Supply Chain Coordination[1]

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Supply chain coordination is among the central issues in supply chain management. A supply chain is coordinated if all supply chain members adopt the actions that optimize the entire system's performance. However, in most cases, supply chain firms are independent, self-interested entities that may deviate from the system-optimal actions. This article provides an introductory review on how firms can use various contractual schemes to achieve supply chain coordination. Discussions on additional issues and potential research directions are also provided.

Keywords: Supply chains, incentives, coordination, channels, contracts, newsvendor, inventory management

A supply chain is a network of firms/entities that convert raw materials and components into final products and then deliver to consumers. If the supply chain is managed by a central planner who is able to control all decisions, then we call it a *centralized supply chain*. The set of actions that can optimize the supply chain's performance is called the *centralized optimal solution*. In practice, however, it is not uncommon for parties within a supply chain to be independent organizations that aim to maximize their own objectives. In this case, we call it a *decentralized supply chain*. The behavior of a decentralized supply chain can be characterized using the *Nash* or *Stackelberg equilibrium* concept (see Encyclopedia Section 3.3.4 Solution Concepts and Algorithms for Noncooperative Games).

Achieving *coordination* is equivalent to achieving the centralized optimal solution for the supply chain.[2] Under the centralized optimal solution, the pie for the entire system is maximized, so each player in the system can enjoy a larger size of the pie. This implies that under supply chain coordination, the players can achieve *Pareto optimal* profit allocations,

[1] This article is an invited introductory review of supply chain coordination to appear in the *Encyclopedia of Operations Research and Management Science*, edited by James J. Cochran and published by Wiley.

[2] This is a typical definition of supply chain coordination in the research literature. A more general definition is that all supply chain members take actions together to increase (not necessarily optimize) total supply chain performance. See Chopra and Meindl (2007) for more details and practical examples.

i.e., it is not possible to increase the profit of one player without hurting the profit of any other player. Clearly, a coordinated supply chain is an ideal situation, since all players can be better off than without coordination. Unfortunately, since the players have different objectives and interests, the equilibrium outcome in a decentralized supply chain often deviates from the centralized optimal solution, thus creating inefficiencies in the supply chain.

How to coordinate a decentralized supply chain is a central issue in supply chain management. One solution is to design a contractual scheme to align the incentives among all players so that the individually optimal actions coincide with the centralized optimal actions. In fact, many commonly observed contracts can serve as coordination devices. This article provides an introductory review on how to achieve the goal of supply chain coordination using such contractual arrangements.

A real-world supply chain could be extremely complex. For example, it may have an intricate network structure involving an arbitrary number of firms, each firm may have private information about its own cost and demand forecast, and the actions taken by firms may not be observable or verifiable. As an illustrational example, throughout this article we consider a simple supply chain consisting of only two firms – a supplier and a retailer. The retailer is modeled as a newsvendor, i.e., she faces a random demand in a single selling season and decides on the quantity to order from the supplier (see Encyclopedia Section 4.4.5.1 Newsvendor Models). (We use "she" for the retailer and "he" for the supplier throughout this article.) Everything is common knowledge and there are no hidden actions. Also, all players are risk neutral so they try to maximize their expected profits. We demonstrate how several commonly observed contracts can be used to coordinate this simple supply chain. We also provide intuitive explanation for why these contracts can realign the incentives of the supply chain members. For a more comprehensive treatment of general supply chain coordination problems, readers are referred to Cachon (2003).

This article is organized as follows. Section 1 introduces the basic model and the concept of *double marginalization* in a decentralized supply chain. Section 2 proposes several contracts to coordinate the supply chain. Section 3 briefly discusses some additional issues in supply chain coordination. Finally, Section 4 concludes.

1 Basic Model

Consider a supply chain consisting of a supplier and a retailer. The retailer sells a product in a single selling season at a fixed price p. Market demand D is random and has a distribution (density) function F (f). The retailer procures the product from the supplier. The supplier incurs a cost c for each unit of product delivered to the retailer. Due to long production and transportation lead times, the retailer has to decide on the order quantity before the market demand is realized.[3] In the case where the demand is less than the order quantity, leftover inventory at the end of the selling season has a unit salvage value $0 \leq v < c$. (Note that there are several additional parameters that we may add into the basic model. For instance, there could be a penalty cost for unsatisfied demand, the retailer may have to incur a unit cost as well for selling the product. However, the introduction of these parameters will not affect the understanding of the coordination contracts. So we omit these parameters for ease of exposition.) For notational convenience, let E denote the expectation operation. Also define $x \wedge y = \min(x, y)$, $x^+ = \max(0, x)$, and $\bar{F} = 1 - F$.

