

Strategic Customer Behavior, Commitment, and Supply Chain Performance

Xuanming Su

Haas School of Business, University of California, Berkeley, California 94720, xuanming@haas.berkeley.edu

Fuqiang Zhang

Olin Business School, Washington University in St. Louis, St. Louis, Missouri 63130, fzhang22@wustl.edu

This paper studies the impact of strategic customer behavior on supply chain performance. We start with a newsvendor seller facing forward-looking customers. The seller initially charges a regular price but may salvage the leftover inventory at a lower salvage price after random demand is realized. Customers anticipate future sales and choose purchase timing to maximize their expected surplus. We characterize the rational expectations equilibrium, where we find that the seller's stocking level is lower than that in the classic model without strategic customers. We show that the seller's profit can be improved by promising either that quantities available will be limited (quantity commitment) or that prices will be kept high (price commitment). In most cases, both forms of commitment are not credible in a centralized supply chain with a single seller. However, decentralized supply chains can use contractual arrangements as indirect commitment devices to attain the desired outcomes with commitment. Decentralization has generally been associated with coordination problems, but we present the contrasting view that disparate interests within a supply chain can actually improve overall supply chain performance. In particular, with strategic customer behavior, we find that (i) a decentralized supply chain with a wholesale price contract may perform strictly better than a centralized supply chain; (ii) contracts widely studied in the supply chain coordination literature (e.g., markdown money, sales rebates, and buyback contracts) can serve as a commitment device as well as an incentive-coordinating device; and (iii) some of the above contracts cannot allocate profits arbitrarily between supply chain members because of strategic customer behavior.

Key words: strategic customer behavior; commitment; supply chains; newsvendor; rational expectations; decentralization

History: Accepted by William S. Lovejoy, operations and supply chain management; received December 15, 2005. This paper was with the authors 5 months for 6 revisions. Published online in *Articles in Advance* July 21, 2008.

1. Introduction

Consumers today have largely been trained to wait for sales. This is a general consensus, widely accepted by practitioners and academics alike. Year after year, market research organizations conduct surveys with holiday season shoppers and find that more than half of them plan to wait for the year-end sales. Together with competitive pressures, this has forced retailers to offer steeper discounts, earlier and earlier into the retail season (Byrnes and Zellner 2004). The inevitable consequence is a vicious cycle: consumers expect increasingly generous discounts, and retailers fulfill these expectations by cutting deeper and deeper into their margins. Decreased profit margins challenge the ability of these businesses to provide an adequate level of retail service, and this leads to decreased customer satisfaction.

The retail industry has long recognized the critical impact of bargain-hunting behavior on the bottom line, and the advent of markdown optimization

offers an opportunity to tackle this issue directly (Sliwa 2003). Markdown optimization balances supply and demand and increases the sell-through rate by setting prices in response to available inventory. As a result, consumers may no longer benefit from blindly waiting for sales because it is now more likely that their desired product will be sold out if they wait for too long. This approach has led to substantial profit increases at several major retailers such as Bloomingdale's and Gap (Kadet 2004). These recent trends suggest not only that strategic consumer behavior is attracting attention in the retail industry, but that active measures are also being adopted to lessen its negative impact.

Although the importance of strategic consumer behavior is widely acknowledged, there has been little research studying its implications on supply chain management. In view of this gap in the literature, this paper has three main objectives. First, we would like to develop a modeling framework to study strategic consumer behavior in supply chains. We begin

with the classic newsvendor setting, which is a fundamental building block in the literature, and proceed to incorporate strategic demand into the model. Second, we would like to use this model to investigate the impact of strategic consumer behavior on supply chain performance. Although it is intuitively clear that the effect on firm profits is negative, the economic mechanisms underlying these effects need to be understood better. The third objective is prescriptive: when consumers are strategic, how can we better manage the supply chain? In a centralized setting, how should firms determine pricing and inventory decisions? In decentralized systems, how should the incentives of various parties (e.g., manufacturers, retailers, and consumers) be coordinated?

Our model builds on the classic newsvendor model. In the usual setup, the newsvendor faces a random aggregate demand X and chooses the stocking quantity Q , and the exogenous parameters are p (regular price), c (cost), and s (salvage price). To incorporate strategic behavior among the consumers (in the demand pool X), we allow the consumers to either buy at the regular price p or wait for the salvage price s . If there is inventory remaining at the salvage price, the consumers who wait may get a good deal; otherwise, they end up without the product. The newsvendor's decision variables are now p (regular price) and Q (quantity); these choices influence the consumers' to-buy-or-to-wait decisions. This model captures the strategic interaction between the newsvendor and the consumers. With this model, we would like to characterize *equilibrium* outcomes (i.e., price, quantity, and consumers' purchase decisions).

The solution approach in this paper follows the rational expectations hypothesis, first proposed by Muth (1961). It states that economic outcomes do not differ systematically from what people expect them to be. Applying this concept to the present setting, we analyze the model above by looking for rational expectations (RE) equilibria, which satisfy the following: (i) given their expectations of future availability, consumers make their purchase (or waiting) decisions, (ii) given his expectations of consumers' willingness to pay, the newsvendor makes his pricing and stocking decisions, and (iii) everyone's expectations are consistent with actual outcomes. In this paper, we first derive the RE equilibrium for the newsvendor model and then extend the concept to the case of decentralized supply chains. A decentralized supply chain consists of a single retailer and a single manufacturer. In this case, we assume that a contractual agreement between them is exogenously specified up front; this is consistent with the existing literature on supply chain contracting. Then the retailer and consumers play the RE equilibrium. In this way, equilibrium outcomes

under decentralization can also be studied using our framework.

There are three main results in this paper. First, we show that, when consumers are strategic, a centralized supply chain may perform strictly *worse* than a decentralized supply chain. This is because, contrary to popular belief, double marginalization may benefit decentralized systems: a reduced stocking quantity intensifies the threat of stock-outs and thus also increases consumers' willingness to pay. Centralized systems, however, are unable to impose similar threats, which are not credible because they will not be fulfilled in RE equilibrium. This challenges the conventional wisdom that centralized systems provide a gold standard for supply chains to strive for, because when consumers are strategic it is possible to surpass this benchmark.

Next, we propose two alternative benchmarks that serve as performance targets. We have already seen that profits can be enhanced when firms use the threat of stock-outs to increase consumers' willingness to pay; alternatively, another means to achieve the same end is to guarantee that future prices will remain high. These two strategies (quantity commitment and price commitment, respectively) induce consumers to purchase early at a higher price by maintaining the exclusivity of the product. In our analysis, we solve for the RE equilibrium between the consumers and the newsvendor under price and quantity commitment. We confirm that commitment power increases profits and that each form of commitment is preferred under different situations. These two commitment benchmarks offer a fresh perspective on the design of decentralized supply chains: with strategic customer behavior, instead of striving for centralized outcomes, we should work toward the commitment outcomes.

Finally, we show that these performance targets can indeed be attained. By structuring appropriate contractual agreements between supply chain parties, decentralized systems can achieve the price-commitment and quantity-commitment outcomes. In other words, supply contracts function *indirectly* as commitment devices. We emphasize "indirectly" because firms do not (and often cannot) make any explicit promises to consumers (e.g., the promise by a firm not to mark down price may not be credible because, after the regular season, the firm has incentives to salvage the leftover products at a lower price). Instead, they use contractual arrangements to "change the rules of the game" to attain the desired equilibrium outcomes. From a mechanism design standpoint, it is not surprising to find that, as long as the class of admissible contractual mechanisms is large enough, significantly better outcomes can be implemented. However, in our case, it turns out that the

following types of contracts are sufficient to implement the commitment outcomes: wholesale price contracts, buybacks, markdown money, and sales rebates. In addition, we identify several features of these contracts that are novel in the current setting with strategic consumers. For instance, buybacks serve to implement price commitment whereas markdown money empowers the retailer with quantity commitment. Also, strategic consumer behavior sometimes imposes constraints on how profits must be allocated between the supply chain parties.

The remainder of this paper is structured as follows. Section 2 provides a literature review. Section 3 introduces our newsvendor model with strategic consumers and analyzes the value of commitment. Sections 4 and 5 demonstrate how to attain our two profit benchmarks (under quantity commitment and price commitment, respectively) using appropriate contractual mechanisms. Section 6 considers several extensions, and §7 concludes. Online Appendix A (provided in the e-companion)¹ provides the proofs of all technical results, and Online Appendix B (provided in the e-companion) generalizes our model to the case with heterogeneous consumer valuations.

