5, 6 and 7 as in the first example. Applying the pairwise coexisting condition (2.3), we can locate supplier $k$’s order space.
segment, if any, to be between those of suppliers 3 and 5. We then apply our algorithm in Section 6 to determine the size of supplier $k$’s order space segment; since $\rho_{3k} = 0.18 > \rho_{13} = 0.16$, supplier 3 remains to have positive order space segment. However, since $\rho_{k5} = 0.79 > \rho_{56} = 0.76$, supplier 5’s market segment is completely taken by the new supplier $k$. We further check $\rho_{k6} = 0.79 < \rho_{67} = 1.72$. It follows that supplier 6 will have positive order space segment. Therefore, after supplier $k$ enters the market, the new coexisting suppliers are suppliers 1, 3, $k$, 6, and 7. The boundaries of their order space segments are $\rho_{13} = 0.16, \rho_{3k} = 0.23, \rho_{k6} = 0.76, \rho_{67} = 1.72$, respectively.

Figure 5.3 describes the new order space segmentation of the coexisting suppliers after supplier $k$ enters the market in the $q-\mu$ space. The process can also be demonstrated by Table 5.2.

**5.1.3 Example Three**

The third example demonstrates the benefit of cost effective matching between suppliers and buyers proposed in this paper. Consider a two-stage supply chain with two suppliers, supplier 1 and supplier 2. The setup cost and inventory holding cost for the two suppliers are $S_1 = 450$, $H_1 = 12$, and $S_2 = 800$, $H_2 = 6$, respectively. By the pairwise coexisting condition, these two suppliers will coexist with the order space segment boundary at $\rho_{12} = 0.105$. Consider a buyer with annual demand $d = 25000$, setup cost $s = 400$, and inventory holding cost $h = 13$. If the buyer follow the EOQ
model to place his order, he should order about $q = 1240$ units each time and about $\mu = 20$ times a year. Since $\rho = \mu/q = 0.016 < \rho_{12}$, supplier 1 matches the buyer better than supplier 2. Once the buyer chooses a supplier, they also have an option of coordinating their inventory policies by lot-sizing. The following table shows the various total system inventory costs based on whether the buyer and the supplier matches or not and whether they coordinate by lot-sizing or not. The numbers in the parenthesis indicate the savings from coordination, matching with the right supplier, and both.

<table>
<thead>
<tr>
<th></th>
<th>Wrong Match</th>
<th>Optimal Match</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Coordination by Lot-sizing</td>
<td>$27908 (100%)$</td>
<td>$25195 (90.3%)$</td>
</tr>
<tr>
<td>Coordination by Lot-sizing</td>
<td>$27568 (98.8%)$</td>
<td>$23505 (84.2%)$</td>
</tr>
</tbody>
</table>

This example clearly shows that the saving from effective matching between suppliers and buyers can be significant and sometimes more significant than that from lot-sizing coordination. In other words, a mismatch between a supplier and a buyer can be very costly, even if a subsequent lot-sizing coordination is implemented. See Chen and Kouvelis (2003) for further analysis on this issue.

In the above example, we intent to choose a retailer which matches with supplier 1 very well and is located far away from the market segment border of the tho suppliers. In order to further illustrate the idea, we change the order profile of the retailer to see how it influences the system cost. Since retailers with same $\rho$ may hold different setup cost and holding cost, we keep the setup cost equal to 400 for this example, and only change holding cost. The following Table 5.3 and Figure 5.5 show the result.

INSERT TABLE 5.3 and FIGURE 5.4 HERE
We have the following observations based on the numerical test results: first, the first stage coordination, market-based matching has primary influence on system cost comparing to the second stage coordination, lot-sizing in our model. Second, as $\rho$ increases, the influence of both matching and lot-sizing coordination decreases. As $\rho$ increases, holding cost increases. When holding cost is significant enough, retailers do not want to keep any inventory, their strategy is to order as minimum as possible. Purchasing from whom, coordination or not does not matter.