1.1 Centralized optimal solution

We first present the centralized optimal solution for the above supply chain. Later we will use this solution as a benchmark for comparison. When the supplier and the retailer are controlled by a central planner, the retailer can obtain the product from the supplier at cost c. So the supply chain's problem reduces to the classic newsvendor problem. Observe that the supply chain's profit is solely determined by the retailer's order quantity. Let Q be the order quantity. Then the supply chain's expected profit is given by

$$\begin{aligned}\pi_c(Q) &= pE(Q \wedge D) + vE(Q - D)^+ - cQ \\ &= (p - v)E(Q \wedge D) + (v - c)Q. \qquad (1)\end{aligned}$$

We use subscript c for centralized supply chain. It is straightforward to show that $\pi_c(Q)$ is concave (i.e., $\pi_c''(Q) < 0$). Thus the following first-order condition characterizes the profit-

[3]This supply chain setting (i.e., a supplier selling through a newsvendor retailer) is standard in the operations literature. In such a setting, the retailer faces a fixed retail price but uncertain market demand. Alternatively, we can model the retailer as a price-setting firm but with deterministic demand. The latter model setting has been widely used in studying channel coordination in the marketing literature. Although it is not the focus of this article, interested readers are referred to Jeuland and Shugan (1983) and Moorthy (1987) for more details on how to coordinate supply chains with deterministic market demand.

maximizing quantity Q_c^* for the centralized supply chain:

$$\left.\frac{d\pi_c(Q)}{dQ}\right|_{Q=Q_c^*} = (p-v)\bar{F}(Q_c^*) + (v-c) = 0$$

or

$$F(Q_c^*) = \frac{p-c}{p-v}. \tag{2}$$

Equation (2) is the critical fractile solution to the classic newsvendor problem. Note that the centralized optimal solution Q_c^* increases in price p and salvage value v and decreases in cost c.

1.2 Wholesale price contract

Next we consider the behavior of a decentralized supply chain. That is, now the supply chain members are independent entities that try to maximize their own objectives. We use a wholesale price contract to highlight how a decentralized supply chain may deviate from the centralized optimal solution. Under the wholesale price contract, the supplier charges a unit price $w > c$ for each unit of product delivered to the retailer. Assume that the wholesale price is exogenously given, i.e., the wholesale price contract has already been established at the outset. The sequence of events is as follows: The retailer places an order at the supplier; the supplier produces the product and delivers to the retailer; then market demand is realized and sales begin; finally, the selling season ends and leftover inventories are salvaged. Below we analyze the behavior of the supply chain under the wholesale price w.

The retailer's problem under the wholesale price arrangement is the same as in the centralized supply chain except that the procurement cost is w rather than c. Given an order quantity Q, the retailer's expected profit now becomes:

$$\begin{aligned} \pi_r(Q) &= pE(Q \wedge D) + vE(Q-D)^+ - wQ \\ &= (p-v)E(Q \wedge D) + (v-w)Q. \end{aligned} \tag{3}$$

We use subscript r for the retailer. Similarly, $\pi_r(Q)$ is concave and the first-order condition for the retailer's profit-maximizing order quantity Q_w^* is given by

$$F(Q_w^*) = \frac{p-w}{p-v}, \tag{4}$$

where the subscript w stands for wholesale price.

By comparing the conditions (2) and (4), we can see that $Q_w^* < Q_c^*$, since F is an increasing function and $w > c$. That is, under the wholesale price contract, the retailer tends to order less than under the centralized optimal solution. Such a result can be explained using the standard risk analysis in the newsvendor problem. Since market demand is uncertain, the retailer essentially bets against demand when making an ordering decision. If demand realization is high, then the retailer loses $p-c$ potential profit for each unit of unmet demand. This is known as *underage cost* for a newsvendor. On the other hand, if demand realization is low, then the retailer incurs a loss of $c-v$ for each unit of leftover inventory. This is called *overage cost* for a newsvendor. It is quite intuitive that all else being equal, the retailer's optimal order quantity increases in the underage cost and decreases in the overage cost. Under the wholesale price contract, the underage cost decreases to $p-w$ while the overage cost increases to $w-v$, which leads to a lower order quantity at the retailer.

