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Essays on Quantitative Analysis of Supply Chain Structures, Contracts and Coordination

A Dissertation Presented for the Doctor of
Philosophy Degree

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Xinjie Shi
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*To My Wife, and My Parents
Thank you all for your love and support.*

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ABSTRACT

This thesis consists of three separate, but related, essays that deal with the topic of how supply chain structure as well as the use of contracts impact performance of a supply chain. The main focus is the analysis of behavior of indirect-sale supply chains in terms of relative bargaining power and decision rights of the participants. Modeling as Stackelberg games, this thesis explores the existence of Nash equilibriums and the issues surrounding supply chain coordination.

In Essay one, “The Role of Decision Structure in Supply Chain Coordination with Stochastic Demand”, the analysis focuses on how different supply chain structures affect the choice of contracts in coordination under a generalized setting in which more powerful agent does not necessarily assume the Stackelberg leadership. This study shows that an optimal coordinating contract is based not only upon the overstock liquidation advantage the supplier/retailer may have, but also upon the specific decision hierarchy in the supply chain.

In Essay two, “Supply Chain Performance with Power Imbalanced Suppliers”, studies the effects of product substitution when suppliers and retailers have an imbalance of decision making power. In particular, we address the questions of structure dominance and why certain supply chain power structures are more stable.

Finally, Essay three, “Supply Chain Coordination with Revenue Sharing Contract when Retailer Sells Store-Brand Products”, a retailer-dominated supply chain coordination problem is investigated when the retailer sells store-brand products. Among many insights developed, it follows that two-parameter revenue-sharing contracts are preferred to both wholesale-price contracts and one-parameter revenue-sharing contracts in supply chain coordination due to its flexibility in profit division.

Keywords and Phrases: Supply Chain Structure, Decision and Power Structure, Wholesale Price Contract, Buyback Contract, Markdown Money Contract, Revenue Sharing Contract, Coordination, Stackelberg Game, Store Brand.

Table of Contents

Chapter 1: Introduction.....	1
1.1 Preliminaries.....	1
1.2 Structure of the Thesis.....	5
1.3 Scope and Limitations.....	9
 Chapter 2: The Role of Decision Structure in Supply Chain Coordination with Stochastic Demand.....	 11
2.1 Introduction.....	11
2.2 Model Assumptions and Supply Chain Decision Structures.....	19
2.2.1 Model Assumptions.....	19
2.2.2 Supply Chain Decision Structures.....	20
2.3 Integrated Supply Chains (S1 & S2).....	23
2.4 S3: Supplier (Captain/Leader/P) vs. Retailer (Associate/Follower/D).....	25
2.4.1 Wholesale Price Contract.....	25
2.4.2 Buyback Contract.....	27
2.4.3 Markdown-money Contract.....	31
2.5 S4: Supplier (Associate/Leader/P) vs. Retailer (Captain/Follower/D).....	34
2.5.1 Wholesale Price Contract.....	34
2.5.2 Buyback Contract.....	35
2.6 S5: Supplier (Associate/Follower/P) vs. Retailer (Captain/Leader/D).....	36
2.7 S6: Supplier (Associate/Follower/D) vs. Retailer (Captain/Leader/P).....	37
2.7.1 Wholesale Price Contract.....	37
2.7.2 Buyback and Markdown-money Contracts.....	37
2.7.3 Comparison: S4 versus S6.....	39
2.8 Structures S7 and S8.....	40
2.9 Structures S9 and S10.....	41
2.10 Conclusions and Future Research.....	41
 Chapter 3: Supply Chain Performance with Power Imbalanced Suppliers.....	 44
3.1 Introduction.....	44
3.2 The Model and Decision Hierarchies.....	49
3.2.1 Supply Chain Structure.....	51
3.3 Equilibrium Analysis of Supply Chain Structures.....	54
3.3.1 Analysis of Structure (S4).....	56
3.4 Analysis of Remaining Structures.....	60
3.4.1 Properties of Retail Prices and Retail Margins.....	60
3.4.2 Wholesale Prices and Order Quantities.....	64
3.5 Supply Chain Performance Analysis.....	65
3.5.1 Supply Chain Structure Dominance.....	66
3.5.2 Supply Chain Profit Allocation.....	70
3.6 Conclusions and Discussions.....	74

Chapter 4: Supply Chain Coordination with Revenue Sharing Contracts when Retailer Sells Store-Brand Products.....	76
4.1 Introduction.....	76
4.2 Model Assumptions.....	80
4.3 Integrated System.....	82
4.4 Revenue-Sharing Contracts under Scenario (S1).....	84
4.4.1 The Case of Retailer Non-Coordinating Decisions (RNCD) under S1.....	85
4.4.2 The Case of Retailer Coordinating Decisions (RCD) under S1.....	88
4.5 Revenue-sharing Contracts under Scenario (S2).....	91
4.5.1 The Case of Retailer Non-Coordinating Decisions (RNCD) under S2.....	92
4.5.2 The Case of Retailer Coordinating Decisions (RCD) under S2.....	95
4.6 Performance Comparison and Decision Strategies.....	97
4.7 Discussions and Conclusions.....	102
References.....	104
Vita.....	114

List of Tables

Table 2.1: Ten Possible Decision Structures.....	23
Table 3.1: Equilibrium Wholesale Prices, Retail Margins, and Retail Prices.....	61
Table 3.2: Equilibrium Stock Quantities and Profits.....	62
Table 4.1: Supplier's Profit under Four Decision Frameworks.....	100

List of Figures

Figure 3.1: Supply Chain Decision Hierarchies.....	52
Figure 3.2: $\pi_{M1}^*/(\pi_{M1}^* + \pi_{M2}^*)$	70
Figure 3.3: π_R^*/π_{SC}^*	71
Figure 3.4: $(\pi_{SC1}^* - \pi_{SC2}^*)/\pi_{SC}^*$	72
Figure 3.5: $\pi_{M1}^*/\pi_{SC1}^* - \pi_{M2}^*/\pi_{SC2}^*$	73
Figure 4.1: Profits in Scenario S1.....	99
Figure 4.2: Supplier Profits.....	101

Chapter 1: Introduction

1.1 Preliminaries

This thesis studies the relationship between the structure of a supply chain and its operational performance. The focus of the thesis is on how structure impacts performance, as well as the use of contracts for enhanced performance of the supply chain. The term “structure” is employed to identify how products flow through the supply chain, how operational decision variables are distributed across the supply chain participants, and each participant’s influence in decision-making for the supply chain, i.e., relative bargaining power of participants.

In any decentralized supply chain consisting of independent firms, if individual decisions turn out to be optimal for the supply chain as a whole, then the supply chain is referred to as being coordinated. In other words, this supply chain achieves the same performance (or efficiency) as an integrated supply chain system in which one firm commits all decisions. However, individual firms may engender inefficient operational behaviors that serve their own best interests; that is, choosing a lower stocking quantity and a higher retail price, contrary to those of an integrated system, to maximize one’s own profits. This leads to the entire supply chain profit becoming inferior to that of the corresponding integrated system. This phenomenon is usually termed “double marginalization” (Spengler 1950), a well-known cause of supply chain inefficiency.

The optimal supply chain performance can be achieved if individual participants agree to contract on a set of executions such that each participant's objective becomes aligned with the supply chain's objective, hence resulting in a coordinated supply chain. Much research has been devoted to identifying and evaluating such contracts to coordinate supply chains, or at least to improve supply chain efficiency. This dissertation research draws on, and contributes to, the same growing stream of literature by emphasizing the impact of supply chain structure on supply chain performance.

A supply chain structure is herein characterized via a three-faceted approach: product flow, decision rights, and bargaining power. As for product flow, if a supplier sells products through an intermediary agent such as a retailer, we refer to it as a traditional indirect-sale structure. Otherwise, if suppliers sell products directly to end customers, it's called a direct-sale structure (Chiang et al. 2003). For example, suppliers may open retail outlets or sell through the internet. A dual structure consisting of both indirect and direct sale practices is also surging in practice due to the rapid deployment of information technologies. Yet another product flow structure is "drop-shipping", where a retailer acquires end customers through either local stores or the internet, but the supplier sends products directly to end customers (Netessine and Rudi 2004). In both direct-sale and drop-shipping, products transfer directly from suppliers to end customers, but the key difference is that the supplier controls the marketing function in a direct-sale structure, whereas in drop-shipping, the retailer engages in the marketing activities.

Considering the decision rights facet, a supply chain structure can be identified by how decision rights are distributed among supply chain participants. Assume a single-supplier-single-retailer supply chain in which a wholesale price is quoted (Cachon 2004).

Two operational decisions must be made in this supply chain: the wholesale price and stocking level, given that the retail price is fixed. If both the wholesale price and stocking level decisions are committed by one firm, it is then an integrated supply chain structure. On the other hand, if the supplier issues the wholesale price and the retailer determines the stocking level, it is termed a retailer-managed inventory (RMI) structure; when the supplier determines the stocking level and the retailer chooses the wholesale price, a vendor-managed inventory (VMI) structure arises.

The third distinguishing feature of a supply chain is the relative bargaining power of each participant. Bargaining power determines how supply chain decisions are initiated and how the supply chain profit is distributed among participants. Assuming a single-supplier-single-retailer supply chain, three alternatives can be identified in this context: the supplier has more bargaining power than the retailer; the retailer has more bargaining power than the supplier; or both firms have equal decision making power.

Using the above three-faceted approach, one may characterize the structure of a given supply chain. However, the focus of this dissertation is limited to indirect-sale supply chains (thus product flow facet is fixed), and therefore, the supply chain is analyzed with respect to relative bargaining power and decision rights of the participants. Consequently, the term supply chain “decision structure” refers to the pair: bargaining power and decision rights. In the sequel, the term supply chain “power structure” is also used synonymously with bargaining power.

In modeling supply chain structure, the existing literature conventionally assumes that a more powerful firm commits decisions first and a less powerful firm issues decisions second. Within the context of Stackelberg game theory (Stackelberg 1934), an

earlier mover (i.e., the first decision maker) is termed the Stackelberg leader, and the second decision maker is termed the Stackelberg follower. On the other hand, in a supply chain where multiple suppliers provide substitutable products to a common retailer, all suppliers are commonly assumed (Choi 1991) to have equal power such that they move simultaneously in decision-making. These standard assumptions, of course, capture certain practices in the real world. However, we can also observe operational behaviors that violate these assumptions. For example, Wal-Mart seeks orders from suppliers in China and Mexico. While Wal-Mart is more powerful than those suppliers, it does not necessarily move first to specify the order quantities. In another instance, a personal-computer manufacturer (e.g. Hewlett Packard) may use central processing units (CPUs) ordered from different suppliers, but the chip supplier Intel usually dominates in that tier (New York Times, 2006). Hence, Intel and other niche suppliers cannot be treated as having equal bargaining power.

In this thesis, these structure-related simplifying assumptions are relaxed. As a result, more general settings can be explored such as the case when a more powerful firm is not making the first decisions, or when suppliers are not sharing the same decision-making power. We believe such settings are important because they not only capture practices that have not been addressed in previous research, but also they can impact supply chain coordination and profit division. Such an exploration can provide useful insights for both academic and practitioner aspects in supply chain management.

1.2 Structure of the Thesis

This dissertation consists of three separate, but related, analytical essays that are titled:

1. “The Role of Decision Structure in Supply Chain Coordination with Stochastic Demand”,
2. “Supply Chain Performance with Power Imbalanced Suppliers”, and
3. “Supply Chain Coordination with Revenue Sharing Contract when Retailer sells Store-Brand Products”.

The research contributions in each chapter are summarized below.

Chapter 2, “The Role of Decision Structure in Supply Chain Coordination with Stochastic Demand”, studies a single period supply chain with one supplier/manufacturer and one retailer. In contrast to the previous literature where one powerful agent assumes both the roles of Stackelberg leader and supply chain captain, we analyze situations in which these two roles in the supply chain are not necessarily aligned with the same agent. We term an agent as a supply chain captain if this agent has more bargaining power than the other agents such that this agent can choose a contract to organize the supply chain in an attempt to capture more profit from the supply chain. However, the stocking decision and pricing decision(s) can be made by either agent. We investigate three forms of contracts for possible supply chain coordination: wholesale-price contract (Lariviere and Porteus 2001), buyback contract (Pasternack 1985), and markdown-money contract (Tsay 2001). A wholesale-price contract indicates that the only term of trade between the supplier and the retailer is the wholesale price, which the retailer uses to order from the supplier. In a buyback contract, the supplier commits to buy back the unsold products

from the retailer subject to certain rules. A markdown-money contract allows the retailer to salvage the unsold products, but the supplier will still issue a full or partial refund to the retailer for those unsold merchandise.

This study shows an optimal coordinating contract is based not only upon the overstock liquidation advantage the supplier/retailer may have, but also upon the existing decision structure of the supply chain. For instance, when the supplier acts as the Stackelberg leader, while the retailer owns the liquidation advantage and plays the role of supply chain captain and determines the stocking level, a wholesale-price contract will easily coordinate the supply chain. Furthermore, this analysis illustrates that the Stackelberg leadership is, however, not always necessary for the supply chain captain to achieve coordination. Moreover, sacrificing the leadership in certain cases allows the captain to achieve more profit. This study verifies the popularity of the wholesale-price contract in practice because it can achieve coordination for several supply chain structures.

Chapter 3, “Supply Chain Performance with Power Imbalanced Suppliers”, studies a supply chain consisting of two suppliers and one retailer. This essay relaxes the standard assumption that the two suppliers have “balanced” power in the supply chain – the assumption that both suppliers move simultaneously and act as either Stackelberg leaders or Stackelberg followers over the retailer, or the assumption that the two suppliers and the retailer all move simultaneously in decision making. This research focuses on situations when the suppliers have an imbalance in their relative power structure such that one supplier can be the Stackelberg leader over the other supplier. This consideration allows investigating a total of eight possible power structures, of which, five have not

been previously studied. Such structures are modeled as either two-stage or three-stage Bertrand Stackelberg hierarchies, or a single-stage non-cooperative game, and important issues such as supply chain performance and stability, and the effects of product substitution (or product competition) are investigated.

In Chapter 3, the following important conclusions are made:

- (1) With increasing product substitution, a multi-supplier-one-retailer supply chain can achieve coordination asymptotically under a simple wholesale pricing mechanism.
- (2) Each supplier's profit consistently decreases when products become more substitutable even if the suppliers dominate the retailer, whereas the retailer benefits from a high degree of substitution regardless of the supply chain power structure.
- (3) A "niche" supplier is not necessarily an underdog in the presence of a larger supplier when seeking to increase the share of its supply chain profit under certain decision power structures.
- (4) In the case of multiple suppliers, "profit percentages" can characterize their relative power differences more accurately than the respective "absolute profits".
- (5) Certain power-imbalanced channels are shown to *dominate* others. Moreover, we show that Manufacturer Stackelberg and Retailer Stackelberg channels are no longer stable structures (as considered in Choi, 1991) when suppliers are able to behave as if they are power imbalanced.

This study can be used to address a number of business strategies in practice. For example, large retailers carry store-brand, along with national-brand substitutable

products in order to avoid suppliers' price collusion and to spur price competition. On the other hand, large suppliers such as those in apparel industries sell through retailers, as well as opening retail outlets to provide the same products because apparel is a highly substitutable product type.

In Chapter 4, "Supply Chain Coordination with Revenue Sharing Contract when Retailer Sells Store-Brand Products", a retailer-dominated supply chain coordination problem is analyzed when the retailer sells store-brand products. The existing literature regarding store brands focuses on identifying and evaluating factors that affect the store-brand success, and the retailers' incentives to choose store-brand strategies. In contrast, this essay studies the retailing supply chain coordination using revenue-sharing contracts when the retailer sells store-brand products. A revenue-sharing contract allows the supplier to share part of the revenue that the retailer generates from carrying the supplier's (outside) products.

In the analysis, the supply chain's decision hierarchy is modeled as a Stackelberg game, and it assumes the retailer gains more bargaining power to move earlier than the outside supplier. Two sets of decision rights (two scenarios) are studied: first, the retailer determines the outside (product) wholesale price in conjunction with her store-brand retail price, and the supplier chooses a retail price for himself; second, the retailer determines the outside retail price along with her own retail price, and the supplier chooses his own wholesale price. The revenue-sharing rate is determined upon negotiation in either case. In each scenario, the outside supplier uses decisions to maximize his own possible profit, but the retailer can either optimize the entire supply

chain for coordination, i.e., *coordinating decisions*, or can optimize her own profit function, i.e., *non-coordinating decisions*.

This essay shows a two-parameter revenue-sharing contract (with both wholesale price and revenue-sharing rate) outperforms both the wholesale-price contract and one-parameter revenue-sharing contract (specified with only a revenue sharing rate) in supply chain coordination due to its flexibility in profit division. Retailer's coordinating decisions lower the market share and profitability of the store-brand products. However, the two-parameter revenue sharing contract allows the retailer to achieve more profit from the entire supply chain.

It is also demonstrated that when the supplier determines his retail price, and when the retailer can specify both the wholesale-price and revenue-sharing rate, the retailer's coordinating decisions lead to Pareto improvement in contrast to her non-coordinating decisions. However, if the revenue-sharing rate is fixed, the retailer will make decisions to optimize her own profits instead. Moreover, when the supplier specifies his wholesale price, a non-coordinating wholesale-price contract is the optimal choice for the retailer. .

1.3 Scope and Limitations

This thesis offers theoretical studies on the supply chain structure and its impact on the performance and the use of contracts in the supply chain. We provide closed-form results in each essay so that insights can be developed for the problem under investigation. The suggestions so-made can be utilized for enhancing supply chain performance in practice.

This thesis has relaxed several assumptions that are widely used in the literature. However, these analyses are contingent on certain limiting assumptions. For instance, throughout this thesis, information is assumed symmetric across the supply chain; although it is common in practice that asymmetric information exists in a supply chain. This aspect is left as a subject for future research and is not within the scope of this dissertation.

A second assumption upon which the results are based is the type of demand functions. In the second and third essays, analyses are conducted based on linear deterministic demand functions that account for product substitution effects. Such demand functions are widely used in the literature and have contributed immensely to generate fruitful insights in numerous cases. Extensions and generalizations to other forms of demand functions are certainly useful avenues for research beyond this dissertation.

Chapter 2:

The Role of Decision Structure in Supply Chain Coordination with Stochastic Demand

2.1 Introduction

In a decentralized supply chain with one supplier and one retailer, if both agents seek to optimize their own expected profits, a sub-optimal solution will be reached. This phenomenon is termed double marginalization (Spengler 1950), a well known cause of supply chain inefficiency. That is, the profit of a decentralized supply chain is less than that of an integrated supply chain due to a lower stock quantity or a higher retail price if the retail price is endogenously determined. For example, Granot and Yin (2005) show that with a buyback contract, and with a uniformly distributed demand, uncoordinated supply chain efficiency is in the order of only 75%. Use of other forms of demand may lead to even worse theoretical efficiency.

Due to the effect of double marginalization, it is desirable to design proper contract forms for the decentralized supply chain to improve its efficiency. A well designed contract can lead to an agent's individual decision being even optimal as a whole for the supply chain. In this case, there will be no double marginalization, that is, the supply chain is coordinated. Contracts that provide coordination have been vastly studied in the literature. For instance, see return policies (Pasternack 1985, Kandel 1996, Tsay 2001), revenue sharing (Cachon and Lariviere 2002), quantity discount (Jeuland and

Shugan 1983, Weng 1995), quantity flexibility (Tsay 1999), sales rebate (Taylor 2002), options contract (Barnes-Schuster et al 2002), price discount or “bill back” contracts (Bernstein and Federgruen 2005). Also, see Cachon (2003), Lariviere (1999), and Sahin and Robinson (2002) for excellent reviews.

In this chapter, the focus is on the problem of supply chain coordination under contracts. However, more attention is devoted to the presence of return policies. Return policies have been studied quite extensively in the literature; a comprehensive review of return policies and their effects under different settings is given below.

A return policy is a commitment by the supplier/manufacturer to refund the unsold merchandise to the retailer. Return policies can stimulate retailers to increase the size of orders because the supplier shares the overstock risk. Meanwhile, return policies can benefit suppliers as well. Given that there are substitutable products in the market, the unsatisfied demand will be lost if the retailer is under-stocked. Furthermore, when the product is new to the market, the retailer has less information about demand than the supplier and the retailer may become conservative in ordering. Return policies can eliminate any hesitation in setting a correct stocking quantity. Padmanabhan and Png (1995) discuss other motivations for return policies, for instance, protecting the brand image by preventing the retailer from selling stale products or discounting unsold goods, supporting end-user return policy, etc. Return policies are widely used in industries such as publishing, pre-recorded music, computer hardware and software, automobile parts, and apparel.

One general format of return policy implemented in practice is the “buyback contract”. Under this contract structure, suppliers commit to buy back the unsold products

from retailers subject to certain rules. Review of the literature shows that there exist different forms of buyback contracts. With regard to quantity limitations in return, there exist partial-return or full-return contracts (Pasternack 1985). With partial return, the retailer can return either up to a certain percentage of the ordered quantities, or the quantity ordered in excess of a predefined minimum order quantity, referred to as “percent rebate policy” and “quantity rebate policy”, respectively, see Webster and Weng (2000). On the other hand, in a full return contract, the supplier accepts all unsold goods with full or partial refund per unit returned. The latter contracts are well addressed in the literature, see Cachon (2003), Emmons and Gilbert (1998), Granot and Yin (2005), Kandel (1996), Lariviere (1999), Padmanabhan and Png (1997), Pasternack (1985), and Tsay (2001), for instance.

Consider a decentralized supply chain with two risk-neutral agents, the supplier and the retailer. Assume that information is symmetric across the supply chain. Suppose the retailer faces a price insensitive stochastic demand. Then, the supply chain participants’ decision problem can be formulated as a newsvendor model. At the beginning of a single selling season, the supplier acts first as a Stackelberg leader to issue a buyback contract and the retailer follows with a stocking decision. Under this setting, Pasternack (1985) shows that a full-return-partial-refund buyback contract can coordinate the supply chain. Furthermore, the coordinating contract in this case has the property that increasing the buyback price yields a higher wholesale price, which thus benefits the supplier rather than the retailer.

Using the same setting as Pasternack, Kandel (1996) examines the problem from an economic perspective. In particular, Kandel assumes both agents optimize their own

expected profits and addresses how agents' bargaining power influences contracting decisions. Kandel shows that the supplier prefers a "consignment contract" in which both the wholesale price and buyback price equal to the retail price if the supplier has more bargaining power. In contrast, when the retailer has more bargaining power, she favors a non-return (wholesale price only) contract.

