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Advance Demand Information, Price Discrimination, and Preorder Strategies

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This paper studies the preorder strategy that a seller may use to sell a perishable product in an uncertain market with heterogeneous consumers. By accepting preorders, the seller is able to obtain advance demand information for inventory planning and price discriminate the consumers. Given the preorder option, the consumers react strategically by optimizing the timing of purchase. We find that accurate demand information may improve the availability of the product, which undermines the seller's ability to charge a high preorder price. As a result, advance demand information may hurt the seller's profit due to its negative impact for the preorder season. This cautions the seller about a potential conflict between the benefits of advance demand information and price discrimination when facing strategic consumers. A common practice to contain consumers' strategic waiting is to offer price guarantees that compensate preorder consumers in case of a later price cut. Under price guarantees, the seller will reduce price in the regular season only if the preorder demand is low; however, such advance information implies weak demand in the regular season as well. This means that the seller can no longer benefit from a high demand in the regular season. Therefore, under price guarantees, more accurate advance demand information may still hurt the seller's profit due to its adverse impact for the regular season. We also investigate the seller's strategy choice in such a setting (i.e., whether the preorder option should be offered and whether it should be coupled with price guarantees) and find that the answer depends on the relative sizes of the heterogeneous consumer segments.

Key words: preorder; advance demand information; price discrimination; strategic consumer behavior; price guarantee
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1. Introduction

Preorder refers to the practice of a seller accepting customer orders before a product is released. Such a practice has become commonplace for a wide variety of products in recent years. Consumer electronic products are among the categories for which preorders are often used. To name a few examples: In 2002, Apple reported the successful use of preorders for both the original and new iMac computers, which revived the fortunes of the then-troubled company (*Wall Street Journal* 2002). When launching the new iPhone 3G S, the third generation of the smart phone, Apple allowed customers to preorder the product to secure the delivery on the release date (Keizer 2009). In early September 2009, Nokia announced that its first Linux-based smart phone, the N900, was available through preorders in the U.S. market (Goldstein 2009). Amazon offered the preorder option to consumers when unveiling the second version of its e-book reader, Kindle 2 (Carnoy 2009). Game consoles, such as Nintendo's Wii and Sony's Playstation 3, had been put on preorder before they were formally released (Martin 2006, Macarthy 2007).

The preorder option is clearly beneficial to consumers because it guarantees prompt delivery on release. This is especially valuable when the product is a big hit and will be hard to find in stores due to its popularity. It is not uncommon for extremely popular gadgets to run out of stock immediately after release. Consumers may have to wait for weeks or even months to get the product. For instance, retailers warned customers in mid-2006 that no Wii units would be available without a preorder until 2007 (Martin 2006). Apple sold out its preorder inventory for iPad before the release of the product (Berndtson 2010). Preorders are often placed by enthusiastic consumers who are eager to be the first to get their hands on a new product.

The preorder strategy may bring significant benefits to the seller as well. First, the seller can gauge how much demand there will be for his product from the preorder sales. For new products with relatively short life cycles, the demand is usually hard to predict, yet matching supply with demand is important. Thus, the advance demand information obtained from preorder sales will be very useful in procurement, production, and inventory planning. The use of preorders has been further promoted by the advent of the Internet and other information technologies that have greatly reduced the costs associated with data collection and processing. It has been reported that by accepting preorders for iPhone 3G S, Apple did not experience the same kind of stockout problems that occurred with its iPhone 3G due to a mismatch between supply and demand (Keizer 2009).

Second, the preorder strategy provides leverage for the seller to charge different prices based on the timing of a customer's purchase. By accepting preorders, the seller can identify the consumer segment that is willing to pay a premium price for guaranteed early delivery. These consumers are either new technology lovers or simply loyal fans of the brand. They are often referred to as "early adopters," and the extra price they pay is called an "early adopter tax." In fact, recently the early adopter tax has received many discussions in various industries (see Nair 2007 for video games; Jack 2007 for Apple's iPhone; and Falcon 2009 for Sony's latest gaming gadget, PSP Go). These discussions are corroborated by the observation that many products on preorder exhibit patterns of price cutting. For example, Nokia started accepting preorders for its N900 smart phone at $649 and then slashed the price to $589 when it was close to release (Goldstein 2009, King 2009). Walmart dropped the preorder price of myTouch 3G Slide from $199.99 to $129.99 shortly before the release (Tenerowicz 2010). Amazon charged a preorder price of $359 for its Kindle 2 and then dropped the price to $299 after the release (Carnoy 2009). Not surprisingly, consumers and market analysts may anticipate such price reductions and make purchasing decisions accordingly. See Coursey (2010) and Tofel (2010) for market conjectures about the iPad's price drop even before it is released.

With the preorder option, a forward-looking customer will choose the timing of purchase: Placing a preorder guarantees the availability of the product, but this is probably at the expense of a higher price; waiting for a lowered price (e.g., after the product is released) sounds quite attractive, but meanwhile the consumer has to face the risk of stockout. How much a consumer is willing to pay for a preorder depends on her valuation of the product and the expectation of future price and availability of the product. The seller needs to base inventory and pricing decisions on the presence of advance demand information and consumers' strategic behavior. Despite the prevalence of the preorder practice, there has been surprisingly little research that analyzes the seller's optimal decisions while taking both demand information updating and forward-looking consumers explicitly into account. In this paper, we study the preorder strategy by developing a modeling framework that incorporates all the important elements mentioned above: the seller's inventory and pricing decisions, advance demand information, and consumers' strategic response. Specifically, we aim to address the following research questions:

What is the value of advance demand information? From the operations point of view, a major benefit of accepting preorders is that the seller can obtain advance demand information. This information helps improve the seller's decision on initial production runs to satisfy demand, and its effectiveness has been frequently lauded in the literature. However, a better match between supply and demand implies that availability of the product becomes less of a concern, which may affect consumers' willingness to pay for a preorder. Thus, it would be interesting to study when advance demand information is valuable to the seller in the presence of strategic consumer behavior.

What is the impact of price guarantees? Consumers may be reluctant to place preorders if they expect a possible price cut in the future. To encourage early purchases, the seller may offer a price guarantee along with the preorder option. That is, a customer would receive a refund if the price declines over time. Price guarantee has become a common industry practice during the past decade (Lai et al. 2010). This raises the question of how price guarantees affect the value of advance demand information.

When and how should a seller use the preorder strategy? A seller may choose to use or not to use the preorder strategy. For example, Apple adopted the preorder strategy for its iMac computers and iPhone 3G S, but not for its iPhone 3G. Furthermore, when a preorder strategy is used, the seller may choose to offer or not to offer the price guarantee. When and how to use the preorder strategy is an important question for the seller.

The rest of this paper is organized as follows. Section 2 reviews the related literature. Section 3 introduces the model setting. Section 4 presents the analysis of the preorder strategy. Section 5 studies the impact of price guarantees. Section 6 compares the preorder strategy and the no-preorder strategy. Sections 7 discusses several extensions of the basic model. Section 8 concludes the paper. All proofs are given in Online Appendix A (provided in the electronic companion; http://dx.doi.org/10.1287/msom.1120.0398).

2. Literature Review

This paper is related to the literature on inventory planning with advance demand information. Fisher and Raman (1996) propose a quick-response strategy under which a retailer utilizes early sales for estimating demand distribution. Eppen and Iyer (1997) study a fashion-buying problem for retailers who can divert inventory to outlet stores using updated demand information. Gallego and Özer (2001, 2003), Özer (2003), and Özer and Wei (2004) study inventory management with advance demand information obtained from customer orders that are placed in advance of their needs. In these papers, the advance demand information is free and exogenously available.