5.1.4 Example Four

The fourth example compares the market sharing situations with and without lot-sizing coordination. We are able to illustrate the two situations in $(h, s)$ space as described in Chapter 4 to compare them. We first consider a two-stage supply chain with two suppliers, supplier 1 and supplier 2. The setup cost and inventory holding cost for the two suppliers are $S_1 = 400$, $H_1 = 16$, and $S_2 = 440$, $H_2 = 14$. We can calculate out the border without lot-sizing coordination is a straight line start with slope $r_{12} = 0.31$. We then find out the new border according to equation (4.7). The two borders before and after lot-sizing are shown on the following Figure 5.6.

INSERT FIGURE 5.6 HERE.

In this example, the market border after lot-sizing coordination looks almost a parallel straight line of the border before coordination, although theoretically we know the border should be a curve which approaches a straight line parallel to the border before lot-sizing coordination. We further check the data table for this example as
Observing the data, as the setup cost $s$ changes evenly from 50 to 2000, the change of holding cost $h$ of the border after lot-sizing changes approach to 15.5556, which is the change of the $h$ of the border before lot-sizing. It supports that the border after lot-sizing coordination approaches a line parallel to the border before lot-sizing coordination. We also did the test for suppliers with different parameters. The results are all the similar, the borders after lot-sizing are almost a straight line paralleling to the borders before lot-sizing.

We further compare the situations of multiple suppliers. A third supplier with $S_3 = 500$, $H_3 = 12$ is added into this market, the borders before lot-sizing are lines with slope $r_{12} = 0.31$, and $r_{23} = 0.79$. The borders before and after lot-sizing coordination are shown on Figure 5.7 as below. We found that the result from chapter 4 is true for multiple suppliers situation too. We also observe that the changes after lot-sizing coordination are small changes, which further support our primary argument, that the influence of lot-sizing coordination is not major.

In conclusion, all the above four numerical examples support the theories of our research. The also support that the first stage coordination, market-based matching has the primary effect in cost-saving of the system, while the second stage coordination, traditional lot-sizing coordination has the secondary effect in cost-saving of the system.
5.2 Implementations

So far, our analysis of the market-based matching and suppliers’ order space segmentation has been based on the assumption that all participating suppliers’ logistic cost structures, or at least their cost curves $C_i(\rho)$ for a buyer order $(\rho, \mu)$, are common knowledge among all suppliers and buyers. In this section, we argue that this assumption is not necessary in implementing the equilibrium market-based matching and pricing. We propose a reverse auction mechanism to achieve the equilibrium predicted by the paper. See McAfee and McMillan (1987), and Milgrom (1987) for excellent surveys on the literature and theory of auctions and Rasmussen (1989) for a textbook level explanation.

Reverse auctions, in which a single buyer puts out a request for a quote on a specified purchase and multiple sellers bid is proved to be one of the most useful application of Business-to-Business (B2B) in supply chain coordination. Their application has been popularized by independent exchanges like FreeMarkets, and can be often executed via Internet technologies either via firm specific Internet portals (Cisco, Wal-Mart, GE, GM, Ford are among the many firms running their own private exchanges for sourcing purpose) or via consortium exchange Internet platforms (like Covisint in the car industry, Exostar in the aerospace industry etc.). For details and many examples on the implementation aspects of online auctions, reverse auctions, and the various B2B exchanges in creating such markets see Kambil and VanHeck (2002) and Hall (2001).

The “second-price sealed-bid” auction, often referred to as Vickrey auction, will
be the right mechanism to achieve the equilibrium stated in Theorem 4 and 5 of our paper in terms of the supplier-buyer matching and pricing. To perform the auction, each buyer requests a bid for his order \((\rho, \mu)\). Each supplier quotes a price through a sealed bid. The buyer with the lowest bid wins the order but pays the second lowest price among all participating suppliers. This auction mechanism dictates all suppliers to bid their prices according to their actual costs involved in executing the order. In particular, a supplier’s bid does not depend on his knowledge on other competing suppliers’ cost structures. Clearly, the supplier whose logistic cost structure matches the order profile best will be able to execute the buyer’s order most cost effectively. As a result, she will bid with the lowest price and therefore win the order. The winning price, according to the auction mechanism, will be the lowest price of her competitors, or the price offered by her closest competitor(s). Apparently, the above auction mechanism achieves the equilibrium predicted by our paper without requiring the common knowledge of suppliers’ cost structures.