Krishnan, Kapuscinski and Butz (2004) introduce retail promotional effort into Pasternack's setting, which is independent of the demand distribution. They assume the retailer stocks before observing the market demand, but she exerts promotional effort after observing the demand. If supply chain agents individually optimize their decisions, then the full-return buyback is better for the retailer in contrast to a non-return policy; however, any advantage to the supplier is ambiguous. Two buyback variants are introduced for coordination and Pareto improvement: effort-sharing buyback and buyback with sales rebate. The "quantity rebate policy" (one form of partial return as termed in Webster and Weng, 2000) can coordinate the supply chain, but if this results in any profit advantages to either agent over the uncoordinated supply chain remain unclear.

Dealing mainly with sales rebates, Taylor (2002) shows the "buyback with sales rebate" can coordinate the supply chain when exercising the retail promotional effort before the exact demand is revealed. One key finding is that buyback alone cannot coordinate the supply chain, regardless of whether the demand distribution depends on the effort – see, Cachon (2002) for the analysis when the demand distribution is dependent on the effort.

If the assumption of price independence of demand is relaxed from the Pasternack (1985) model, a buyback contract no longer coordinates the supply chain (Lariviere 1999,

Bernstein and Federgruen 2005, and Cachon 2003). However, the buyback contract may still be better for both agents in contrast to a wholesale-price contract (Emmons and Gilbert, 1998). Granot and Yin (2005) demonstrate that this attribute depends on the demand properties. When the average demand function is nonlinear, e.g., a negative power function, a buyback contract may no longer be superior to a wholesale-price contract from the supplier's perspective.

In the preceding models, information symmetry is assumed for supply chain agents. In contrast, Ha (2001) investigates a situation when the retailer incurs a marginal cost, which is private, for each product it orders. In contrast to the coordinated situation that occurs when information is symmetric, coordination is un-reachable, and a higher retail price and lower stocking quantity will be observed in this case. Lariviere (2002) studies the case where the retailer is capable of gaining more accurate demand information through costly forecasting, and compares the performance of a buyback contract and a quantity flexibility contract, which is a "percent rebate policy" with a full refund. Sahin and Robinson (2002) offer an excellent review on physical flow coordination in terms of the degree of information sharing.

In all of the preceding work, buyback contracts are studied within the framework of risk neutrality. However, Gan, Sethi and Yan (2004) show that buybacks combined with a "side payment" can coordinate the supply chain when both agents are risk averse. Tsay (2002) adopts Padmanabhan and Png (1997)'s demand model to analyze how risk sensitivity affects agents' decisions and how a return policy alters those dynamics. In such a case, ignoring risk sensitivity can dramatically affect supplier's profit.

In the previous work, stochastic demand is investigated within a newsvendor model to analyze supply chain contracts. However, in Padmanabhan and Png (1997), and Butz (1997), uncertain demand is modeled by two linear demand functions within a binomial distribution with fixed probabilities. The retailer stocks before knowing which demand curve is realized, but the retail price is set after the demand function is observed. Padmanabhan and Png show that when demand is uncertain, a buyback contract increases the supplier profit by attenuating retail price competition if demand is low or intensifying competition if demand is high, given that both agents are self-interested. Unlike Padmanabhan and Png (1997), in which the retailer's stocking quantity is assumed to be lower than the high demand and a full-return-full-refund policy is employed, Butz (1997) assumes a full-return-partial-refund policy, and the retailer is persuaded to order the same quantity as in the case of high demand. In this context, the retailer has the intention to lower the retail price to sell more than the system-wide optimized quantity.

Marvel and Peck (1995) model the demand uncertainty in two parts: customer arrivals uncertainty and uncertainty over consumers' valuation of the products. The uncertainty in customer arrivals induces the supplier to offer a buyback contract, whereas valuation uncertainty results in the retailer setting a higher retail price. This model partially explains why suppliers can be conservative in offering return mechanisms.

Another form of return policy contracts is referred to as "markdown-money" (Tsay 2001). Unlike buyback contracts, the supplier gives up the salvage opportunity to the retailer but still compensates the retailer with partial credit for each unsold unit. This contract format applies to products whose unit production cost is low, and thus, salvage value is trivial and the supplier can avoid product-return related costs, e.g. transportation

cost and storage cost. Tsay concludes that the specific format of this return policy is influenced by the salvage advantage. That is, if the supplier holds the salvage advantage, coordination can be reached by a buyback contract; otherwise, a markdown-money contract will coordinate the supply chain.

All preceding literature is based on one conventional assumption: the agent that holds the negotiation power moves as the Stackelberg leader in the decision hierarchy. This assumption results from a fact that in a Stackelberg game hierarchy, first-moving agent has the advantage to choose the best action set if it can perfectly anticipate the second-moving agent's response. However, the main concern of each agent is to achieve as much profit as possible from the supply chain, but it must be noted that the Stackelberg leadership position cannot always guarantee more profit. For example, Gal-Or (1985) and Dowrick (1986) prove that if the profit functions are upwards sloping, the Stackelberg follower will achieve more profit when each agent intends to maximize his own profit; Lariviere and Porteus (2001) conclude that the Stackelberg follower may capture more profit than the Stackelberg leader does using a simple wholesale-price contract.

In this chapter, we assume that a powerful agent need not necessarily be a Stackelberg leader; furthermore, the stocking decision and the pricing decision(s) of a contract can be set by either agent. These relaxations allow us to consider ten possible structures, some of which have been addressed in the literature; however, we provide a more in-depth analysis. For example, Kandel (1996) studies the scenario that the retailer holds the negotiation power and the pricing right, and each agent intends to optimize its

own profit. We illustrate under this scenario how coordination can be reached using contracts.

We study a newsvendor model and investigate three contracts for coordination: wholesale-price contract, buyback contract, and markdown-money contract. Our study shows that a supply chain-coordinating contract depends not only upon the salvage advantage that the supplier/retailer may have, but also upon the existing decision structure. For example, Tsay (2001) identifies that when the retailer has the salvage advantage, only a markdown-money contract can coordinate the supply chain. We show that it is true when the supplier holds the negotiation power and functions as the Stackelberg leader, but in other cases, the markdown-money contract is outperformed by a wholesale-price contract with respect to coordination. Meanwhile, a Stackelberg leadership position is not always necessary for a powerful agent in achieving coordination; moreover, sacrificing the leadership in certain cases allows the agent to achieve more profit. For example, a retailer that has the negotiation power can be better-off acting as a Stackelberg follower in choosing the stocking level, instead of being a Stackelberg leader. Managerial insights are also discussed in the sequel.

The remainder of the chapter is organized as follows. Section 2.2 contains the model assumptions, and illustrations of the supply chain decision structure by clarifying the difference between the Stackelberg leader/follower positions and the bargaining power positions in a supply chain. Section 2.3 provides an integrated supply chain model as the benchmark. Section 2.4 investigates three contract formats when the supplier serves as both the supply chain captain and the Stackelberg leader. Sections 2.5-2.9

discuss which contract(s) should be employed for coordination under various decision structures. Conclusions are in Section 2.10.

2.2 Model Assumptions and Supply Chain Decision Structures

2.2.1 Model Assumptions

We consider a supply chain consisting of one supplier and one retailer in a single period. All decision makers are risk neutral and information is symmetric within the supply chain. The supply chain faces a stochastic demand; thus, a newsvendor model can be employed to determine the stocking decision before agents observe the demand. Furthermore, the retail price is exogenously determined before the selling season and it will remain constant throughout the selling season. We further assume that the production cost is the only cost faced by the supplier. The retailer does not suffer any cost except paying a wholesale price per unit to the supplier. The supplier has no capacity limitation in determining the stock size. At the end of the selling season, either the supplier will buy back and salvage the unsold products, or the retailer will salvage the unsold items per contract terms if such exist. Either party can have the unsold-product salvage advantage, and neither one suffers a loss of goodwill due to possible unsatisfied customer demand. We use the following notations throughout the chapter.

π_R : retailer's expected profit;

π_M : supplier/manufacturer's expected profit;

$\pi_{SC} = \pi_M + \pi_R$: supply chain expected profit;

π_I : integrated supply chain expected profit;

p : retail price per unit;
 w : wholesale price per unit;
 c : supplier production cost per unit;
 s_M : salvage value per unit from the supplier;
 s_R : salvage value per unit from the retailer;
 $s = \max\{s_M, s_R\}$;
 b : buyback price per unit;
 m : markdown-money price per unit;
 Q : stocking quantity;
 x : stochastic market demand (r.v. and $x \geq 0$);
 $f(x)$: demand p.d.f. function , $f(x) \geq 0$;
 $F(x)$: demand c.d.f. function;
 $E[.]$: mathematical expectation w.r.t $F(x)$.

To avoid any arbitrage opportunity to any agent, we have the following parameter constraints: $c \leq w \leq p$ and $0 < s_M$ (or s_R) $\leq c \leq b \leq p$.

2.2.2 Supply Chain Decision Structures

In a traditional supply chain structure, the supplier assumes the wholesale-pricing right, while the retailer specifies the stocking size whilst retaining the inventory. Vendor-Managed Inventory (VMI) represents another structure in which the supplier is endowed with stocking decision rights, but the retailer still owns the inventory (see, e.g., Bernstein et al. 2005). The recent advances in information technology has lead to two more supply chain strategies: direct sales and drop-shipping practices. In direct sales practice, a

supplier overlooks the intermediary retailer and sells products directly to the end customers. Therefore, the supplier specifies the stocking size, owns the inventory and overstock risk. However, the choice of either a traditional structure, a direct sales structure, or a dual structure that combines both the traditional and direct sales practices may depend on the characteristics of the competitive circumstances such as customer acceptance of the products, see Chiang et al (2003), for instance.

In drop-shipping practice, the retailer assumes the marketing function to acquire customers through either the internet or local retail stores; the supplier is responsible for holding inventories and transferring products directly to the end customers. The supplier in general is associated with the stocking rights and owns the overstock risk, but it may not have the negotiation power in comparison to the retailer. See Netessine and Rudi (2004) for in-depth discussions.

Our supply chain decision structure is mainly defined based on the traditional supply chain features: the retailer owns the inventories; the overstock risk can be associated with either party, or both. In contrast, the decision structure incorporates a flexibility that, as noted earlier, each supply chain participant can specify the stocking decision or pricing decision, and either one can move as a Stackelberg leader regardless of who carries the bargaining power.

For the ease of exposition, we call the more powerful agent, the *supply chain captain*, and the other, the *supply chain associate*. At the beginning of a selling season,

the supply chain captain¹ will choose a contract format to organize the supply chain; the supply chain associate will accept the contract type and participate in the supply chain if such contract and relevant terms assure enough profit. Since coordination generates the same total supply chain profit as the integrated system, and since the captain is capable of achieving more profit than the associate does from the supply chain, the captain thus has the incentive to seek coordination. In contrast, the supply chain associate will always try to maximize his own profit in the decision making process.

Stocking and pricing parameters are present in all three contract formats discussed here, namely, wholesale-price, buyback, and markdown-money contracts. A given agent may determine one or more (or none) of the above parameters in a decentralized supply chain. After the captain chooses a contract type, the contracting terms are determined over time, and thus, the contracting process can be modeled as a Stackelberg game.

Let H be a contract format chosen by the captain. Let S_H be the subset of contract terms (parameters) determined by the Stackelberg leader under the contract format H , and $\bar{S}_H$ be the remaining subset of contract terms chosen by the Stackelberg follower. Furthermore, let the index 1 refer to the captain and 2 refer to the associate. The supply chain decision structure can then be modeled as the following three-stage dynamic decision process:

Captain (1) determines $H \rightarrow$ Leader (1 or 2) determines $S_H \rightarrow$ Follower (2 or 1) determines $\bar{S}_H$.

¹ In the remainder of this essay, we may use “captain” and “associate” to refer to the supply chain captain and supply chain associate, while “leader” and “follower” are used to refer to the Stackelberg leader and Stackelberg follower, respectively.

Using **P** to represent the contract's pricing term and **D** to represent the stocking term, we list ten possible dynamics in Table 2.1 for the supply chain decision structure, where an empty set ($\emptyset$) indicates the case when an agent is not making decisions.

The first two structures S1 and S2 in Table 2.1 represent the case of an integrated supply chain where either the supplier or the retailer makes both the stocking and the pricing decisions. However, the remaining eight structures are concerned with a decentralized supply chain. We investigate how these decision structures influence the choice of contracts for supply chain coordination in the remainder of this chapter.

2.3 Integrated Supply Chains (S1 & S2)

In an integrated supply chain, one agent makes all decisions for the entire supply chain, whereas in a decentralized supply chain, each agent is free to make its own decision. Thus, an integrated situation leads to the highest total profits possible in a supply chain, and we use the integrated supply chain as a benchmark to measure the performance of decentralized supply chains.

Table 2.1: Ten Possible Decision Structures

Structure	Captain	Leader	Follower
S1	Supplier	Supplier (P, D)	Retailer ($\emptyset$)
S2	Retailer	Retailer (P, D)	Supplier ($\emptyset$)
S3	Supplier	Supplier (P)	Retailer (D)
S4	Retailer	Supplier (P)	Retailer (D)
S5	Retailer	Retailer (D)	Supplier (P)
S6	Retailer	Retailer (P)	Supplier (D)
S7	Supplier	Retailer (P)	Supplier (D)
S8	Supplier	Supplier (D)	Retailer (P)
S9	Retailer	Supplier (D)	Retailer (P)
S10	Supplier	Retailer (D)	Supplier (P)

The integrated supply chain's total expected profit:

$$\pi_I = pE[\min[x, Q]] + sE[\max[0, Q - x]] - cQ. \quad (2.3.1)$$

The first term in the right hand side of (2.3.1) corresponds to the expected revenue; the second term corresponds to the expected salvage value from the unsold products; and the third is the total production cost. Upon simplification,

$$\pi_I = (p - c)Q - (p - s) \int_0^Q F(x) dx. \quad (2.3.2)$$

Since π_I is concave in Q , setting $d\pi_I/dQ = (p - c) - (p - s)F(Q) = 0$ leads to

$$Q_I^* = F^{-1}\left(\frac{p - c}{p - s}\right), \quad (2.3.3)$$

and Q_I^* is stock quantity that maximizes π_I . With a given retail price, the maximized expected supply chain profit is then,

$$\pi_I^* = (p - c)F^{-1}\left(\frac{p - c}{p - s}\right) - (p - s) \int_0^{F^{-1}(\frac{p - c}{p - s})} F(x) dx. \quad (2.3.4)$$

Both the optimized stocking quantity and supply chain profit increase in the salvage value s , the decision maker will thus assign the agent having the salvage advantage (not necessarily himself) the salvaging rights of the unsold products.

In any decentralized supply chain with each partner trying to maximize its own profit, we have $\pi_{SC}^* \leq \pi_I^*$, where π_{SC}^* is the maximized profit of a decentralized supply chain. However, if a contract can be designed such that it enables the agent having the salvage advantage to salvage the unsold products, and Q_I^* turns out to be the order size of the agent who determines Q , then $\pi_{SC}^* = \pi_I^*$ can be attained, i.e., the supply chain can be

coordinated. We investigate how salvage advantage affects the choice of contracts for coordination in each of the decentralized supply chain decision structure in the following sections.

2.4 S3: Supplier (Captain/Leader/P) vs. Retailer (Associate/Follower/D)

In S3, the supplier is the supply chain captain who determines the contract type, as well as the Stackelberg leader in determining $\mathbf{P}$, one subset of contract parameters; and the retailer (associate), plays the role of Stackelberg follower to choose the stocking size. We investigate three contract types for coordination: the wholesale-price contract, buyback contract, and markdown-money contract.

2.4.1 Wholesale Price Contract

Wholesale-price contracts have seen numerous applications in practice and they have been extensively explored in the literature, see Lariviere and Porteus (2001), and Cachon (2004) for recent work in this regard. Under a wholesale-price contract, the contract's pricing term $\mathbf{P}$ refers to the wholesale price w . The two agents' expected profit functions are,

$$\pi_M = (w - c)Q \quad (2.4.1)$$

$$\pi_R = (p - w)Q - (p - s_R)E[Q - x]^+ = (p - w)Q - (p - s_R) \int_0^Q F(x)dx. \quad (2.4.2)$$

The supply chain expected profit is then

$$\pi_{SC} = (p - c)Q - (p - s_R)E[Q - x]^+ = (p - c)Q - (p - s_R) \int_0^Q F(x)dx. \quad (2.4.3)$$

Under S3, using backward induction, we first calculate the Stackelberg follower (retailer) stocking quantity that maximizes its own expected profit. Given a retail price and a wholesale price, the retailer's profit function (2.4.2) is concave and the unique optimum order size:

$$Q^* = F^{-1}\left(\frac{p-w}{p-s_R}\right). \quad (2.4.4)$$

The supplier has two options in choosing the wholesale price: either optimize the total supply chain profit function, or optimize its own profit function. With former option, substituting (2.4.4) in (2.4.3), solve

$$\max_w \pi_{SC} = (p-c)F^{-1}\left(\frac{p-w}{p-s_R}\right) - (p-s_R)\int_0^{F^{-1}\left(\frac{p-w}{p-s_R}\right)} F(x)dx. \quad (2.4.5)$$

The first order optimality condition of (2.4.5) yields $w^* = c$, and the second order condition reveals that $w^* = c$ solves (2.4.5). However, the supplier achieves no profit when $w^* = c$. Furthermore, because Q^* in (2.4.4) increases in s , substituting $w^* = c$ in (2.4.4), we have $Q^* = F^{-1}((p-c)/(p-s_R)) \leq Q_I^* = F^{-1}((p-c)/(p-s))$ and $\pi_{SC}^* \leq \pi_I^*$ due to $s_R \leq s_M$. This result is due to the fact that the retailer is responsible for salvaging the unsold products under a wholesale-price contract whereas it does not have the salvage advantage ($s_R \leq s_M$). Therefore, the supplier has to set $w^* = c$ when $s_R = s$, or $w^* < c$ if $s_R < s_M$ to ensure coordination. That is, the supplier would need to loose money in order to maintain the performance of the supply chain.

On the other hand, the supplier may choose a wholesale price to maximize its own possible profit. Because the optimized wholesale price in this case is subject to the

inversion of the demand distribution, and a closed-form inversion of the c.d.f. is not always available for general distributions, we assume a uniformly distributed demand with $f(x) = 1/2\beta$, where $x \in [0, 2\beta]$ and $\beta > 0$. In this case, the supplier's optimized wholesale price is $w^* = (p + c)/2 > c$, which leads to the expected profit $\pi_M^* = \beta(p - c)^2 / (2(p - s_R))$; the retailer orders $\beta(p - c)/(p - s_R)$ and achieves $\pi_R^* = \beta(p - c)^2 / (4(p - s_R))$; and the total supply chain profit is $3\beta(p - c)^2 / (4(p - s_R))$. For benchmarking, the relevant coordinating order size is $2\beta(p - c)/(p - s_R)$ and supply chain profit is $\beta(p - c)^2 / (p - s_R)$ (given that $s_R \geq s_M$). Consequently, the supplier benefits by optimizing its own profit function even though the retailer orders 50% less than the coordinating order size; and the supply chain total profit is 25% less than the case of the coordinated supply chain.

2.4.2 Buyback Contract

The buyback contract represents a major form of return policies, where the retailer can return the unsold products to the supplier and claim refund per item. Here we consider a full-return-partial-refund buyback contract. Our analysis follows Pasternack (1985), the first work discussing coordination using buyback contracts. In this case,

$$\pi_M = (w - c)Q - (b - s_M) E[Q - x]^+ = (w - c)Q - (b - s_M) \int_0^Q F(x) dx \quad (2.4.6)$$

$$\pi_R = (p - w)Q - (p - b)E[Q - x]^+ = (p - w)Q - (p - b) \int_0^Q F(x) dx, \quad (2.4.7)$$

and the entire supply chain's expected profit

$$\pi_{SC} = \pi_M + \pi_R = (p - c)Q - (p - s_M) \int_0^Q F(x) dx. \quad (2.4.8)$$

The retailer's optimized order quantity:

$$Q^* = F^{-1}\left(\frac{p-w}{p-b}\right). \quad (2.4.9)$$

Substituting (2.4.9) in (2.4.8) and taking the first order derivative w.r.t. w , and letting $d\pi_{SC}/dw=0$, we have

$$w^* = \frac{p(c-s_M)+b(p-c)}{p-s_M}. \quad (2.4.10)$$

The second order condition $d^2\pi_{SC}/dw^2 < 0$. Therefore, if the supplier chooses a wholesale price of (2.4.10), the entire supply chain has the largest possible profit. Note that the optimized wholesale price is independent of the demand distribution and it increases in the buyback price.

The supply chain profit function (2.4.8) is not jointly concave in (w, b) when the supplier determines the prices, which allows the supply chain to be optimized with a series of solutions of (w, b) (also see Lariviere 1998); namely, the coordinated supply chain profit can be smoothly divided between the two agents by changing the buyback price. The determination of the buyback price depends on the bargaining power between the two agents.

Substituting (2.4.10) in (2.4.9) leads to $Q^* = F^{-1}((p-c)/(p-s_M))$. The supply chain is coordinated when the supplier has the salvage advantage ($s_M = s$). Using w^* see (2.4.10), in (2.4.6) and (2.4.7),

$$\begin{aligned}
\pi_M^* &= \frac{(p-c)(b-s_M)}{p-s_M} F^{-1}\left(\frac{p-c}{p-s_M}\right) - (b-s_M) \int_0^{F^{-1}\left(\frac{p-c}{p-s_M}\right)} F(x) dx \\
&= \frac{b-s_M}{p-s_M} \left\{ (p-c) F^{-1}\left(\frac{p-c}{p-s_M}\right) - (p-s_M) \int_0^{F^{-1}\left(\frac{p-c}{p-s_M}\right)} F(x) dx \right\} \\
&= \frac{b-s_M}{p-s_M} \pi_{SC}^*
\end{aligned} \tag{2.4.11}$$

$$\begin{aligned}
\pi_R^* &= \frac{(p-c)(p-b)}{p-s_M} F^{-1}\left(\frac{p-c}{p-s_M}\right) - (p-b) \int_0^{F^{-1}\left(\frac{p-c}{p-s_M}\right)} F(x) dx \\
&= \frac{p-b}{p-s_M} \left\{ (p-c) F^{-1}\left(\frac{p-c}{p-s_M}\right) - (p-s_M) \int_0^{F^{-1}\left(\frac{p-c}{p-s_M}\right)} F(x) dx \right\}, \\
&= \frac{p-b}{p-s_M} \pi_{SC}^*
\end{aligned} \tag{2.4.12}$$

where $\pi_{SC}^* = (p-c) F^{-1}\left(\frac{p-c}{p-s_M}\right) - (p-s_M) \int_0^{F^{-1}\left(\frac{p-c}{p-s_M}\right)} F(x) dx$.