When the seller faces price-sensitive customers, advance demand information becomes an endogenous outcome of pricing. Tang et al. (2004) and McCardle et al. (2004) study the benefits of an advance booking discount program by which a retailer offers a price discount to consumers who make early order commitments prior to the selling season. Boyacı and Özer (2010) investigate the capacity planning strategy for a seller who collects purchasing commitments of price-sensitive customers. In these papers, the advance demand is realized based on an aggregate demand function. Similar to these papers, we also consider the dependence between advance demand information and pricing. However, we differ in that we model consumers' strategic purchasing decisions explicitly. Because of strategic waiting of consumers, we show that more accurate advance demand information does not necessarily benefit the seller.

Existing papers that study advance selling with strategic consumers typically consider the situations where consumers have uncertain value (or demand) about the product or service (e.g., sport event tickets, books, videos, computer games, etc.) when making advance purchases. In these papers, value uncertainty causes price discounts for advance selling (an exception is Xie and Shugan 2001, who show that a premium advance-selling price may be possible when the capacity is relatively small). This line of research often assumes that the product quantity (service capacity) is fixed, and models advance selling as a tool to increase market participation (e.g., Xie and Shugan 2001, Yu et al. 2007, Alexandrov and Lariviere 2012) or segment the market (e.g., Dana 1998, Chu and Zhang 2011). Zhao and Stecke (2010) and Prasad et al. (2011) consider a newsvendor retailer who uses advance selling to obtain advance demand information. Differently from the above studies, we focus on the situations in which consumers face relatively certain product value but uncertain product availability. This is plausible for consumer electronic goods, for which there is usually sufficient information for consumers to evaluate the product before its release, but short product life cycles and unpredictable market make it difficult to match supply with demand. In this case, consumers are willing to pay a premium preorder price to secure product availability. In our model, preorder is driven by both benefits of premium profits and advance demand information, and we study the interplay between these two forces.

There has been a growing interest in studying the impact of strategic consumer behavior on a seller's inventory decision (e.g., Su and Zhang 2008, 2009). Cachon and Swinney (2009) and Swinney (2011) examine the quick-response strategy that allows the seller to replenish inventory after the selling season starts. They focus on the value of a late ordering opportunity (after demand is realized), whereas we investigate the value of an early selling opportunity (before inventory is ordered). Cachon and Swinney (2009) find that early demand information is more valuable under strategic consumer behavior, which is in contrast with our findings. There is a key difference between these two papers: In Cachon and Swinney (2009), consumers may wait for a clearance sale, the probability of which is *lower* if the seller can better match supply with demand using advance demand information; in our model, consumers may wait for a price cut in the regular season after preorder sales, and the product availability in regular selling is *higher* when more advance demand information is obtained from preorder sales. Swinney (2011) shows that quick response may hurt a seller's profit when consumers face uncertain product valuations. We establish a parallel result that advance demand information may be detrimental to a seller's profit, which does not depend on value uncertainty of the product. Huang and Van Mieghem (2009) study the value of online click tracking, which allows a seller to collect advance demand information for pricing and inventory planning. In their model, because clicking is separated from purchasing, advance demand information from click tracking always benefits the seller.

This paper is related to the literature that studies the use of price guarantees in intertemporal pricing. Png (1991) is one of the first to study the impact of offering most-favored-customer protection (i.e., price guarantee) in a two-period pricing problem. In Png's model, a seller wishes to sell a fixed inventory to two types of consumers. The size of the total consumer pool is fixed, but the relative sizes of the two types are uncertain (so there is a perfect negative correlation between the demand segments). We differ from Png (1991) in important ways: First, we endogenize the seller's inventory decision, which takes the preorder sales as an input. Second, we study the effect of advance demand information by allowing general correlation between demand segments. Lai et al. (2010) examine the value of using price guarantees for a newsvendor seller who has the opportunity to mark down the product at the end of the selling season. In their problem, the seller determines the inventory before accepting consumer orders; therefore, they do not include the element of advance demand information. Levin et al. (2007) analyze a dynamic pricing problem with fixed capacity and price guarantees. They focus on determining the optimal dynamic price and guarantee policies by assuming myopic consumers.

Finally, dynamic pricing problems have been widely studied in the revenue management literature. The objective of these studies is to find the optimal pricing and capacity (inventory) allocation rules to maximize a seller's revenue/profit. Elmaghraby and Keskinocak (2003) and Talluri and van Ryzin (2004) provide comprehensive reviews of these studies. Recently, there have been an increasing number of papers that incorporate consumers' strategic response to a seller's pricing or capacity decisions; see, for example, Su (2007), Aviv and Pazgal (2008), Elmaghraby et al. (2008), Liu and van Ryzin (2008), Yin et al. (2009), Levin et al. (2009), Jerath et al. (2009), and Mersereau and Zhang (2012). The contribution of our paper is to consider the capacity decision along with demand updating in a dynamic pricing problem, which, to the best of our knowledge, has not yet been addressed.

3. Model

A seller sells a perishable product in a two-period time horizon. The product is released at the beginning of the second period (i.e., the regular selling season), but the seller may accept preorders in the first period (i.e., the preorder season). There are two types of consumers in the market: The high type has a valuation v_H and the low type has a valuation v_L for the product, where $v_H > v_L$. For instance, the high type may refer to technology-savvy consumers. The difference between these two valuations may represent the high-type consumers' stronger preference over the product technology; or, it may be interpreted as the additional psychological value a technology-savvy consumer obtains from owning the product (Darlin 2010). Product valuation is deterministic, which means that there is sufficient information for consumers to evaluate the product before its release. This is typically the case for consumer electronic products. Many firms nowadays use exhibitions, advertising, and their websites to offer demonstration and detailed product information to consumers, and comprehensive product reviews can often be found in professional media columns before the release. Consumers are infinitesimal, as widely assumed in the literature. Usually, the technology-savvy consumers are early adopters who follow the market trend closely. Therefore, we assume all the high-type consumers arrive in the first period whereas all the low-type consumers arrive in the second period (see Moe and Fader 2002 for a similar assumption). In §7 we relax this assumption and examine the robustness of our results. Because early adopters value being among the first to own the product, we assume that the valuation v_H will be discounted by a factor $\delta \le 1$ if a high-type consumer chooses to wait and purchase the product in the second period; that is, a high-type consumer's valuation becomes δv_H in the second period. We assume $\delta v_H > v_L$. All players are risk neutral and forward looking, i.e., the seller aims to optimize his total expected profit, and the consumers maximize their expected net utility.

Market demand is uncertain in both periods. Let X_i denote the demand of type i ($i = H, L$), where X_i follows a normal distribution Φ_i (density ϕ_i) with mean μ_i and standard deviation σ_i. Let $\lambda_i = \mu_i/\sigma_i$ be the ratio between the mean and standard deviation of X_i (i.e., the reciprocal of the coefficient of variation). Bivariate normal distribution has been commonly used in the literature, especially when modeling demand information updating (see, e.g., Fisher and Raman 1996, Tang et al. 2004). Let $\rho \in (-1, 1)$ be the correlation coefficient between X_H and X_L. A positive correlation corresponds to situations where the primary uncertainty is on the total size of the market but not on the portion of each market segment, whereas a negative correlation relates to situations where the total size of the market is relatively certain, but the relative sizes of the two demand types are uncertain. For ease of exposition, we will focus on $\rho \ge 0$ in this paper; the analysis of the case $\rho < 0$ is similar and will be discussed in §7.1. We may view ρ as an indicator of the accuracy of advance demand information. That is, a larger ρ means less uncertainty in the second-period demand with the observation of the first-period demand. Define $X \equiv (X_H - \mu_H)/\sigma_H$, which follows the standard normal distribution; let Φ (ϕ) denote the distribution (density) function for the standard normal distribution. We will work with X instead of X_H due to their one-to-one relationship. For a given realization x of X, the updated low-type demand $\tilde{X}_L(x)$ follows a normal distribution with mean $\tilde{\mu}_L(x) = \mu_L + \rho\sigma_L x$ and standard deviation $\tilde{\sigma}_L = \sigma_L\sqrt{1-\rho^2}$.