Implementation of the second-price sealed bid auction has the obvious shortcoming that the suppliers end up revealing their cost \(C(\rho)\) for the particular retail order \((\rho, \mu)\). Therefore, the supplier runs into the risk that within a few rounds of reverse auction transactions with a particular buyer, his detailed logistic cost structure gets revealed. The revealed cost structure information may negatively affect the supplier’s future negotiation with the buyer. As is well known in the theory and practice of Vickrey auctions, they work only when trust prevails among the buyers and suppliers. That is why the use of reliable independent third parties, such as FreeMarkets, or independent management boards to run the consortium exchanges, can facilitate the effective execution of such sourcing market mechanisms.
Recent global outsourcing practices suggest that global logistic intermediaries (e.g., Li & Fung and TAL Apparel in the retail industry, Flextronics and Solectron in the electronics industry, and Adaptec and Xilinx in the semiconductor manufacturing) can perform in an equally effective way as the “matchmaker” role between buyers and suppliers using their knowledge of the sourcing cost structures of supply networks in certain regions of the world. The most fitting example among them is Li & Fung. Li & Fung is a global supply chain integrator that provides high value front-and-back end services to mostly large buyers such as Gymboree or The Limited. On the front end, a Li & Fung decision might be fully dedicated to serve the buying needs of a large customer. At the back end, through a network of 20 or so branch offices, Li & Fung maintains unique knowledge about and relationships with an extensive supplier network. Li & Fung has a network of 7,500 suppliers on more than 30 countries. Through this network, and the knowledge on its suppliers’ cost and other operating conditions, the company is able to provide its customers with fully customized sourcing solutions. Li & Fung has been extremely successful, and its success exemplifies the value generated from supply chain coordination through matching customer orders with right suppliers. This example also proves that the market-based matching between suppliers and buyers can be effectively implemented through credible market intermediaries, such as Li & Fung, without the fear of information leakage.

5.3 Concluding Remarks

In this paper, we place emphasis on clearly identifying the matching of buyers’ order profile to suppliers’ logistic cost structures as the first-order effect and main source of
supply chain coordination benefits for supply chains with significant economies of scale, and then analyze the resulting equilibrium from a market based matching of suppliers and buyers in a pre-identified order space, we suggest effective ways for implementing the derived equilibrium without strict information requirements. Exploiting the supplier set with ample size and diverse logistics costs, buyers can devise price directed market mechanisms to allocate different buyer orders to the suppliers with the right cost structure without having to worry much about subsequent lot-sizing coordination with the chosen suppliers. As demonstrated in Chen and Kouvelis (2003), lot-sizing coordination has an almost second order effect (in some cases less than 15% of the optimal total supply chain cost). Our analysis in the current paper identifies the segment of the buyer order space a specific supplier could win by exploiting the advantage of her logistic cost structure as well as the price that the winning supplier ends up offering in this price competitive supply environment. As a byproduct of our analysis, each supplier can effectively estimate her segment of buyer’s order space. Finally, we show the implications of new supplier entries on order space segmentation for the existing suppliers, and offer constructive suggestions on actions suppliers could take in this competitive environment.