It is clear that the supplier's expected profit increases, while the retailer's expected profit decreases in the buyback price.

Similar to Bernstein and Federgruen (2005), since $0 < s_M \leq b \leq p$, set

$$b = s_M + \alpha(p - s_M), \tag{2.4.13}$$

where $\alpha \in [0, 1]$. Substituting (2.4.13) back into (2.4.10)-(2.4.12) leads to

$$w^* = c + \alpha(p - c), \quad \pi_M^* = \alpha \pi_{SC}^*, \quad \pi_R^* = (1 - \alpha) \pi_{SC}^*. \tag{2.4.14}$$

Proposition 2.4.1: *Under a buyback contract:*

(a) *If $s_M \geq s_R$, the buyback contract coordinates the supply chain; when $s_R > s_M$, the*

supply chain cannot be coordinated with a buyback contract.

(b) *Improving the buyback price increases the wholesale price, and thus increases the supplier's profit at the expense of the retailer's profitability.*

(c) *The optimal wholesale price is independent of the demand distribution.*

In the case when the retailer has the salvage advantage ($s_R \geq s_M$), the buyback contract cannot coordinate the supply chain since $Q^* = F^{-1}((p-c)/(p-s_M)) < Q_I^*$, even if the supplier optimizes the entire supply chain.

Intuitively, a higher buyback price allows more profit to the retailer in that the supplier compensates more to the retailer for the unsold products. However, a higher buyback price corresponds to a higher α according to (2.4.13), and the retailer has to pay a higher wholesale price to the supplier, which allows the supplier to share a higher percentage of the supply chain profit at the expense of the retailer, see (2.4.14).

Due to the property (c) in Proposition 2.4.1, the supplier can contract with multiple independent retailers using a uniform buyback contract and save the cost for negotiating and managing terms of contracts with each retailer. More importantly, such a uniform contract policy is within the Robinson-Patman Act², a Federal Trade Commission (FTC) act that prohibits the seller from using discriminatory prices on buyers at the same functional level.

Comment: Intuitively, the buyback price can be as low as s_R when $s_M > s_R$, but the supplier will incur a negative profit if the buyback price is less than s_M . To see this, let

$b = s_R + \alpha(p - s_R)$, then according to (2.4.10)-(2.4.12),

$w^* = p - (1 - \alpha)((p - s_R)(p - c)/(p - s_M))$, $\pi_M^* = (1 - (1 - \alpha)(p - s_R)/(p - s_M))\pi_{SC}^*$, and

$\pi_R^* = ((1 - \alpha)(p - s_R)/(p - s_M))\pi_{SC}^*$.

² From www.ftc.gov

That is, when $s_R \leq b < s_M$, we have $w^* < c$, $\pi_M^* < 0$, and $\pi_R^* > \pi_{SC}^*$, the supplier achieves a negative profit.

To summarize, $\pi_I^* = \pi_{BSC}^* \geq \pi_{WSC}^*$ in S3 if $s_M = s$, where π_{BSC}^* and π_{WSC}^* represent the expected supply chain profits when the supplier optimizes the entire supply chain using the buyback contract and wholesale-price contract, respectively. The supplier can use the buyback contract for coordination when $s_M \geq s_R$. Alternatively, $\pi_I^* = \pi_{WSC}^* > \pi_{BSC}^*$ when $s_R \geq s_M$, while the supplier has no incentive for coordination without any make-up arrangement such as a side payment. A markdown-money contract overcomes this shortcoming.

2.4.3 Markdown-money Contract

The markdown-money contract is a form of return policy, see Tsay (2001), where the supplier allows the retailer to salvage the unsold products and keep the salvage values. Furthermore, the supplier pays a markdown price for each unsold unit to the retailer. Markdown-money contracts appear in situations such as when retailer has the salvage advantage. For instance, in the publishing industry, unsold products may have little salvage value while the overstock processing and transportation costs remain relatively high. In such a case, the retailer should salvage the unsold items instead of returning them to the supplier. The supplier only requests the retailer to tear off the front pages or other identifications of the unsold items to claim markdown credits.

The markdown-money contract has the following profit functions:

$$\pi_M = (w - c)Q - mE[Q - x]^+ = (w - c)Q - m \int_0^Q F(x)dx \quad (2.4.15)$$

$$\pi_R = (p - w)Q - (p - (m + s_R))E[Q - x]^+ = (p - w)Q - (p - (m + s_R)) \int_0^Q F(x) dx \quad (2.4.16)$$

$$\pi_{SC} = (p - c)Q - (p - s_R) \int_0^Q F(x) dx. \quad (2.4.17)$$

Again, the retailer's profit function is concave in Q and it can be shown that

$$Q^* = F^{-1}\left(\frac{p - w}{p - (m + s_R)}\right). \quad (2.4.18)$$

Substituting (2.4.18) in (2.4.17) and with a given markdown price m ,

$$\begin{aligned} \frac{d\pi_{SC}}{dw} &= \frac{-(p - c)}{[p - (m + s_R)] f(x_0)} + \frac{(p - s_R)(p - w)}{[p - (m + s_R)]^2 f(x_0)} = 0 \\ \Rightarrow w^* &= \frac{c(p - s_R) + m(p - c)}{p - s_R}. \end{aligned} \quad (2.4.19)$$

The second order condition indicates w^* in (2.4.19) leads to a global maximum of (2.4.17). Substituting w^* into (2.4.18),

$$Q^* = F^{-1}\left(\frac{p - c}{p - s_R}\right). \quad (2.4.20)$$

Furthermore, substituting (2.4.19) and (2.4.20) in (2.4.15) and (2.4.16),

$$\pi_M^* = \frac{m(p - c)}{p - s_R} F^{-1}\left(\frac{p - c}{p - s_R}\right) - m \int_0^{F^{-1}(\frac{p - c}{p - s_R})} F(x) dx = \frac{m}{p - s_R} \pi_{SC}^* \quad (2.4.21)$$

$$\begin{aligned} \pi_R^* &= \frac{(p - c)(p - (m + s_R))}{p - s_R} F^{-1}\left(\frac{p - c}{p - s_R}\right) - (p - (m + s_R)) \int_0^{F^{-1}(\frac{p - c}{p - s_R})} F(x) dx \\ &= \frac{p - (m + s_R)}{p - s_R} \pi_{SC}^*, \end{aligned} \quad (2.4.22)$$

where $\pi_{SC}^* = (p - c)F^{-1}\left(\frac{p - c}{p - s_R}\right) - (p - s_R) \int_0^{F^{-1}(\frac{p - c}{p - s_R})} F(x) dx$.

To avoid any retailer arbitrage, the markdown price should be no larger than $(p - s_R)$. Let $m = \alpha(p - s_R)$, where $0 \leq \alpha \leq 1$. Then,

$$w^* = c + \alpha(p - c), \pi_M^* = \alpha\pi_{MSC}^*, \text{ and } \pi_R^* = (1 - \alpha)\pi_{MSC}^*. \quad (2.4.23)$$

When $\alpha = 0$, $m = 0$ and $w = c$, and the markdown-money contract is equivalent to a wholesale-price contract in which case the supplier achieves no profit.

Except for salvaging unsold products on the retailer side, the markdown-money contract functions the same way as a buyback contract as shown in (2.4.14) and (2.4.23). Consequently, the following conclusions can be similarly achieved under a markdown-money contract.

Proposition 2.4.2: *Under a markdown-money contract,*

(a) *When $s_R = s$, a markdown-money contract coordinates the supply chain.*

Markdown price can be used to allocate the supply chain profit between the supplier and the retailer at any desirable proportion.

(b) *Increasing the markdown-money price increases the supplier's profit at the expense of the retailer's profitability.*

(c) *The optimum wholesale price is independent of the demand distribution.*

Overall, we have the following conclusions for S3.

Proposition 2.4.3: *When the supplier has the salvage advantage ($s_M \geq s_R$), the buyback contract coordinates the supply chain; if the retailer has the salvage advantage ($s_R \geq s_M$), the supplier will use a markdown-money contract for coordination. The wholesale-price contract shall not be used for coordination in S3.*

2.5 S4: Supplier (Associate/Leader/P) vs. Retailer (Captain/Follower/D)

The preceding section investigated which contract can coordinate the supply chain when the supplier serves as both the supply chain captain and the Stackelberg leader. S4 has the same Stackelberg game hierarchy as in S3 except that the retailer acts as the captain. Before the selling season, the retailer chooses a contract type, the supplier is then allowed to announce the price(s) first, and the retailer follows with a stocking decision.

2.5.1 Wholesale Price Contract

Assuming that the retailer adopts a wholesale-price contract, S4 has the same profit functions as those of the S3 under a wholesale-price contract. (In fact, in all three types of contracts under analysis, the relevant profit functions remain unchanged among all eight decentralized structures.) The supplier sets a wholesale price such that $c \leq w \leq p$. As the captain, the retailer will choose the stocking level $Q^* = F^{-1}((p - c)/(p - s_r))$ to optimize the supply chain.

Note that the supplier's wholesale price is not an optimized result in this structure, and the retailer's global stocking decision does not depend on the wholesale price. These observations may mislead us that the supplier can set any wholesale price it wants. However, if the wholesale price is set too high, the captain (retailer) can refuse to order from the supplier. There are two ways to determine the wholesale price: supplier bidding and negotiation. When the supply market is competitive, the retailer will choose a supplier that bids with the lowest wholesale price. Alternatively, the retailer can target one supplier and negotiate the wholesale price as low as possible; otherwise, she will

threaten not to contract with that supplier. Due to information symmetry, the supplier knows the retailer will order a large stocking quantity and it realizes that requesting a high wholesale price may leave itself substituted by other suppliers. The supplier will thus join the supply chain when the wholesale price goes beyond its target level.

The wholesale-price contract leads to the supply chain coordination if $s_R > s_M$. Furthermore, in contrast to the markdown-money contract, a wholesale-price contract has fewer pricing terms such that it is easier to implement, and thus outperforms the markdown-money contract for coordination.

S4 wholesale-price contract can well address decision processes in large retailing supply chains. For instance, Wal-Mart seeks orders from suppliers (like Chinese and Mexican vendors) that have the lowest wholesale prices (and in general having the lowest production costs). The suppliers' profit margins minimal, but they are guaranteed with large orders by the retailer.

2.5.2 Buyback Contract

When $s_M \geq s_R$, a buyback contract should be introduced for coordination. Like the wholesale-price contract, a buyback contract's pricing terms, the wholesale price and buyback price, are not solely determined by the supplier. Rather, their determination relies on the firms' bargaining power and the competitiveness of the supply market. The captain and follower (retailer) will choose the stocking size $Q^* = F^{-1}((p - c)/(p - s_M))$ to coordinate the supply chain.

The S4 buyback contract distinguishes with that of S3 in that the wholesale price in S4 is no longer a function of the buyback price. That is, with a given wholesale price,

increasing the buyback price will benefit the retailer; if the buyback price is fixed, a higher wholesale price will benefit the supplier. As such, the retailer can negotiate a higher buyback price as well as a lower wholesale price to achieve more profit. This property is consistent with the common intuition that a high buyback price benefits the retailer while a high wholesale price benefits the supplier.

Proposition 2.5.1: *In S4, the wholesale-price contract coordinates the supply chain when $s_R \geq s_M$, while the buyback contract is employed for coordination if $s_M \geq s_R$. The determination of the contracts' pricing terms depends on both firms' bargaining power and the competitiveness of the supply market.*

2.6 S5: Supplier (Associate/Follower/P) vs. Retailer (Captain/Leader/D)

In S5, the captain retailer serves as the Stackelberg leader in dictating the stocking size, and the supplier follows with a pricing decision. Similar to S4, the captain (retailer) can choose either a wholesale-price contract or a buyback contract for coordination per the salvage advantage, and commits an order quantity that optimizes the supply chain. However, the coordinating stocking decision in either contract is a function of the supplier's production cost, which results in different stocking quantities with respect to different suppliers. Therefore, this decision structure leads to higher transaction costs for the retailer due to the fact that the retailer has to specify different stocking levels in light of a number of suppliers and negotiate prices with each of them. Meanwhile, the supplier-bidding option in setting pricing terms is not applied in S4. Consequently, the S5 decision hierarchy is outperformed by S4 from the retailer's perspective.

2.7 S6: Supplier (Associate/Follower/D) vs. Retailer (Captain/Leader/P)

In S6, the retailer determines the contract type as well as the pricing terms, while the supplier follows with a stocking decision. Kandel (1996) analyzes the same structure but assumes both agents seek to maximize their own profits, We investigate situations when the retailer seeks coordination in its decision making.

2.7.1 Wholesale Price Contract

Under a wholesale-price contract, the retailer chooses a wholesale price w such that $w > c$ to have the supplier involved in the supply chain, and the follower (supplier) determines a stocking quantity. Note that the supplier's decision problem (2.4.1) is a linear function of Q , and the supplier bears no overstock risk in this case. Therefore, with a positive profit margin, the supplier has the incentive to supply a quantity of products that exceeds the supply chain optimum. On the other hand, the retailer bears the overstock risk, and will not accept the extra products above the stocking level that optimizes the supply chain, and in this case, coordination is developed if $s_R = s$. One point worth mentioning is, if the wholesale price is set below the supplier's expectation, the supplier can stock less than Q_I^* , and thus coordination is not available in such a case.

2.7.2 Buyback and Markdown-money Contracts

In contrast to wholesale-price contracts, the buyback contract and markdown-money contract may also develop coordination by sharing the overstock risk with the supplier.

Under a buyback contract, the supplier chooses a stocking level to maximize its own profit in (2.4.6), and we thus obtain,

$$Q^* = F^{-1}\left(\frac{w-c}{b-s_M}\right). \quad (2.7.1)$$

Substituting (2.7.1) in the supply chain profit function (2.4.8) and under the first order conditions of optimality,

$$w^* = \frac{p(c-s_M) + b(p-c)}{p-s_M}. \quad (2.7.2)$$

Letting $b = s_M + \alpha(p-s_M)$, where $\alpha \in [0,1]$, then

$$w^* = c + \alpha(p-c), \quad \pi_M^* = \alpha \pi_{SC}^*, \quad \pi_R^* = (1-\alpha) \pi_{SC}^*, \quad (2.7.3)$$

where $\pi_{SC}^* = (p-c)F^{-1}\left(\frac{p-c}{p-s_M}\right) - (p-s_M) \int_0^{F^{-1}\left(\frac{p-c}{p-s_M}\right)} F(x)dx$. The above results are

identical to those of the S3 under a buyback contract. However, the captain (retailer) will seek a lower buyback price, i.e., a lower α , to achieve more profit.

For markdown-money contracts, the mathematical results again remain identical to those in S3 under a markdown-money contract, that is, assuming $m = \alpha(p-s_R)$ for $\alpha \in [0,1]$,

$$w^* = c + \alpha(p-c), \quad \pi_M^* = \alpha \pi_{MSC}^* \text{ and } \pi_R^* = (1-\alpha) \pi_{MSC}^*, \quad (2.7.4)$$

where $\pi_{MSC}^* = (p-c)F^{-1}\left(\frac{p-c}{p-s_R}\right) - (p-s_R) \int_0^{F^{-1}\left(\frac{p-c}{p-s_R}\right)} F(x)dx$. When $s_R \geq s_M$, the

markdown-money also achieves coordination. Note that in contrast to the wholesale-price contract, the markdown-money contract not only complicates the transactions with an additional pricing term, more importantly, this contract type concerns the supplier since

he has to pay for unsold products that are invisible (to the supplier) and are salvaged by the retailer, which can lead to implementing challenges in practice. In this sense, the markdown-money contract is outperformed by the wholesale-price contract.

Proposition 2.7.1: *In S6, the wholesale-price contract outperforms the markdown-money contract for coordination when $s_R \geq s_M$. A buyback contract can be used for coordination if $s_M \geq s_R$, and the retailer will decrease the buyback price to achieve more profit.*

2.7.3 Comparison: S4 versus S6

In S4, the captain (retailer) acts as the Stackelberg follower in determining the stock size, which renders the supply chain coordinated in that the stocking quantity is the only decision variable that affects coordination. In contrast, the retailer has to set the price(s) to induce the supplier to choose a stocking quantity for coordination in S6.

In the case of a wholesale-price contract, the wholesale price will be negotiated such that $c < w < p$ holds in both S4 and S6. The buyback contract's pricing terms in S4 and S6 are determined such that the wholesale price is independent of the buyback price in S4, while the latter independence does not hold in S6. Therefore, the retailer can seek a high buyback price as well as a low wholesale price in S4. In contrast, the retailer has to set a low buyback price that induces a low wholesale price to share a high supply chain profit in S6. To summarize, S4 assures the retailer a higher degree of control for coordination in comparison to S6.

2.8 Structures S7 and S8

The supplier captains the supply chain and determines the quantity in both Structures S7 and S8. In S7, the supplier introduces a contract type first, the Stackelberg leader (retailer) then chooses a pricing decision, and then the captain (supplier) commits a stock level. To coordinate the supply chain, the supplier determines $Q^* = F^{-1}((p - c)/(p - s_R))$ if $s_R \geq s_M$, or $Q^* = F^{-1}((p - c)/(p - s_M))$ if $s_M \geq s_R$, which are independent of the contract's pricing terms, while the price determination depends on the relative bargaining power of the agents.

In S8, the supplier specifies a contract type, as well as a supply quantity at either $Q^* = F^{-1}((p - c)/(p - s_R))$ or $Q^* = F^{-1}((p - c)/(p - s_M))$. Similar to S7, the determination of the pricing term(s) is based upon the agents' bargaining power.

Even though Structures S7 and S8 have different Stackelberg hierarchies, the supplier always chooses a stocking quantity that optimizes the supply chain, regardless of his Stackelberg position. This observation is consistent with the statement in Stackelberg (1934) that sometimes even the firms themselves do not know who is the leader and who is the follower.

Proposition 2.8.1: *In structures S7 and S8, a wholesale-price contract can be chosen to coordinate the supply chain if the retailer has the salvage advantage, while a buyback contract can be used for coordination when the supplier has the salvage advantage.*

2.9 Structures S9 and S10

In Structures S9 and S10, the supply chain captain assumes the Stackelberg follower position in choosing contracts' pricing term(s). However, the profit functions of the supply chain are independent of w , b , and m , see (2.4.3), (2.4.8), and (2.4.17). Therefore, coordination cannot be induced by captain's pricing decisions under any contract type in this case. On the other hand, the agent who acts as the leader (the supplier in S9 and the retailer in S10) to choose Q cannot expect what the follower's reactions will be since the follower's objective profit function is independent of the pricing terms. To summarize, S9 and S10 are infeasible structures.

2.10 Conclusions and Future Research

In this chapter, we relaxed the standard assumption in the literature that a supply chain captain does also act as the Stackelberg leader. This allows us to investigate ten possible supply chain decision structures in terms of coordination. In each decentralized decision structure, we analyzed the effect of contract type, namely, the wholesale-price contract, buyback contract, or markdown-money contract, and their role in achieving supply chain coordination.

The use of a particular contract type to achieve coordination depends not only on the agent having the overstock salvage advantage, but also upon the supply chain decision hierarchy. For example, when the retailer captains the supply chain and acts as the Stackelberg follower to determine the stocking level (S4), coordination can be achieved using either a wholesale-price contract or a buyback contract.

As for the supply chain captain, the Stackelberg leadership is not always necessary for coordination and for seeking more profit. For example, the retailer captains the supply chain in Structures S4, however, being the follower allows the retailer to have the products with the lowest wholesale price using supplier-biddings.

In the case of a buyback contract, the general intuition is that a higher buyback price leads to a higher wholesale price, thus assuring more profit for the supplier. In the foregoing analysis, it is shown that the wholesale price is not necessarily a function of the buyback price (as in the case of S4 and S7). Therefore, a retailer can seek a high buyback price along with a low wholesale price, and a supplier may retain a low buyback price as well as a low wholesale price.

In S3, the markdown-money contract has to be used for coordination when the retailer has the salvage advantage; while in other decentralized structures, the wholesale-price contract outperforms the markdown-money contract due to its easier implementary. This conclusion partially explains why the markdown-money contract is uncommon in practice.

Several extensions deserve further efforts. We assumed that the retail price is exogenously determined in this chapter. It is also useful to consider how (or whether) coordination can be achieved in different decision structures when the retail price is endogenously determined. Agents are assumed risk neutral in our research. In contrast, if either or both agents are risk averse, questions such as how can coordination be reached, and how the profit is split within the supply chain, are worthy of further research. Another noteworthy extension is the analysis on information structure. For instance,

when private information exists, how both agents react in different structures will be an interesting issue to explore.

Chapter 3:

Supply Chain Performance with Power Imbalanced Suppliers

3.1 Introduction

We study a supply chain (or supply channel) where multiple suppliers/manufacturers supply substitutable products or components to a common downstream firm or retailer. Such multi-agent supply chains widely exist in manufacturing, retailing, and service industries. Manufacturers seldom produce all parts by themselves, but outsource them to upstream suppliers. For example, Dell and Hewlett Packard produce personal computers with components supplied by a variety of upstream suppliers; General Motors and Ford assemble vehicles but outsource most parts to numerous independent upstream firms. Retailers such as Home-Depot, Best-Buy, and Wal-Mart, carry multiple brands in the same product categories. In the service industry, for instance, Dutch bank ABN AMRO in 2005 outsourced its IT operations to five providers with entire contracts valued at \$ 2.24 billion over five years (Gibson 2005).

In this chapter, we focus on the influence of each agent's decision-making power on the strategic interactions and performance within a multi-supplier-one-retailer supply chain. Such interactions in a supply chain are typically modeled as either two-stage Stackelberg games or one-stage non-cooperative games with all suppliers sharing an equal or balanced decision-making power over/under the retailer (Choi 1991). That is, all suppliers are assumed to act as either Stackelberg leaders or followers over the retailer, or

all supply chain parties move simultaneously in decision-making. We relax this conventional assumption to examine situations when suppliers have an unequal decision-making power over each other so that one or more suppliers can exercise Stackelberg leadership over the other suppliers. This relaxation allows us to extend and generalize the results of the multi-supplier-one-retailer power-balanced supply chain studied by Choi (1991). As a result, five additional configurations for supply chains under power imbalance are analyzed in this chapter by modeling them as either two-stage or three-stage Bertrand Stackelberg games. This chapter focuses on such questions as supply chain performance and stability, effects of product substitution, and strategies used by agents with different decision-making power.