An alternative explanation of the above under-ordering result emerges from the marginal analysis (see Moorthy 1987 for the use of marginal analysis in channel coordination under deterministic demand). Under centralized control, the retailer's (i.e., the supply chain's) expected profit in (1) can be divided into two parts: the revenue part, $pE(Q \wedge D) + vE(Q - D)^+$, and the cost part, cQ. The retailer's optimal order quantity is achieved at the point where the marginal revenue equals the marginal cost. Note that under the wholesale price contract, the retailer's revenue function in (3) is the same as the supply chain's revenue function. This means that the retailer's marginal revenues are the same in both cases. However, the retailer's marginal cost increases from c (in the centralized supply chain) to w (in the wholesale price contract). Figure 1 uses a numerical example to visualize how the retailer's optimal order quantity is determined. In this example, $c = 3$, $p = 5$, $v = 2$, and the demand D follows a normal distribution with mean 100 and standard deviation 30. In a centralized supply chain, the retailer's optimal order quantity Q_c^* is determined by equalizing the marginal revenue and the marginal cost $c = 3$. Similarly, in a decentralized supply chain, the retailer's optimal order quantity Q_w^* is determined by equalizing the marginal revenue and the marginal cost $w = 3.5$. We can see that a higher marginal cost leads to a lower order quantity for the retailer (i.e., $w > c$ leads to $Q_w^* < Q_c^*$).

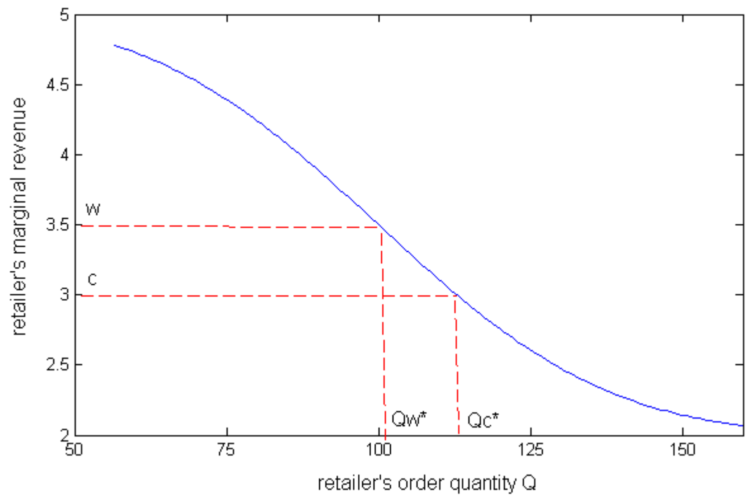

Figure 1. Retailer's marginal revenue as a function of order quantity Q
($c = 3, p = 5, v = 2, w = 3.5, D$ is normal with $N[100, 30^2]$)

Since the supply chain profit depends on the retailer's order quantity, it means that the wholesale price contract does not maximize the supply chain's performance. This is the so-called *double marginalization* problem: The wholesale price exists because the supplier requires a unit profit margin $w - c$ on top of that for the retailer, which in turn leads to a lower order quantity by the retailer and creates inefficiencies in the supply chain. Such an effect was first identified in Spengler (1950). For the same numerical example described above, Figure 2 shows the supplier's, the retailer's, and the supply chain's expected profits as functions of the wholesale price w. As we can see, the supply chain's profit curve declines as the wholesale price increases. That is, a more severe double marginalization problem leads to higher efficiency loss for the supply chain. The retailer's profit also decreases in the wholesale price, which is intuitive. The supplier's profit curve is slightly different: It increases first and then decreases in wholesale price. This is because while a higher wholesale price means a higher unit profit margin, it also forces the retailer to order less. So the supplier's profit is not monotone in wholesale price.

The double marginalization problem implies that more sophisticated contractual arrangements (relative to the wholesale price contract) are needed to induce the retailer to order the centralized optimal solution. From the above marginal analysis, we essentially need to design a contractual scheme in which the retailer's marginal revenue and marginal cost curves intercept at the supply chain's optimal solution, Q_c^*. We show in the next section how to achieve this goal via carefully designed contractual arrangements.