We first describe the seller's problem. The seller sets a preorder price p_1 in the first period. Given this price, the high-type consumers make their preorder decisions. After the number of preorders q is received, the seller decides the second-period price p_2 and the total production/order quantity $q + Q$, where Q is the quantity used to satisfy the second-period demand. There is a constant unit cost c ($c < v_L$) for the product. Unsold products at the end of the second period have negligible salvage value, and there is no penalty for unsatisfied demand. Thus, in the second period the seller essentially faces a newsvendor problem with pricing. Note that the seller observes the preorder quantity and may use this information to update his belief about the second-period demand when making the quantity decision.

Next we describe the consumers' problem. The problem for a low-type consumer is trivial: As she arrives in the second period, she buys the product if and only if $p_2 \le v_L$. A high-type consumer, arriving in the first period, needs to decide whether she should place a preorder or delay the purchasing to the next period. If she places a preorder, then she pays the price p_1 and will definitely receive the product; otherwise, she may purchase the product at a possibly lower price p_2 in the regular season, but under the risk that the product is no longer available. Whether a consumer is willing to preorder depends on her belief of the rationing risk, i.e., the chance the product will be available in the second period. We model such a belief using a parameter $\theta \in (0,1)$: A consumer believes that a θ portion of consumers remaining in the market will get the product before her. On one extreme, $\theta = 0$ means a consumer is optimistic and believes that she will be the first in the waiting line; on the other extreme, $\theta = 1$ means that the consumer is pessimistic and thinks she will be the last in the waiting line. Cachon and Swinney (2009) provide a detailed discussion of this modeling approach and focus on specific θ values for tractability. For ease of exposition, we assume $\theta = 1/2$ in this paper. The qualitative insights will remain if this assumption is relaxed (see Lemma 6 in Online Appendix A for the analysis of general θ). An alternative approach is to use the proportional rationing rule (see, e.g., Png 1991). Again, this will not change the main results as shown by the extension in §7.3.

4. Preorder Strategy

In this section we analyze the seller's preorder strategy. In the analysis, we start with the seller's price and quantity decisions in the second period, assuming that all high-type consumers have chosen to preorder given the first-period price. Then we analyze the seller's first-period price decision, which induces the high-type consumers to preorder under a rational expectations equilibrium.

In the second period, with the number of preorders q received in the first period, the seller must determine the price p_2 and the order quantity Q to satisfy the second-period demand (besides the quantity q to be ordered for the preorder demand). Because all high-type consumers are assumed to choose preorder, the number of preorders is equal to the high-type demand, $q = x_H$, and only the low-type consumers are present in the second period. Thus, it is optimal for the seller to set $p_2 = v_L$. The seller's order quantity Q depends on the high-type demand realization x_H. Define $z_L \equiv \Phi^{-1}((v_L - c)/v_L)$, where $\Phi(z_L)$ is the critical fractile for the low-type demand. Then the optimal order quantity for the second period is given by

$$Q(x) = \tilde{\mu}_L(x) + z_L \tilde{\sigma}_L, \tag{1}$$

where $\tilde{\mu}_L(x) = \mu_L + \rho\sigma_L x$ and $\tilde{\sigma}_L = \sigma_L\sqrt{1-\rho^2}$ are the mean and standard deviation of the updated low-type demand $\tilde{X}_L(x)$ for $x \equiv (x_H - \mu_H)/\sigma_H$. The resulting profit for the second period is

$$\Pi_L(x) = (v_L - c)(\mu_L + \rho\sigma_L x) - v_L\phi(z_L)\sigma_L\sqrt{1-\rho^2}. \tag{2}$$

Note that the expected second-period profit is $\mathbb{E}[\Pi_L(X)] = \Pi_L(0)$ because $\mathbb{E}[X] = 0$. Throughout the paper we use $\mathbb{E}$ to denote the expectation operation.

In the first period, a high-type consumer will choose between preorder and wait. We consider symmetric strategies for the high-type consumers because they are homogeneous. Let r denote the consumers' reservation preorder price, at which they are indifferent between preorder and wait. If a consumer preorders at price r, then she receives a net utility $v_H - r$; if she waits, then her expected utility is $(\delta v_H - p_2)\xi$, where ξ is the consumer's belief of the availability of the product in the second period. By definition we know that $v_H - r = (\delta v_H - p_2)\xi$ or $r = v_H - (\delta v_H - p_2)\xi$. Here we assume a consumer always preorders if there is a tie, because the seller can always reduce the price by an infinitely small amount to break the tie; see Png (1991) and Xie and Shugan (2001) for similar assumptions. The seller must form a belief ξ_r about the consumers' reservation price r. Given the belief ξ_r, it is clear that the seller's optimal price to induce preorder is $p_1 = \xi_r$.

We focus on the rational expectations (RE) equilibrium of the above game. This equilibrium concept has been recently applied to various settings in the marketing and operations literatures (see Su and Zhang 2009 and the references therein). In any RE equilibrium, the players' beliefs must be consistent with the actual outcome, and the players have no unilateral incentives to deviate. Specifically, the equilibrium requires the following conditions: (i) $p_1 = \xi_r$; (ii) $p_2 = v_L$; (iii) the seller orders the quantity according to (1) for the second period; (iv) $\xi_r = r$; and (iv) the consumer's belief of product availability in the second period satisfies

$$\begin{aligned}\xi &= \mathbb{E}\left[\Pr\left(\frac{\tilde{X}_L(X)}{2} < Q(X)\right)\right]\\ &= \mathbb{E}\left[\Phi\left(\frac{\lambda_L + \rho X}{\sqrt{1-\rho^2}} + 2z_L\right)\right],\end{aligned} \tag{3}$$

where the second equality is by plugging $\tilde{X}_L(x)$ and $Q(x)$ into the first expression. Among these conditions, (i), (ii), and (iii) state that the seller chooses the profit-maximizing decisions, whereas (iv) and (v) are the consistency conditions (players' beliefs are consistent with the actual outcome). The above discussion leads to the following proposition that characterizes the equilibrium outcome of the game.

Proposition 1. *There is a unique RE equilibrium under the preorder strategy. In the equilibrium, the seller sets* $p_1 = v_H - (\delta v_H - p_2)\xi$ *and* $p_2 = v_L$, *where* ξ *is given in* (3), *and all consumers will preorder in the first period.*

For notational convenience, define $\Delta = \delta v_H - v_L$. From Proposition 1, the seller's total expected profit is (we use superscript p for preorder strategy):

$$\Pi^p = (v_H - \Delta\xi - c)\mu_H + \Pi_L(0), \tag{4}$$

where $(v_H - \Delta\xi - c)\mu_H$ is the seller's first-period profit, and $\Pi_L(0)$ is the second-period profit.

4.1. Impact of Demand Correlation (ρ)

What is the value of advance demand information in the preorder strategy? The accuracy of the advance information can be measured by the demand correlation, ρ. For the positive domain, a higher ρ corresponds to more accurate advance information (i.e., the uncertainty of the low-type demand is lower after updating). In this subsection, we investigate how the seller's profit depends on ρ.