Choi (1991) examines a retailing channel consisting of two suppliers and one retailer and analyzes three possible channel configurations with power balanced suppliers; namely, the Manufacturer Stackelberg (MS) structure in which both suppliers act as the Stackelberg leaders over the retailer, the Retailer Stackelberg (RS) structure where the retailer assumes leadership with respect to power-balanced suppliers, and the Vertical Nash (VN) structure in which all participants have equal decision-making power. The above supplier balanced-power structures have also been empirically tested, for instance see, Besanko et al. (1998) who use the VN model to validate price endogeneity, or Sudhir (2001) who investigates vertical interactions within the context of MS and VN structures.

Kadiyali et al. (2000) also study and empirically test interactions within a multi-supplier-single channel using a somewhat generalized Choi's power models, but the

supplier-supplier interactions are subsumed within the retailer's interaction with each supplier.

Besides Choi (1991)'s two-supplier-single-retailer case, channel interactions have been studied in terms of the number of agents involved, for instance, for the case of one supplier and one retailer, Jeuland and Shugan (1983) and Moorthy (1987) investigate channel coordination mechanisms, Netessine and Rudi (2004) investigate drop-shipping in terms of three power structures similar to Choi (1991). Given a channel with one supplier and two retailers, Ingene and Parry (1995) consider supply chain coordination with "quantity discounts" and "two-part tariff". With two suppliers and two retailers, McGuire and Staelin (1983) study agents' pricing strategies under exclusive dealership structures, and starting from that, Moorthy (1988) answers the question "why strategic interaction among suppliers makes it possible for decentralization to be a Nash equilibrium strategy"; Choi (1996) and Trivedi (1998) both consider agents' pricing interactions when retailers carry products from both suppliers; Lee and Staelin (1997) study the value of Stackelberg pricing leadership within the concept of vertical strategic interaction under different channel structures.

However, in the cases of one-supplier-two-retailer or two-supplier-two-retailer channels, to the best of our knowledge, the existing literature has not considered the effect of power imbalance within the supplier or retailer groups.

On the other hand, multi-supplier-single-retailer supply chains have been studied quite extensively in the context of complementary products being offered by different suppliers. For instance, in assembly supply chains with a common assembler (retailer), Gerchak and Wang (2004) assume all suppliers move simultaneously as either

Stackelberg leaders or followers over the common assembler. They study supply chain coordination and systems performance issues under contracts such as wholesale price, buyback, or revenue sharing contracts, see Cachon (2003) and Lariviere (1999) for excellent reviews on supply chain contracts. Granot and Yin (2004) study system performance and supplier coalition under the assumption of suppliers having equal power for two cases: first, suppliers move to set wholesale prices and the retailer follows by setting the stock size; second, the retailer moves first in setting wholesale prices and suppliers follow with stocking decisions who also retain the overstock risk. Wang (2005) also studies system performance, but assumes the retailer serve as the Stackelberg leader over the suppliers, and suppliers can move either simultaneously or sequentially in pricing and production decisions; also see Jiang and Wang (2005). Bernstein and DeCroix (2004) investigate multi-tier assembly systems in which the downstream firm(s) holds higher decision-making power over the upstream agents, and all firms at the same tier move simultaneously. Carr and Karmarkar (2005) and Corbett and Karmarkar (2001) study competition within a multi-echelon assembly supply chain with a deterministic demand assumption, where the former assumes a VN configuration while the latter assumes a MS power structure.

In the preceding assembly systems models, production quantities at each echelon remain the same as (or proportional to) the final assembly quantities. In contrast, in many other situations, it is the common operational practice that downstream firms order substitutable components from different upstream suppliers. Under product substitution, however, modeling and characterizing multi-supplier-one-retailer supply chain in stochastic environment turn out to be quite complex. Consequently, analysis of vertical

interactions in such an environment is usually simplified via a one-supplier-one-retailer newsvendor model; see, for instance, Cachon (2003) and Lariviere (1999).

In this chapter, we study a multi-supplier-one-retailer power-imbalanced supply chain in which suppliers offer substitutable products. We assume a linear deterministic demand function that captures the substitution effects (which is also a measure of product competition). We obtain closed-form equilibrium results that facilitate insight on supply chain performance under power imbalance and substitution effects. To the best of our knowledge, this is the first instance of a detailed analysis for such supply chains. In the sequel, the following conclusions are reached in this chapter:

- (1) With increasing product substitution, a multi-supplier-one-retailer supply chain can achieve coordination asymptotically under a simple wholesale pricing mechanism.
- (2) Each supplier's profit consistently decreases when products become more substitutable even if the suppliers dominate the retailer, whereas the retailer benefits from a high degree of substitution regardless of the supply chain power structure.
- (3) A "niche" supplier is not necessarily an underdog in the presence of a larger supplier when seeking to increase the share of its supply chain profit under certain decision power structures.
- (4) In the case of multiple suppliers, "profit percentages" can characterize their relative power differences more accurately than the respective "absolute profits".
- (5) Certain power-imbalanced channels are shown to *dominate* others. Moreover, we show that Manufacturer Stackelberg and Retailer Stackelberg channels are no longer

stable structures (as claimed in Choi, 1991) when suppliers are able to behave as if they are power imbalanced.

It is a common practice that a firm orders from power-imbalanced (or asymmetric) multiple suppliers for satisfying its end demands for products and services, and thus, such systems deserve in-depth investigation. For example, a PC assembler such as Dell or Hewlett Packard use CPUs from different suppliers, but Intel dominates the CPU supplier market. Wal-Mart offers customers national-brand beverages such as Pepsi and Coca-Cola along with beverages supplied by niche players. IBM Global services pockets \$1.87 billions from Dutch bank ABN AMRO's \$2.24 billion IT outsourcing contracts, and the four other IT service providers share the remaining outsourcing budget.

The remainder of the chapter is organized as follows: Section 2 presents the model and relevant assumptions along with different supply chain structures; Section 3 provides derivations and closed-form equilibrium results under power-imbalance; detailed comparisons of different supply chain structures are presented in Section 4. Section 5 focuses on supply chain performance as well as channel structure stability. Section 6 concludes the chapter. The required notation is introduced as it becomes necessary.

3.2 The Model and Decision Hierarchies

Consider a supply chain where one retailer carries substitutable products from two suppliers (supplier 1 and supplier 2) in a single business season. Suppose the two suppliers are asymmetric in size and assume that Supplier 1 is larger than supplier 2. This

size difference affects the Stackelberg pricing positions that suppliers can have, as illustrated next. The supplier i is paid a wholesale unit price w_i by the retailer who in turn charges a retail price p_i from the end customers, where the supplier index i ($=1,2$) denotes the specific supplier, and thus the specific product i sold to the retailer.

Consider the linear deterministic function for retailer demand given by,

$$q_i = a_i - bp_i + t(p_j - p_i), i, j=1,2, i \neq j, \quad (3.2.1)$$

where the coefficient a_i (> 0) represents the product “market base” (see Tsay and Agrawal, 2000) that is invariant to the retail prices, b (> 0) represents product i ’s demand sensitivity on its own retail price, and t (≥ 0) denotes the degree of product substitution, which accounts for the effect of retail price differences of the two substitutable products. Note that a unit price discount offered by both suppliers simultaneously thus results in both demands q_1 and q_2 increasing by b units. In the sequel, (3.2.1) is normalized by setting $b=1$ to simplify the presentation. Observe that $t=0$ represents the case when the two products are completely independent, and as t increases, the degree of product substitution (hence, the competition between the two products) increases.

Demand models similar to that in (3.2.1) have been used by Choi (1996), McGuire and Staelin (1983), Trivedi (1998), Tsay and Agrawal (2000), for instance. It must be noted that Choi’s (1991) demand function, namely, $q_i = a - bp_i + tp_j$ has resulted in the counter-intuitive implication that equilibrium retail prices grow when products become more substitutable in the structures analyzed by the author. The demand-price relationship on (3.2.1), in contrast, can be shown to eliminate such implications.

We shall use the following notation: π_{Mi} is supplier (manufacturer) i 's profit, π_R is the retailer's total profit in selling both product types, π_{SCi} is the total supply chain (SC) profits generated due to (only) product i , and π_I is the total SC profits due to both product types. Denoting the unit production costs by c_i , wholesale prices by w_i , and assuming the stock size to be equal to the (deterministic) demand, the following expressions hold:

$$\pi_{Mi} = (w_i - c_i)q_i \quad (3.2.2)$$

$$\pi_R = \sum_{i=1}^2 (p_i - w_i)q_i \quad (3.2.3)$$

$$\pi_{SCi} = (p_i - c_i)q_i \quad (3.2.4)$$

$$\pi_I = \sum_{i=1}^2 \pi_{SCi} . \quad (3.2.5)$$

Furthermore, it is assumed that information is symmetric across the supply chain, and each supply chain agent makes decisions to maximize his/her own profit.

3.2.1 Supply Chain Structure

Given the information symmetry in the supply chain, the chronological order in which each agent is making pricing decisions impacts the relative profit potential of each agent. Such a chronology in the decision hierarchy is often the result of the relative power that each agent holds in the supply chain. Accordingly, for the two-supplier-one-retailer supply chain, eight possible relative power configurations can be proposed, as depicted in Figure 3.1, where M1 and M2 denote the suppliers 1 and 2, respectively, and R denotes

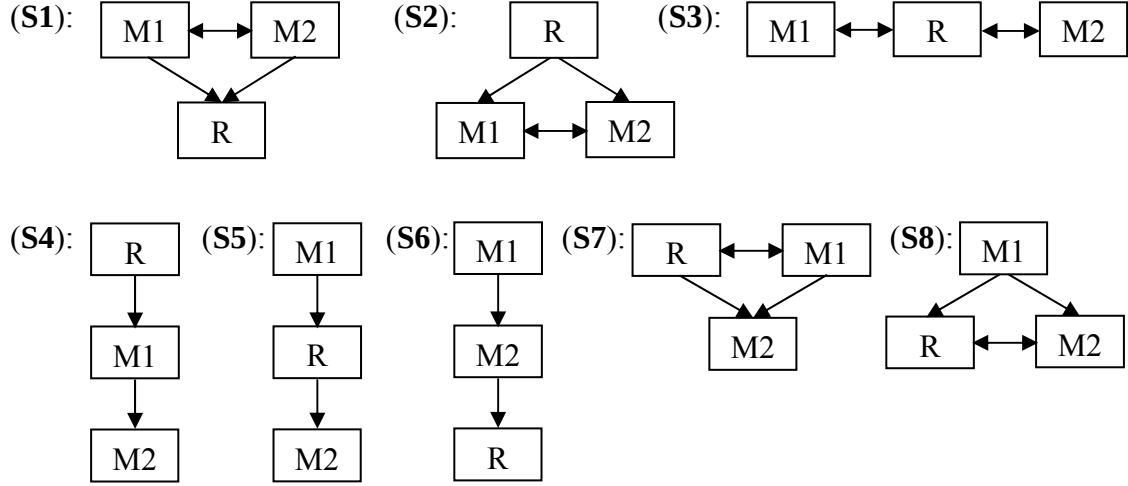


Figure 3.1 Supply Chain Decision Hierarchies

the retailer. If M1 holds more (bargaining) power than M2 in the supply chain, it is represented by $M1 \rightarrow M2$ in Figure 3.1. $M1 \leftrightarrow M2$ indicates that M1 and M2 both have equal decision-making power. The eight distinct structures are marked (S1) through (S8).

Note that the structures (S1), (S2), and (S3) correspond to both suppliers having equal power, which is the case considered in Choi (1991). In this case, both suppliers move simultaneously over each other in making decisions. (S1) is representative of two large suppliers with equal power supplying to a small retailer, whereas (S2) illustrates the retailer being relatively larger compared to two equally-sized suppliers. (S3) is concerned with the case when all three agents share an equal decision-making power such that no one can gain pricing leadership over the others. (S1), (S2), and (S3) are appropriately termed Manufacturer Stackelberg (MS), Retailer Stackelberg (RS), and Vertical Nash (VN), respectively. Choi (1991) offers in-depth discussions, including the existence of unique Nash equilibria for these three relative power structures.

In contrast, structures (S4) through (S8) underscore the presence of power imbalance between the suppliers. For example, when a very large retailer such as Wal-Mart selling beverages provided by a large supplier such as Coca-Cola or Pepsi, along with beverages produced by smaller niche suppliers, the retailing supply chain power structure typically resembles that in (S4). On the other hand, in (S5), supplier 1 has power over a mid-sized retailer who carries products from both his and of another relatively smaller supplier that has relatively less power than the retailer in the supply chain. Structure (S6) models a situation when both suppliers are more powerful than the retailer along with the relatively larger supplier M1 further dominating the supplier M2. We offer three-stage Bertrand Stackelberg game-theoretic analyses of these structures.

On the other hand, Structures (S7) and (S8) have only two decision tiers and they can be modeled as two-stage games. Unlike (S1) and (S2) where the two suppliers are power-balanced, in (S7) and (S8), the retailer shares equal power with one supplier. In (S7), Retailer has balanced power with the supplier 1 and they both act as Stackelberg leaders over Supplier 2, whereas in (S8), the retailer has balanced power with Supplier 2 and they both play the role of Stackelberg followers in the supply chain.

In the ensuing analyses, the following terminology will be applied: the member with the highest hierarchy in decision making, i.e., the agent who moves first, is termed the *Stackelberg leader*, while the member with the lowest hierarchy, i.e., moving last, is termed the *Stackelberg follower*. When there exists an intermediate decision maker, as in the case of (S4), (S5), and (S6), such an agent is termed a *Stackelberg middler*.

3.3 Equilibrium Analysis of Supply Chain Structures

Let us first consider the structure (S4) where the retailer is the leader, the supplier 1 is a middler and the supplier 2 is a follower. The retailer chooses the retail margins m_1 and m_2 at the first stage of decision making by taking both suppliers' *reaction* functions into account, where $m_1 = p_1 - w_1$ and $m_2 = p_2 - w_2$; at the second stage of decision making, the middler M1 chooses a wholesale price w_1 that is conditional on the retail margin m_1 , as well as by taking into account of M2's reaction function; finally, at the third stage, the follower M2's wholesale price is conditioned on both decisions m_2 and p_1 , where $p_1 = w_1 + m_1$. Using backward induction, M2's reaction function π_{M2}^* is obtained as

$$\pi_{M2}^*(p_1, m_2) := \max_{w_2} \{ \pi_{M2}(p_1, p_2, m_2) : p_2 - w_2 = m_2 \}, \quad (3.3.1)$$

where

$$\pi_{M2}(p_1, p_2, m_2) = (w_2 - c_2)q_2 = (w_2 - c_2)[a_2 - p_2 + t(p_1 - p_2)] \quad (3.3.2)$$

under the demand function in (3.2.1), normalized with $b=1$. By expressing π_{M2} as a function of the single decision variable w_2 , (3.3.1) is a univariate unconstrained concave maximization problem. The first order optimality condition, i.e., setting the derivative to zero, yields $a_2 + tp_1 + (t+1)(c_2 - m_2 - 2w_2) = 0$, and thus, supplier 2's optimal prices are

$$w_2^* = [a_2 + tp_1 + (t+1)(c_2 - m_2)]/[2(t+1)] \text{ and } p_2^* = w_2^* + m_2. \quad (3.3.3)$$

Substituting (3.3.3) in the supplier 1's (middler's) problem, and given the retail margin m_1 , the supplier 1's profit π_{M1}^* is determined by solving

$$\pi_{M1}^*(p_2^*, m_1) := \max_{w_1} \{ \pi_{M1}(p_1, p_2^*, m_1) : p_1 - w_1 = m_1 \}, \quad (3.3.4)$$

where

$$\pi_{M1}(p_1, p_2^*, m_1) = (w_1 - c_1)q_1 = (w_1 - c_1)[a_1 - p_1 + t(p_2^* - p_1)]. \quad (3.3.5)$$

Supplier 1's problem in (3.3.4) is also a concave univariate maximization problem, and thus, the first order condition of optimality yields

$$w_1^* = [ta_2 + 2(t+1)a_1 + (t^2 + t)(m_2 + c_2) + (t^2 + 4t + 2)(c_1 - m_1)] / [2(t^2 + 4t + 2)]. \quad (3.3.6)$$

Given both suppliers' reaction functions w_1^* and w_2^* in (3.3.3) and (3.3.6), respectively, the retailer's profit objective, $\pi_R(m_1, m_2, p_1^*, p_2^*)$ for $p_1^* = w_1^* + m_1$ and $p_2^* = w_2^* + m_2$, is jointly concave in (m_1, m_2) since the Hessian matrix is negative-definite as evident by $\partial^2 \pi_R / \partial m_1^2 < 0$, $\partial^2 \pi_R / \partial m_2^2 < 0$, and

$$\begin{vmatrix} \frac{\partial^2 \pi_R}{\partial m_1^2} & \frac{\partial^2 \pi_R}{\partial m_1 \partial m_2} \\ \frac{\partial^2 \pi_R}{\partial m_1 \partial m_2} & \frac{\partial^2 \pi_R}{\partial m_2^2} \end{vmatrix} = \begin{vmatrix} -\frac{t^2 + 4t + 2}{2(t+1)} & t/2 \\ t/2 & -\frac{(t+1)(t^2 + 8t + 4)}{2(t^2 + 4t + 2)} \end{vmatrix} = 2t + 1 > 0. \quad (3.3.7)$$

Therefore, there exists a unique Nash equilibrium.

The optimized retail margins (m_1^*, m_2^*) are determined from the retailer's first order conditions, i.e., by setting the gradient vector of π_R to zero, which yields

$$m_1^* = \frac{a_1(t+1) + a_2t - c_1(2t+1)}{2(2t+1)}, \quad (3.3.8)$$

$$m_2^* = \frac{a_2(t+1) + a_1t - c_2(2t+1)}{2(2t+1)}. \quad (3.3.9)$$

Using forward substitution, optimal wholesale prices in (3.3.3) and (3.3.6) are then obtained as

$$w_1^* = \frac{(3t^2 + 12t + 6)c_1 + (t^2 + t)c_2 + ta_2 + 2(t+1)a_1}{4(t^2 + 4t + 2)}, \quad (3.3.10)$$

$$w_2^* = \frac{(t^3 + 4t^2 + 2t)c_1 + (2t^2 + 2t)a_1 + (3t^2 + 8t + 4)a_2 + (7t^3 + 31t^2 + 36t + 12)c_2}{8(t+1)(t^2 + 4t + 2)}. \quad (3.3.11)$$

3.3.1 Analysis of Structure (S4)

Note that the demand parameter a_i reflects customer brand loyalty and market share, and a larger supplier in general has a larger market base over small suppliers. Meanwhile, a larger supplier in general has a smaller unit production cost c_i due to possible economies of scale. The equilibrium results in (3.3.8)-(3.3.11) capture not only the effect of power imbalance in Structure (S4), but also effects due to brand loyalty as well as economies of scale in production. In order to better understand the effects due to power imbalance alone, we suppress these other effects by setting $a_1 = a_2 = a$ and $c_1 = c_2 = c$ for the remainder of this section. In this case, the equilibrium results are simplified as

$$m_1^* = m_2^* = (a - c) / 2^1, \quad (3.3.12)$$

$$w_1^* = \frac{(3t + 2)a + (4t^2 + 13t + 6)c}{4(t^2 + 4t + 2)}, \quad w_2^* = \frac{(5t^2 + 10t + 4)a + (8t^3 + 35t^2 + 38t + 12)c}{8(t+1)(t^2 + 4t + 2)}, \quad (3.3.13)$$

$$p_1^* = \frac{(2t^2 + 11t + 6)a + (2t^2 + 5t + 2)c}{4(t^2 + 4t + 2)}, \quad p_2^* = \frac{(2t^2 + 11t + 6)a + (2t^2 + 5t + 2)c}{4(t^2 + 4t + 2)}, \quad (3.3.14)$$

$$q_1^* = \frac{(3t + 2)(a - c)}{8(t + 1)}, \quad q_2^* = \frac{(5t^2 + 10t + 4)(a - c)}{8(t^2 + 4t + 2)}, \quad (3.3.15)$$

¹ Note that it may mislead the reader that the retail margins are equal to half of the difference between the market base and production cost. This is due to the normalization that $b=1$ was set as mentioned earlier, for if not, margins are $m_1^* = m_2^* = (a - bc) / 2b$.

$$\pi_{M1}^* = \frac{(3t+2)^2(a-c)^2}{32(t+1)(t^2+4t+2)}, \quad \pi_{M2}^* = \frac{(5t^2+10t+4)^2(a-c)^2}{64(t+1)(t^2+4t+2)^2}, \quad (3.3.16)$$

$$\pi_R^* = \frac{(8t^3+29t^2+28t+8)(a-c)^2}{16(t+1)(t^2+4t+2)}, \quad (3.3.17)$$

$$\pi_{SC}^* = \frac{(32t^5+287t^4+836t^3+992t^2+512t+96)(a-c)^2}{64(t+1)(t^2+4t+2)^2}, \quad (3.3.18)$$

where $a > c$ is necessary to ensure non-negative production quantities in (3.3.15). Also, it follows that the retailer charges the same retail margin $m_1^* = m_2^* = (a-c)/2$ from both suppliers in (S4). The following proposition establishes the qualitative aspects of the equilibrium behavior, where the “integrated system” refers to the two-supplier-single-retailer supply chain being controlled by a single agent (i.e., a coordinated supply chain).

Proposition 3.1: In structure (S4),

- (1) Both suppliers’ retail prices monotonically decrease in t and they reach the integrated system’s retail prices as $t \rightarrow \infty$.
- (2) Both wholesale prices monotonically decrease in t and they reach the respective unit production cost as $t \rightarrow \infty$.
- (3) Both product quantities increase in t .
- (4) Both suppliers’ profits monotonically decrease in t and they vanish asymptotically.
- (5) The retailer’s profit monotonically increases in t and it reaches the total supply chain profit as $t \rightarrow \infty$.
- (6) The total supply chain profits increase in t and converges to the integrated system profit as $t \rightarrow \infty$.