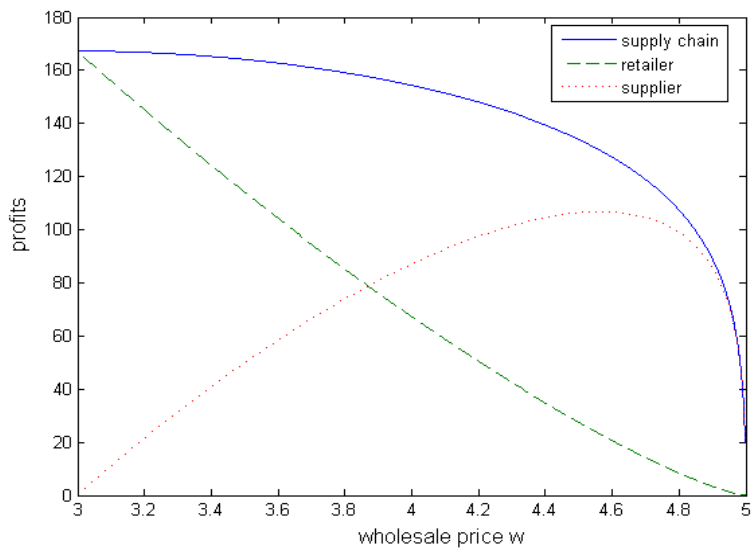

Figure 2. Supply chain members' profits as functions of the wholesale price w ($c = 3, p = 5, v = 2, D$ is normal with $N[100, 30^2]$)

2 Supply Chain Coordination Contracts

The above analysis has shown that the wholesale price contract induces the retailer to order less than the supply chain optimal quantity. We need to increase the retailer's order quantity in order to achieve coordination. In this section, we show that several commonly observed contracts in practice can achieve coordination by manipulating the retailer's marginal revenue and/or marginal cost curves. To save space, we focus on the following three contract formats: buyback, quantity discount, and revenue-sharing contracts.

2.1 Buyback contract

A buyback contract contains two parameters (w, b): The retailer pays a wholesale price w to the supplier; at the same time, the supplier agrees to buy back the leftover inventories at a buyback price b ($v < b < c$). (If $b \leq v$, then the buyback is useless because the retailer is better off salvaging the leftover inventories by herself; if $b \geq c$, then the retailer will order infinity.) This is also known as return policies. For example, in the book industry, many publishers offer buyback terms to retailers, i.e., unsold books can be returned to the publisher at the end of the selling season for a certain price. Notice that the supplier does not have to physically take the products back in a buyback contract; rather, he only needs to subsidize the disposed excess stock. Pasternack (1985) was among the first to study buyback contracts in the context of the newsvendor problem. Intuitively, buyback price b improves the retailer's marginal revenue from salvaging the leftover products (i.e., from v to b) and thus should increase her order quantity, and a large enough b should bring the retailer's order quantity back to the centralized optimal solution. (Equivalently, we may use the underage and overage cost concepts to explain why buyback contracts work. In particular, the buyback policy can induce the retailer to order more because it reduces the retailer's overage cost from $c - v$ to $c - b$.) Next we confirm this conjecture.

Under the buyback contract, the retailer's expected profit can be written as:

$$\begin{aligned} \pi_r(Q) &= pE(Q \wedge D) + bE(Q - D)^+ - wQ \\ &= (p - b)E(Q \wedge D) + (b - w)Q, \end{aligned} \tag{5}$$

which is concave in Q. Through manipulation, we can derive the first-order condition for the retailer's profit-maximizing order quantity, Q_b^*:

$$\left.\frac{d\pi_r(Q)}{dQ}\right|_{Q=Q_b^*} = (p - b)\bar{F}(Q_b^*) + (b - w) = 0,$$

which gives

$$F(Q_b^*) = \frac{p - w}{p - b}. \tag{6}$$

We use subscript b for buyback. To coordinate the supply chain, we need $Q_b^* = Q_c^*$, or

$$\frac{p - w}{p - b} = \frac{p - c}{p - v} \tag{7}$$

by comparing (2) and (6). Thus any combination of values for (w, b) that satisfy Equation (7) can coordinate the supply chain. Note that there are an infinite number of solutions to (7). Now the question is: Which one should we use to coordinate the supply chain? It turns out that different solutions of (w, b) correspond to different profit allocations between the supplier and the retailer. To see this, let

$$w = p - \phi(p - c) \text{ and } b = p - \phi(p - v), \tag{8}$$

where $0 \leq \phi \leq 1$ is a constant. It is easy to verify that condition (7) holds, so the pair (w, b) given in (8) coordinates the supply chain. Further, the retailer's expected profit in (5) can now be written as

$$\begin{aligned} \pi_r(Q) &= \phi(p-v)E(Q \wedge D) + \phi(v-c)Q \\ &= \phi\pi_c(Q). \end{aligned} \tag{9}$$