2. Literature Review

When making a purchase decision, consumers choose from various alternatives, including the option of delaying the purchase. For example, whether or not a consumer makes a purchase depends on her expectations of what future prices will be. The forward-looking behavior of consumers has been widely documented in the consumer behavior literature, for example, Jacobson and Obermiller (1990), Krishna et al. (1991), Krishna (1994), and Ho et al. (1998), among others. This stream of research focuses on consumers' impressions of retailers' pricing patterns and its impact on consumers' purchasing decisions.

Given its prevalence and importance, strategic consumer behavior has been studied extensively across various disciplines. There is a stream of research in economics and marketing that examines durable goods markets with strategic consumers. This has been inspired by Coase (1972), who showed that durable goods monopolists will end up earning zero profits because, as long as prices are above marginal cost, strategic consumers will anticipate and wait for price reductions. Bulow (1982) contributes the important insight that a durable good monopolist prefers to rent his product rather than to sell it, because this avoids the competition from secondhand markets operated primarily by strategic consumers. Two

recent studies that are most relevant to this paper are Desai et al. (2004) and Arya and Mittendorf (2006), both of which compare centralized and decentralized distribution channels for durable goods under strategic consumer behavior. Desai et al. show that, under certain conditions, strategic decentralization through the addition of a retailer in the distribution channel can increase a manufacturer's profits if the manufacturer can commit to future wholesale prices with the retailer. Arya and Mittendorf show that the benefits of decentralization are robust against changes in the manufacturer's ability to commit. Our paper is similar in spirit because we also find that a decentralized supply chain may outperform a centralized one as a result of strategic consumer behavior, but we demonstrate this finding in a different setting with seasonal products and stochastic demand (rather than durable goods with deterministic demand).

Strategic consumer behavior has recently been studied by operations management researchers. In particular, the literature on dynamic pricing of finite inventories is related to our paper. Aviv and Pazgal (2008) study optimal pricing of a seasonal product with the presence of forward-looking consumers. There is a single price reduction, and the authors examine the optimal timing and extent of discounts. Elmaghraby et al. (2008) investigate optimal markdown mechanisms in the presence of rational customers with multi-unit demands. Cho et al. (2007) analyze optimal customer responses when facing an exogenously specified dynamic pricing policy. Gallien (2006) shows that the optimal prices should increase over time when selling a finite inventory to customers arriving over an infinite horizon. Su (2007) considers a heterogeneous population of strategic as well as myopic customers and shows that, depending on the customer composition, optimal price paths could involve either markups or markdowns. Yu et al. (2007) study advance selling with limited capacity under various demand scenarios. These papers assume that the initial capacity is exogenously given, which differs from our model. Liu and van Ryzin (2008) study quantity decisions instead of price decisions in a capacity-rationing model with strategic customers. Yin et al. (2007) analyze a fashion retailer's ordering decision in a model where strategic customers arrive to the store according to a Poisson process and the prices are announced before the selling season starts. They focus on the impact of two different display formats (display all versus display one) on the seller's expected profits. There are also papers that consider strategic consumers in dynamic auction settings (see, e.g., Caldentey and Vulcano 2007, Gallien and Gupta 2007). All of the above papers study only the interaction between strategic consumers and a single seller,

¹ An electronic companion to this paper is available as part of the online version that can be found at <http://mansci.journal.informs.org/>.

whereas our paper also considers the vertical relationship between manufacturers and retailers.

Our paper builds on the well known newsvendor problem: find the optimal order quantity that maximizes the seller's expected profit under probabilistic demand. There have been several recent developments of the newsvendor model that are most relevant. Petruzzi and Dada (1999) summarize and extend the newsvendor model literature with pricing decisions. In their model, the aggregate demand is characterized as a function of the retail price together with a random shock. We also consider pricing decisions for the retailer, but in our model individual consumers may react rationally to the retailers' ordering quantity as well as prices. Dana and Petruzzi (2001) study a newsvendor problem in which customer demand is dependent on both price and inventory level. In their model, customers who visit the newsvendor forego an exogenous outside option (or, equivalently, they face a traveling cost). A higher likelihood of availability induces more customer visits and stimulates demand. This yields a higher optimal stocking level for the newsvendor. In contrast, in our model, strategic customer behavior leads to a lower optimal stocking level. This is because strategic waiting by customers compromises the retailer's ability to charge a high price in the regular selling season, and a remedy for the retailer is to limit the ordering quantity so that customers are discouraged from waiting for the sale. Cachon and Kok (2007) reinterpret the salvage price as a market-clearing price. They endogenize the clearance pricing decision and focus on how to estimate the salvage value from historical data. A literature review on the newsvendor model and its extensions can be found in Silver et al. (1998) and Khouja (1999).

There exists an enormous literature on supply chain contracting with a newsvendor retailer. The focus is on how to design a contractual relationship between the retailer and supplier to maximize supply chain efficiency. It has been shown that a variety of contracts can eliminate double marginalization by aligning firms' incentives. Some of the contracts can also split the supply chain profit arbitrarily between firms. For a detailed survey of the literature on supply chain contracting, the readers are referred to Cachon (2003). It is worth pointing out that so far the customary practice has been to use the centralized optimal solution as the benchmark to evaluate various contracts. However, with the presence of strategic consumers, commitment becomes a critical issue in addition to centralization, and the centralized optimal solution benchmark may not be appropriate anymore.

3. Newsvendor Model with Strategic Customers

3.1. Basic Setup

This paper builds upon the newsvendor inventory model. There is a single seller who must determine how many units of a product to stock. The seller faces random demand $X \geq 0$, which can be interpreted as the total mass of (infinitesimal) consumers in the market. Let us denote the distribution and density of X by F and f . We assume that the demand distribution has an increasing failure rate, that is, $f(x)/(1 - F(x))$ is increasing in x ; this assumption is satisfied by many commonly observed distributions. For technical reasons, we also assume that f is continuous and has a connected support, and $f(0) > 0$. Each unit of the product costs c but is valued by customers at v . That is, v is customers' utility from consuming the product. Leftover units can be sold in an exogenous salvage market at s per unit. We assume that $s < c < v$.

Our model departs from the classic setup by introducing strategic customers. Specifically, customers recognize that the product may become available on the salvage market at price s . To maximize individual expected surplus, customers choose between buying immediately (at full price) or waiting for the sale (at salvage price). If the regular selling price is too high, customers may find it worthwhile to wait for the sale, even if the product may be sold out by then. Let r denote customers' reservation price or their willingness to pay in the regular selling season. Clearly, we know that $r < v$ if there is a positive probability that customers can get the product at the lower salvage price s . This setup can directly be compared against the standard newsvendor model, in which the selling price is v and all customers buy at this price upon the realization of demand X .

In our model, the seller's decisions include price p and quantity Q ; the former is observed by the customers, but the latter is not. Customers choose their reservation price r , which is not observed by the seller. All parties form beliefs over relevant quantities that are not observed: the seller forms beliefs ξ_r over consumers' reservation prices, and consumers form beliefs ξ_{prob} over the probability of availability on the salvage market (which depends on the seller's inventory Q).

We shall adopt the following sequence of events. First, the seller privately forms beliefs ξ_r over consumers' reservation prices and then optimally chooses the price p and quantity Q , given these beliefs. Recall that customers may observe the selling price but not the stocking quantity. Then, customers privately form beliefs ξ_{prob} over their chances of obtaining the product on the salvage market and then form their reservation prices r based on these beliefs. Next, the

random demand X is realized. Then, sales occur at the full price p (provided that the selling price p does not exceed customers' reservation price r). Finally, all remaining units are sold at the salvage price s .

Based on the chronology above, we first describe the consumer's decision problem. We use "he" to refer to the seller and "she" to refer to the consumer. Consider a particular consumer who forms the belief that she will obtain the product with probability ξ_{prob} if she waits for the sale. (Note that here a point estimate of the availability probability is sufficient because the distribution of the possible outcomes is binary: the product is either available or not.) Based on these expectations, the consumer's expected surplus if she faces an actual regular price p is

$$\max\{v - p, (v - s)\xi_{\text{prob}}\}. \quad (1)$$

The first term is the surplus from buying at the regular price p , and the second term is the expected surplus if she waits for the sale, where there is probability ξ_{prob} that she earns surplus $v - s$ and probability $1 - \xi_{\text{prob}}$ that she earns zero surplus (if the product is out of stock). Because the consumer chooses the more attractive option between buying and waiting, she will buy at price p if and only if $v - p \geq (v - s)\xi_{\text{prob}}$. In other words, given expectations ξ_{prob} , the consumer's reservation price for the product is

$$r(\xi_{\text{prob}}) = v - (v - s)\xi_{\text{prob}}. \quad (2)$$

For tractability, we make the following two assumptions. First, we consider homogeneous customers who share the same beliefs ξ_{prob} and the same reservation price r . In Online Appendix B, we relax this assumption and consider more elaborate models of consumer behavior to demonstrate the robustness of our results. Second, we assume that consumers are risk neutral and that they do not discount future payoffs. Section 6.1 provides a discussion of the impact of introducing a discount factor.