Based on Equation (4), the derivative of Π^p with respect to ρ can be written as

$$\frac{d\Pi^p}{d\rho} = -\Delta\mu_H \frac{d\xi}{d\rho} + \frac{d}{d\rho}\Pi_L(0). \tag{5}$$

The demand correlation ρ affects both the first-period profit (through its influence on ξ, the equilibrium belief of product availability in the second period) and the second-period profit $\Pi_L(0)$. It is clear that $(d/d\rho)\Pi_L(0) = v_L\phi(z_L)\sigma_L(\rho/\sqrt{1-\rho^2})$ is positive—more accurate advance demand information helps the seller better match supply with demand, thus improving the second-period profit. The effect of ρ on the first-period profit depends on its impact on ξ, which is characterized in Lemma 1.

Lemma 1. (i) *For* $c < v_L < 2c$ (*i.e.,* $z_L < 0$), ξ *is increasing in* ρ.
(ii) *For* $v_L \geq 2c$ (*i.e.,* $z_L \geq 0$), ξ *is decreasing in* ρ.

Lemma 1 suggests that the availability probability ξ may either increase or decrease in the demand correlation ρ, depending on z_L.[1] When $v_L < 2c$, then $z_L < 0$, and the order quantity decreases in the updated demand variance $\tilde{\sigma}_L$ based on Equation (1). Because a greater ρ reduces the variance of the updated demand, both the order quantity Q and its associated product availability ξ increase in ρ. If $v_L \geq 2c$, then $z_L \geq 0$, and the seller will order more when facing greater demand uncertainty $\tilde{\sigma}_L$. This causes the product availability ξ to decrease in ρ. Because the first-period price hinges upon the product availability, the result in Lemma 1 implies that depending on the problem parameters, advance demand information may or may not help price discrimination in a preorder setting.

Now we are ready to analyze the influence of ρ on the seller's total profit in the preorder strategy. A higher ρ means lower uncertainty about the low-type demand in the second period, which helps improve the second-period profit. However, more accurate demand information may reduce the first-period profit at the same time: Based on Lemma 1(i), a higher ρ may lead to greater availability in the second period, which prevents the seller from charging a high preorder price (see Proposition 1). Therefore, the seller's total profit may not necessarily increase with ρ. Define the following threshold value

$$\tilde{\mu}(\rho) \equiv -\frac{v_L\phi(z_L)\sigma_L}{2\Delta z_L\phi(2z_L\sqrt{1-\rho^2}+\lambda_L)} \tag{6}$$

with the following property:

Lemma 2. (i) *For* $z_L \in (-\lambda_L/2, 0)$, $\tilde{\mu}(\rho)$ *increases in* ρ.
(ii) *For* $z_L \leq -\lambda_L/2$, $\tilde{\mu}(\rho)$ *is quasi-convex in* ρ.

The threshold $\tilde{\mu}(\rho)$ plays a critical role in the relationship between the seller's total profit and ρ as shown in the following proposition.

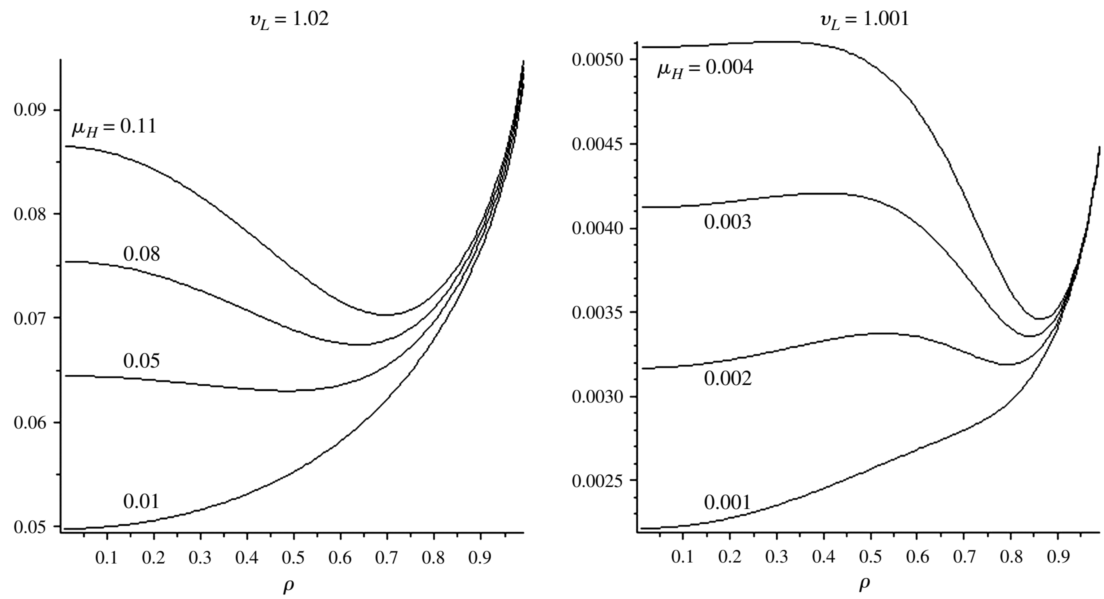
Proposition 2. (i) *If* $c < v_L < 2c$ (*i.e.,* $z_L < 0$), *then* Π^p *increases in* ρ *when* $\mu_H < \tilde{\mu}(\rho)$, *and decreases in* ρ *when* $\mu_H \geq \tilde{\mu}(\rho)$. *In particular, there exists an* $\varepsilon_v > 0$ *such that* Π^p *always decreases in* ρ *if* $v_L < c + \varepsilon_v$.
(ii) *If* $v_L \geq 2c$ (*i.e.,* $z_L \geq 0$), *then* Π^p *always increases in* ρ.

Proposition 2 suggests that the seller's profit increases in ρ only when the low-type valuation is sufficiently large ($v_L \geq 2c$) or the high-type demand is relatively small ($\mu_H < \tilde{\mu}(\rho)$). The intuition is as follows: When v_L is large, a greater ρ improves the second-period profit and also the preorder price. When v_L is small, increasing ρ has a negative effect on the preorder price. This negative effect, however, is dominated by the positive effect on the second-period profit if μ_H is low. Therefore, more accurate advance information benefits the seller either when v_L is large or when μ_H is small.

Figure 1 illustrates the situations in which the profit may decrease in ρ. It draws Π^p as a function of ρ for different μ_H and v_L values. If v_L is less than $2c$ but not too small ($-\lambda_L/2 < z_L < 0$), $\tilde{\mu}(\rho)$ is increasing (Lemma 2(i)). Thus, Π^p decreases in ρ when ρ is relatively low. This case is shown in the plot on the left.

[1] Lemma 6 in Online Appendix A studies general $\theta \in (0,1)$ and identifies a similar threshold structure based on the value of z_L.

Figure 1 Impact of ρ on the Seller's Profit in the Preorder Strategy



Note. $\mu_L = 5$, $\lambda_H = 3$, $\lambda_L = 4.5$, $v_H = 2$, $c = 1$, and $\delta = 1$.

When v_L is very small ($z_L \leq -\lambda_L/2$), $\tilde{\mu}(\rho)$ is quasi-convex (Lemma 2(ii)). Thus, Π^p decreases in ρ when ρ is intermediate. This case is shown in the plot on the right.