That is, the buyback contract in (8) not only coordinates the supply chain, but also assigns a portion ϕ ($0 \leq \phi \leq 1$) of the supply chain profit to the retailer (the supplier gets a portion of $1-\phi$). The ability to achieve arbitrary allocation of profits between supply chain members is a desirable property. In many cases, the supply chain members have unequal bargaining powers and, as a result, they may require different profit allocations in order to participate in coordination. From the above analysis, it is clear that buyback contracts can serve both purposes well (i.e., coordination and arbitrary profit allocation). It follows from (8) that a lower ϕ corresponds to a higher b, which implies that a higher buyback price leads to a lower retailer profit. This is mainly because a higher buyback price is associated with a higher wholesale price w.

Finally, there are some variations of the buyback contract in practice. For instance, it is common that fashion manufacturers use the so-called "markdown money" to compensate the retailers for liquidated items via clearance pricing. In a markdown money contract, the markdown money can be a percentage of the price markdown, or it can be a rebate credit for each unit of salvaged product. Both forms of the markdown money have the same effect on the retailer's decision as the buyback term in the buyback contract. Another related example is quantity flexibility (or backup agreement). In a quantity flexibility contract, similarly, the supplier charges a wholesale price but subsidizes the retailer for unsold units. To be specific, the supplier is fully responsible for a portion of the retailer's order (note that the supplier provides partial protection on the retailer's entire order in the buyback contract). See Eppen and Iyer (1997) and Tsay (1999) for more discussion of quantity flexibility contracts.

2.2 Quantity discount contract

The buyback contract coordinates supply chains by altering the retailer's marginal revenue curve. Similarly, to achieve coordination, we may manipulate the retailer's marginal cost curve so that it crosses the marginal revenue curve precisely at Q_c^*, the order quantity that is optimal for the supply chain. Consider the following so-called quantity discount contract: The supplier charges the retailer a unit wholesale price $w(Q)$, which is a function of the order quantity Q. This is also called an "all-unit" quantity discount, because the wholesale price applies to the entire order quantity. By definition of the quantity discount, we focus on $w'(Q) < 0$, i.e., wholesale price functions that are decreasing in order quantity. This type of arrangement is quite common in practice, where a buyer enjoys a lower price by buying more (e.g., many consumer packaged goods suppliers routinely offer incentives to induce large order quantities from their retailers). Next we analyze this quantity discount contract.

Under this contract, the retailer's expected profit is given by

$$\begin{aligned}\pi_r(Q) &= pE(Q \wedge D) + vE(Q - D)^+ - w(Q)Q \\ &= (p - v)E(Q \wedge D) + (v - w(Q))Q. \end{aligned} \tag{10}$$

Similar to the analysis of buyback contracts in Section 2.1, we try to express the retailer's profit function $\pi_r(Q)$ as a fraction of the supply chain's profit. Let

$$w(Q) = (1 - \phi)(p - v)\left(\frac{E(Q \wedge D)}{Q}\right) + \phi(c - v) + v, \tag{11}$$

where $0 \le \phi \le 1$ is a constant. Plugging the above $w(Q)$ into (10) gives

$$\begin{aligned}\pi_r(Q) &= \phi(p - v)E(Q \wedge D) + \phi(v - c)Q \\ &= \phi\pi_c(Q). \end{aligned} \tag{12}$$

Hence under the quantity discount scheme in (11), the retailer's incentive is aligned with the supply chain's because $\pi_r(Q) = \phi\pi_c(Q)$. The retailer keeps ϕ $(0 \le \phi \le 1)$ portion of the supply chain profit. Since

$$\frac{d\left(\frac{E(Q\wedge D)}{Q}\right)}{dQ} = \frac{\bar{F}(Q)Q - E(Q \wedge D)}{Q^2} = -\frac{\int_0^Q xf(x)dx}{Q^2} < 0,$$

we know $w(Q)$ is a decreasing function of Q, i.e., $w(Q)$ represents a quantity discount scheme. Note that $w(Q) \to \phi(c - v) + v \le c$ as $Q \to \infty$, which means that the wholesale price the supplier charges could be lower than the cost c. However, this will never be the retailer's optimal choice because the supplier's, and therefore all parties' profits are negative when the order quantity is excessively large.