Proof. It can be shown that

$$\frac{dp_1^*}{dt} = -\frac{(3t^2 + 4t + 2)(a - c)}{4(t^2 + 4t + 2)^2} < 0, \quad \frac{dp_2^*}{dt} = -\frac{(5t^4 + 20t^3 + 32t^2 + 20t + 4)(a - c)}{8(t + 1)^2(t^2 + 4t + 2)^2} < 0. \quad (3.3.19)$$

Similarly, $dw_1^*/dt < 0$, $dw_2^*/dt < 0$, $dq_1^*/dt > 0$, $dq_2^*/dt > 0$, $d\pi_{M1}^*/dt < 0$, $d\pi_{M2}^*/dt < 0$,

$d\pi_R^*/dt > 0$, and $d\pi_{SC}^*/dt > 0$. Furthermore, if the optimal retail prices of a corresponding

integrated supply chain are denoted by $p_{1(I)}^*$ and $p_{2(I)}^*$ for the two products, then it can be

shown that $p_{1(I)}^* = p_{2(I)}^* = (a + c)/2$, and $\lim_{t \rightarrow \infty} p_1^* = p_{1(I)}^*$ and $\lim_{t \rightarrow \infty} p_2^* = p_{2(I)}^*$. As a result, the

decentralized structure (S4) resembles an integrated system when the two products are

perfectly substitutable, i.e., $t \rightarrow \infty$, and $\lim_{t \rightarrow \infty} \pi_{M1}^* = \lim_{t \rightarrow \infty} \pi_{M2}^* = 0$, with the retailer capturing

the entire supply chain profit. ■

It can be further shown that

$$\frac{d^2 p_1^*}{dt^2} = \frac{(3t^3 + 6t^2 + 6t + 4)(a - c)}{2(t^2 + 4t + 2)^3} > 0, \quad (3.3.20)$$

$$\text{and} \quad \frac{d^2 p_2^*}{dt^2} = \frac{(5t^6 + 30t^5 + 84t^4 + 130t^3 + 102t^2 + 36t + 4)(a - c)}{4(t + 1)^3(t^2 + 4t + 2)^3} > 0, \quad (3.3.21)$$

and thus, p_1^* and p_2^* are convex (and decreasing) in t . Therefore, at lower levels of t , a

change of substitution drastically affects the retail prices, consequently, the profits of

each supply chain agent changes substantially. In contrast, at relatively higher levels of t ,

a change of substitution has far less impact on the retail prices and the profits of each

agent.

Considering the retailer profit π_R^* as the combination of profits π_{R1}^* (of product type 1) and π_{R2}^* (of product type 2), and thus $\pi_R^* = \pi_{R1}^* + \pi_{R2}^*$, it can be shown that $\pi_{R2}^* > \pi_{R1}^* > \pi_{M2}^* > \pi_{M1}^*$ for all $t > 0$. When the two products are completely un-substitutable, i.e., $t = 0$, we have $\pi_{R2}^* = \pi_{R1}^* > \pi_{M2}^* = \pi_{M1}^*$. That the Stackelberg middler M1 achieves a lower profit than the (less powerful) follower M2 results from the fact that the retailer charges the same retail margin from both suppliers, whereas M2 charges lower wholesale unit price than M1 does, which in turn, leads to a lower retail price and thus a higher stock quantity for M2 products so as to offset the loss of lower wholesale price.

Let π_{SCi}^* denote the optimized profits generated from supplier i 's product, where $\pi_{SC1}^* = \pi_{M1}^* + \pi_{R1}^*$ and $\pi_{SC2}^* = \pi_{M2}^* + \pi_{R2}^*$. Thus, π_{Mi}^* / π_{SCi}^* represents the profit percentage that the supplier i achieves from his own products. It follows that

$$\pi_{SC1}^* - \pi_{SC2}^* = -\frac{t^2(8t^3 + 43t^2 + 36t + 8)(a - c)^2}{64(t + 1)(t^2 + 4t + 2)^2} \leq 0, \quad (3.3.22)$$

$$\pi_{M1}^* / \pi_{SC1}^* - \pi_{M2}^* / \pi_{SC2}^* = \frac{2t^2(t^2 + 4t + 2)}{(2t^2 + 11t + 6)(4t^3 + 25t^2 + 34t + 12)} \geq 0. \quad (3.3.23)$$

Thus, the profit contribution from M1 products to the supply chain is less than that of M2 products; however, the ratio of profit that supplier M1 shares from the sale of his own products is larger than that of M2, as stated below.

Proposition 3.2: *The supplier power imbalance that exists in (S4) allows the more powerful supplier to obtain a higher “profit percentage” from his products, in comparison to what the small (less powerful) supplier is able to, at all levels of product*

substitution. However, the total dollar profit in the supply chain due to the small supplier's products dominates that of the large supplier.

3.4 Analysis of Remaining Structures

Equilibrium analyses of all structures in Figure 3.1 can be performed analogously to that of (S4), presented in the preceding section. The resulting optimal solutions, along with those of the integrated supply chain (coordinated by one agent), are summarized in Tables 3.1 and 3.2 in the end of this chapter, where c is set to be 0 for ease of exposition. In the remainder of this section, properties of these structures are investigated.

3.4.1 Properties of Retail Prices and Retail Margins

Retail prices follow the results in Proposition 3.1 in all eight structures, the proof of which follows analogously by referring to Table 3.1:

Proposition 3.3: *In structures (S1) through (S8), equilibrium retail prices of both products decrease monotonically in t ; moreover, they coincide with the corresponding integrated supply chain's retail prices as products become completely substitutable, i.e., as $t \rightarrow \infty$.*

It follows that when products are completely un-substitutable, i.e., $t = 0$, retail prices of both product types are higher in all structures (S1)-(S8) compared to those of an integrated supply chain, see Table 3.1. Let the subscript $n = 1, 2, \dots, 8$, represent the particular structure under consideration, and let $n = 0$ represent the case of the integrated

Table 3.1: Equilibrium Wholesale Prices, Retail Margins, and Retail Prices

	w_1^*	w_2^*	m_1^*	m_2^*	p_1^*	p_2^*
S0	N/A	N/A	N/A	N/A	$\frac{a}{2}$	$\frac{a}{2}$
S1	$\frac{a}{t+2}$	$\frac{a}{t+2}$	$\frac{a(t+1)}{2(t+2)}$	$\frac{a(t+1)}{2(t+2)}$	$\frac{a(t+3)}{2(t+2)}$	$\frac{a(t+3)}{2(t+2)}$
S2	$\frac{a}{2(t+2)}$	$\frac{a}{2(t+2)}$	$\frac{a}{2}$	$\frac{a}{2}$	$\frac{a(t+3)}{2(t+2)}$	$\frac{a(t+3)}{2(t+2)}$
S3	$\frac{a}{2t+3}$	$\frac{a}{2t+3}$	$\frac{a(t+1)}{2t+3}$	$\frac{a(t+1)}{2t+3}$	$\frac{a(t+2)}{2t+3}$	$\frac{a(t+2)}{2t+3}$
S4	$\frac{a(3t+2)}{4(t^2+4t+2)}$	$\frac{a(5t^2+10t+4)}{8(t+1)(t^2+4t+2)}$	$\frac{a}{2}$	$\frac{a}{2}$	$\frac{a(2t^2+11t+6)}{4(t^2+4t+2)}$	$\frac{a(4t^3+25t^2+34t+12)}{8(t+1)(t^2+4t+2)}$
S5	$\frac{a(3t+2)}{2(t^2+4t+2)}$	$\frac{a(5t^2+10t+4)}{8(t+1)(t^2+4t+2)}$	$\frac{a(t+2)(2t+1)}{4(t^2+4t+2)}$	$\frac{a}{2}$	$\frac{a(2t^2+11t+6)}{4(t^2+4t+2)}$	$\frac{a(4t^3+25t^2+34t+12)}{8(t+1)(t^2+4t+2)}$
S6	$\frac{a(3t+2)}{2(t^2+4t+2)}$	$\frac{a(5t^2+10t+4)}{4(t+1)(t^2+4t+2)}$	$\frac{a(t+2)(2t+1)}{4(t^2+4t+2)}$	$\frac{a(4t^3+15t^2+14t+4)}{8(t+1)(t^2+4t+2)}$	$\frac{a(2t^2+11t+6)}{4(t^2+4t+2)}$	$\frac{a(4t^3+25t^2+34t+12)}{8(t+1)(t^2+4t+2)}$
S7	$\frac{a(3t+2)}{3(t^2+4t+2)}$	$\frac{a(3t^2+7t+3)}{6(t+1)(t^2+4t+2)}$	$\frac{a(3t^2+9t+4)}{6(t^2+4t+2)}$	$\frac{a}{2}$	$\frac{a(3t^2+15t+8)}{6(t^2+4t+2)}$	$\frac{a(3t^3+18t^2+25t+9)}{6(t+1)(t^2+4t+2)}$
S8	$\frac{a(4t+3)}{2(2t^2+6t+3)}$	$\frac{a(8t^2+15t+6)}{6(t+1)(2t^2+6t+3)}$	$\frac{a(2t+1)(2t+3)}{4(2t^2+6t+3)}$	$\frac{a(12t^3+40t^2+39t+12)}{12(t+1)(2t^2+6t+3)}$	$\frac{a(4t^2+16t+9)}{4(2t^2+6t+3)}$	$\frac{a(12t^3+56t^2+69t+24)}{12(t+1)(2t^2+6t+3)}$

Note: (1) S0 represents the integrated system, S1-S8 represent Structures 1 to 8, respectively;

(2) Subscripts 1 & 2 for prices and production quantities correspond to supplier 1 and 2 products, respectively.

Table 3.2 Equilibrium Stock Quantities and Profits

	q_1^*	q_2^*	π_{M1}^*	π_{M2}^*	π_R^*
S0	$a/2$	$a/2$	$\emptyset$	$\emptyset$	$\emptyset$
S1	$a(t+1)[2(t+2)]^{-1}$	$a(t+1)[2(t+2)]^{-1}$	$a^2(t+1)/[2(t+2)^2]$	$a^2(t+1)/[2(t+2)^2]$	$a^2(t+1)^2/[2(t+2)^2]$
S2	$\frac{a(t+1)}{2(t+2)}$	$\frac{a(t+1)}{2(t+2)}$	$a^2(t+1)/[4(t+2)^2]$	$a^2(t+1)/[4(t+2)^2]$	$a^2(t+1)/[2(t+2)]$
S3	$\frac{a(t+1)}{2t+3}$	$\frac{a(t+1)}{2t+3}$	$a^2(t+1)/[(2t+3)^2]$	$a^2(t+1)/[(2t+3)^2]$	$2a^2(t+1)^2/[(2t+3)^2]$
S4	$\frac{a(3t+2)}{8(t+1)}$	$\frac{a(5t^2+10t+4)}{8(t^2+4t+2)}$	$\frac{a^2(3t+2)^2}{32(t+1)(t^2+4t+2)}$	$\frac{a^2(5t^2+10t+4)^2}{64(t+1)(t^2+4t+2)^2}$	$\frac{a^2(8t^3+29t^2+28t+8)}{16(t+1)(t^2+4t+2)}$
S5	$\frac{a(3t+2)}{8(t+1)}$	$\frac{a(5t^2+10t+4)}{8(t^2+4t+2)}$	$\frac{a^2(3t+2)^2}{16(t+1)(t^2+4t+2)}$	$\frac{a^2(5t^2+10t+4)^2}{64(t+1)(t^2+4t+2)^2}$	$\frac{a^2(16t^3+49t^2+44t+12)}{32(t+1)(t^2+4t+2)}$
S6	$\frac{a(3t+2)}{8(t+1)}$	$\frac{a(5t^2+10t+4)}{8(t^2+4t+2)}$	$\frac{a^2(3t+2)^2}{16(t+1)(t^2+4t+2)}$	$\frac{a^2(5t^2+10t+4)^2}{32(t+1)(t^2+4t+2)^2}$	$\frac{a^2 \left(\begin{array}{l} 32t^5 + 201t^4 + 444t^3 \\ + 432t^2 + 192t + 32 \end{array} \right)}{64(t+1)(t^2+4t+2)^2}$
S7	$\frac{a(3t+2)}{6(t+1)}$	$\frac{a(3t^2+7t+3)}{6(t^2+4t+2)}$	$\frac{a^2(3t+2)^2}{18(t+1)(t^2+4t+2)}$	$\frac{a^2(3t^2+7t+3)^2}{36(t+1)(t^2+4t+2)^2}$	$\frac{a^2(18t^3+63t^2+60t+17)}{36(t+1)(t^2+4t+2)}$
S8	$\frac{a(4t+3)}{12(t+1)}$	$\frac{a(8t^2+15t+6)}{6(2t^2+6t+3)}$	$\frac{a^2(4t+3)^2}{24(t+1)(2t^2+6t+3)}$	$\frac{a^2(8t^2+15t+6)^2}{36(t+1)(2t^2+6t+3)^2}$	$\frac{a^2 \left(\begin{array}{l} 288t^5 + 1552t^4 + 3120t^3 \\ + 2940t^2 + 1314t + 225 \end{array} \right)}{144(t+1)(2t^2+6t+3)^2}$

Note: The total supply chain profits, $\pi_{SC}^* = \pi_{M1}^* + \pi_{M2}^* + \pi_R^*$. For S0, $\pi_{SC}^* = a/2$.

supply chain. Thus, optimal retail price p_{ni}^* and retail margin m_{ni}^* refer to supplier i 's ($i = 1, 2$) products under structure (Sn). The following properties hold for $0 \leq t < \infty$:

$$p_{41}^* = p_{51}^* = p_{61}^* \geq p_{11}^* = p_{21}^* \geq p_{81}^* > p_{71}^* \geq p_{31}^* > p_{01}^* \quad (3.4.1)$$

$$p_{42}^* = p_{52}^* = p_{62}^* > p_{12}^* = p_{22}^* \geq p_{72}^* > p_{82}^* \geq p_{32}^* > p_{02}^* \quad (3.4.2)$$

$$m_{21}^* = m_{41}^* > m_{31}^* \geq m_{71}^* > m_{81}^* \geq m_{11}^* \geq m_{51}^* = m_{61}^* \quad (3.4.3)$$

$$m_{22}^* = m_{42}^* = m_{52}^* = m_{72}^* > m_{32}^* \geq m_{82}^* > m_{12}^* \geq m_{62}^*, \quad (3.4.4)$$

where equality in “ $\geq$ ” holds only when $t = 0$.

(3.4.1) and (3.4.2) indicate that all three-tier power structures lead to the same highest retail prices for both products, while the supplier power-balanced two-tier structures (S1) and (S2) have the same second highest retail prices for both suppliers. In contrast, when the three agents are power balanced, i.e., (S3), retail prices are the lowest. Structures (S7) and (S8), where the two suppliers are power-imbalanced, the supplier having the same power level as the retailer obtains the lower retail price.

Interestingly, whenever the retailer has power advantage over a supplier, she will charge the same highest retail margin (i.e., $a/2$) while those suppliers that dominate (or power-balanced with) the retailer will be charged less than $a/2$. This is evident in results for structures (S2), (S4), (S5), and (S7).

When the two suppliers are power imbalanced, i.e., structures (S4)-(S8), as follows from Table 3.1,

$$p_{41}^* \geq p_{42}^*, p_{51}^* \geq p_{52}^*, p_{61}^* \geq p_{62}^*, p_{71}^* < p_{72}^*, \text{ and } p_{81}^* > p_{82}^* \quad (3.4.5)$$

$$m_{41}^* = m_{42}^*, m_{51}^* < m_{52}^*, m_{61}^* \leq m_{62}^*, m_{71}^* < m_{72}^*, \text{ and } m_{81}^* < m_{82}^*. \quad (3.4.6)$$

Thus, the more powerful supplier's products command a higher retail price than those of the weaker supplier in all of the imbalanced structures except (S7), where the retailer and supplier 1 equally dominate supplier 2. In terms of retail margins, the retailer charges higher margins from supplier 2 than from supplier 1 unanimously, except in (S4) where the retailer acts as the leader of both suppliers and charges the same margin.

3.4.2 Wholesale Prices and Order Quantities

Similar to the analysis of (S4) in Section 3.3, it can be shown that the wholesale prices decrease in t for all eight structures.

Proposition 3.4: *In structures (S1)-(S8), both suppliers' wholesale prices monotonically decrease in t and they are asymptotic to the production costs as products approach perfect substitution, i.e., $t \rightarrow \infty$.*

For each power-imbalanced structure, for $0 \leq t < \infty$,

$$w_{41}^* \geq w_{42}^*, w_{51}^* \geq w_{52}^*, w_{61}^* \geq w_{62}^*, w_{71}^* > w_{72}^*, \text{ and } w_{81}^* > w_{82}^*, \quad (3.4.7)$$

where equality in “ $\geq$ ” holds when $t = 0$. That is, the more powerful supplier charges a higher wholesale price in all structures where suppliers are power imbalanced. However, the order quantities have the following property:

Proposition 3.5: *In structures (S1)-(S8), both suppliers' production quantities monotonically increase in t .*

Under an integrated system, the optimal order quantity is $a/2$ for each product type. For the eight structures of the supply chain in Figure 3.1, it can be shown that as

product substitution becomes perfect ($t \rightarrow \infty$), only in (S1), (S2), (S3), and (S7) that the optimal quantity reaches $a/2$ for each product type. However, for all remaining structures (S4), (S5), (S6), and (S8), supplier 1 obtains a lower order quantity (while supplier 2 obtains a higher order quantity) than $a/2$ under perfect product substitution. In the case of independent products, i.e., $t = 0$, all eight structures result in order quantities smaller than $a/2$ for either product type.

Furthermore, for $0 \leq t < \infty$, it turns out that the order quantities when suppliers are power imbalanced follow the relations

$$q_{41}^* \leq q_{42}^*, q_{51}^* \leq q_{52}^*, q_{61}^* \leq q_{62}^*, q_{71}^* > q_{72}^*, \text{ and } q_{81}^* < q_{82}^*. \quad (3.4.8)$$

The equality of “ $\leq$ ” in (3.4.8) holds only when $t = 0$. Note that supplier 2 delivers more quantity than supplier 1 in all of the imbalanced structures, except (S7) where the more powerful supplier is power balanced with the retailer, formally stated as:

Proposition 3.6: *When two power-imbalanced suppliers sell through a common retailer, the small supplier captures more market share (more products sold) than the large supplier except when the larger supplier is power balanced with the retailer.*

3.5 Supply Chain Performance Analysis

In this section, we focus on how the supply chain profits are allocated by agent type or the product type under different power-imbalanced SC decision hierarchies. We employ both absolute, as well as relative, dollar profits allocations. The following result holds for absolute dollar profits.

Proposition 3.7: *Both suppliers' profits monotonically decrease, while the retailer's profit increases as the degree of product substitution t increases. Moreover, the total supply chain profit monotonically increases in t . When the two products are completely substitutable, i.e., $t \rightarrow \infty$, the retailer captures the entire supply chain profit, which thus coincides with the case of an integrated supply chain coordinated by the retailer.*

Proof. Using the equilibrium results in Table 3.2, these results can be proven in a straightforward manner. ■

The above result is consistent with those in Propositions 3.3 and 3.4, where both the retail prices and wholesale prices decrease in product substitution t in either product type. Proposition 3.7 explains why it is a common practice for a retailer to carry products from competitive suppliers regardless of her power position. By carrying multiple products from the same category to spur competition, the retailer improves her own profits, as well as the entire supply chain profits. When markets are highly competitive (hence t is sufficiently large), being a retailer proves to be more profitable than being a supplier, which thus justifies why large suppliers open retail outlets in addition to selling through external retailers.

3.5.1 Supply Chain Structure Dominance

Given the relative profit potential of each agent in different SC structures, we focus on whether certain decision structures can emerge dominant over the others. Identifying such dominating structures helps developing insight as to their economic stability. To this end, we define a certain weak form of dominance, termed PSD-criterion, or power sacrifice/splitting dominance, when agents are allowed to reconfigure themselves so as to

make a transition from one structure to another. “*Power-sacrifice*” refers to the case when an agent willingly moves to a lower tier, and “*power-splitting*” refers to an agent having a power-sharing agent who moves to a lower tier. In a structure transition, agents are allowed to move only towards a lower-tier direction. For instance, when (S7) emerges in a transition from (S8), M2 is subject to “power-sacrifice”, the retailer R is subject to “power-splitting”, and M1 is subject to a “power-sacrifice”.

Definition 3.1 (Dominance): *The structure (S_k) is said to PSD dominate structure (S_j) , denoted by $(S_k) \succ (S_j)$, if and only if every agent who is subject to “power-sacrifice” or “power-splitting” in the transition from (S_j) to (S_k) is better-off in structure (S_k) compared to structure (S_j) , for $j, k = 1, \dots, 8$.*

In applying the PSD criterion, an agent is assumed “better-off” if his/her profit increases. Thus, in the previous example of structure transition from (S8) to (S7), all three agents must be better off in (S7) compared to (S8) in order for $(S7) \succ (S8)$ to hold. Notice that PSD may also be applied under different metrics such as relative profit or percentage supply chain profit allocation. However, the focus here is on absolute profits. Furthermore, we define a structure to be *stable* as follows:

Definition 3.2 (Stability): *Structure (S_k) is said to be a “stable structure” if and only if $(S_j) \not\succ (S_k)$, $j = 1, \dots, 8$, $j \neq k$.*

The complete set of PSD dominance relationships as well as stability results are presented in the following theorem.

Theorem 3.1:

- i) $(S6) \succ (S1)$ for $0 \leq t < \infty$, and $(Sj) \nprec (S1)$, $j \neq 6$, for $t \geq 0$. Moreover, $(S6) \nprec (Sj)$, $j \neq 1$, for all $t \geq 0$.
- ii) $(S4) \succ (S2)$ for $0 \leq t < \infty$, and $(Sj) \nprec (S2)$, $j \neq 4$, for $t \geq 0$. Moreover, $(S4) \nprec (Sj)$, $j \neq 2$, for all $t \geq 0$.
- iii) $(S3) \succ (S4)$ for $1.47 \leq t \leq 11.59$, and $(Sj) \nprec (S4)$, $j \neq 3$, for $t \geq 0$. Also, $(S3) \nprec (Sj)$, $j \neq 4$, for all $t \geq 0$.
- iv) $(S8) \succ (S5)$ for $t > 0.92$, and $(Sj) \nprec (S5)$, $j \neq 8$, for $t \geq 0$. Moreover, $(S8) \nprec (Sj)$, $j \neq 5$, for all $t \geq 0$.
- v) Structures $(S3)$, $(S6)$, $(S7)$, and $(S8)$ are stable for $0 \leq t < \infty$; structure $(S4)$ is stable for $t \notin [1.47, 11.59]$; moreover, structure $(S5)$ is stable for $0 \leq t < 0.92$.

Proof. (i): Transition $(S1) \rightarrow (S6)$ involves M1 subject to power-splitting and M2 subject to power-sacrifice, and both M1 and M2 are better off in this transition, for $0 \leq t < \infty$, and thus, $(S6) \succ (S1)$ holds. Furthermore, the transition $(S1) \rightarrow (Sj)$, $j \neq 6$, $\forall t$, cannot assure that all involved agents are better off, and thus, $(Sj) \nprec (S1)$, $j \neq 6$, $\forall t$. Similarly, transition $(Sj) \rightarrow (S6)$, $j \neq 1$, $\forall t$, cannot assure that all involved agents are better off, which implies $(S6) \nprec (Sj)$, $j \neq 1$, $\forall t$.