We also explain how buyers can implement this matching of orders to suppliers with reverse auctions or through the series of logistics and global trading intermediaries such as FreeMarkets, Li & Fung, Flextronics and Adaptec. As we have argued, at the equilibrium of the market-based matching, the winning supplier will execute the buyer’s order by offering the lowest price (i.e., just covering the cost) of her “neighbor” competitor. By the nature of this result, the second-price sealed bid auction seems to be a natural and effective mechanism to implement the market-based matching. The
usual fears of revelation of excessive cost information on the part of the winning supplier
become less relevant in the business environment of today, where buyers, or their
logistical intermediaries, such as FreeMarkets, inspect the supplier production process
to verify feasibility and validity of submitted bid prior to awarding winning contracts
after the reverse suction. And in some cases, global logistical intermediaries can be
perfect implementers of this competitive equilibrium due to their knowledge of supplier
cost structures in certain sourcing regions of the world. Pursuing this line of thought,
one can argue that our paper has provided a theoretical underpinning that explains
the value model that such third party global logistic intermediaries provide, and why
they enjoy a much higher profit margin than their traditional competitors. (e.g., Li &
Fung can charge up to 10% of certain outsourcing transaction when traditional trading
companies with limited supplier sets only get 1 – 2%).
Bibliography


<table>
<thead>
<tr>
<th>Reference</th>
<th>No. of Channel Stage</th>
<th>Channel Type *</th>
<th>No. of retailer</th>
<th>Determinant Demand</th>
<th>No. of supplier</th>
<th>Claimed Contribution</th>
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<td>Clark and Scarf (1960)</td>
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<td>C</td>
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<td>Yes</td>
<td>1</td>
<td>Military logistic problem</td>
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<tr>
<td>Baligh and Richartz (1964)</td>
<td>&gt;=2</td>
<td>C</td>
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<td>Yes</td>
<td>&gt;=1</td>
<td>Consider No. of levels and firms in each level to minimize contact cost in the network</td>
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<td>Graves and Schwarz (1977)</td>
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<td>&gt;=2</td>
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<td>1</td>
<td>Non-stationary replenishment interval</td>
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<td>Jeuland and Shugan (1983)</td>
<td>2</td>
<td>CO</td>
<td>1</td>
<td>No</td>
<td>1</td>
<td>Compare coordination with decentralization. Consider pricing role in coordination.</td>
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<td>Monahan (1984)</td>
<td>2</td>
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<td>Yes</td>
<td>1</td>
<td>Discount strategy to increase supplier profit</td>
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<td>Lal and Staelin (1984)</td>
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<td>C</td>
<td>&gt;=1</td>
<td>Yes</td>
<td>1</td>
<td>Optimal central solution assuming supplier replenish its stock infrequently</td>
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<tr>
<td>Rosenblatt and Lee (1985)</td>
<td>2</td>
<td>CO</td>
<td>1</td>
<td>Yes</td>
<td>1</td>
<td>Coordination benefit both supplier and buyer</td>
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<tr>
<td>Lee and Rosenblatt (1986)</td>
<td>2</td>
<td>CO</td>
<td>1</td>
<td>Yes</td>
<td>1</td>
<td>Consider both setup cost and holding cost</td>
</tr>
<tr>
<td>Banerjee (1986)</td>
<td>2</td>
<td>C</td>
<td>1</td>
<td>Yes</td>
<td>1</td>
<td>Quantity the benefit to supplier and buyer respectively. Optimal discount schedule.</td>
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<td>Roundy (1985 1986)</td>
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<td>Power of two policy</td>
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<td>Moorthy (1987)</td>
<td>2</td>
<td>CO</td>
<td>1</td>
<td>No</td>
<td>1</td>
<td>a two-party tariff instead of quantity discount</td>
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<td>Choi (1991)</td>
<td>2</td>
<td>D</td>
<td>1</td>
<td>No</td>
<td>2</td>
<td>Two suppliers compete for one retailer</td>
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<td>O'Brien and Shaffer (1993)</td>
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<td>Nonlinear Pricing when two suppliers contract with a retailer monopolist</td>
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<td>Choi (1996)</td>
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<td>D</td>
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<td>Lee and Whang (1997)</td>
<td>&gt;=2</td>
<td>D</td>
<td>1</td>
<td>No</td>
<td>1</td>
<td>Consignment policy for redistributing inventory holding costs among parties</td>
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<td>Lee, Padmanabhan, and Whang. (1997)</td>
<td>2</td>
<td>D</td>
<td>&gt;=1</td>
<td>No</td>
<td>1</td>
<td>Information flow and bullwhip effect</td>
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<td>Agrawal and Tsay (1998)</td>
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<td>No</td>
<td>1</td>
<td>Increase profitability of supply chain need not be at eh expense of end customer</td>
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<td>Cachon and Lariviere (1999)</td>
<td>2</td>
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<td>2</td>
<td>No</td>
<td>1</td>
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<td>Marx and Shaffer (1999, 2001a, 2001 b)</td>
<td>2</td>
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<td>1</td>
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<td>2</td>
<td>Sequential contracting between two suppliers and one retailer</td>
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<td>Chen, Federgruen and Zheng (2001)</td>
<td>2</td>
<td>CO</td>
<td>&gt;=1</td>
<td>Yes</td>
<td>1</td>
<td>Extension of power of two policy without central player</td>
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<td>Munson and Rosenblatt (2001)</td>
<td>3</td>
<td>CO</td>
<td>1</td>
<td>Yes</td>
<td>1</td>
<td>Lumpy demand coordination</td>
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<td>Shaffer (2001)</td>
<td>2</td>
<td>D</td>
<td>&gt;=1</td>
<td>No</td>
<td>&gt;=1</td>
<td>Barging power between suppliers and retailers</td>
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<tr>
<td>Tsay et 02</td>
<td>2</td>
<td>CO</td>
<td>&gt;=1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Chiang and Monahan</td>
<td>2</td>
<td>CO</td>
<td>2</td>
<td>Yes</td>
<td>1</td>
<td>Distribution between direct sale and company owned store</td>
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</tbody>
</table>