The above analysis delivers a message that more accurate advance demand information (higher ρ) does not necessarily improve a seller's profitability. This is in contrast with the traditional wisdom that early sales information (e.g., test sales, preorders) helps a firm better forecast demand and hence increase profit (e.g., Fisher and Raman 1996). The new driving force underlying our model is the counteracting effects of advance demand information and price discrimination: Because of strategic consumer behavior, a better ability to match supply with demand may actually prevent the firm from charging premium prices to extract consumer surplus. The negative effect of ρ can be substantial in some situations: In the extreme case where ξ is close to 1 with a large ρ, the seller has to charge a preorder price almost equal to the regular-season price v_L, losing the opportunity to price-discriminate different customer segments. This can lead to substantial profit loss of the seller if the product value is highly diverse between the two customer segments (large Δ) or the high-type customer segment is large (high μ_H). Practically speaking, our results imply that the preorder strategy could be less attractive when preorders are highly predictive of the regular-season demand.

5. Preorder with Price Guarantee

Under a price guarantee, a consumer will be compensated if the product price declines over time. For example, Apple promises to refund the difference if price is dropped within 14 days of purchase.[2] A purpose of price guarantee is to eliminate consumers' incentives to wait for markdowns so the seller can enjoy quicker sales at a relatively high price. Generally, there should be some technological requirements for implementing a price guarantee, and it might be costly to satisfy these requirements (e.g., the seller has to invest in hardware and manpower to monitor transactions and manage the refunding process). For simplicity, we assume that all necessary technologies are already in place and there is a zero implementation cost. Under this assumption, we study the impact of the price guarantee on the seller's preorder strategy. We aim to answer the following two questions: First, when should a seller offer a price guarantee along with the preorder option? Second, how does the introduction of the price guarantee affect the value of advance demand information?

5.1. Value of Price Guarantee

With a price guarantee, the seller needs to determine not only the prices p_1 and p_2 in the two periods, but also the refund η paid to each preorder consumer if $p_2 < p_1$. An intuitive special case is $\eta = p_1 - p_2$, which we call a full-price guarantee. Most of the existing literature focuses on this special case (see, e.g., Png 1991, Lai et al. 2010). Here we consider the general case without imposing any restriction on η.[3] Similar

[2] http:// store.apple.com/Catalog/US/Images/salespolicies.html (last accessed August 8, 2012).

[3] We have also analyzed the full-price guarantee and obtain similar qualitative results. In particular, the full-price guarantee

to the preorder mechanism without price guarantee, we first analyze the seller's decisions in the second period, assuming that all high-type consumers have chosen to preorder. Then we analyze the seller's decisions in the first period that induce consumers to preorder under a rational expectations equilibrium.

Under a price guarantee, the second-period price is not necessarily $p_2 = v_L$ because the seller may choose to maintain a high price to avoid refunding the earlier buyers. At the beginning of the second period, the seller's price decision depends on the realization of the high-type demand in the first period, x_H, or equivalently, $x = (x_H - \mu_H)/\sigma_H$. Specifically, the price will be reduced if and only if the profit from the low-type consumers, $\Pi_L(x)$, is greater than the total refund, $\eta(\mu_H + \sigma_H x)$, where $\Pi_L(x)$ is given in (2). Define the breakeven level of x to be

$$\hat{x}(\eta) \equiv \frac{\Pi_L(0) - \eta\mu_H}{\eta\sigma_H - (v_L - c)\rho\sigma_L}. \tag{7}$$

Negative demand realizations from a normal distribution may cause impractical price reduction decisions. For instance, the seller may reduce the price when the high-type demand is negative, because in this case the refund becomes essentially a net transfer to the seller; or, the seller may not reduce the price simply because the size of the low-type segment could be negative. To avoid these unrealistic scenarios, we follow the literature (e.g., Fisher and Raman 1996) to assume hereafter the probability of negative demand is negligible; that is, we treat $\Pr(X_H \le 0)$ and $\Pr(X_L \le 0 \mid X_H)$ as zero as an approximation. It can be shown that such an approximation is accurate in the asymptotic situation where the probability of negative demand approaches zero (see Online Appendix A for more explanation). In addition, numerical experiments indicate that the qualitative insights derived under this approximation will hold when the coefficient of variation is reasonably small (λ_i reasonably large).[4] Lemma 3 reveals how the price reduction decision depends on the refund η and high-type demand realization x.

Lemma 3. (i) *If* $\eta \le (v_L - c)\rho(\sigma_L/\sigma_H)$, *then price reduction will always happen.*

(ii) *If* $\eta > (v_L - c)\rho(\sigma_L/\sigma_H)$, *then price reduction happens when* $x < \hat{x}(\eta)$, *and* $\hat{x}(\eta)$ *decreases in* η.

For $\eta < (v_L - c)\rho(\sigma_L/\sigma_H)$, the seller will always reduce the price regardless of x to benefit from serving the low-type consumers. This case essentially reduces to our original preorder strategy with an effective preorder price $p_1 - \eta$. Hence, without losing generality, we restrict our attention to $\eta \ge (v_L - c)\rho(\sigma_L/\sigma_H)$. In this case, price reduction occurs only when the preorder demand is relatively small ($x < \hat{x}$); otherwise, the seller will keep the price at p_1 to avoid refunding the large group of preorder consumers. Our original preorder strategy can be considered as one with a price guarantee in which the refund is so low that the price will always be dropped, i.e., $\hat{x} \ge \lambda_H$.

Next we analyze the seller's first-period decision on the preorder price p_1 and refund η. Note that the price reduction threshold, $\hat{x}(\eta)$, depends on η but not on p_1. If a high-type consumer preorders, her expected utility is $u_1(p_1, \eta) = v_H - p_1 + \eta\Phi(\hat{x}(\eta))$; if she waits till the second period, her expected utility is $u_2(p_1, \eta) = \Delta\hat{\xi}(\hat{x}(\eta))$, where

$$\begin{aligned}\hat{\xi}(\hat{x}) &\equiv \mathbb{E}\left[\Pr\left(\frac{\tilde{X}_L(X)}{2} < Q(X), X < \hat{x}\right)\right]\\ &= \mathbb{E}\left[\Phi\left(\frac{\lambda_L + \rho X}{\sqrt{1-\rho^2}} + 2z_L\right)\middle| X \le \hat{x}\right]\Phi(\hat{x})\end{aligned} \tag{8}$$

is the probability that the product is available at the low price ($p_2 = v_L$) in the second period. By comparing Equations (8) and (3), we know $\hat{\xi}(\hat{x}) \le \xi$.

Given η, the optimal p_1 must satisfy $u_1(p_1, \eta) = u_2(p_1, \eta)$ so that the high-type consumers will preorder. This gives

$$p_1(\eta) = v_H + \eta\Phi(\hat{x}(\eta)) - \Delta\hat{\xi}(\hat{x}(\eta)). \tag{9}$$

Because there is a one-to-one relationship between $\hat{x}$ and η, we will work with the decision variable $\hat{x}$ instead of η, which is more convenient. For any given $\hat{x}$, we have $\eta(\hat{x}) = \Pi_L(\hat{x})/(\mu_H + \sigma_H\hat{x})$ and p_1 given by Equation (9). Thus, the seller's profit can be written as (we use the superscript g for price guarantee):

$$\begin{aligned}\Pi^g(\hat{x}) &= (p_1(\hat{x}) - c)\mu_H\\ &\quad + \mathbb{E}[\Pi_L(X) - \eta(\hat{x})(\mu_H + \sigma_H X) \mid X < \hat{x}]\Phi(\hat{x})\\ &= (v_H - \Delta\hat{\xi}(\hat{x}) - c)\mu_H\\ &\quad + \mathbb{E}[\Pi_L(X) - \eta(\hat{x})\sigma_H X \mid X < \hat{x}]\Phi(\hat{x}).\end{aligned} \tag{10}$$

When should the seller provide a price guarantee? We may compare the seller's profits under the preorder strategy with and without price guarantee. From (10), the profit margin from the high-type consumers in the price guarantee mechanism is $v_H - \Delta\hat{\xi}(\hat{x}) - c$, which is greater than the one without a price guarantee, $v_H - \Delta\xi - c$. This is true because a price guarantee enables the seller to charge a higher preorder price by discouraging consumers from waiting. Such an observation suggests that offering a price

performs very close to optimal. More details can be found in Online Appendix B (available in the electronic companion; http://dx.doi.org/10.1287/msom.1120.0398).