Claims (ii), (iii), and (iv) can be proven analogously.

For claim (v), any transition from structures $(S3)$, $(S6)$, $(S7)$, or $(S8)$ to other structures cannot assure all agents with power-sacrifice and/or power-splitting are better off, and thus, these structures remain stable for $0 \leq t < \infty$. As shown in (iii), $(S3)$ PSD-

dominates (S4) for $1.47 \leq t \leq 11.59$, while no other structure PSD-dominates (S4). Therefore, structure (S4) is stable for $t \notin [1.47, 11.59]$. Using (iv), it also follows that (S5) is stable for $0 \leq t \leq 0.92$. ■

When suppliers are power-balanced as in (S1) or (S2), it is more profitable for the suppliers to re-align themselves as if they are power-imbalanced (S6 or S4, respectively) since $(S6) > (S1)$ and $(S4) > (S2)$, see Theorem 1, i.e., (S1) and (S2) are not stable structures. This finding is consistent with the empirical studies, for instance, Kadiyali et al. (2000), where the authors claim that there is difficulty in supporting the existence of SC structures (S1) and (S2) when real-world data is used.

According to Theorem 3.1, (S4) is stable only for sufficiently low levels or high levels of product substitution, while (S5) is stable only when t is sufficiently small. Thus, it appears that as product competition intensifies under (S4), the retailer and the powerful supplier are better off by moving to (S3); however, if the competition is allowed to escalate to sufficiently high levels (i.e., $t > 11.59$), the stronger supplier will become worse off compared to staying under (S4). Considering $(S4) > (S2)$ for $t > 0$, and since $(S3) > (S4)$ for $t \in [1.47, 11.59]$, it can be concluded that for relatively fair competition, a dominant retailer (as in S2) would be willing to let the power advantage vanish and share equal power with both suppliers as in (S3).

3.5.2 Supply Chain Profit Allocation

As it develops, the more powerful agent may not make the most profit in the case of a power imbalanced supply chain. Figure 3.2 depicts the case for the two suppliers, where the relative profit allocation is plotted against the product substitution (competition) over different structures. It is evident that the two suppliers achieve supply chain profit quite unevenly. Notably, the weaker supplier reaps more profit in structures (S4) and (S6) for $t > 0$, and in (S8) for $t > t^* (= \sqrt{3}/8)$. Only in (S5), (S7), or in (S8) under sufficiently low levels of substitution, the stronger supplier commands a higher profit relative to the weaker supplier. Also note that an even allocation of profits between the two suppliers is not possible under any of the power-imbalanced scenarios, provided product substitution is significant.

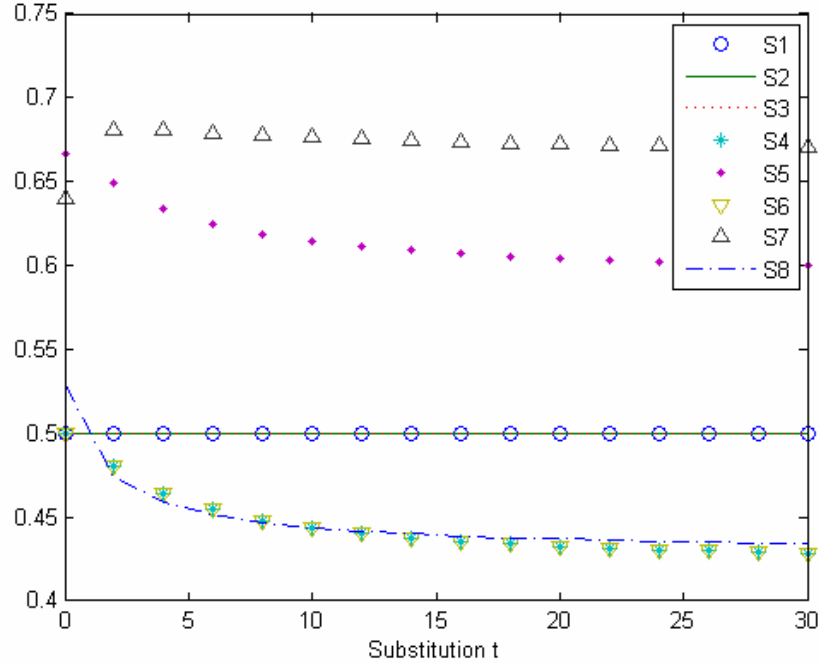


Figure 3.2: $\pi_{M1}^* / (\pi_{M1}^* + \pi_{M2}^*)$

As for the retailer's profit, as shown in Figure 3.3, the retailer enjoys a larger fraction of the supply chain profits as substitution increases while suppliers are left with increasingly smaller percentage of the supply chain profits across all structures. However, at very low level of product competition, the retailer surrenders this profit superiority over the suppliers in structures (S1), (S6), and (S8), where the retailer's decision power is the weakest.

Which supplier's products contribute the most to the supply chain profits? This question is addressed in Figure 3.4. For supplier-power-balanced structures such as (S1), (S2), and (S3), both product lines equally contribute to supply chain profits. However, under power imbalance in suppliers, it is evident from Figure 3.4 that products from the

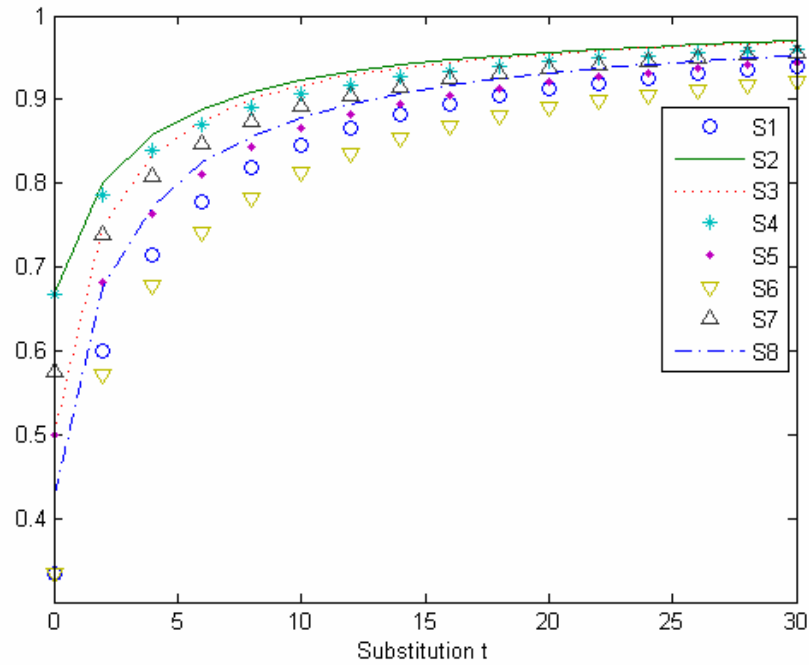


Figure 3.3: π_R^* / π_{SC}^*

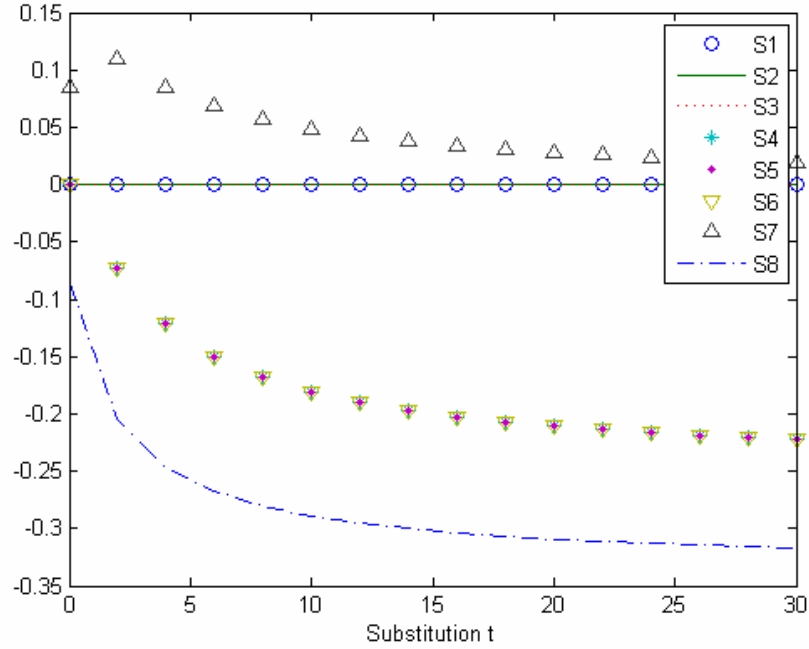


Figure 3.4: $(\pi_{SC1}^* - \pi_{SC2}^*) / \pi_{SC}^*$

weaker supplier are responsible for most profits, and that contribution increases with product substitution for all structures except (S7). In (S7), nevertheless, the additional contribution from the products of the more powerful supplier diminishes and equalizes with that of the weaker supplier when substitution is increased significantly.

Although the weaker supplier's products are responsible for most profits in the supply chain, as Figure 3.5 illustrates, the weaker supplier retains only a smaller percentage of those profits compared to the powerful supplier. This is indeed true across all structures, with (S5) having the highest disparity in profit sharing for the weak supplier. As competition increases, however, such disparities begin to disappear. Thus, the following characterization holds:

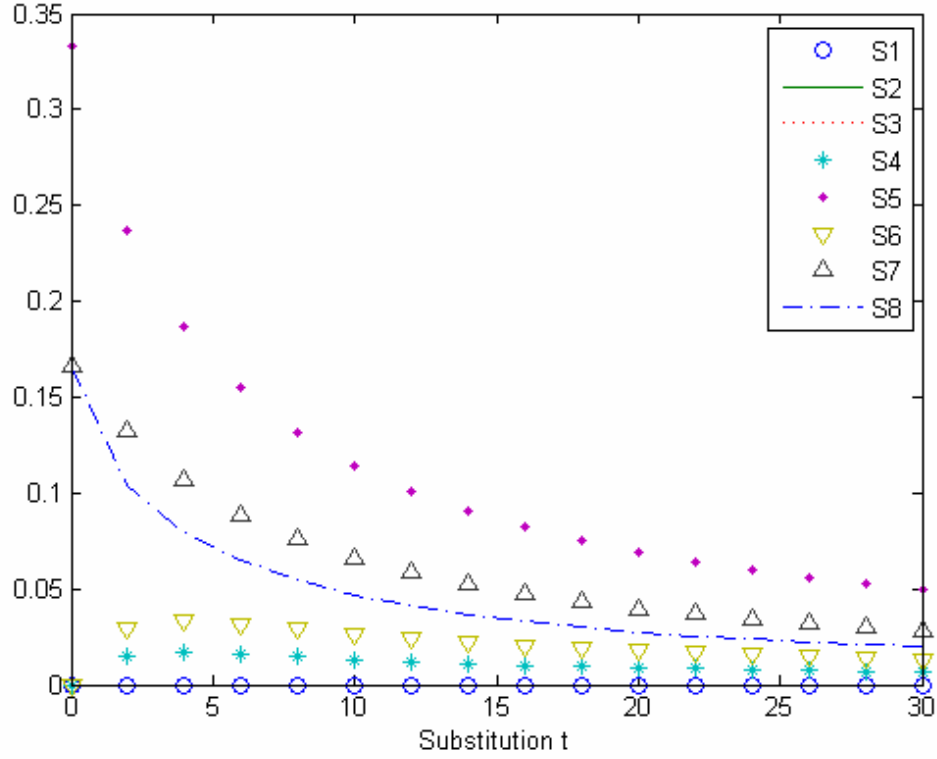


Figure 3.5: $\pi_{M1}^* / \pi_{SC1}^* - \pi_{M2}^* / \pi_{SC2}^*$

Proposition 3.8: *The relative power advantage of a supplier (over the other supplier) allows him to retain a higher percentage of the profit generated by his/her own products (in the supply chain) consistently at all levels of product substitution and in all supply chain structures.*

While the individual agents in a supply chain could be better/worse-off under power imbalance, the supply chain as a whole can benefit under certain power balanced structures. It can be shown for $t > 0$ that

$$\pi_{SC3}^* > \pi_{SC7}^* > \pi_{SC8}^* > \pi_{SC1}^* = \pi_{SC2}^* > \pi_{SC4}^* = \pi_{SC5}^* = \pi_{SC6}^*, \quad (3.5.1)$$

which implies that the most power-imbalanced structures generate the lowest total profits for the supply chain. In contrast, when suppliers are offering independent products, i.e., $t=0$,

$$\pi_{SC3}^* > \pi_{SC7}^* = \pi_{SC8}^* > \pi_{SC1}^* = \pi_{SC2}^* = \pi_{SC4}^* = \pi_{SC5}^* = \pi_{SC6}^* \quad (3.5.2)$$

holds, and thus, supplier power imbalances may not necessarily degrade the supply chain total profits.

3.6 Conclusions and Discussions

In this chapter a two-supplier-one-retailer supply chain was investigated when suppliers have unequal decision-making power, thus allowing one supplier to become a Stackelberg leader over the other supplier. This consideration results in a set of eight different channel structures, of which five have not been studied in the literature. We model such situations as either two-stage or three-stage Bertrand Stackelberg hierarchies, or one-stage non-cooperative games. Using a linear deterministic demand model that allows for product substitution effects, we investigate important questions such as supply chain performance, effects of product substitution, and structure dominance and stability.

Most notably, the following conclusions are reached: (i) A multiple-supplier-one-retailer supply chain performs as an integrated system when the degree of product substitution is sufficiently large, (ii) The suppliers' profits consistently decrease when products become more substitutable, even if suppliers dominate the retailer. The retailer benefits from a high degree of substitution in all possible structures, (iii) In a two-supplier-one-retailer supply chain, a small (niche) supplier may achieve more profit than

a large supplier, (iv) “Absolute profits” cannot reflect the power structure of the multi-supplier supply chain. However, “profit percentage” of each agent can represent the relative power differences more accurately. (v) Certain supply chain structures are dominant over the others, which implies that the relevant agents are better-off in making a transition to dominating channel decision structure. Moreover, there exist channel structures that exhibit stability in that a structure transition is not likely to occur so long as agents are profit maximizers. In this context, both the Manufacturer-Stackelberg (S1) and the Retailer-Stackelberg (S2) structures (Choi, 1991) do not exhibit stability.

Relatively small suppliers are, in general, regarded as underdogs in sharing profits in the supply chain. However, the present analysis reveals that a small supplier may even achieve more profit than the relatively large supplier, which provides one explanation why niche suppliers thrive in markets that are dominated by giant suppliers. Empirical studies based upon power-balanced supplier structures indicate certain inconsistency between the theoretical models and observed real data, and in this context, our study offers a realistic alternative viewpoint.

One limitation of the analysis in this chapter is the assumption of a linear deterministic demand model, which essentially simplified the analysis resulting in closed-form statistics. Under the first three structures of Figure 3.1, Choi (1991) shows that derivation of closed-form results is analytically challenging when certain forms of nonlinear demand models are used. Furthermore, unique Nash equilibrium is no longer guaranteed in those cases. Our future research will address these issues.

Chapter 4:

Supply Chain Coordination with Revenue-Sharing Contracts when Retailer Sells Store-Brand Products

4.1 Introduction

Store brands, or private labels, are those for which a retailer has control in pricing, stocking, shelf placement, and marketing promotions. Store brands have emerged as important sources of profits and have fostered better negotiation positions for the retailer with outside suppliers. Therefore, store brands have seen substantial inroads in a variety of product categories and have resulted in significant growth over the years. ACNielsen Inc. (2005)¹ recently released its annual investigation on store brands across 38 countries and 80 product categories, where it is stated that store-brand products represent a 17% value-sales share and a 5% growth over the previous year. In particular, the North American store brands had a share of 16%, and its growth was even more significant at 7%.

Academic research on the subject of store brands has also gained considerable attention. For example, Cotterill et al. (2000) investigate the relationship between the store-brand market share and influences such as pricing behaviors, retail concentration, and cross-price elasticity; Hoch and Banerji (1993) discuss factors such as quality, advertising, and price discounts that affect store-brand success; Raju et al. (1995)

¹ We appreciate the permission of ACNielsen to cite the data.

investigate the impact of competition on the introduction and performance of store brands; Chintagunta et al. (2002) and Pauwels and Srinivasan (2004) offer studies on the effect of store-brand entry; Sayman et al. (2002) and Morton and Zettelmeyer (2004) study strategies for store-brand positioning in the retailer-manufacturer negotiations; Mills (1995) and Narasimhan and Wilcox (1998) examine the role of store brands in transaction negotiations, for instance.

However, the existing literature primarily focuses on identifying and evaluating factors, as supported by empirical evidence, which influence the store-brand market share and the incentives on store brands. Furthermore, many such studies assume a wholesale-price contractual arrangement between the outside suppliers and retailers, i.e., retailers pay a wholesale unit price to suppliers and keep all the sales revenues. To the best of our knowledge, academic literature on does not consider using contracts for coordination in supply chains involving store-brands. A supply chain is said to be coordinated if individual decisions turn out to be optimal for the supply chain as a whole. This chapter addresses the question of coordination under the application of revenue-sharing contracts by which the retailers commit to share the sales revenue with the suppliers. Revenue-sharing contracts have seen significant applications in practice. For instance, (outside) suppliers such as Pepsi and Coca-Cola pay lump-sum fees to Wal-Mart for using shelf space, and they are compensated with certain percentages of sales revenues from their products. Consequently, the presence of store brands can significantly affect the supplier-retailer interactions, and thus, such effects deserve in-depth analysis.

Revenue-sharing contracts are common in many applications, e.g., video rental industry (Cachon and Lariviere 2005, Dana and Spier 2001), assembly systems (Gerchak

and Wang 2004), and E-Commerce (Wang et al. 2005). Cachon and Lariviere (2005) show that revenue-sharing is a possible contractual agreement for supply chain coordination. See Cachon (2003), Lariviere (1999), and Sahin & Robinson (2002) for excellent reviews on various mechanisms for coordination.

Besides the interaction between store brands and non-store brands, channel interactions have been studied in terms of the number of agents involved. For instance, for the case of one supplier and one retailer, Jeuland and Shugan (1983) and Moorthy (1987) investigate channel coordination under “quantity discounts”. With two suppliers and one retailer, Choi (1991) studies supplier-retailer interactions under different decision-making power structures, and starting from that, Kadiyali et al (2000) consider a certain generalization of Choi’s power models to measure supplier-retailer interactions in which supplier-supplier interactions are subsumed. Given a channel with one supplier and two retailers, Ingene and Parry (1995) consider coordination with “quantity discounts” and “two-part tariff”. With two suppliers and two retailers, McGuire and Staelin (1983) study agents’ pricing strategies for exclusive dealership structures where each retailer carries only products from one supplier. In this context, Moorthy (1988) answers the question, “why strategic interaction among suppliers makes it possible for decentralization to be a Nash equilibrium strategy.” Choi (1996) and Trivedi (1998) both consider agents’ pricing interactions when retailers carry products from both suppliers; Lee and Staelin (1997) study the value of Stackelberg pricing leadership within the concept of “vertical strategic interaction” under different channel structures.

In this chapter, we investigate channel interactions when the retailer carries both the national-brand and store-brand products. Assuming the retailer has more bargaining

power in the supply chain, we model the situation as a Stackelberg game under a revenue-sharing contract.

This study shows that a two-parameter revenue-sharing contract in which the retailer pays a wholesale unit price, along with a certain percentage of sales revenue to the supplier, can allocate the supply chain profit flexibly by adjusting the revenue-sharing rate. In contrast, the profit division under a (usual) wholesale-price contract, or a one-parameter revenue-sharing contract, is uniquely determined in terms of the relative demand functions and production costs. A one-parameter revenue-sharing contract refers to the case when the only contractual parameter is the percentage of sales revenue paid by the retailer to the supplier.

It follows that when the revenue-sharing rate is fixed, the retailer will let the supplier determine his retail price and make decisions to optimize her own profit function, i.e., *non-coordinating decision*. When the supplier specifies his wholesale price, a non-coordinating wholesale-price contract is the optimal choice for the retailer. It is also shown that when the supplier determines his retail price, and when the retailer can specify both the wholesale-price and the revenue-sharing rate, the retailer's *coordinating decisions* lead to Pareto improvement in contrast to her non-coordinating decisions.

The remainder of the chapter is organized as follows: Section 4.2 presents the model assumptions; Section 4.3 offers the integrated system as a benchmark; two scenarios for the revenue-sharing contract implementation are discussed in Sections 4.4 and 4.5; Section 4.6 discusses the agents' performance and decision strategies; Conclusions are in Section 4.7.

4.2 Model Assumptions

Consider a one-supplier/manufacturer-one-retailer supply chain within a single business season. The outside supplier sells national-brand products through a large retailer, and is paid with a wholesale unit price, along with a certain percentage of retailer's revenue from his products. The outside retail price and wholesale price can be determined by either the supplier or the retailer, while the revenue-sharing rate is determined based upon negotiation. Besides carrying outside products, the retailer also sells her store-brand products and determines that retail price by herself. We assume the store-brand products are produced from an integrated system managed by the retailer, thus ignoring the dynamics involving the retailer and any suppliers of the store-brand products. We consider two decision scenarios, S1 and S2, for analysis:

- i. **Scenario (S1):** The retailer determines the outside (product) wholesale price as well as the retail price for the store-brand product, while the supplier chooses the retail price for his own products.
- ii. **Scenario (S2):** The retailer determines the outside retail price and the retail price of store brands, while the supplier chooses his own wholesale price.

In each scenario, the outside supplier makes decisions to maximize his own profits, while the retailer has the option of either maximizing the total supply chain profits (termed a coordinating decision), or optimizing her own profits (termed a non-coordinating decision). Given the assumption that the retailer has more decision power (than the outside supplier), the retailer is assumed to play the role of Stackelberg leadership.

Therefore, under S1, the retailer first issues the store-brand retail price (p_0) and the wholesale price (w), and then, the outside supplier follows with his retail price (p_1). On the other hand, under S2, the retailer first determines p_0 and p_1 , and then the supplier follows with his decision w . The following additional notation is employed throughout the chapter.

π_{SC} : Supply chain profit,

π_M : Outside supplier profit,

π_R : Retailer profit,

q_0 : Retailer store-brand product demand,

q_1 : Outside product demand,

r : Revenue-sharing rate for outside product and $0 \leq r \leq 1$,

c_0 : Store-brand production cost ($c_0 \leq p_0$),

c_1 : Outside production cost ($c_1 \leq p_1$).