*Coordinated by quantity discount(CO), Centralized (C), Decentralized without coordination(D) ** One supplier, one buyer channel (Linear); One supplier, multiple buyers (Divergent)
Figure 1.1
Figure 2.1: The Equilibrium Order Space Segmentation in the 2-Supplier Case

Figure 2.2: The Equilibrium Order Space Segmentation in the N-Supplier Case

Figure 2.3: The Equilibrium Pricing Strategy for Multiple Coexisting Suppliers
Figure 3.1: Situation I
The market sharing for Suppliers $l$ and $k$

Figure 3.2: Situation II
The market sharing for Suppliers $l$ and $k
Table 3.1: Comparison of PMS and SPS

<table>
<thead>
<tr>
<th>Nash Equilibrium Price</th>
<th>Profit Maximization Strategy (PMS)</th>
<th>Sale promotion Strategy (SPS)</th>
</tr>
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<tbody>
<tr>
<td>( \delta \leq -6K\rho )</td>
<td>( P_l = C_l ); ( P_k = C_l - K/q )</td>
<td>( P_l = C_l ); ( P_k = C_l - K/q )</td>
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<td>(-6K\rho &lt; \delta \leq -2K\rho )</td>
<td>( P_l = \frac{K}{q} + \frac{2}{3} C_i + \frac{1}{3} C_i ); ( P_k = \frac{K}{q} + \frac{2}{3} C_i + \frac{1}{3} C_i )</td>
<td>( P_l = C_l ); ( P_k = C_l - K/q )</td>
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<td>(</td>
<td>\delta</td>
<td>&lt; 2K\rho )</td>
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<td>( 2K\rho \leq \delta \leq 6K\rho )</td>
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<td>( \delta \geq 6K\rho )</td>
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<td>( P_l = C_k - K/q ); ( P_k = C_k )</td>
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</tbody>
</table>