[4] For example, with $\lambda_H = 3$ and $\lambda_L = 4$, the probability of a negative X_H is only 0.0014 and the conditional probability of a negative X_L is at most 0.004. The main insights hold in this example, even without the approximation.

guarantee will be more effective if the size of the high-type consumers is larger. Indeed, Proposition 3 confirms this intuition. We use $\Pi^g = \max_\eta \Pi^g(\eta)$ to denote the seller's optimal profit in the price guarantee mechanism.

Proposition 3. *Suppose λ_H is fixed. Then there exists a $\hat{\mu}_H^g$ such that $\Pi^g > \Pi^p$ (i.e., the seller should offer a price guarantee in the preorder strategy) if and only if $\mu_H > \hat{\mu}_H^g$.*

Proposition 3 suggests that a price guarantee is beneficial to the seller only when μ_H is above a threshold value, $\hat{\mu}_H^g$ (a closed-form expression of $\hat{\mu}_H^g$ can be found in the proof). In other words, the size of the high-type consumer segment must be large enough to warrant the use of price guarantees; otherwise, the seller should not offer a price guarantee. Two points are worth mentioning about this threshold result: First, fixing λ_H implies that the standard deviation of the high-type demand changes proportionally with the mean. We find from numerical analysis that a similar result holds when σ_H, rather than λ_H, is fixed. That is, the result can be extended to settings with a fixed standard deviation. Second, the threshold $\hat{\mu}_H^g$ depends on the relative sizes of the two consumer segments. Analogously, it can be shown that for a fixed λ_L, there is a threshold $\hat{\mu}_L^g$ such that the price guarantee is preferred if and only if $\mu_L < \hat{\mu}_L^g$. This is the counterpart of Proposition 3 and is therefore omitted.

5.2. Impact of ρ Under Price Guarantee

We have shown in §4.1 that a higher ρ may decrease the seller's profit in the preorder strategy because of the strategic waiting behavior. The underlying reason is that when $z_L < 0$, a higher ρ improves the product availability in the second period, and thus the seller has to charge a lower preorder price. How does this result change when price guarantees are used? Here we investigate the impact of ρ under price guarantees. As an intermediate result, Lemma 4 reveals the effect of ρ on the probability that the product is available at the low price in the second period, $\hat{\xi}$.

Lemma 4. (i) *For $c < v_L < 2c$ (i.e., $z_L < 0$) and a given $\hat{x}$, $\mathrm{d}\hat{\xi}/\mathrm{d}\rho \le 0$ at $\rho = 0$, and there exists $\varepsilon_\rho > 0$ such that $\mathrm{d}\hat{\xi}/\mathrm{d}\rho \ge 0$ for $\rho \ge 1-\varepsilon_\rho$.*

(ii) *For $v_L \ge 2c$ (i.e., $z_L \ge 0$) and a given $\hat{x}$, $\hat{\xi}(\hat{x}) = \Phi(\hat{x})$ is independent of ρ.*

Recall from Lemma 3 that a price reduction occurs only when the high-type demand is relatively low ($x < \hat{x}$), which indicates a weak low-type demand as well. Therefore, in case of a price reduction, a higher ρ implies both smaller *mean* and *variance* for the updated low-type demand. Whereas the effect on the variance drives the second-period product availability to increase in ρ with $z_L < 0$, the effect on the mean does the opposite. Therefore, as shown in Lemma 4(i), $\hat{\xi}$ may decrease (thus the preorder price may increase) in ρ when ρ is small. This is in contrast to the result without a price guarantee that ξ is always increasing in ρ for $z_L < 0$. When $z_L \ge 0$, under the assumption that the probability of negative demand is negligible, it can be shown that the second-period product availability upon price reduction is one, independent of ρ. Thus, $\hat{\xi}$ (and ξ) is independent of ρ for $z_L \ge 0$, as shown in Lemma 4(ii).

Because the influence of ρ on the product availability applies only when there is a price reduction, a price guarantee will mitigate the negative effect of ρ on the preorder price. Furthermore, the price guarantee may even reverse the effect when ρ is small, as suggested by Lemma 4(i). However, in the meantime the price guarantee prevents the seller from serving a large low-type segment, because the price is reduced to target the low-type segment only when the segment is relatively small. This implies that the price guarantee introduces an adverse effect of ρ on the second-period profit. To better understand the impact of ρ on the seller's total profit, we focus on two special cases: the case when v_L is small (close to c) and the case when v_L is large (greater than $2c$). When v_L is very small, the second-period profit is negligible, and the effect of ρ focuses on the price and profit in the preorder period. When $v_L \ge 2c$, the product availability in the second period (conditional on a price reduction) is independent of ρ according to Lemma 4(ii); thus, the effect of ρ is primarily on the second-period profit.

Proposition 4. (i) *There exists $\varepsilon, \varepsilon_{\rho 1}, \varepsilon_{\rho 2} > 0$ such that, if $v_L - c < \varepsilon$, then $\mathrm{d}\Pi^g/\mathrm{d}\rho > 0$ for $\rho = 0$ and $\mathrm{d}\Pi^g/\mathrm{d}\rho < 0$ for $\rho > 1-\varepsilon_{\rho 1}$, with $\mathrm{d}\hat{\mu}_H^g/\mathrm{d}\rho < 0$ for $\rho = 0$ and $\mathrm{d}\hat{\mu}_H^g/\mathrm{d}\rho > 0$ for $\rho > 1-\varepsilon_{\rho 2}$.*

(ii) *When $v_L \ge 2c$ (i.e., $z_L \ge 0$), Π^g is quasi-convex (first decreasing and then increasing) in ρ; in addition, $\hat{\mu}_H^g$ is increasing in ρ.*

When v_L is very small, we know from Proposition 2(i) that the seller's profit without price guarantee always decreases in ρ. With a price guarantee, however, Proposition 4(i) shows that the seller's profit is increasing in ρ for ρ close to 0, and decreasing in ρ for ρ close to 1. Through numerical experiments, we observe that Π^g is quasi-concave over $\rho \in [0, 1)$. This difference results from the fact that the price guarantee mitigates and may even reverse the negative effect of ρ on the preorder price, especially when ρ is small.

Proposition 4(ii) also indicates that $\hat{\mu}_H^g$ decreases in ρ when ρ is close to 0, and increases in ρ when ρ is close to 1. Again, we observe from numerical experiments that $\hat{\mu}_H^g$ is quasi-convex over $\rho \in [0, 1)$. Thus, when v_L is small, price guarantees are favored only for intermediate ρ; when ρ is either high or low, the preorder strategy without price guarantee is better.

When $v_L \geq 2c$, recall from Proposition 2(ii) that the seller's profit without price guarantee is always increasing in ρ. Interestingly, Proposition 4(ii) shows that, with the optimal price guarantee, the seller's profit may be *decreasing* in ρ for sufficiently small ρ. That is, more accurate advance demand information may hurt the seller's profit under price guarantees even when it would only benefit the seller without a price guarantee. This result is due to the negative effect of ρ on the second-period profit introduced by the price guarantee. In comparison, note that without price guarantee, the negative effect of ρ is realized only on the first-period profit.