It is assumed that the information is symmetric across the supply chain, the store-brand and national-brand products are substitutable, and both product demands are linear deterministic in prices. In particular, the two products are assumed to have the following format for their demand functions:

$$q_0 = a_0 - b_0 p_0 + t p_1 \quad (4.2.1)$$

$$q_1 = a_1 - b_1 p_1 + t p_0 \quad (4.2.2)$$

where a_0 and a_1 represent “market bases” of the two products, i.e., the demand if all prices are set to zero, which thus describe customer brand loyalty of each product type;

b_0 and b_1 measure the demand sensitivity on relative retail prices; t indicates the degree of product substitution or competition, where a larger t represents a higher degree of substitution (higher product competition). It is necessary that all demand parameters are nonnegative, i.e., $a_0, a_1, b_0, b_1, t \geq 0$, and $t \leq \min\{b_0, b_1\}$ for demands to be well-behaved, see Ingene and Parry (1995). We further assume that $a_i - b_i p_i \geq 0$, for $i = 0, 1$, which indicates that demands are positive even when there is no competition ($t=0$).

The profit functions are then given by,

$$\pi_{SC} = (p_0 - c_0)q_0 + (p_1 - c_1)q_1 \quad (4.2.3)$$

$$\pi_M = ((1-r)p_1 + w - c_1)q_1 \quad (4.2.4)$$

$$\pi_R = (rp_1 - w)q_1 + (p_0 - c_0)q_0 \quad (4.2.5)$$

4.3 Integrated System

We first obtain the optimal results for an integrated (or centrally coordinated) system in which one agent makes decisions for the entire supply chain. We use these results as benchmarks for performance comparison with the corresponding decentralized supply chain, where each agent makes decisions independently (in a hierarchical manner). For a decentralized supply chain, if the individual decisions lead to the same optimal performance of the integrated system, then the decentralized supply chain is said to be coordinated.

The integrated-system profit π_{SC} is thus a function of the two retail prices p_0 and p_1 , and the first order partial derivatives are

$$\frac{\partial \pi_{SC}}{\partial p_0} = a_0 + b_0 c_0 - t c_1 - 2b_0 p_0 + 2t p_1, \quad \frac{\partial \pi_{SC}}{\partial p_1} = a_1 - t c_0 + b_1 c_1 - 2b_1 p_1 + 2t p_0, \quad (4.3.1)$$

and the second order partial derivatives are

$$\frac{\partial^2 \pi_{SC}}{\partial p_0^2} = -2b_0 < 0, \quad \frac{\partial^2 \pi_{SC}}{\partial p_1^2} = -2b_1 < 0, \quad \text{and} \quad \frac{\partial^2 \pi_{SC}}{\partial p_0 \partial p_1} = 2t. \quad (4.3.2)$$

The determinant of the Hessian matrix,

$$\begin{vmatrix} \frac{\partial^2 \pi_{SC}}{\partial p_0^2} & \frac{\partial^2 \pi_{SC}}{\partial p_0 \partial p_1} \\ \frac{\partial^2 \pi_{SC}}{\partial p_0 \partial p_1} & \frac{\partial^2 \pi_{SC}}{\partial p_1^2} \end{vmatrix} = 4b_0 b_1 - 4t^2 > 0,$$

since $t \leq \min\{b_0, b_1\}$, which guarantees a unique solution to the problem: $\max_{p_0, p_1} \pi_{SC}$.

Setting the gradient of $\pi_{SC} = 0$, the first order conditions yield

$$p_{0(I)}^* = \frac{1}{2}c_0 + \frac{a_1 t + a_0 b_1}{2(b_0 b_1 - t^2)}, \quad p_{1(I)}^* = \frac{1}{2}c_1 + \frac{a_0 t + a_1 b_0}{2(b_0 b_1 - t^2)}, \quad (4.3.3)$$

and substituting (4.3.3) in (4.2.1) and (4.2.2), we have

$$q_{0(I)}^* = \frac{1}{2}(a_0 - b_0 c_0 + t c_1), \quad q_{1(I)}^* = \frac{1}{2}(a_1 - b_1 c_1 + t c_0), \quad (4.3.4)$$

where $p_{0(I)}^*$ and $q_{0(I)}^*$, and $p_{1(I)}^*$ and $q_{1(I)}^*$ represent the optimal store-brand retail price and order quantity, and outside retail price and order quantity, respectively, for the integrated-system, whose total maximized supply chain profit

$$\pi_{SC(I)}^* = p_{0(I)}^* q_{0(I)}^* + p_{1(I)}^* q_{1(I)}^*.$$

The optimal retail prices consist of corresponding production costs and parameters of both demand functions. Also, note that

$$\frac{\partial p_{0(I)}^*}{\partial b_0} = -\frac{b_1(a_1t + a_0b_1)}{2(b_0b_1 - t^2)^2} < 0, \quad \frac{\partial p_{0(I)}^*}{\partial b_1} = -\frac{t(a_0t + a_1b_0)}{2(b_0b_1 - t^2)^2} < 0, \quad (4.3.5)$$

$$\frac{\partial p_{1(I)}^*}{\partial b_0} = -\frac{t(a_1t + a_0b_1)}{2(b_0b_1 - t^2)^2} < 0, \quad \frac{\partial p_{1(I)}^*}{\partial b_1} = -\frac{b_0(a_0t + a_1b_0)}{2(b_0b_1 - t^2)^2} < 0, \quad (4.3.6)$$

$$\frac{\partial p_{0(I)}^*}{\partial t} = \frac{a_1t^2 + a_1b_0b_1 + 2a_0b_1t}{2(b_0b_1 - t^2)^2} > 0, \quad \frac{\partial p_{1(I)}^*}{\partial t} = \frac{a_0t^2 + a_0b_0b_1 + 2a_1b_0t}{2(b_0b_1 - t^2)^2} > 0, \quad (4.3.7)$$

$$\frac{\partial \pi_{SC(I)}^*}{\partial c_0} = -\frac{1}{2}(a_0 - b_0c_0) - \frac{1}{2}tc_1 < 0, \quad \frac{\partial \pi_{SC(I)}^*}{\partial c_1} = \frac{1}{2}[b_1c_1 - a_1 - c_0t] < 0. \quad (4.3.8)$$

Proposition 4.3.1: *The following hold for the integrated system at the optimum:*

- (a) *Both retail prices are increasing in the corresponding production costs; both order quantities are decreasing in the corresponding production costs and increasing in the competitor's production costs.*
- (b) *Retail prices are increasing in the market bases (a_0, a_1) and the degree of product substitution t ; also, retail prices decrease with increasing b_0 and b_1 .*
- (c) *The total supply chain profit decreases in production costs c_0 and c_1 .*

4.4 Revenue-Sharing Contracts under Scenario (S1)

Under S1, with a two-parameter revenue-sharing contract, the retailer chooses the wholesale price as well as the store-brand retail price, and the outside supplier specifies his own retail price. The outside supplier's profit maximization decision is conditional on the revenue-sharing rate and the retailer's decisions (p_0, w) . Therefore, we first solve the outside supplier's problem: $\max_{p_1} \pi_M$, which yields

$$\frac{d\pi_M(p_0, p_1, r, w)}{dp_1} = t(1-r)p_0 - 2b_1(1-r)p_1 - b_1w + a_1 + b_1c_1, \quad (4.4.1)$$

and setting $d\pi_M(p_0, p_1, r, w)/dp_1=0$,

$$p_1^* = \frac{(1-r)(a_1 + tp_0) + b_1(w - c_1)}{2b_1(1-r)}. \quad (4.4.2)$$

Since $d^2\pi_M/dp_1^2 = -2(1-r)b_1 < 0$, p_1^* in (4.4.2) solves the outsider's problem.

4.4.1 The Case of Retailer Non-Coordinating Decisions (RNCD) under S1

In a non-coordinating decision framework, the retailer utilizes the supplier's (reaction) retail price function in (4.4.2) to choose both the wholesale price and the retail price for store-brand products such that her own profit function is maximized, i.e., $\max_{p_0, w} \pi_R$:

$$\frac{\partial \pi_R(p_1^*, r)}{\partial w} = \frac{b_1(w - c_1) + (1-r)(a_1 - tc_0 - a_1r - tp_0r + 2tp_0 + b_1w)}{-2(1-r)^2}, \quad (4.4.3)$$

$$\begin{aligned} \frac{\partial \pi_R(p_1^*, r)}{\partial p_0} &= r^2(a_1t + t^2p_0) + r(2a_0b_1 + 2b_0b_1c_0 + t^2p_0 - c_0t^2 - tb_1w - 4b_0b_1p_0) \\ &\quad + (c_0t^2 + 2b_1wt + 4b_0b_1p_0 - a_1t - tb_1c_1 - 2t^2p_0 - 2b_0b_1c_0 - 2a_0b_1) \end{aligned} \quad (4.4.4)$$

The second order partial derivatives are

$$\frac{\partial^2 \pi_R}{\partial w^2} = \frac{b(2-r)}{-2(1-r)^2} < 0, \quad \frac{\partial^2 \pi_R}{\partial p_0^2} = \frac{rt^2 + 2t^2 - 4b_0b_1}{2b_1} \leq 0, \quad \text{and} \quad \frac{\partial^2 \pi_R}{\partial w \partial p_0} = \frac{(r-2)t}{2(1-r)}, \quad (4.4.5)$$

and thus, the determinant of the Hessian matrix,

$$\begin{vmatrix} \frac{\partial^2 \pi_R}{\partial w^2} & \frac{\partial^2 \pi_R}{\partial w \partial p_0} \\ \frac{\partial^2 \pi_R}{\partial w \partial p_0} & \frac{\partial^2 \pi_R}{\partial p_0^2} \end{vmatrix} = \frac{(2-r)(b_0b_1 - t^2)}{(1-r)^2} > 0,$$

which ensures that the first order solutions jointly maximize the retailer's profit function.

That is,

$$p_{0(S1,NC)}^* = \frac{1}{2}c_0 + \frac{a_1t + a_0b_1}{2(b_0b_1 - t^2)}, \quad (4.4.6)$$

$$w_{(S1,NC)}^* = \frac{(A - 2C)r^2 + (4C - A)r + (Bc_1 - 2C)}{(2 - r)B}, \quad (4.4.7)$$

where $A = a_0b_1t + a_1t^2 + c_0t^3 - b_0b_1c_0t$, $B = 2b_0b_1^2 - 2b_1t^2$, and $C = a_0b_1t + a_1b_0b_1$, and $A, B, C \geq 0$. In (4.4.6) and (4.4.7), the subscript pair (S1, NC) refers to the scenario S1, and that it is in a non-coordinating decision. Substituting $p_{0(S1,NC)}^*$ and $w_{(S1,NC)}^*$ in the outside retail price function (4.4.2) gives

$$p_{1(S1,NC)}^* = \frac{1}{B(2 - r)} \left\{ (A - 2C)r + (3C + \frac{B}{2}c_1 - A) \right\}. \quad (4.4.8)$$

Note that
$$\frac{dp_{1(S1,NC)}^*}{dr} = -\frac{a_1 - b_1c_1 + tc_0}{2b_1(r - 2)^2} < 0, \quad (4.4.9)$$

which implies that $r=1$ yields the lowest outside retail price under the case of RNCD, that

is, the smallest $p_{1(S1,NC)}^* = \frac{1}{2}c_1 + \frac{a_0t + a_1b_0}{2(b_0b_1 - t^2)}$, which is identical to the corresponding price

in the integrated system, see (4.3.3). Therefore, the retailer's non-coordinating decision increases the outside retail price in comparison to the integrated system. Meanwhile, the revenue-sharing contract reduces to a wholesale-price contract with $w_{(S1,NC)}^* = c_1$ when $r=1$. Also note that

$$\frac{dw_{(S1,NC)}^*}{dr} = \frac{a_0b_1t + 2a_1b_0b_1 - a_1t^2}{2b_1(b_0b_1 - t^2)} + \frac{b_1c_1 - a_1}{b_1(r - 2)^2} + \frac{tc_0(r^2 - 4r + 2)}{2b_1(r - 2)^2}, \quad (4.4.10)$$

and
$$\frac{d^2 w_{(S1,NC)}^*}{dr^2} = -\frac{2(a_1 - b_1 c_1 + c_0 t)}{b_1 (2-r)^3} < 0, \quad (4.4.11)$$

i.e.,
$$\frac{dw_{(S1,NC)}^*}{dr} = \frac{2b_1 c_1 (b_0 b_1 - t^2) + b_1 t (a_0 - b_0 c_0) + c_0 t^3}{2b_1 (b_0 b_1 - t^2)} > 0 \text{ when } r=1, \text{ which is the smallest}$$

value of (4.4.10). Therefore, $dw_{(S1,NC)}^*/dr > 0$ for $r \in [0,1]$, the non-coordinating wholesale price increases in the revenue-sharing rate.

When $r=0$ (thus, the outside supplier retains all sales revenue), it follows that $w_{(S1,NC)}^* < 0$, which implies that the retailer is paid a (wholesale) price of $|w_{(S1,NC)}^*| = [b_0(a_1 - b_1 c_1) + t^2 c_1 + a_0 t][2(b_0 b_1 - t^2)]^{-1}$, and $p_{1(S1,NC)}^* = (3C - 0.5Bc_1 - A)(2B)^{-1}$ in this case.

Under the retailer non-coordinating decision (RNCD) framework, the store-brand retail price (4.4.6) is identical to that of the integrated system, see (4.3.3), while the outside retail price decreases in r due to (4.4.9). The following relationships hold on order quantities.

Proposition 4.4.1: *When $0 \leq r < 1$ and under RNCD, $p_{1(S1,NC)}^* > p_{1(I)}^*$, $q_{0(S1,NC)}^* > q_{0(I)}^*$ and $q_{1(S1,NC)}^* < q_{1(I)}^*$ hold.*

Retailer non-coordinating decisions lead to the outside supplier delivering a quantity less than that of the corresponding integrated system, while the retailer delivers more store-brand products at all levels of product substitutability, which thus improves the retailer's market share. The outside supplier's profit in this case is

$$\pi_{M(S1,NC)}^* = \frac{1}{(r-2)^2} \frac{1-r}{4b_1} [a_1 - b_1 c_1 + t c_0]^2, \quad (4.4.12)$$

and thus
$$\frac{d\pi_{M(S1,NC)}^*}{dr} = \frac{r}{(r-2)^3} \frac{[a_1 - b_1c_1 + tc_0]^2}{4b_1} \leq 0, \quad (4.4.13)$$

which implies that under RNCD, the outside supplier achieves his maximum profit of $[a_1 - b_1c_1 + tc_0]^2 (16b_1)^{-1}$ when $r=0$.

The retailer pockets a profit of $\pi_{R_M(S1,NC)} = (rp_1 - w)q_1$ from outside products, and using the non-coordinating wholesale price and retail prices in (4.4.6)-(4.4.8), it can be shown that

$$\pi_{R_M(S1,NC)}^* = \frac{[a_1 - b_1c_1 + tc_0][a_1b_0 + a_0t + t^2c_0 - b_0b_1c_0]}{4(2-r)(b_0b_1 - t^2)} > 0, \quad (4.4.14)$$

i.e., the retailer profits from carrying the outside products for all $r \in [0,1]$.

Let $\pi_{R(S1,NC)}$ represent the retailer's total profit from selling both products, i.e.,

$$\pi_{R(S1,NC)}^* = (rp_1^* - w^*)q_1^* + (p_0^* - c_0)q_0^*. \text{ Then, for } r \in [0,1],$$

$$d\pi_{R(S1,NC)}^* / dr = [a_1 - b_1c_1 + tc_0]^2 (4b_1(r-2)^2)^{-1} > 0. \quad (4.4.15)$$

That is, an increasing revenue-sharing rate enhances the retailer's total profit. However, because $p_{0(S1,NC)}^*$ is independent of r , see (4.4.6), and an increasing r leads to a lower $p_{1(S1,NC)}^*$ as in (4.4.9), as well as a lower store-brand order quantity, a higher revenue-sharing rate undermines the store-brand's profitability.

4.4.2 The Case of Retailer Coordinating Decisions (RCD) under S1

Suppose the retailer makes decisions to optimize the total supply chain profit in an attempt to achieve coordination. Substituting p_1^* of (4.4.2) into the total channel profit

function π_{SC} in (4.2.3), the gradient expressions of π_{SC} are:

$$\frac{\partial \pi_{SC}(p_0, w)}{\partial w} = \frac{t(1-r)(c_0 - p_0) + b_1(c_1 r - w)}{2(1-r)^2}, \quad (4.4.16)$$

$$\text{and, } \frac{\partial \pi_{SC}(p_0, w)}{\partial p_0} = \frac{\left\{ r(2a_1 t + 3p_0 t^2 - c_0 t^2 + 2a_0 b_1 + 2b_0 b_1 c_0 - 4b_0 b_1 p_0 - b_1 c_1 t) \right\} + (c_0 t^2 - 3p_0 t^2 + 4b_0 b_1 p_0 - 2a_0 b_1 - 2b_0 b_1 c_0 + b_1 w t - 2a_1 t)}{2b_1(r-1)}. \quad (4.4.17)$$

The second order partial derivatives of π_{SC} are

$$\frac{\partial^2 \pi_{SC}(p_0, w)}{\partial p_0^2} = \frac{-4b_0 b_1 + 3t^2}{2b_1} < 0, \quad \frac{\partial^2 \pi_{SC}(p_0, w)}{\partial w^2} = \frac{-b_1}{2(1-r)^2} < 0, \quad (4.4.18)$$

and the determinant of the Hessian matrix is

$$\begin{vmatrix} \frac{\partial^2 \pi_{SC}}{\partial p_0^2} & \frac{\partial^2 \pi_{SC}}{\partial p_0 \partial w} \\ \frac{\partial^2 \pi_{SC}}{\partial p_0 \partial w} & \frac{\partial^2 \pi_{SC}}{\partial w^2} \end{vmatrix} = \frac{b_0 b_1 - t^2}{2(1-r)^2} > 0. \quad (4.4.19)$$

Therefore, the supply chain profit function is strictly concave in (p_0, w) for $0 \leq r < 1$.

Setting $\nabla \pi_{SC}(p_0, w) = 0$ yields

$$p_{0(S1,C)}^* = \frac{1}{2}c_0 + \frac{a_1 t + a_0 b_1}{2(b_0 b_1 - t^2)}, \quad (4.4.20)$$

$$\text{and } w_{(S1,C)}^* = \frac{1}{B}[(A + Bc_1)r - A], \quad (4.4.21)$$

Subscript S1 refers to the scenario and C refers to retailer's coordinating decision (RCD) framework. Observe that $p_{0(S1,C)}^*$ is identical to that of the integrated system.

Observe that the store-brand retail price is independent of revenue-sharing rate, see (4.4.20). In contrast, the wholesale price monotonically increases in r due to (4.4.21). As

such, the highest wholesale price under a “coordinating revenue-sharing” contract equals the outside supplier’s production cost. On the other hand, when $r=0$, $w_{(S1,C)}^* = -A/B \leq 0$, i.e., the supplier pays a wholesale price to the retailer for receiving all the sales revenue.

Substituting (4.4.20) and (4.4.21) back into the outside retail price in (4.4.2), we have

$$p_{1(S1,C)}^* = \frac{1}{2}c_1 + \frac{a_0t + a_1b_0}{2(b_0b_1 - t^2)}. \quad (4.4.22)$$

Optimal retail prices (4.4.20) and (4.4.22) are identical to those of the corresponding integrated system. That is,

Proposition 4.4.2: *When the retailer makes decisions to optimize the overall supply chain profits, the two-parameter revenue-sharing contract achieves coordination.*

Note that as $r \rightarrow 1$, the retailer attains all the sales revenue and the two-parameter revenue-sharing contract reduces to a wholesale-price contract, which leaves no profit for the supplier due to $w_{(S1,C)}^* = c_1$ in this case. Alternatively, if $r = A(A + Bc_1)^{-1}$, then $w_{(S1,C)}^* = 0$, i.e., the two-parameter revenue-sharing contract simplifies as a one-parameter revenue-sharing contract.

Proposition 4.4.3: *When the outside supplier determines his retail price, the wholesale-price contract cannot be used for coordination, and the one-parameter revenue-sharing rate is uniquely determined by the costs and demand parameters of both agents.*

For products ordered from the outside supplier,

$$\pi_{M(S1,C)}^* = [(1-r)p_{1(S1,C)}^* + w_{(S1,C)}^* - c_1]q_{1(S1,C)}^*, \quad (4.4.23)$$

and

$$\pi_{R-M(S1,C)}^* = (rp_{1(S1,C)}^* - w_{(S1,C)}^*)q_{1(S1,C)}^*, \quad (4.4.24)$$

where $\pi_{M(S1,C)}^*$ is the outside-supplier's profit, and $\pi_{R_M(S1,C)}^*$ is the retailer's profit from selling outside products. Noting (4.4.20)-(4.4.22), we have,

$$\pi_{M(S1,C)}^* = \frac{(1-r)[b_1c_1 - a_1 - c_0t]^2}{4b_1}, \quad (4.4.25)$$

$$\pi_{R_M(S1,C)}^* = \frac{\left([a_1 - b_1c_1 + c_0t] \{b_0b_1[a_1 - b_1c_1] + a_1t^2(1-r) + b_1t^2c_1 + c_0t^3(1-r) + b_1t(a_0 - b_0c_0)\} \right)}{4b_1(b_0b_1 - t^2)} > 0, \quad (4.4.26)$$

Letting $r = 0$,

$$\pi_{M(S1,C)}^* = \frac{[b_1c_1 - a_1 - c_0t]^2}{4b_1}, \quad \pi_{R_M(S1,C)}^* = \frac{[a_1 - b_1c_1 + c_0t][a_1t^2 + c_0t^3 + a_0b_1t - b_0b_1c_0t]}{4b_1(b_0b_1 - t^2)}. \quad (4.4.27)$$

That is, when the supplier captures all sales revenue from his products, the retailer still profits from outside products since $w_{(S1,C)}^* = -A/B \leq 0$ holds, that is, the supplier pays a unit price of A/B to the retailer. Therefore, the retailer can always profit from selling outside products when the supplier chooses the retail price. Also note that for the retailer's total profit $\pi_{R(S1,C)}^*$,

$$\frac{d\pi_{R(S1,C)}^*}{dr} = \frac{(a_1 - b_1c_1 + c_0t)^2}{4b_1} > 0, \quad (4.4.28)$$

i.e., a higher revenue-sharing rate increases the retailer's total profit.