**Market share**

| \( \delta \leq -6K\rho \) | \( x_p = 0 \); \( x_s = 0 \) |
| \(-6K\rho < \delta \leq -2K\rho \) | \( x_p = \frac{\delta}{12K\rho} + 0.5 \); \( x_s = 0 \) |
| \(|\delta| < 2K\rho \) | \( x_p = \frac{\delta}{12K\rho} + 0.5 \); \( x_s = \frac{\delta}{4K\rho} + 0.5 \) |
| \( 2K\rho \leq \delta < 6K\rho \) | \( x_p = \frac{\delta}{12K\rho} + 0.5 \); \( x_s = 1 \) |
| \( \delta \geq 6K\rho \) | \( x_p = 1 \); \( x_s = 1 \) |

Note:  
(*1): when \( \delta \) in this range, supplier \( k \) may choose the SPS to eliminate supplier \( l \) from the market;  
(*2): when \( \delta \) in this range, no supplier is able to eliminate another;  
(*3): when \( \delta \) in this range, supplier \( l \) may choose the SPS to eliminate supplier \( k \) from the market.
Figure 4.1: The Change of Equilibrium Order Space Segmentation Description in the 2-Supplier Case

Figure 4.2: The Comparison of Market Segmentation before and after Lot-sizing Coordination
Figure 5.1: The Equilibrium Order Space Segmentation for Coexisting Suppliers in Example 1

Figure 5.2: The Distribution of the Retail Demand in Example 1

Figure 5.3: The Equilibrium Market Shares for Coexisting Suppliers in Example 1

Figure 5.4: The Equilibrium Order Space Segmentation for Coexisting Suppliers in Example 2
Table 5.2: Demonstration of the Process in Example 2

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<tr>
<th>Suppliers</th>
<th>H</th>
<th>S</th>
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<td>1</td>
<td>16</td>
<td>400</td>
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Figure 5.5: System Costs Comparison in Example 3
### Table 5.3: System Cost Comparison in Example 3

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| 300                    | 12 | 0.020| 1          | 23479             | 21213     | 25715         | 25100     | 91.3%       | 82.5%     | 100.0%       | 97.6%     |
| 300                    | 24 | 0.040| 1          | 30832             | 30000     | 32150         | 31937     | 95.9%       | 93.3%     | 100.0%       | 99.3%     |
| 300                    | 36 | 0.060| 1          | 35825             | 35496     | 36793         | 36742     | 97.4%       | 96.5%     | 100.0%       | 99.9%     |
| 300                    | 48 | 0.080| 1          | 40249             | 39686     | 40696         | 40620     | 98.9%       | 97.5%     | 100.0%       | 99.8%     |
| 300                    | 60 | 0.100| 1          | 43500             | 43474     | 44000         | 43955     | 98.9%       | 98.8%     | 100.0%       | 99.9%     |
| 300                    | 72 | 0.120| 2          | 46556             | 46476     | 47013         | 46989     | 99.0%       | 98.9%     | 100.0%       | 100.0%    |
| 300                    | 84 | 0.140| 2          | 49442             | 49295     | 49723         | 49699     | 99.4%       | 99.1%     | 100.0%       | 100.0%    |
| 300                    | 96 | 0.160| 2          | 52178             | 51962     | 52291         | 52249     | 99.8%       | 99.4%     | 100.0%       | 99.9%     |
| 300                    | 108| 0.180| 2          | 54504             | 54498     | 54624         | 54616     | 99.8%       | 99.8%     | 100.0%       | 100.0%    |
| 300                    | 120| 0.200| 2          | 56745             | 56723     | 56872         | 56846     | 99.8%       | 99.7%     | 100.0%       | 100.0%    |
| 300                    | 132| 0.220| 2          | 58908             | 58864     | 58992         | 58992     | 99.9%       | 99.8%     | 100.0%       | 100.0%    |
Figure 5.6: The Comparison of Market Segmentation with and without Lot-sizing Coordination for Two Coexisting Suppliers in Example 4

Figure 5.6: The Comparison of Market Segmentation with and without Lot-sizing Coordination for Multiple Coexisting Suppliers in Example 4
Table 5.4: Data of Market Segmentation before and after Lot-Sizing Coordination for Example 4, Figure 5.6

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