Next, we consider the seller's decision problem. The two decisions are stocking quantity Q and regular selling price p . Suppose that the seller expects that all customers have a reservation price ξ_r . Given these beliefs, it is clear that he will choose price $p = \xi_r$ and quantity $Q(p) = \arg \max_Q \Pi(Q, p)$, where $\Pi(Q, p) = (p - s)E(X \wedge Q) - (c - s)Q$ is the newsvendor profit function, which has a unique maximizer. We use " \wedge " throughout the paper for the minimum operator. Notice that, given beliefs ξ_r , the seller is essentially considering facing a standard newsvendor problem with a fixed price.

3.2. Rational Expectations Equilibrium

DEFINITION 1. A RE equilibrium $(p, Q, r, \xi_{\text{prob}}, \xi_r)$ satisfies the following: (i) $r = v - (v - s)\xi_{\text{prob}}$, (ii) $p = \xi_r$, (iii) $Q = \arg \max_Q \Pi(Q, p)$, (iv) $\xi_{\text{prob}} = F(Q)$, and (v) $\xi_r = r$.

Conditions (i), (ii), and (iii) assert that, under expectations ξ_{prob} and ξ_r , the seller and all consumers will rationally choose the appropriate utility-maximizing actions, as discussed above. The final two conditions require that expectations must be consistent with outcomes. In (iv), the expectations ξ_{prob} must concur with the actual probability of obtaining the product if an individual consumer waits for the sale. This actual probability can be calculated as follows. In equilibrium, the seller prices the product at consumers' reservation price, so all consumers will buy the product. Consider an individual consumer who deviates and waits instead. Because this customer is infinitesimally small, the mass of remaining consumers is X . Hence, this individual will face a stockout if $X > Q$. On the other hand, if $X \leq Q$, this individual consumer will get the product at salvage price. Therefore, when an individual consumer waits, he will obtain the product with probability $F(Q)$, which must be consistent with his beliefs ξ_{prob} , as shown in (iv). Here, we have implicitly assumed efficient rationing: customers who wait for the sale have the highest priority to receive the product in the salvage market. This is reasonable because customers who are interested in a particular product and are eagerly waiting for a sale are also the ones who are more likely to get the product when the sale actually takes place. Finally, in (v), the seller must correctly anticipate consumers' reservation price.

As an aside, we note that this situation can alternatively be modeled as a simultaneous-move game in which the seller sets price and quantity while customers choose their reservation prices. The reader may wish to verify that the RE equilibrium described above is indeed a Nash equilibrium in this simultaneous-move game and that there exist other pure-strategy, symmetric (among consumers) Nash equilibria. We have chosen to focus on the RE equilibrium, which is quite intuitive and helps to make explicit the deliberations of all parties.

Notice that the conditions for a RE equilibrium in Definition 1 can be reduced to a pair of equations in p and Q only: $p = v - (v - s)F(Q)$, and $Q = \arg \max_Q \Pi(Q, p)$. These two conditions will be used to explicitly characterize the RE equilibrium below.

PROPOSITION 1. *In the RE equilibrium, all consumers buy immediately, and the seller's price and quantity are characterized by*

$$p_c = s + \sqrt{(v - s)(c - s)}, \quad \bar{F}(Q_c) = \sqrt{\frac{c - s}{v - s}}. \quad (3)$$

All proofs are given in Online Appendix A. Here, we have used \bar{F} to denote $1 - F$, and the subscript c in p_c and Q_c stands for "centralized" (because we are considering a centralized system with a single seller).

We will also use Π_c to denote the seller’s profit under the RE equilibrium.

It is instructive to compare the equilibrium price and quantity in our model with that in the classical newsvendor model, where customers are not strategic and are willing to pay their valuation v for the product (so the seller also charges v). In terms of price, the equilibrium price p_c must lie between c and v , because $p_c - s$ is the geometric mean of $v - s$ and $c - s$. Unsurprisingly, strategic consumer behavior forces the seller to price below v . Next, in terms of quantity, the equilibrium stocking quantity Q_c is also lower than the optimal stocking quantity Q_0 in the standard newsvendor model. Observe that $Q_0 > Q_c$ because

$$\bar{F}(Q_0) = \frac{c - s}{v - s} < \sqrt{\frac{c - s}{v - s}} = \bar{F}(Q_c). \quad (4)$$

When confronted with strategic customers, the seller lowers his stocking quantity. This is because the seller hopes to increase customers’ willingness to pay by restricting the availability of the product and maintaining an image of exclusivity. Generating scarcity and competition among buyers is quite a natural strategy to adopt. In a related study, Liu and van Ryzin (2008) also demonstrate the effectiveness of rationing strategies. Similarly, in auctions, an increased number of bidders often induces more aggressive bidding behavior (see, e.g., Bulow and Klemperer 1996, Vulcano et al. 2002).

3.3. Value of Commitment

Can the seller do better than the RE equilibrium outcome described above? Yes, provided that he is able to make binding commitments on his own actions. In this section, we consider two distinct types of commitment power: quantity commitment (keeping quantities low) and price commitment (keeping prices high). Practical examples of quantity commitment include limited editions of cars, furniture, and collectors’ items, whereas price commitment may arise in the form of “one-price” or “no-haggle” policies. Both strategies may increase the seller’s profits by guaranteeing to customers that his product is sufficiently exclusive: it is not available in large quantities, and it cannot be purchased at low prices. The seller’s optimal profit levels under quantity commitment and price commitment will be used as profit benchmarks for the remainder of our analysis.

We begin by discussing quantity commitment. Suppose the seller has at his disposal some commitment device that convinces customers that exactly Q units of his product will be available for the entire time horizon of relevance. This commitment device could take the form of advertising campaigns, long-term reputation concerns, or supply-side constraints, but

we do not model it explicitly. Given that Q units are available, customers no longer need to form rational expectations ξ_{prob} because they know for sure that if they wait for the sale (while all other customers buy), their chances of getting the product on the salvage market is $F(Q)$. In other words, when the seller commits to sell Q units, customers are willing to pay (and the seller also charges) price $p(Q) = v - (v - s)F(Q)$. Given this selling price, the seller’s profits, as a function of the quantity Q that he commits to, is

$$\begin{aligned} \Pi_q(Q) &= (p(Q) - s)E(X \wedge Q) - (c - s)Q \\ &= (v - s)\bar{F}(Q)E(X \wedge Q) - (c - s)Q. \end{aligned} \quad (5)$$

The seller will thus stock the optimal quantity $Q_q^* = \arg \max_Q \Pi_q(Q)$ and charge price $p_q^* = v - (v - s) \cdot F(Q_q^*)$, and the corresponding optimal profit level under quantity commitment is denoted Π_q^* ; the subscript q stands for “quantity commitment.” Here, quantity commitment allows the seller to actively manipulate the selling price $p(Q)$ as a function of the chosen quantity Q ; on the other hand, in the absence of quantity commitment, the price p is determined by equilibrium rational expectations.

LEMMA 1. $\Pi_q(Q)$ has a unique maximizer Q_q^* .

We next compare the quantity-commitment optimal outcome with the RE equilibrium outcome.

PROPOSITION 2. (i) $Q_q^* \leq Q_c$ and $\Pi_q^* \geq \Pi_c$.

(ii) For fixed s and v , there exist thresholds c_l and c_h ($c_l \leq c_h$) such that $\Pi_q^* - \Pi_c$ is decreasing in c for $c \leq c_l$ and $c \geq c_h$.

(iii) For fixed c and s , there exist thresholds v_l and v_h ($v_l \leq v_h$) such that $\Pi_q^* - \Pi_c$ is increasing in v for $v \leq v_l$ and $v \geq v_h$.