4.5 Revenue-sharing Contracts under Scenario (S2)

Under the decision scenario (S2), the outside supplier chooses the wholesale price conditioned on his retail margin and the store-brand retail price, given that the retailer

specifies both retail prices. Let m be the retail margin of outside products, then $p_1 = w + m$ and $dp_1/dw = 1$, and the outside supplier's decision problem is, $\max_w \pi_M$, where

$$\pi_M = [(1-r)p_1 + w - c_1]q_1 = [(1-r)(w + m) + w - c_1][a_1 - b_1(w + m) + tp_0]. \quad (4.5.1)$$

The corresponding first-order and second-order conditions of the outside-supplier profit function are

$$\frac{d\pi_M(p_0, p_1)}{dw} = (1-r)(a_1 - b_1p_1 + tp_0) - b_1[(1-r)p_1 + w - c_1], \quad (4.5.2)$$

$$\frac{d\pi_M^2}{dw^2} = -2b_1(1-r) < 0. \quad (4.5.3)$$

Therefore, the first order solution leads to the unique optimal wholesale price

$$w^* = c_1 + \frac{a_1(2-r) - b_1p_1(3-2r) + tp_0(2-r)}{b_1}. \quad (4.5.4)$$

4.5.1 The Case of Retailer Non-Coordinating Decisions (RNCD) under S2

In the non-coordinating decision framework, the retailer chooses retail prices to optimize her own profit function, i.e., $\max_{p_0, p_1} \pi_R$. The second order conditions in this case are

$$\frac{\partial^2 \pi_R}{\partial p_0^2} = -2b_0 - \frac{2(2-r)t^2}{b_1} < 0, \quad \frac{\partial^2 \pi_R}{\partial p_1^2} = -2b_1(3-r) < 0, \quad \frac{\partial^2 \pi_R}{\partial p_0 \partial p_1} = 2t(3-r), \quad (4.5.5)$$

and the determinant of the Hessian matrix

$$\begin{vmatrix} \frac{\partial^2 \pi_R}{\partial p_0^2} & \frac{\partial^2 \pi_R}{\partial p_0 \partial p_1} \\ \frac{\partial^2 \pi_R}{\partial p_0 \partial p_1} & \frac{\partial^2 \pi_R}{\partial p_1^2} \end{vmatrix} = 4(3-r)(b_0b_1 - t^2) > 0. \quad (4.5.6)$$

That is, the retailer profit function is jointly concave in (p_0, p_1) for $0 \leq r \leq 1$. Setting

$\nabla \pi_R(p_0, p_1) = 0$ results in the optimized retail prices,

$$p_{0(S2, NC)}^* = \frac{1}{2}c_0 + \frac{a_1t + a_0b_1}{2(b_0b_1 - t^2)}, \quad (4.5.7)$$

and
$$p_{1(S2, NC)}^* = \frac{1}{B(3-r)} \left\{ (A-2C)r + \left[\frac{Bc_1}{2} + 5C - 2A \right] \right\}, \quad (4.5.8)$$

where A, B, and C are defined in Section 4.4.1. It is clear that the store-brand retail price is independent of r and it is identical to the corresponding integrated system's retail price.

Note that

$$\frac{dp_{1(S2, NC)}^*}{dr} = -\frac{(b_0b_1 - t^2)(a_1 - b_1c_1 + c_0t)}{B(3-r)^2} < 0. \quad (4.5.9)$$

Accordingly, the outside retail price is the smallest when $r=1$, that is,

$p_{1(S2, NC)}^*|_{r=1} = (6C - 2A + Bc_1)(4B)^{-1}$. In comparison to the integrated system's, $p_{1(I)}^*$,

$$p_{1(S2, NC)}^*|_{r=1} - p_{1(I)}^* = \frac{(b_0b_1 - t^2)(a_1 - b_1c_1 + c_0t)}{2B} > 0. \quad (4.5.10)$$

This comparison indicates that the supply chain will not be coordinated with retailer's non-coordinating decisions for $r \in [0,1]$.

Proposition 4.5.1: *Under decision scenario S2, and retailer's non-coordinating framework, the store-brand retail price remains identical to that of the integrated system, while the outside retail price is higher than the corresponding retail price of the integrated system for $r \in [0,1]$.*

The above result resembles a similar property as in the case of S1, see Proposition 4.4.1, that the retailer's non-coordinating decisions increase her market share due to

product substitutability, while the total supply chain profit declines in comparison to the integrated system.

Letting $T = a_0t + a_1b_0$, the non-coordinating optimal results in S2 are represented as

$$w_{(S2,NC)}^* = \frac{-[(a_1 + c_0t)C + b_1T]r^2 + [(2a_1 + 2tc_0)C + 4b_1t^2]r + (3b_1c_1C - 3b_1T)}{2b_1C(3-r)}, \quad (4.5.11)$$

$$\pi_{M(S2,NC)}^* = \frac{(a_1 - b_1c_1 + tc_0)^2(2-r)}{4b_1(3-r)^2}, \quad (4.5.12)$$

$$\pi_{R_M(S2,NC)}^* = \frac{(a_1 - b_1c_1 + tc_0)[T - (b_0b_1 - t^2)c_1]}{4(b_0b_1 - t^2)(3-r)}, \quad (4.5.13)$$

where $w_{(S2,NC)}^*$ is the wholesale price, $\pi_{M(S2,NC)}^*$ is the supplier profit, and $\pi_{R_M(S2,NC)}^*$ is the retailer profit shared from outside products. Note that

$$\frac{d\pi_{M(S2,NC)}^*}{dr} = \frac{(1-r)(a_1 - b_1c_1 + c_0t)^2}{4b_1(2-r)^3} > 0, \quad (4.5.14)$$

$$\frac{d\pi_{R_M(S2,NC)}^*}{dr} = \frac{(a_1 - b_1c_1 + tc_0)[T - (b_0b_1 - t^2)c_1]}{4(b_0b_1 - t^2)(3-r)^2} > 0, \quad (4.5.15)$$

and for the retailer's total profit $\pi_{R(S2,NC)}^*$, we have

$$\frac{d\pi_{R(S2,NC)}^*}{dr} = \frac{(a_1 - b_1c_1 + tc_0)^2}{4b_1(3-r)^2} > 0. \quad (4.5.16)$$

Therefore, an increasing revenue-sharing rate leads to higher profit for the supplier. Moreover, the retailer's total profits as well as profit generated from outside products increase as revenue-sharing rate increases. As such, under the scenario S2, both the supplier and the retailer maximize their profits when $r=1$, which indeed is a wholesale-price contract.

Proposition 4.5.2: *Under decision scenario S2, when the retailer seeks to optimize her own profit, a wholesale-price contract assures both the supplier and the retailer the largest possible profits.*

4.5.2 The Case of Retailer Coordination Decisions (RCD) under S2

In coordinating decisions, the retailer chooses retail prices on the basis of the entire supply chain, which leads to the same retail prices as those of the integrated system:

$$p_{0(S2,C)}^* = \frac{1}{2}c_0 + \frac{a_1t + a_0b_1}{2(b_0b_1 - t^2)} \text{ and } p_{1(S2,C)}^* = \frac{1}{2}c_1 + \frac{a_0t + a_1b_0}{2(b_0b_1 - t^2)}. \quad (4.5.17)$$

Using forward substitution,

$$w_{(S2,C)}^* = \frac{1}{B} \left\{ [A + Bc_1]r + [C - 2A - \frac{Bc_1}{2}] \right\}. \quad (4.5.18)$$

As in the case of S1, see (4.4.21), the coordinating wholesale price increases in r , and given the same revenue-sharing rate, it can be shown that the difference between the coordinating wholesale prices under S2 and S1 is $(a_1 - b_1c_1 + tc_0)(2b_1)^{-1} > 0$.

Proposition 4.5.3: *For any given revenue-sharing rate, the coordinating wholesale price under S2 is larger than that under S1, where the price difference is constant at $(a_1 - b_1c_1 + tc_0)(2b_1)^{-1}$.*

The supplier profit is,

$$\pi_{M(S2,C)}^* = \frac{(2-r)[a_1 - b_1c_1 + tc_0]^2}{4b_1}. \quad (5.19)$$

It is clear that the supplier's profit decreases in r , which is different from the non-coordinating case, see (4.5.14). As a result, the supplier's profit ranges from

$[a_1 - b_1c_1 + tc_0]^2(4b_1)^{-1}$ to $[a_1 - b_1c_1 + tc_0]^2(2b_1)^{-1}$ under retailer's coordinating decisions under scenario S2.

For the retailer's total profit $\pi_{R(S2,C)}^*$, it can be shown that

$$\frac{d\pi_{R(S2,C)}^*}{dr} = \frac{(a_1 - b_1c_1 + tc_0)^2}{4b_1} > 0, \quad (4.5.20)$$

i.e., the retailer's total profit increases in the revenue-sharing rate. That is, the retailer achieves the highest profit when $r=1$, and the two-parameter revenue-sharing contract reduces to a wholesale-price contract in this case.

Furthermore, it can be shown that $w_{(S2,C)}^* = (a_1 + b_1c_1 + tc_0)(2b_1)^{-1} > c_1$ for $r=1$. In contrast to the case of S1, where the coordinating wholesale-price contract leaves no profit for the supplier since the optimal wholesale price equals the production cost, the supplier can still make profit under S2.

The one-parameter revenue-sharing contract does not apply in scenario S2 in that the wholesale price is the supplier's decision variable. Also note that in both scenarios and both coordinating and non-coordinating decisions, the store-brand retail prices are always set optimal as for the entire supply chain, which partially explains why the store-brand products are always observed with low prices.

Proposition 4.5.4: *The store-brand retail prices are consistently set the same as that of the integrated system, regardless of the decision rights scenarios or the retailer's preference for coordinating or non-coordinating decisions.*

4.6 Performance Comparison and Decision Strategies

The preceding sections analyzed retailer's four possible decision frameworks, namely, the case of S1/RNCD, S1/RCD, S2/RNCD, and S2/RCD. Our focus next is on conditions under which the retailer chooses one of these frameworks for decision making. We first analyze the retailer's decision making under scenario S2 in which the supplier specifies the wholesale price.

As shown in Section 4.5, the retailer's total profits increase in the revenue-sharing rate in both RNCD and RCD frameworks, see (4.5.16) and (4.5.20). Furthermore, it can be shown that

$$\pi_{R(S2,NC)}^* \big|_{r=0} - \pi_{R(S2,C)}^* \big|_{r=1} = \frac{(a_1 - b_1 c_1 + t c_0)^2}{12 b_1} > 0. \quad (4.6.1)$$

That is, under scenario S2, the least possible profit for the retailer under non-coordinating decisions is larger than the largest possible profit under coordinating decisions. Combining with the result in Proposition 4.5.2 that a wholesale-price contract maximizes the profits for both the retailer and the supplier under retailer's non-coordinating decisions, the following conclusion is reached:

Proposition 4.6.1: *When the supplier chooses the wholesale price, a non-coordinating wholesale-price contract is the optimal choice for the retailer.*

Under S1, where the supplier chooses his retail price, the retailer's total profit in both non-coordinating and coordinating decisions increase in r , see (4.4.13) and (4.4.25). Comparing the retailer's non-coordinating profits under the two scenarios S1 and S2, it can be shown that,

$$\pi_{R(S1,NC)}^* \big|_{r=0} - \pi_{R(S2,NC)}^* \big|_{r=1} = 0. \quad (4.6.2)$$

That is, under non-coordinating decisions, the retailer's smallest total profit under S1 is equal to the largest possible total profit under S2. From the retailer's perspective, the retailer's non-coordinating two-parameter contract under S1 thus outperforms any contracting decision under scenario S2. Also note that in S1, for a given revenue-sharing rate r , where $0 \leq r \leq 1$, it can be shown that $\pi_{R(S1,NC)}^* > \pi_{R(S1,C)}^*$. The following result thus holds:

Proposition 4.6.2: *When the revenue-sharing rate is fixed, the retailer will let the supplier determine his retail price and make decisions to optimize her own profit function.*

Suppose there is an (outside) niche supplier and the supplier-retailer transactions occur only if the supplier is assured with a minimum profit level of H under a revenue-sharing contract. Consider the case of S1. The retailer is then able to set both the wholesale price and the revenue-sharing rate to capture the rest of the supply chain profit. Furthermore, given that the supplier assumes H in S1 and $H = \pi_{M(S1,NC)}^*(r_1)$, where r_1 is the revenue-sharing rate and $r_1 \in [0,1]$, the retailer's total profit using non-coordinating decisions is $\pi_{R(S1,NC)}^*(r_1) = \pi_{SC(S1,NC)}^*(r_1) - H \leq \pi_{SC(S1,C)}^* - H$ since $\pi_{SC(S1,NC)}^*(r_1) \leq \pi_{SC(S1,C)}^*$, noting that the coordinated supply chain attains the highest profit $\pi_{SC(S1,C)}^*$ independent of the revenue sharing rate. Therefore, the retailer can issue a revenue-sharing rate r_2 such that $\pi_{R(S1,C)}^*(r_2) = \pi_{SC(S1,C)}^* - H'$. Due to $\pi_{SC(S1,NC)}^*(r_1) \leq \pi_{SC(S1,C)}^*$, there exists a feasible range of r_2 that corresponds to any $r_1 \in [0,1]$ for $H' \geq H$ and $\pi_{R(S1,C)}^*(r_2) \geq \pi_{R(S1,NC)}^*(r_1)$.

That is, given a minimum required profit H for the supplier to be achieved under RNCD, the retailer can alternatively specify a coordinating revenue-sharing rate r_2 to assure both agents more profit in contrast to the non-coordinating decisions.

Proposition 4.6.3: *Under S1, for any profit level that the supplier achieves in retailer's non-coordinating decisions, there exist a retailer coordinating decision that specifies an alternative pair of wholesale price and revenue-sharing rate that leads to Pareto improvement.*

The property of Proposition 4.6.3 can be illustrated in Figure 4.1.

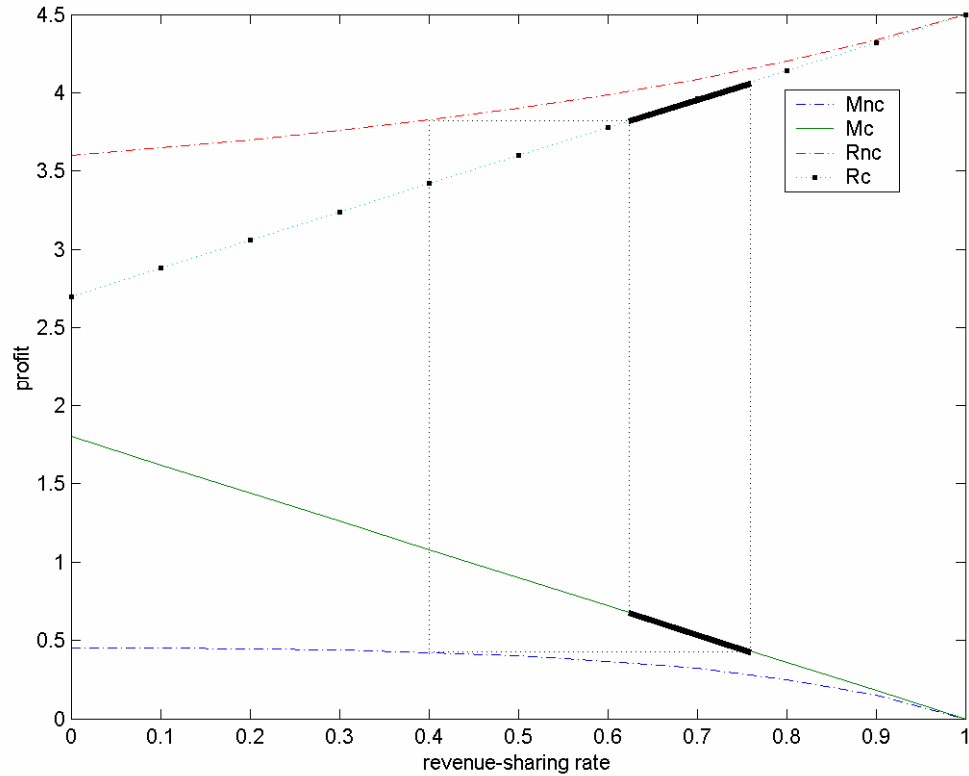


Figure 4.1 Profits under Scenario S1

Figure 4.1 is based on the equilibrium results of S1 and by setting $a_0 = a_1 = 10$, $b_0 = b_1 = 5$, $t = 1$, and $c_0 = c_1 = 1$. In the legend of the figure, “Mnc” represents the supplier’s profit under RNCD, “Mc” represents his profit under RCD, “Rnc” is the retailer’s non-coordinating profit, and “Rc” is the retailer’s coordinating profit.

In terms of the supplier’s non-coordinating profit achieved at $r = 0.4$, there exists a Pareto area noted by $r \in [0.61, 0.72]$ where the retailer’s coordinating decisions allow both agents to achieve better profits.

From the supplier’s standpoint, a retailer coordinating decision leads to higher profit than a non-coordinating decision at any revenue-sharing rate. To see this, define the constant $D = (a_1 - b_1 c_1 + t c_0)^2 (4 b_1)^{-1}$. Then, the outside supplier’s profits under the four decision frameworks can be shown in Table 4.1, where profits are indicated per unit of D . Also in the same table, the lower and upper bounds on these profits are shown as r varies from 0 to 1. Indeed, r need not take on the same value in different decision frameworks.

Observe that the supplier total profit range covered by the non-coordinating (RNCD) decisions is $[0, 1/4] \cup [2/9, 1/4] = [0, 1/4]$, while that due to coordinating (RCD)

Table 4.1: Supplier’s Profit under Four Decision Frameworks

	(S1, RNCD)	(S1, RCD)	(S2, RNCD)	(S2, RCD)
Supplier profit/ D	$\frac{1-r}{(2-r)^2}$	$1-r$	$\frac{2-r}{(3-r)^2}$	$2-r$
Supplier profit range/ D	$[0, 1/4]$	$[0, 1]$	$[2/9, 1/4]$	$[1, 2]$

decisions is $[0,1] \cup [1,2] = [0,2]$. Since $[0,1/4] \subset [0,2]$, it follows that at any level of r , the supplier is better-off under coordinating decisions, so long as $K \in [0,2]$, where K the supplier's profit per unit D . In particular, if $K \in [1/4,1]$, then retailer must use the (S1,C) framework, whereas if $K \in [1,2]$, the retailer must use the (S2,C) decision framework. Indeed, for $K > 2$, there is no feasible relationship between the retailer and the supplier.

A graphical illustration of the above analysis is in Figure 4.2 using the same parameters as in Figure 4.1. The legends Ms1nc, Ms1c, Ms2nc, and Ms2c represent the supplier profits per unit D in frameworks of S1/RNCD, S1/RCD, S2/RNCD, and S2/RCD, respectively.

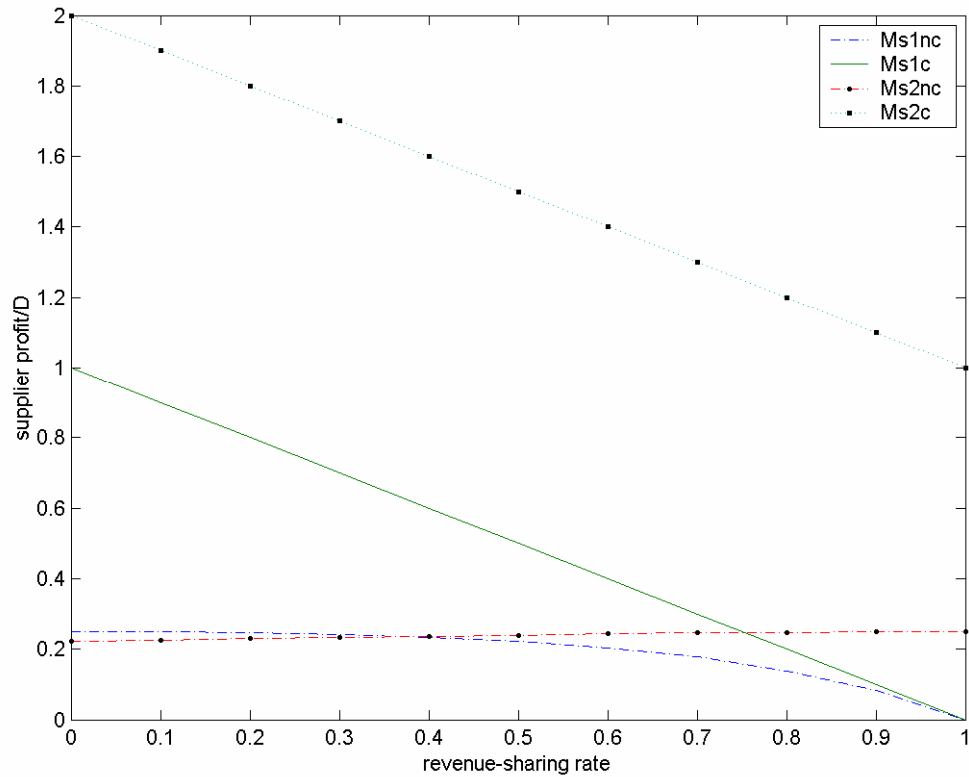


Figure 4.2: Supplier Profits

4.7 Discussions and Conclusions

This chapter investigates the supply chain coordination problem when the retailer sells store-brand products in a single retailer-single supplier framework. We modeled the (outside) supplier-retailer interactions via revenue-sharing contracts and assumed the retailer always takes the role of Stackelberg leadership. Two scenarios of decision making are studied: first, the supplier chooses his own retail price only, and second, the supplier determines his own wholesale price only.

Our research shows that a two-parameter revenue-sharing contract with its ability to share profit flexibly outperforms a wholesale-price contract or a one-parameter revenue-sharing contract. When the supplier is “let” to choose his retail price and the retailer can justify both the wholesale price and the revenue-sharing rate, the retailer’s coordinating decisions generate Pareto improvement over non-coordinating decisions, although coordination undermines market share and profitability of the store-brand product. In contrast, when the supplier determines his wholesale price, a non-coordinating wholesale-price contract is an optimal choice for the retailer.

This research offers certain practical implications. For instance, in the case of Wal-Mart, a one-parameter revenue-sharing contract limits her share of revenue that is uniquely determined by both products’ cost and demand structures, whereas the two-parameter revenue-sharing contracts have the flexibility in allocating profits. This research also illustrates the importance of store-brand strategy. For example, the existence of store brands not only provides a source of profit for retailers but also, it avoids suppliers’ pricing collusion due to the fact that any such high pricing allows the

store-brand products to capture more market share and thus more profit from store-brand product.

Our future research will focus on how information asymmetry impacts the decision in a supply chain with retailer selling store-brand and outside supplier products with a revenue-sharing contract.

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