Given Equation (12), we know that any order quantity that maximizes the retailer's profit will also maximize the supply chain's profit. Essentially, it implies that by using a properly designed quantity discount contract, we can achieve supply chain coordination and arbitrarily allocate profits between the supply chain members.

2.3 Revenue-sharing contract

So far we have introduced two coordination contracts: buyback and quantity discount contracts. In buyback contracts, a buyback term is used to improve the retailer's marginal revenue curve and thus induce the retailer to take the supply chain optimal action. In quantity discount contracts, a non-linear wholesale price function is used to manipulate the retailer's marginal cost curve so that it intersects with the marginal revenue curve at the supply chain optimal quantity. What happens if we use certain contractual schemes to adjust both the marginal revenue and marginal cost curves? In this subsection, we study revenue-sharing contracts that can achieve supply chain coordination by manipulating both the retailer's marginal revenue and marginal cost curves. The practice of revenue-sharing has been observed, for instance, in the video rental industry, where studios offer movie copies to rental stores at relatively cheap prices, and as a compensation, the rental stores agree to share revenue with the studios.

Let $\{w, \lambda\}$ denote a revenue-sharing contract, where w is the wholesale price and λ is the revenue share (i.e., the portion of the supply chain's expected revenue) obtained by the retailer. To be more specific, the retailer pays the supplier w for each unit of product, and meanwhile the retailer keeps λ portion of the revenue from either selling or salvaging each unit of product. Under revenue sharing, the retailer's expected profit is given by

$$\begin{aligned}\pi_r(Q) &= \lambda[pE(Q \wedge D) + vE(Q-D)^+] - wQ \\ &= \lambda(p-v)E(Q \wedge D) + (\lambda v - w)Q. \end{aligned} \tag{13}$$

Consider the following parameters values for the revenue-sharing contract:

$$w = \phi c \text{ and } \lambda = \phi, \tag{14}$$

where $0 \leq \phi \leq 1$ is a constant. Then the retailer's profit becomes

$$\begin{aligned}\pi_r(Q) &= \phi(p-v)E(Q \wedge D) + \phi(v-c)Q \\ &= \phi\pi_c(Q). \end{aligned} \tag{15}$$

Thus the revenue-sharing scheme in (14) achieves coordination and assigns a portion of ϕ ($0 \leq \phi \leq 1$) profits to the retailer. Note that in a coordinating revenue-sharing contract, there is $w = \phi c \leq c$, which implies that the supplier should charge a wholesale price that is not greater than his cost. Therefore, instead of charging a markup when selling to the retailer, the supplier makes profits solely from sharing the revenue with the retailer.

It is worth mentioning that we may go one step further to coordinate a supply chain via profit sharing. That is, both firms agree to take actions to maximize the supply chain's objective, and then split the total profits between themselves. Another related coordination device is the so-called two-part tariff contract. In this type of contract, the supplier delegates all decisions to the retailer (i.e., the retailer serves as a central planner for the entire supply chain), and in return, the retailer compensates the supplier using a lump-sum payment. Both the profit-sharing and the two-part tariff notions are essentially equivalent to vertical integration, where supply chain firms merge into one. Although intuitive, it may not always be appropriate to propose the use of vertical integration as a coordination solution. In fact, there could be numerous factors that may prevent firms from easily integrating with each other in a supply chain (e.g., firms would like to gain control of their own decisions, there may be additional administration costs due to more complex organizational structure, and different firms may be endowed with different amounts of information, etc). More discussion of the comparison between revenue-sharing and other coordination contracts can be found in Cachon and Lariviere (2005).

3 Additional Issues

The previous section proposes three different supply chain coordination contracts (i.e., buy-back, quantity discount, and revenue-sharing). All three contracts are able to induce supply chain optimal actions and allocate profits between firms in a flexible way. Although they seem to work equally well, they have different implications in practice. In particular, some contracts might be relatively easier to implement than others under different situations. A detailed discussion of the advantages and the disadvantages of the coordination contracts is beyond the scope of this short article. Moreover, we have illustrated the three contracts using the simplest supply chain setting. Most practical situations are much more complex than the one described in the previous sections. As a result, the above three contracts may or may not be able to coordinate these more complex supply chains. In this section, we briefly explain the additional issues that may complicate our supply chain coordination analysis. The purpose is to provide a preliminary introduction of more realistic problem settings, but not to give a thorough solution to these new coordination problems. Nevertheless, we list the representative references that address these additional issues.