Result (i) in Proposition 2 confirms our earlier statement that quantity commitment enhances the seller’s profits. This is done by committing to a stocking quantity Q_q^* that is lower than the RE equilibrium Q_c . Recall that in the RE equilibrium the seller has already restricted availability by stocking at a level Q_c that is lower than the corresponding quantity Q_0 in the absence of strategic customers. Our current result tells us that the seller can do better by limiting his available quantities even further. Indeed, creating artificial shortages is not an uncommon practice. For instance, Zara, one of the largest Spanish fashion retailers, is well known for limiting production quantities to induce customers to pay the regular selling prices (Ferdows et al. 2004). Furthermore, popular toys and electronic gadgets routinely go out of stock every holiday season (see Wingfield and Guth 2005). In these cases, scarcity also serves as a marketing tool in generating hype and allure, which further increases the

desirability of the product. Results (ii) and (iii) characterize the impact of model parameters on the value of commitment. They suggest that quantity commitment tends to be more valuable as the product becomes more profitable (either v increases or c decreases).

We stress that an external commitment device is critical in realizing the optimal quantity Q_q^* . The seller's promises, by themselves, are not credible, because when the seller lacks a commitment device the quantity Q_q^* cannot be sustained in a RE equilibrium. To see this, note from Definition 1 that, to sustain Q_q^* in equilibrium, the required expectations are $\xi_{\text{prob}} = F(Q_q^*)$ and $\xi_r = r$, and the required selling and reservation prices are $p = r = v - (v - s)F(Q_q^*)$. This set of values is the only candidate that satisfies conditions (i), (ii), (iv), and (v) in Definition 1, but with these values the remaining condition (iii) contradicts the definition of Q_q^* . Intuitively, this means that the seller has an incentive to deviate from stocking the quantity Q_q^* once the market believes in it, so these expectations will not be formed in the first place. Specifically, under the expectations that only Q_q^* is available, customers would be willing to pay $p(Q_q^*)$, but, once customers are willing to pay this much, it is in the seller's interests to raise the stocking level above Q_q^* , so the initial expectations of Q_q^* would have been inconsistent and cannot be part of a RE equilibrium. However, this problem vanishes if the seller possesses some external commitment device. Alternatively, credibility can also be sustained by establishing a reputation, but such issues are not captured in our model.

Next, we turn to price commitment. Suppose that the seller can credibly commit to future prices after demand has been realized. It is sufficient to consider the case in which the seller commits to maintain ex post prices at exactly v . (If guaranteed ex post prices are strictly between v and s , the seller can do better by instead promising v because this decreases customers' option value of waiting and increases their willingness to pay; if the guaranteed ex post price is s , it is as good as none because we are back to the RE equilibrium.) Now, committing to maintain prices at v is equivalent to eliminating the markdown opportunity provided by the salvage market. If these promises were credible, customers would be willing to pay v at the start. Therefore, under price commitment, our model reduces to the standard newsvendor model (with zero salvage value). The seller charges $p_p^* = v$, and his profit function is $\Pi_p(Q) = vE(X \wedge Q) - cQ$. The optimal selling quantity is $Q_p^* = \arg \max_Q \Pi_p(Q)$, and the optimal profit level is Π_p^* . Here, the subscript p stands for "price commitment." The following proposition compares the performance of price commitment to the RE equilibrium outcome.

PROPOSITION 3. (i) For fixed s and v , there is a threshold c_l such that $\Pi_p^* \geq \Pi_c$ for $c \leq c_l$ and there is a threshold c_h such that $\Pi_p^* \leq \Pi_c$ for $c \geq c_h$. In addition, there exist thresholds \hat{c} such that $\Pi_p^* - \Pi_c$ is decreasing in c for $c \leq \hat{c}$.

(ii) For fixed c and s , there exists a threshold v_l such that $\Pi_p^* \leq \Pi_c$ for $v \leq v_l$ and there is a threshold value v_h such that $\Pi_p^* \geq \Pi_c$ for $v \geq v_h$. In addition, there exist thresholds \hat{v} such that $\Pi_p^* - \Pi_c$ is increasing in v for $v \geq \hat{v}$.

Proposition 3 shows that price commitment may increase the seller's profits above the RE equilibrium level. Specifically, the inequality $\Pi_p^* \geq \Pi_c$ holds when the production cost c is relatively low and when the valuation v is relatively high. However, there also exist situations where $\Pi_p^* < \Pi_c$. Therefore, unlike quantity commitment, price commitment is not unambiguously beneficial. Proposition 3 also sheds light on when price commitment is valuable: under certain conditions, price commitment tends to be more valuable when the product becomes more profitable (either v increases or c decreases).

For the remainder of this section, we compare quantity commitment and price commitment.

PROPOSITION 4. (i) For fixed c and v , there is a threshold $\hat{s} \geq 0$ such that $\Pi_q^* \geq \Pi_p^*$ if and only if $s \geq \hat{s}$.

(ii) For fixed c and s , there is a threshold v_l such that $\Pi_q^* \geq \Pi_p^*$ for $v \leq v_l$ and there is a threshold value v_h such that $\Pi_q^* \geq \Pi_p^*$ for $v \geq v_h$.

This result states that quantity commitment is preferred over price commitment when customer valuation v is low and the salvage value s is high (i.e., both are close to production cost c). One interpretation, as follows, draws upon the comparison between mass and niche markets. Quantity commitment is preferred in mass markets: in these environments, the product is tailored to the average consumer and there are ample salvage opportunities (so v and s are close together). On the other hand, there are also niche markets, which target specific high-end customer segments, but the resulting degree of customization may constrain the transfer of the product to alternative sources of demand (so v and s are far apart); under these conditions, price commitment is preferred.

Quantity commitment and price commitment are both desirable strategies that sometimes arise in practice. However, in most situations, these strategies may not be feasible because the seller lacks an appropriate commitment device. In this case, what can the seller do? Our analysis thus far suggests that the seller would have to contend with the RE equilibrium outcome. This may be true in a centralized system (single seller) but not for decentralized systems. In the following sections, we show that contractual arrangements between supply chain parties can serve as a surrogate commitment device, so as to attain the optimal profit benchmarks Π_q^* and Π_p^* with commitment.

As a result, a decentralized supply chain may yield higher profits than a centralized supply chain.

4. Achieving Quantity Commitment in Decentralized Supply Chains

In the previous section, customers purchase the product from a single seller. This section extends the newsvendor model to a supply chain setting. That is, we consider a manufacturer distributing a product through a retailer. In this context, we interpret c as the manufacturer’s production cost and s as the retailer’s salvage value, and v and X characterize market demand in the same way as before. The sequence of events is as follows: first, the contractual agreements between the manufacturer and the retailer are exogenously established; then, the retailer and customers make their pricing, stocking, and purchase decisions according to a RE equilibrium; finally, demand is realized during the selling season, and unsold products are salvaged. In this decentralized setting, we assume that the manufacturer and the retailer are independent firms acting according to their own interests. Our goal is to design supply contracts to attain the profit benchmarks of a centralized system with quantity commitment, Π_q^* .

We begin by analyzing the simplest contract: a pure wholesale price contract. Then, we will also analyze markdown allowances, buybacks, and linear sales rebates. These contracts are widely used and relatively simple to analyze (because payments depend linearly on quantities). We demonstrate that, under appropriate contractual parameters, the decentralized supply chain can attain the quantity-commitment benchmark Π_q^* .

4.1. Wholesale Price Contracts

A wholesale price contract specifies the unit price w ($w \geq c$) that the manufacturer charges the retailer. We assume that the wholesale price w is determined through some negotiation process between the manufacturer and the retailer, which is beyond the scope of this paper. However, we may consider w a proxy of firms’ relative bargaining power: a higher w reflects a more favorable position for the manufacturer. See Cachon (2003) for more discussion about wholesale price contracts.

Under a wholesale price contract, the retailer’s profit function is

$$\Pi_w^r(Q, p) = (p - s) E(X \wedge Q) - (w - s)Q. \quad (6)$$

Here, the subscript w stands for “wholesale price” and the superscript r stands for “retailer.” (Later, we will use the superscript m to refer to the manufacturer’s profit function.) The RE equilibrium between the retailer and the consumers is derived similarly as

before. Therefore, following the argument of Proposition 1, the retailer’s order quantity Q_w and retail price p_w in RE equilibrium is given by

$$\bar{F}(Q_w) = \frac{w - s}{p_w - s} = \sqrt{\frac{w - s}{v - s}}, \quad (7)$$

$$p_w = s + (v - s)\bar{F}(Q_w) = s + \sqrt{(v - s)(w - s)}.$$

In this RE equilibrium, profits to the retailer and the manufacturer are given, respectively, by

$$\begin{aligned} \Pi_w^r &= (p_w - s) E(X \wedge Q_w) - (w - s)Q_w \\ &= (v - s)\bar{F}(Q_w) E(X \wedge Q_w) - (v - s)\bar{F}^2(Q_w)Q_w, \end{aligned} \quad (8)$$

$$\Pi_w^m = Q_w(w - c) = Q_w[(v - s)\bar{F}^2(Q_w) - (c - s)], \quad (9)$$

and total supply chain profits are $\Pi_w \equiv \Pi_w^r + \Pi_w^m = (v - s)\bar{F}(Q_w) E(X \wedge Q_w) - (c - s)Q_w$.