From Proposition 3, the seller prefers to use a price guarantee when $\mu_H > \hat{\mu}_H^g$. Proposition 4(ii) suggests that, for $v_L \geq 2c$, the seller is less likely to use a price guarantee as ρ increases. This is again due to the adverse effect of a higher ρ on the second-period profit. Such an effect is substantial for large v_L, making price guarantees less attractive as ρ increases.

6. No-Preorder Strategy

When should the seller offer the preorder option? In this section, we compare the preorder strategy with the no-preorder strategy. With no preorder, the product is sold only in the regular selling season (i.e., after the product is released). As a result, the seller does not have advance demand information when deciding the order quantity. In this case, the seller may charge a high price to target the high-type consumers first, and then drop the price to satisfy the low-type consumers if there is still inventory left. For ease of exposition, we divide the regular season into two stages, and let p_1 and p_2 ($p_1 \geq p_2$) denote the prices in the two stages (we use "stage" to distinguish from the notion of "period" used in the previous sections). Below we study the game under no preorder and then compare the three strategies we have examined so far. Again, we analyze the equilibrium in which all high-type consumers purchase in the first stage; in this equilibrium, the second-stage price p_2 is set to v_L to target the low-type consumers. As in the previous models, if a high-type consumer waits to purchase in the second stage, the product value is discounted to δv_H for the loss of early-adopter advantages.

Let the seller's order quantity be Q. If a high-type consumer delays purchasing to the second stage, she faces the availability probability

$$\xi^n(Q) = \Pr(X_H + \theta X_L < Q) = \Phi\left(\frac{Q - \mu_a}{\sigma_a}\right), \tag{11}$$

where $\mu_a = \mu_H + \theta\mu_L$ and $\sigma_a = \sqrt{\sigma_H^2 + \theta^2\sigma_L^2 + 2\rho\theta\sigma_L\sigma_H}$ are the mean and standard deviation of $X_H + \theta X_L$. The superscript n stands for no preorder. In the RE equilibrium, for a given Q, the first-stage price satisfies

$$p_1(Q) = v_H - \Delta\xi^n(Q). \tag{12}$$

Given Q and p_1, the seller's total profit is

$$\Pi^n(p_1, Q) = (p_1 - v_L)\,\mathbb{E}[\min(Q, X_H)] + v_L\,\mathbb{E}[\min(Q, X_H + X_L)] - cQ.$$

The seller's optimal order quantity Q^n is given by the first-order condition $(\partial/\partial Q)\Pi^n(p_1, Q) = 0$ for p_1 defined in (12). The seller's total profit in equilibrium can be written as

$$\Pi^n = \Delta(1 - \xi^n(Q^n))\,\mathbb{E}[\min(Q^n, X_H)] + v_L\,\mathbb{E}[\min(Q^n, X_H + X_L)] - cQ^n, \tag{13}$$

where $\Delta(1 - \xi^n(Q^n))$ represents the premium margin from the high-type consumers.

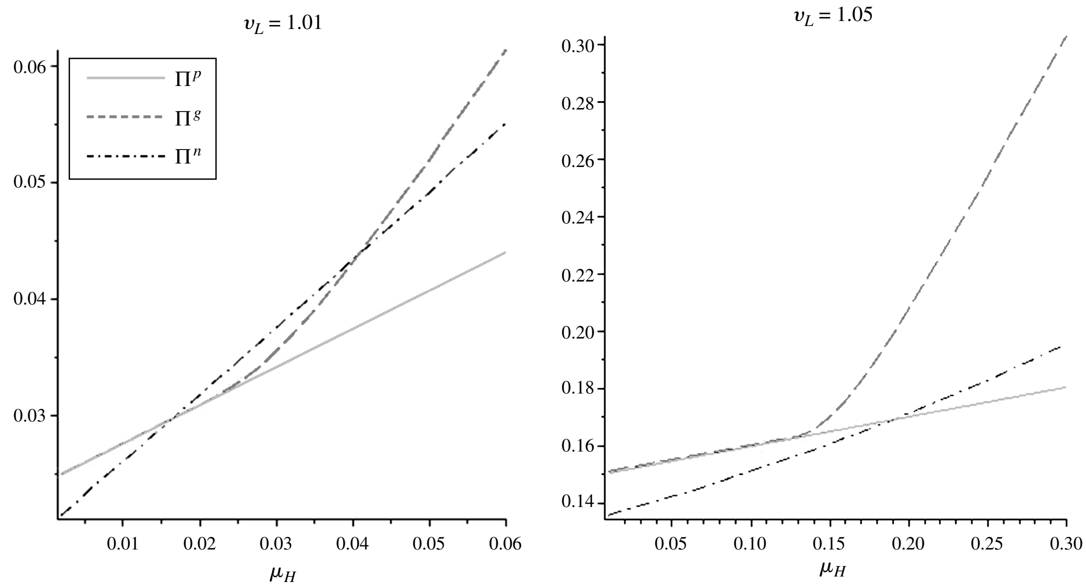
We may compare the seller's profit in Equation (13) to that under the preorder strategy in Equation (4), which leads to the following result.

Proposition 5. *Suppose σ_H is fixed. There exists a $\hat{\mu}_H^n$ such that $\Pi^p > \Pi^n$ (i.e., the seller prefers the preorder strategy over the no-preorder strategy) if and only if $\mu_H < \hat{\mu}_H^n$.*

Proposition 5 states that the preorder strategy should be used if and only if the size of the high-type demand is less than a threshold value, $\hat{\mu}_H^n$. Through numerical experiments we find that a similar threshold value exists when λ_H, rather than σ_H, is fixed. Thus, we conclude that the preorder strategy outperforms the no-preorder strategy when the relative size of the high-type customers is smaller than a certain threshold. The intuition can be explained as follows. Without advance demand information, the future product availability tends to be lower, thus raising a high-type consumer's willingness to pay at the beginning. With a greater profit margin from the high-type consumers, the no-preorder strategy benefits more from the expansion of the high-type demand segment than the preorder strategy. It can be shown that both Π^p and Π^n are linearly increasing in μ_H (for fixed σ_H). Thus, the search of $\hat{\mu}_H^n$ is straightforward, as shown in the proof of the proposition.

Thus far we have studied three different strategies: no preorder, preorder, and preorder with price guarantee. The threshold values in Propositions 3 and 5 may help the seller make pairwise comparisons of the strategies. However, ranking all three strategy choices is difficult. Hence, we rely on an extensive numerical study to obtain some insights. We report two main observations from the numerical analysis. First, as μ_H increases, the seller's optimal strategy shifts from preorder to no preorder and then to preorder with price guarantee. Second, the range for the

Figure 2 Comparison of Π^p, Π^g, and Π^n for Different μ_H and v_L Values



Note. $\mu_L = 5$, $\lambda_L = 4.5$, $\lambda_H = 3$, $v_H = 2$, $c = 1$, and $\delta = 1$.

no-preorder strategy to stand out may degenerate to zero, especially when v_L is large. Figure 2 shows a representative example, where the left plot illustrates the first observation and the right plot shows the second observation.