3.1 Multiple periods

The basic model in Section 1 considers a single-period problem in which the retailer makes an ordering decision only once. The single-period model is appropriate for perishable products that have short life cycles (e.g., books, fashion items, high-tech products). For products with longer life spans, a multi-period model might be more reasonable. In this case, the retailer can regularly replenish inventory from the supplier, and the supply chain may become a two-echelon inventory system (when the supplier makes to stock) or a production-inventory system (when the supplier makes to order). Cachon and Zipkin (1999) and Caldentey and Wein (2003) study how to coordinate these two different systems, respectively.

3.2 Multiple retailer decisions

There is a single decision in the basic model, that is, the retailer's order quantity. Coordination is relatively easy because one only needs to make sure the retailer adopts the supply chain's optimal order quantity. However, in practice, there are many situations where the retailer needs to make more than one decision. One of the common decisions made by a retailer is sales effort. Imagine that a retail store influences demand by using promotional displays, offering shopping assistance, and giving out gift cards and coupons. Taylor (2002) and Krishnan, Kapusciski, and Butz (2004) study how to coordinate a supply chain in which the retailer makes both ordering and sales effort decisions. In particular, they investigate the so-called sales rebate contract where the supplier charges a wholesale price and at the same time compensates the retailer with a rebate for each unit sold beyond a certain target sales level. Another decision a retailer often makes is the retail price. How to coordinate a price-setting newsvendor? It turns out that the buyback contract does not work in this case in general. However, it can be shown that the revenue-sharing contract can still coordinate such a supply chain (see Cachon and Lariviere 2005 for details).

3.3 Other supply chain structures

A real-world supply chain may consist of a number of connected firms with various network structures. From a research point of view, we need to first understand the following three building-block structures: serial, assembly, and distribution supply chains. In a serial supply chain, there is only a single firm at each stage. The basic model studied in Section 1 is a typical example. An assembly supply chain consists of one manufacturer at the downstream stage, but there could be multiple suppliers at the upstream stage. The manufacturer uses the complementary components delivered by the suppliers to assemble a final product. To coordinate such an assembly system, one needs to consider both the vertical relationship (between the suppliers and the manufacturer) and also the horizontal relationship (between the suppliers). Bernstein and DeCroix (2006) and Zhang (2006) study assembly inventory systems under periodic review and propose coordination schemes accordingly. Distribution supply chains are also commonly seen in practice: For example, a supplier sells his product through multiple independent retailers. Recent research that addresses the coordination problem for distribution supply chains can be found in Chen, Federgruen, and Zheng (2001), Bernstein and Federgruen (2005), Narayanan, Raman, and Singh (2005), and Krishnan and Winter (2007).

3.4 Asymmetric information

When supply chain members are independent organizations, it is natural that they are endowed with different types and amounts of information about the supply chain. For example, the supplier may possess private information about production cost, while the retailer may have superior information about market demand. Two types of asymmetric information have been widely investigated in the supply chain management literature: cost and demand information. When asymmetric information is present, supply chain coordination is not always achievable. This is because supply chain coordination requires information sharing among the supply chain firms, but truthful information sharing may not be in the interest of the information holders. Chen (2003) provides a review of the information-sharing literature in supply chain management (see also Encyclopedia Section 4.4.6.1 Information Sharing in Supply Chains).

3.5 Strategic customer behavior

The traditional supply chain management literature models customer demand at an aggregate level and does not consider forward-looking customer behavior. This is clearly a simplification because demand is composed of individual consumers who may consciously react to market conditions. In the above basic model, there is a selling price p in the regular selling season, and then there is a salvage price $v < p$ in the markdown season. If a consumer anticipates a lower price after the regular season, this may affect her purchasing decision in the regular season. Specifically, if she waits, she may get the same product at a lower price, but she has to face the risk of a stockout after the regular selling season. How does this kind of consumer behavior affect supply chain management, and in particular, supply chain coordination? A recent research development is to explicitly incorporate the consumer side into the picture. Su and Zhang (2008) study the impact of such strategic customer behavior on supply chain performance. Interestingly, they demonstrate that under the presence of strategic consumer behavior, a decentralized supply chain with a wholesale price contract can perform strictly better than a centralized supply chain. The reason is that a wholesale price (and thus double marginalization) actually helps the retailer credibly commit to a low order quantity, which in turn induces the consumers to be willing to pay a high price in the regular season. This implies that the centralized optimal solution is not always the best benchmark for evaluating supply chain performance. Under strategic customer behavior, such a benchmark can be surpassed.