Observe that the wholesale price w can be used as a control lever for the supply chain to induce a particular equilibrium stocking quantity. The reasoning is as follows. Because the equilibrium quantity Q_w is decreasing in w , there is a one-to-one relationship between $Q_w \in [0, Q_c]$ and $w \in [c, v]$. (Recall that Q_c is the RE equilibrium quantity in the centralized system.) Therefore, by varying w between c and v , the system can realize any equilibrium quantity within the corresponding range. Although this particular quantity has to conform to the requirements of an RE equilibrium, it is *as if* the supply chain could specify it at the outset. In this sense, a simple wholesale price contract provides the supply chain with some degree of quantity-commitment power.

To emphasize the dependence of these equilibrium quantities on the wholesale price w , we sometimes write $Q_w(w)$, $p_w(w)$, $\Pi_w^r(w)$, $\Pi_w^m(w)$, $\Pi_w(w)$. It turns out that quantity-commitment power can significantly enhance supply chain profits. This is made precise in the next proposition, which follows from Lemma 1 and Proposition 2.

PROPOSITION 5. *There exists some $w^* \in (c, v)$ such that*

(i) *For every $w \in (c, w^*]$, equilibrium total profits in the decentralized system under the wholesale price contract w exceed equilibrium profits in the centralized system; that is, $\Pi_w(w) \geq \Pi_c$.*

(ii) *The wholesale price contract $w = w^*$ enables the decentralized system to achieve the optimal profit under quantity commitment Π_q^* .*

This is a surprising result: Proposition 5(i) states that the profit of a centralized supply chain is dominated by the profits of a decentralized supply chain under an array of wholesale price contracts. In this paper, by “centralized” we mean that the supply chain is controlled by a central planner who wishes

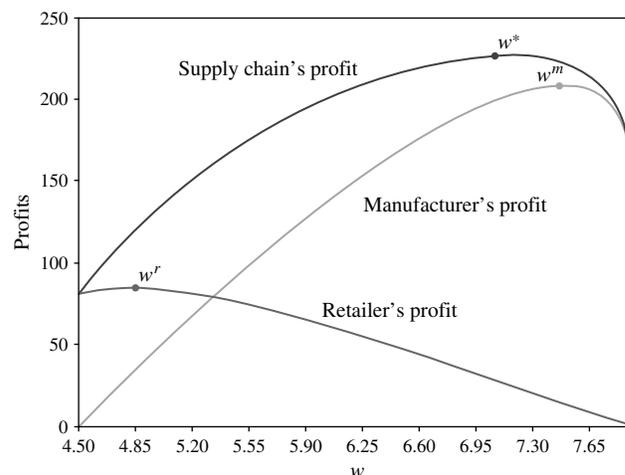
to maximize the entire supply chain's profit. It has been a customary practice to use centralized management as a benchmark to study channel efficiency in the operations and marketing literature. Proposition 5(i) delivers a message that the centralized optimal profit may not always be the highest possible profit that a supply chain can achieve. In particular, there have been numerous studies addressing the inefficiency caused by double marginalization: i.e., when $w > c$, the retailer orders less than the optimal quantity for the entire supply chain. In contrast, we present a model in which increasing the wholesale price beyond c actually improves the supply chain's profit. The reason is that a higher wholesale price will enable the retailer to charge a higher retail price to forward-looking consumers in equilibrium, and varying the wholesale price alters only the transfer payment between the supply chain members.

Proposition 5(ii) goes one step further. It states that a decentralized supply chain can achieve Π_q^* , the optimal profit under the quantity commitment, by using a wholesale price contract $w = w^*$. This wholesale price induces the optimal quantity Q_q^* in equilibrium. A similar situation where a wholesale price contract can coordinate a supply chain is when horizontal competition is present. For example, Netessine and Zhang (2005) demonstrate that, in a distribution channel with a manufacturer and multiple retailers, the substitution effect among the retailers can offset the double marginalization effect and thus retain the supply chain optimal outcome. The driving forces underlying our model are different: we have strategic consumers on top of double marginalization, and a wholesale price contract can serve as a coordination device to balance these two opposite forces.

Although the wholesale price contract w^* allows the supply chain to attain the profit benchmark Π_q^* , it enforces a particular division of profits between the retailer and the manufacturer (their shares are $\Pi_w^r(w^*)$ and $\Pi_w^m(w^*)$, respectively). Yet each individual party may prefer some wholesale price other than w^* and may negotiate for their preferences. Because it may not be possible for both parties to agree upon the wholesale price w^* , it now becomes important to understand each party's preferences over alternative wholesale prices.

We proceed by asking the following two questions. First, if given the choice, what wholesale price would the retailer and the manufacturer select? In other words, how are the quantities $w^r \in \arg \max_w \Pi_w^r(w)$ and $w^m \in \arg \max_w \Pi_w^m(w)$ characterized, and are they unique? Second, how do these unilaterally preferred wholesale prices w^r and w^m compare with the system-optimal wholesale price w^* ? The following lemma deals with these questions.

Figure 1 Comparison of the Profit Functions



Note. Demand follows a normal distribution $N(100, 400)$, and parameter values are $c = 4.5$, $s = 4$, and $v = 8$.

LEMMA 2. (i) The maximizers w^r and w^m are unique. (ii) $w^r < w^* < w^m$.

Consistent with this result, Figure 1 shows a numerical example with the retailer, manufacturer, and supply chain profit functions (against wholesale price w) and their maximizers.

We are interested in characterizing the set of Pareto optimal wholesale price contracts. A contract is Pareto optimal if there exists no alternative such that some firm is strictly better off and no firm is worse off. We have the next proposition, which follows from Lemmas 1 and 2.

PROPOSITION 6. The set of Pareto optimal wholesale price contracts is $w \in [w^r, w^m]$. In particular, if $w^r > c$, then the wholesale price $w = c$ is Pareto dominated by any $w \in [c, w^r]$.

The proposition sheds some light on how the allocation of bargaining power affects supply chain efficiency: because $w^r < w^* < w^m$, the supply chain optimum is achieved somewhere in the middle, and any extreme allocation of bargaining power is not good for the supply chain. This is in contrast with some of the existing results in the literature. Lariviere and Porteus (2001) acknowledge that, with wholesale price contracts, an increase in retail power can improve supply chain performance. When studying the pull contracts (i.e., the retailer chooses the wholesale price and orders only as needed during the selling season), Cachon (2004) finds that the opposite is true: increasing the supplier's bargaining power (in the form of a higher minimum profit requirement) would increase supply chain efficiency. Our model provides a more balanced view by noting that well balanced bargaining power may achieve the most efficient outcome for a supply chain. Now, consider the

following question: if the retailer has absolute bargaining power, will it offer a wholesale price $w = c$ and squeeze the manufacturer's profit to zero? Not necessarily. Note that the problem faced by the retailer with varying wholesale price w is equivalent to the problem faced by the single seller with varying production cost c . If we view the seller's profit Π_c as a function of c , then w^r is essentially the production cost that maximizes the seller's profit. Therefore, if $w^r > c$ (i.e., the profit-maximizing production cost is greater than the actual cost), then the contract with $w = c$ is Pareto dominated by any $w \in [c, w^r]$ (such as in Figure 1). That is, under certain conditions, both the retailer and the manufacturer may prefer a higher wholesale price. The fact that the retailer may voluntarily invite a higher wholesale price is quite interesting.

4.2. Markdown Money Contracts

We now study markdown money contracts. Apart from realizing the profit benchmark Π_q^* in decentralized systems, they also offer additional flexibility in that they permit arbitrary profit allocations.

With a markdown money contract the manufacturer charges the retailer a unit price w_m but pays the retailer m per unit salvaged at the end of the season. We require $w_m - s - m \geq 0$ because otherwise the retailer will order an infinite quantity. Such a contract has been widely observed in the retail industry, and m is called markdown money.

Another related class of contracts is sales rebates. Suppose that the manufacturer sells to the retailer at a wholesale price w_r but, as an incentive to generate sales, offers to pay r for each unit sold at regular price. Now, observe that a markdown money contract (w_m, m) with $m < 0$ is equivalent to a sales rebate contract with $w_r = w_m + |m|$ and $r = |m|$. In other words, rather than interpreting $m < 0$ as a penalty for not selling, we may see it as a reward for selling. We emphasize that our analysis allows for $m < 0$; the only required condition is $w_m - s - m \geq 0$ as explained above. When the need arises, we use the terminology *positive* markdown contracts ($m \geq 0$) and sales rebates ($m < 0$) to distinguish between the two cases; otherwise, we generally use "markdown money contracts" to refer to both cases.

Under a markdown money contract, the retailer's profit function is

$$\Pi_m^r(Q, p) = (p - s - m)E(X \wedge Q) - (w_m - s - m)Q. \quad (10)$$

Here, the subscript m stands for "markdown money." The RE equilibrium between the retailer and the consumers is derived similarly as before: the retailer's order quantity Q_m and retail price p_m satisfy

$$\bar{F}(Q_m) = \frac{w_m - s - m}{p_m - s - m}, \quad p_m = s + (v - s)\bar{F}(Q_m). \quad (11)$$

Next, we show that markdown money contracts can achieve the profit benchmark Π_q^* while splitting total profits arbitrarily between the manufacturer and the retailer. Let λ denote the retailer's profit share that the supply chain wishes to realize. Next, let λ^* denote the retailer's profit share under the wholesale price contract attaining Π_q^* , and let w^* and p^* denote the corresponding wholesale and retail prices. With this additional notation, we have the following proposition.

PROPOSITION 7. *Let $\lambda \in [0, 1]$. Under the markdown money contract*

$$\begin{aligned} w_m &= \left(1 - \frac{\lambda}{\lambda^*}\right)p^* + \frac{\lambda}{\lambda^*}w^* \quad \text{and} \\ m &= \left(1 - \frac{\lambda}{\lambda^*}\right)(p^* - s), \end{aligned} \quad (12)$$

the optimal profit under quantity commitment Π_q^ is achieved and the retailer's share is $\lambda\Pi_q^*$.*

Markdown money contracts represent an improvement over the wholesale price contracts in §4.1 because the former can attain the quantity-commitment benchmark Π_q^* while allocating profits arbitrarily. However, with markdown money contracts, the manufacturer needs to verify the number of salvaged units, and this might give rise to additional monitoring costs. Nevertheless, a powerful member in the supply chain may still prefer a profit allocation scheme other than the one resulting from w_q^* (i.e., the wholesale price contract yielding Π_q^*). It is well known in the operations literature that markdown money contracts can coordinate supply chains and allocate total profits arbitrarily. Such a result continues to hold in our model with strategic customers when quantity commitment is desirable.

In terms of implementation, it is useful to check whether we need a positive markdown money contract or a sales rebate contract. The following proposition provides the answer.

PROPOSITION 8. *Suppose we wish to attain the profit benchmark Π_q^* while allocating a fraction $\lambda \in [0, 1]$ of it to the retailer.*

(i) *When $\lambda \leq \lambda^*$, we can use a positive markdown money contract with*

$$\begin{aligned} w_m &= \left(1 - \frac{\lambda}{\lambda^*}\right)p^* + \frac{\lambda}{\lambda^*}w^* \geq w^* \quad \text{and} \\ m &= \left(1 - \frac{\lambda}{\lambda^*}\right)(p^* - s). \end{aligned} \quad (13)$$

(ii) *When $\lambda > \lambda^*$, we can use a sales rebate contract with*

$$\begin{aligned} w_r &= \left(1 - \frac{\lambda}{\lambda^*}\right)s + \frac{\lambda}{\lambda^*}w^* > w^* \quad \text{and} \\ r &= \left|1 - \frac{\lambda}{\lambda^*}\right|(p^* - s). \end{aligned} \quad (14)$$

This result indicates that, when using markdown money contracts, the wholesale price (whether w_m or w_r) is at least as large as the pure wholesale price w^* attaining Π_q^* . In other words, in return for offering markdown allowances (or sales rebates), manufacturers charge higher wholesale prices. Indeed, it is not surprising that many retailers perceive markdown money as “getting their money back” (see Hurlbut 2005).

Proposition 8 also reveals that, although both positive markdowns and sales rebates can be used to attain the profit benchmark Π_q^* , the former allocates a smaller share to the retailer. Specifically, using positive markdowns to attain Π_q^* imposes a profit cap of $\lambda^* \Pi_q^*$ on the retailer, and using sales rebates imposes a profit cap of $(1 - \lambda^*) \Pi_q^*$ on the manufacturer. Therefore, our model suggests that a strong manufacturer (when λ is small) should offer positive markdown money, whereas a strong retailer (when λ is large) should demand sales rebates. For example, in practice, positive markdowns are often offered by luxury fashion designers; however, whether the division of bargaining power in this example agrees with our prediction is an open empirical question.

Nevertheless, positive markdown allowances appear to be the norm in today’s retail environment despite the presence of increasingly dominant retailers. Because strong retailer power is incompatible with the cap on their profits (under positive markdown allowances), our analysis suggests that internal discord may arise. Indeed, the recent controversy over markdown money has sparked several heated arguments between retailers and their suppliers (see Rozhon 2005). On one hand, retailers are demanding substantial amounts of markdown money from their suppliers and threatening not to place orders for the upcoming season if the suppliers do not pay. On the other hand, suppliers accuse retailers of marking down items more aggressively than necessary and refuse to share their burden of lost margins. From a practical viewpoint, it would be interesting to see whether adopting sales rebates (rather than markdown allowances) would ease this tension in the retail sector.

5. Achieving Price Commitment in Decentralized Supply Chains

In this section, we show that decentralized supply chains can attain the price-commitment benchmark profit Π_p^* using buyback contracts. Under these contracts, the manufacturer sells to the retailer at wholesale price w_b and agrees to buy back unsold items at b per unit after demand is realized. However, they do not allow an arbitrary division of profits.

5.1. Buyback Contracts

There are two separate cases to consider. When $b < s$, the retailer would be better off directing excess inventory into his salvage market rather than selling them back to the manufacturer. The buyback option is as good as none, and the (w_b, b) contract reduces to a pure wholesale contract, which has already been studied above. Therefore, our study of buyback contracts focuses on the case where $b \geq s$. In this case, the option of selling excess inventory back to the manufacturer becomes more attractive than marking down the price. Remarkably, this buyback provision eliminates the salvage market, thereby inducing all customers to pay the maximum regular price of v . We stress that this is possible only if excess inventory is actually delivered back to the manufacturer (or disposed of). Mere monetary transfers are insufficient because the retailer has to “burn his own bridge” to convince customers that he is unable to activate his salvage market after all intra-supply-chain transactions have occurred. Like the monitoring costs associated with a markdown money contract, there are also costs for implementing a buyback contract: for example, shipping costs for returns or costs for disposing the unsold products. However, these costs are assumed to be negligible because including them does not generate any additional insights.

Observe that buyback contracts resemble the markdown money contracts studied in §4.2. The only difference lies in whether goods are physically returned to the manufacturer. Most studies in the operations literature overlook this difference, but we emphasize its importance in achieving price commitment. In addition, our model highlights two other differences. First, markdown allowances are used to achieve quantity commitment, but buybacks are used to achieve price commitment. Second, markdown money contracts can allocate profits arbitrarily between supply chain members whereas buybacks cannot.

We now proceed with the analysis. Suppose that a buyback contract (w_b, b) with $b \geq s$ has been established at the outset. In this environment, the RE equilibrium (between the retailer and the strategic customers) dictates that prices (selling price, reservation price, and anticipated reservation price) are all $p = r = \xi_r = v$ and the anticipated probability of low-price availability is $\xi_{\text{prob}} = 0$. Then, the retailer faces the profit function

$$\Pi'_b(Q) = (v - b) E(X \wedge Q) - (w_b - b)Q \quad (15)$$

and chooses the quantity Q'_b satisfying $\bar{F}(Q'_b) = (w_b - b)/(v - b)$. Here, the subscript b stands for “buyback.” We also define $\Pi''_b(Q)$ and $\Pi_b(Q) = \Pi''_b(Q) + \Pi''_m(Q)$ as the manufacturer’s profits and total supply chain profits (under the buyback contract), as

a function of the retailer's order quantity Q . These profit functions, respectively, are

$$\begin{aligned}\Pi_b^m(Q) &= bE(X \wedge Q) + (w_b - c - b)Q \quad \text{and} \\ \Pi_b(Q) &= vE(X \wedge Q) - cQ.\end{aligned}\quad (16)$$

Total supply chain profit $\Pi_b(Q)$ is maximized at Q_b satisfying $\bar{F}(Q_b) = c/v$. Observe that total supply chain profits under the buyback contract $\Pi_b(Q)$ coincide with the profit function of the centralized system with price commitment, $\Pi_p(Q)$, so their maximizers also coincide. Therefore, if the supply chain can be coordinated to produce and stock the optimal quantity Q_b , the price commitment profit benchmark Π_p^* can be attained. The next proposition shows that this can indeed be done, but only for a certain range of profit allocations.