4 Conclusions

A decentralized supply chain consists of independent firms that wish to maximize their own objectives. As a result, the firms' actions often deviate from the actions that optimize the supply chain's performance. This article provides an introductory review on how firms can use various contractual schemes to achieve supply chain coordination. Three commonly observed contracts have been analyzed: buyback, quantity discount, and revenue-sharing contracts. It has been shown that for a simple, two-stage supply chain, all these contracts can realign the firms' incentives to induce supply chain optimal actions. In addition, by properly choosing the contract parameters, we can achieve arbitrary profit allocations among supply chain firms.

For illustrational purpose, we focus on a simple supply chain setting in this article. Additional issues that complicate the coordination analysis may exist. We provide a brief discussion of these issues as well. Some of the issues have already been addressed in the supply chain management literature, but some of them deserve further research attention.

For example, the topic of information sharing has not been fully explored. Also, strategic customer behavior opens a new and promising research arena in supply chain management. Finally, there has recently been a fast-growing interest in studying the effect of supply uncertainties on firms' sourcing decisions. How to coordinate a supply chain with unreliable supply is an interesting topic for future research, too.

References

Bernstein, F., G.A. DeCroix. 2006. Inventory policies in a decentralized assembly system. *Operations Research* **54**(2) 324-336.

Bernstein, F., A. Federgruen. 2005. Decentralized supply chains with competing retailers under demand uncertainty. *Management Science* **51**(1) 18-29.

Cachon, G.P. 2003. Supply chain coordination with contracts. *Handbooks in Operations Research and Management Science*. Steve Graves, Ton de Kok, eds.

Cachon, G.P., M. Lariviere. 2005. Supply chain coordination with revenue sharing: strengths and limitations. *Management Science* **51**(1) 30-44.

Cachon, G.P., P.H. Zipkin. 1999. Competitive and cooperative inventory policies in a two-stage supply chain. *Management Science* **45**(7) 936-953.

Caldentey, R.A., L. Wein. 2003. Analysis of a decentralized production-inventory system. *Manufacturing & Service Operations Management* **5**(1) 1-17.

Chen, F. 2003. Information sharing and supply chain coordination. *Handbooks in Operations Research and Management Science*. Steve Graves, Ton de Kok, eds.

Chen, F., A. Federgruen, Y.-S. Zheng. 2001. Coordination mechanisms for a distribution system with one supplier and multiple retailers. *Management Science* **47**(5) 693-708.

Chopra, S., P. Meindl. 2003. Supply chain management: strategy, planning, and operations. Prentice Hall, 2nd edition.

Eppen, G.D., A.V. Iyer. 1997. Backup agreements in fashion buying-the value of upstream flexibility. *Management Science* **43**(11) 1469-1484.

Jeuland, A., S. Shugan. 1983. Managing channel profits. *Marketing Science* **2**(3) 239-272.

Krishnan, H., R. Kapusciski, D.A., Butz. 2004. Coordinating contracts for decentralized supply chains with retailer promotional effort. *Management Science* **50(1)** 48-63.

Krishnan, H., R.A. Winter. 2007. Vertical control of price and inventory. *American Economic Review* **97**(5) 1840-1857.

Moorthy, S. 1987. Managing channel profits: comment. *Marketing Science* **6** 375-379.

Narayanan, V.G., A. Raman, J. Singh. 2005. Agency costs in a supply chain with demand uncertainty and price competition. *Management Science* **51**(1) 120-132.

Pasternack, B. 1985. Optimal pricing and return policies for perishable commodities. *Marketing Science* **4**(2) 166-176.

Spengler, J. 1950. Vertical integration and antitrust policy. *Journal of Political Economy* **58** 347-352.

Su, X., F. Zhang. 2008. Strategic customer behavior, commitment, and supply chain performance. *Management Science* **54**(10) 1759-1773.

Taylor, T. 2002. Supply chain coordination under channel rebates with sales effort effects. *Management Science* **48**(8) 992-1007.

Tsay, A. 1999. Quantity-flexibility contract and supplier-customer incentives. *Management Science* **49** 1339-1358.

Zhang, F. 2006. Competition, cooperation, and information sharing in a two-echelon assembly system. *Manufacturing & Service Operations Management* **8**(3) 273-291.