PROPOSITION 9. *Let $\lambda \in [0, 1 - s/v]$. Under the buyback contract*

$$w_b = \lambda c + (1 - \lambda)v \quad \text{and} \quad b = (1 - \lambda)v, \quad (17)$$

the RE equilibrium outcome attains the price-commitment profit benchmark Π_p^ for the system. Furthermore, the retailer's profit is $\lambda\Pi_p^*$, and the manufacturer's profit is $(1 - \lambda)\Pi_p^*$.*

Our results identify a new role that buyback contracts play when customers are strategic: they serve as a commitment device. The ability to commit to strategic customers, combined with the ability to coordinate on mutually beneficial actions, allows supply chains to attain the profit levels of a centralized system with price commitment. This may not even be an alternative when a centralized seller operates in isolation. Industry evidence seems to be consistent with the above analysis. For example, buyback or return policies are widely used in the book industry. Instead of marking down prices, major retailers such as Barnes & Noble return the unsold books to their publishers when the selling season ends. The returned copies are then sold to companies specializing in bargain books, or books that cannot be sold are simply pulped for a total loss. There is an ongoing debate in the book industry over whether returns should be eliminated: although some retailers claim that they are willing to mark down books and sell them on the spot, most publishers are leery of the change (see Trachtenberg 2005). In fact, one major concern is that readers may learn to wait until books are cheaper. We suspect that the book industry, in spite of losses due to returns, may still be using such a practice as a price-commitment device to extract higher profits.

As Proposition 9 illustrates, buyback contracts impose an upper bound of $1 - s/v$ on the retailer's profit share. Typically, the ability to allocate profits

arbitrarily between parties is an important criterion in evaluating different contractual formats. The possibility of arbitrary profit allocations separates the coordination process from the allocation process: the supply chain can concentrate on maximizing the size of the pie before negotiating over individual shares. In the current case, the upper bound on retailer share may create problems, especially when the retailer is powerful relative to the manufacturer. In an era with retailers becoming increasingly dominant (see Messinger and Narasimhan 1995, Bloom and Perry 2001), retailers may actively negotiate against the profit cap imposed on them by optimal buyback agreements. This suggests that using buyback contracts as a price-commitment device may face implementation challenges. Yet, ironically, it is precisely these profit caps (due to condition $b \geq s$) that make buybacks effective in providing price commitment. The inevitable consequence is that attaining price commitment via buyback arrangements may no longer be feasible in the current environment.

Another limitation is that buyback contracts are not renegotiation proof and hence their usefulness is limited. Recently there have been several studies looking at the issue of renegotiation in supply chains, for instance, Iyer and Villas-Boas (2003) and Plambeck and Taylor (2007).

6. Extensions and Discussion

6.1. Discount Factor

Suppose that consumers use a discount factor of $\delta \in [0, 1]$ on end-of-season payoffs. Then, given that the anticipated probability of availability is ξ_{prob} , the consumer's expected surplus from waiting for a sale is now $\delta\xi_{\text{prob}}(v - s)$ instead of $\xi_{\text{prob}}(v - s)$ as before. This implies that the consumer's reservation price would be $r = v - \delta\xi_{\text{prob}}(v - s)$.

In the centralized case, the RE equilibrium quantity Q_δ is now characterized by

$$\delta\bar{F}^2(Q_\delta) + (1 - \delta)\bar{F}(Q_\delta) = \frac{c - s}{v - s}. \quad (18)$$

Observe that when $\delta = 1$ we have $\bar{F}(Q_\delta) = \sqrt{(c - s)/(v - s)}$, which agrees with Proposition 1. On the other hand, when $\delta = 0$, we have $\bar{F}(Q_\delta) = (c - s)/(v - s)$, which is intuitive because setting $\delta = 0$ eliminates the viability of the salvage market, so consumers never wait for the sale and we return to the standard newsvendor model. As δ increases from 0 to 1, consumers become more patient and the effect of strategic behavior becomes more salient: equilibrium price and quantity both decrease, as is necessary to encourage start-of-season purchases, and this leads to lower seller profits.

In the decentralized case, time discounting also does not affect the qualitative nature of our results. Contractual agreements can still be used to attain the price-commitment and quantity-commitment outcomes. However, because Π_p^* is independent of δ whereas Π_q^* decreases as δ increases, increased consumer patience (higher δ) creates a bias in favor of price commitment.

There are at least two alternative interpretations of the discount factor. First, the same construction above can be used to capture risk aversion. Some consumers are willing to pay a risk premium on end-of-season surplus as it involves the risk of stockouts, so they adopt a discount factor of $\delta < 1$. On the other hand, risk-seeking preferences would require $\delta > 1$. The second alternative interpretation of the discount factor involves estimation errors. If consumers consistently underestimate availability, we can model this using $\delta < 1$; analogously, we can use $\delta > 1$ to represent overestimation.

6.2. Customer Arrival Process

Our basic model is an extension of the newsvendor setup, and we use a single random variable to capture one-shot demand. In reality, it would be more natural to assume that customers arrive over time. Because our focus is on supply chain contracting issues, we abstract from dynamic pricing and continue to assume that the seller may charge at most two different prices: a regular-season price and a markdown price after all customers have arrived. As before, each customer's buy-or-wait decision depends on the comparison between the product price and the customer's reservation price. Because both of these are independent of the sequence of customer arrivals, the equilibrium outcome of this game as well as our earlier results remain unchanged.

Furthermore, suppose that customers have discounted valuations; i.e., a later arrival is associated with a lower valuation for the product. Assume that the range of customer valuations is $[v_0, v_1]$; i.e., the first arrival has a valuation v_1 , and the last arrival has a valuation v_0 . Then we face a heterogeneous customer valuation model discussed in Online Appendix B: arrival time can be used to index the customers (θ is the arrival time), and the corresponding distribution function G can be constructed using the dynamic arrival process. From the discussion in Online Appendix B, our main insights remain unchanged.

6.3. Endogenous Salvage Price

So far we have assumed a constant salvage value s . This enables us to study the impact of strategic customer behavior on the classic newsvendor model, as well as the impact on supply chain contracting.

However, more generally, there may be price effects on the salvage market. To capture price effects on the salvage market, suppose that the salvage price s is a decreasing function of the number of leftover units Q_l , denoted by $s(Q_l)$. As a benchmark for comparison, we consider $s = s(0) < c$ in our basic model. Then with endogenous salvage value $s(Q_l)$, increasing the seller's quantity Q has a two-fold effect: first, it will increase product availability in the salvage market; second, it will decrease the salvage price $s(Q_l)$ because Q_l will be stochastically larger. Note that only the first effect exists in the basic model with $s = s(0)$. Thus, in the model with endogenous salvage value $s(Q_l)$, customers would have more incentive to wait, compared to in the basic model with a constant salvage price $s(0)$. As a result, the seller's optimal quantity would be even lower. This implies that the effect of strategic customer behavior will be stronger when we consider price effects on the salvage market.

6.4. Bargain Hunters and Price Takers

So far, our analysis assumes that all customers are strategic bargain hunters and may wait for end-of-season sales. To improve realism, we may also consider myopic customers, who either purchase the product at regular price or leave the market. Let ϕ and $\bar{\phi} = 1 - \phi$, respectively, denote the fraction of strategic and myopic consumers, and we continue to assume that all consumers have valuation v . In this environment, the seller may either set a regular price below v to induce strategic consumers to buy (which brings us back to the previous analysis) or price the product at v and sell only to myopic consumers (in this case, the demand is effectively $\bar{\phi}X$, and this becomes a standard newsvendor problem). As long as the fraction ϕ of strategic consumers is large enough, the first alternative is preferred and our earlier model applies.

7. Conclusion

Strategic consumer behavior has largely been overlooked in the supply chain management literature. This paper attempts to fill this gap. Our basic premise is that consumers look ahead and plan purchases with future opportunities in mind. By doing so, consumers force firms to compete against their own future selves. This can be alleviated if firms can somehow "promise" to consumers that future purchase opportunities will be unattractive: either prices will remain high or availability will be limited. However, in most situations, such commitments are not credible because firms will be better off not fulfilling these commitments at the time they become due.

Decentralized supply chains, on the other hand, can make credible commitments to consumers in an

indirect way. Through appropriate contractual mechanisms, supply chain parties can structure the incentive system such that it will indeed be in the best interests of at least one party to maintain high prices or low availability in the future. Indirectly, these outcomes discourage strategic behavior and increase supply chain profits. Whereas decentralization has generally been associated with coordination problems, we present the contrasting view that disparate interests within a supply chain can actually be used to realize improved outcomes. In fact, decentralized supply chains sometimes perform strictly better than their centralized counterparts.

Future research can extend our line of inquiry in several directions. First, this research can be extended to study the performance of alternative supply contracts (such as quantity discounts or revenue sharing contracts) in the presence of strategic customer behavior. Beyond supply contracts, it would also be interesting to study consumer contracts (such as most-favored-customer protection agreements, which promise to reimburse the difference if prices fall in the future). Second, many operational strategies (e.g., quick response and collaborative forecasting) are designed to minimize supply–demand mismatches by creating more flexible replenishment opportunities or improving the demand forecast. One point of view is that improving service levels may hurt firms' profits because this places customers in a better position to game against them. Another perspective is that these strategies help to mitigate strategic consumer waiting by reducing leftover inventory. It would be interesting to investigate how the introduction of customer behavior affects the incentives for adopting these operational strategies. Third, a similar analysis can be conducted in a setting with horizontal competition. In this case, how do strategic consumers influence the competitive landscape? In general, we believe that strategic consumer behavior is a fruitful research topic. Beyond supply chain settings, similar issues also arise in revenue management and in service contexts.

8. Electronic Companion

An electronic companion to this paper is available as part of the online version that can be found at <http://mansci.journal.informs.org/>.

Acknowledgments

The authors thank Gérard Cachon, Fangruo Chen, Rachel Chen, Terry Hendershott, Teck Ho, Ganesh Iyer, Cuihong Li, William Lovejoy, Tom Marschak, Serguei Netessine, Erica Plambeck, Terry Taylor, Miguel Villas-Boas, Candace Yano, Shuya Yin, and Hao Zhang for their helpful comments. They also thank the associate editor and reviewers and seminar participants at Hong Kong University of Sci-

ence and Technology, Shanghai Jiaotong University, University of California, Irvine, Washington State University in St. Louis, the MSOM 2006 Conference in Atlanta, Georgia, and the INFORMS 2006 Annual Meeting in Pittsburgh, Pennsylvania.

References

- Arya, A., B. Mittendorf. 2006. Benefits of channel discord in the sale of durable goods. *Marketing Sci.* 25(1) 91–96.
- Aviv, Y., A. Pazgal. 2008. Optimal pricing of seasonal products in the presence of forward-looking consumers. *Manufacturing Service Oper. Management* 10(3) 339–359.
- Bloom, P., V. Perry. 2001. Retailer power and supplier welfare. *J. Retailing* 77 379–396.
- Bulow, J. I. 1982. Durable-goods monopolists. *J. Political Econom.* 90(2) 314–332.
- Bulow, J. I., P. D. Klemperer. 1996. Auctions vs. negotiations. *Amer. Econom. Rev.* 86(1) 180–194.
- Byrnes, N., W. Zellner. 2004. Playing the discount game. *Bus. Week* (December 13).
- Cachon, G. P. 2003. Supply chain coordination with contracts. S. C. Graves, T. de Kok, eds. *Handbooks in OR & MS. Volume II, Supply Chain Management: Design, Coordination and Operation*. North Holland, Amsterdam, 227–339.
- Cachon, G. P. 2004. The allocation of inventory risk in a supply chain: Push, pull, and advance-purchase discount contracts. *Management Sci.* 50(2) 222–238.
- Cachon, G. P., A. G. Kok. 2007. Implementation of the newsvendor model with clearance pricing: How to (and how not to) estimate the salvage value. *Manufacturing Service Oper. Management* 9(3) 276–290.
- Caldentey, R., G. Vulcano. 2007. Online auction and list price revenue management. *Management Sci.* 53(5) 795–813.
- Cho, M., M. Fan, Y. P. Zhou. 2007. A study of an online fare-track and order system. Working paper, University of Washington Business School, Seattle.
- Coase, R. H. 1972. Durability and monopoly. *J. Law Econom.* 15(1) 143–149.
- Dana, J. D., N. C. Petrucci. 2001. The newsvendor model with endogenous demand. *Management Sci.* 47(11) 1488–1497.
- Desai, P., O. Koenigsberg, D. Purohit. 2004. Strategic decentralization and channel coordination. *Quant. Marketing Econom.* 2 5–22.
- Elmalghraby, W., A. Gulcu, P. Keskinocak. 2008. Optimal markdown mechanisms in the presence of rational customers with multi-unit demands. *Manufacturing Service Oper. Management* 10(1) 126–148.
- Ferdows, K., M. A. Lewis, J. A. D. Machuca. 2004. Rapid-fire fulfillment. *Harvard Bus. Rev.* 82(11) 104–110.
- Gallien, J. 2006. Dynamic mechanism design for online commerce. *Oper. Res.* 54(2) 291–310.
- Gallien, J., S. Gupta. 2007. Temporary permanent buyout prices in online auctions. *Management Sci.* 53(5) 814–833.
- Ho, T.-H., C. S. Tang, D. R. Bell. 1998. Rational shopping behavior and the option value of variable pricing. *Management Sci.* 44(12) S145–S160.
- Hurlbut, T. 2005. The markdown blues, revisited. *Inc.com* (March).
- Iyer, G., M. Villas-Boas. 2003. A bargaining theory of distribution channels. *J. Marketing Res.* 40 80–100.
- Jacobson, R., C. Obermiller. 1990. The formation of expected future prices: A reference price for forward-looking consumers. *J. Consumer Res.* 16 420–432.
- Kadet, A. 2004. The price is right. *Smart Money* (December) 90–94.

- Khouja, M. 1999. The single-period (newsvendor) problem: Literature review and suggestions for future research. *Omega* 27 537–553.
- Krishna, A. 1994. The impact of dealing patterns on purchase behavior. *Marketing Sci.* 13(4) 351–373.
- Krishna, A., I. Currim, R. Shoemaker. 1991. Consumer perceptions of promotion activity. *J. Marketing* 55 4–16.
- Lariviere, M., E. Porteus. 2001. Selling to the newsvendor: An analysis of price-only contracts. *Manufacturing Service Oper. Management* 3(4) 293–305.
- Liu, Q., G. J. van Ryzin. 2008. Strategic capacity rationing to induce early purchases. *Management Sci.* 54(6) 1115–1131.
- Messinger, P., C. Narasimhan. 1995. Has power shifted in the grocery channel? *Marketing Sci.* 14(2) 189–223.
- Muth, J. F. 1961. Rational expectations and the theory of price movements. *Econometrica* 29 315–335.
- Netessine, S., F. Zhang. 2005. Positive vs. negative externalities in inventory management: Implications for supply chain design. *Manufacturing Service Oper. Management* 7(1) 58–73.
- Petruzzi, N., M. Dada. 1999. Pricing and the newsvendor problem: A review with extensions. *Oper. Res.* 47(2) 183–194.
- Plambeck, E. L., T. A. Taylor. 2007. Implications of renegotiation for optimal contract flexibility and investment. *Management Sci.* 53(12) 1872–1886.
- Rozhon, T. 2005. First the markdown, then the showdown. *New York Times* (February 25) C1.
- Silver, E. A., D. F. Pyke, R. P. Peterson. 1998. *Inventory Management and Production Planning Scheduling*, 3rd ed. John Wiley, New York.
- Sliwa, C. 2003. Retailers explore price optimization. *ComputerWorld* (January 20), <http://www.computerworld.com/industrytopics/retail/story/0,10801,77714,00.html>.
- Su, X. 2007. Inter-temporal pricing with strategic customer behavior. *Management Sci.* 53(5) 726–741.
- Trachtenberg, J. A. 2005. Shelf life: Quest for best seller creates a pileup of returned books. *Wall Street Journal* (June 3) A1.
- Vulcano, G., G. van Ryzin, C. Maglaras. 2002. Optimal dynamic auctions for revenue management. *Management Sci.* 48(11) 1388–1407.
- Wingfield, N., R. A. Guth. 2005. Why shortages of hot gifts endure as a Christmas ritual. *Wall Street Journal* (December 2) B1.
- Yin, R., Y. Aviv, A. Pazgal, C. S. Tang. 2007. The implications of customer purchasing behavior and in-store display formats. Working paper, University of California, Los Angeles.
- Yu, M., R. Kapuscinski, H.-S. Ahn. 2007. Advance selling with limited capacity and customers' dependent valuations. Working paper, Ross School of Business, University of Michigan, Ann Arbor.