Here is the intuition behind these observations: Based on Proposition 5, we know the preorder strategy dominates the no-preorder strategy when μ_H is relatively small ($\mu_H < \hat{\mu}_H^n$). From Proposition 3, we know the price guarantee strategy outperforms the preorder strategy when μ_H is relatively large ($\mu_H > \hat{\mu}_H^g$). Therefore, the preorder strategy is optimal among the three when μ_H is sufficiently small ($\mu_H < \min(\hat{\mu}_H^n, \hat{\mu}_H^g)$). Now we focus on the comparison between the no-preorder strategy and the price guarantee strategy. In the no-preorder strategy, the profit margin from the high-type consumers is independent of μ_H. In the price guarantee strategy, by contrast, the profit margin from the high-type consumers is increasing in μ_H: Because of the refund liability, the seller is less likely to reduce the price when facing a larger μ_H; this reduces a high-type consumer's incentive to wait, leading to a higher preorder price. Hence, under the price guarantee strategy, the profit margin from the high-type consumers will be higher than that in the no-preorder strategy when μ_H is sufficiently large. This suggests that the price guarantee strategy dominates the no-preorder strategy for large μ_H. Thus, the no-preorder strategy can only stand out for intermediate μ_H. However, such a range may degenerate to zero when v_L is large for the following reason. With a large v_L, the advance demand information obtained from the preorder sales will be more valuable because selling to the low-type consumers is highly profitable. Therefore, for large enough v_L, the seller should always accept preorders, either with or without a price guarantee.

7. Extensions

The basic model studied in the previous sections is built on some assumptions that help maintain analytical tractability and reveal the key driving forces underlying the results. This section relaxes some of the assumptions and discusses their implications to the analysis and results.

7.1. Negative Demand Correlation ($\rho < 0$)

So far we have focused on $\rho \geq 0$ in the analysis. This is appropriate when modeling new product introductions, of which the total market size is variable and each consumer segment expands with the total market. There may be situations where the total market size is relatively certain, but the portion of each consumer segment is variable. These situations can be captured by a negative demand correlation (see, for example, a model with $\rho = -1$ in Png 1991). For completeness, here we provide a brief discussion of negative demand correlation.

With a negative ρ, a small ρ (thus a large $|\rho|$) means more accurate advance information. A negative ρ does not change the analysis of the preorder strategy without price guarantee in §4. By replacing ρ with $-\rho$, it can be readily shown that all results in §4 apply to $\rho \in (-1, 0]$ as well. Next we discuss the preorder strategy with price guarantee.

Under a price guarantee, the seller will lower the price in the second period if and only if the realized high-type demand is less than a threshold. In contrast to the case of positive ρ, now $\rho < 0$ means that price reduction occurs when the low-type demand is relatively high. That is, as $|\rho|$ increases, the variance of the low-type demand under price reduction becomes smaller, whereas the mean becomes stochastically larger. Therefore, under a negative demand correlation, the negative effect of advance information introduced by price guarantees on the second-period profit does not exist anymore.

Although $\rho < 0$ removes the negative impact of increasing $|\rho|$ on the second-period profit, interestingly, it aggravates the negative effect on the first-period profit. This is because, with a higher $|\rho|$, the low-type demand in case of price reduction tends to be larger, which motivates the seller to order more to satisfy demand in the regular season. This improves the product availability in the regular season and leads to a lower preorder price. Thus, for $\rho < 0$, a higher $|\rho|$ will have a stronger adverse impact on the preorder price under a price guarantee; as a result, the seller's optimal preorder price always decreases in $|\rho|$.

To summarize, with negative ρ, all results about the preorder strategy without price guarantee remain. Under a price guarantee and $\rho < 0$, a larger $|\rho|$ hurts the first-period profit (in a stronger way compared to $\rho \geq 0$), but always improves the second-period profit. Therefore, with $\rho < 0$, we still have the result that more accurate advance demand information may hurt a seller's profit under a price guarantee, although this result is solely caused by the conflict between advance demand information and price discrimination.

7.2. Mixed Arrivals

It has been assumed in the basic model that the high-type consumers arrive in the preorder season, whereas the low-type consumers appear in the regular season. As a result, the regular price is always v_L and lower than the preorder price. In this subsection we extend the basic model to consider a mixed arrival model where the high-type customers arrive in both periods. For simplicity, we still assume that all the low-type consumers show up in the regular selling season.[5] Let β ($\beta \leq 1$) be the fraction of high-type consumers to arrive in the preorder season ($1-\beta$ is the fraction in the regular season). We use $X_{1H} = \beta X_H$ and $X_{2H} = (1-\beta)X_H$ to denote the high-type demand in the preorder and regular seasons, respectively. Let the correlation coefficient between X_{1H} and X_L be ρ. Thus, the seller can update his belief about both the low-type demand and second-period high-type demand after observing X_{1H}: Given a realization $x_{1H} = \mu_{1H} + \sigma_{1H}x$, the updated distribution of $\widetilde{X}_L$ will have a mean $\tilde{\mu}_L(x) = \mu_L + \rho\sigma_L x$ and standard deviation $\tilde{\sigma}_L = \sigma_L\sqrt{1-\rho^2}$, and the high-type demand in the regular season will be $\tilde{x}_{2H}(x) = (1/\beta - 1)x_{1H}$. We further assume $\delta = 1$ in this extension. The rest of the model setting is the same as before. Our basic model represents a special case with $\beta = 1$. The purpose of this subsection is to examine whether the key insight carries over from the basic model with $\beta = 1$ to general $\beta < 1$. The detailed analysis is provided in Online Appendix A. Here we highlight the key findings.

First we describe the case without price guarantee. The seller's decisions are as follows: In the preorder season, the seller sets a price p_1 to satisfy the high-type customers. Then, after observing the preorder demand X_{1H}, she updates her belief about future demand (X_{2H} and X_L) and determines the order quantity Q; meanwhile, she also sets a price $p_2 > v_L$ to induce the high-type customers to purchase in the regular season. Finally, if there is still leftover inventory, the seller lowers the price to $p_3 = v_L$ to clear the inventory. In fact, we may view this as a three-stage model where p_i denotes the price in stage i ($i = 1, 2, 3$). The customers in each stage decide whether they want to purchase immediately or wait until the next stage. Again we focus on the rational expectations equilibrium under symmetric strategies for the high-type consumers. In the equilibrium, all the high-type customers in stage 1 will preorder at price p_1, and all the high-type customers in stage 2 will purchase at price p_2.

Note that p_2 depends on the realization of the preorder demand X_{1H}, or $X = (X_{1H} - \mu_{1H})/\sigma_{1H}$. It can be shown that $p_1 = \mathbb{E}[p_2(X)]$; thus, depending on the realization of X, both $p_1 > p_2$ and $p_1 < p_2$ may happen: If the realization of X is low, then the product availability in stage 3 will be low, and this allows the seller to charge a high price p_2 in stage 2; the opposite is true when the realization of X is high. Therefore, for the more general setting, we may observe a preorder price that is either higher (i.e., a premium preorder price) or lower (i.e., a discount preorder price) than the regular price. In the advance selling (preorder) literature, a discount advance selling price is attributed to the uncertainty in product valuation, whereas we have shown that a discount preorder price is possible even without valuation uncertainty. Despite the more complex pricing patterns, our result about the impact

[5] A more general model is to allow some low-type consumers in the preorder season as well. However, this will not change the analysis as long as the preorder sales target the high-type customers only. In this case, the low-type consumers will wait to purchase the product in the regular season. For fashion and innovative products, the high-type consumers usually dominate in the preorder season whereas the low-type consumers dominate in the regular season, and they differ substantially in their willingness to pay. It is unlikely the seller sets a low price to satisfy both types of consumers in the preorder season. Therefore, we focus on the situation where the preorder sales target the high-type consumers only.

of ρ remains unchanged as shown in the next proposition. That is, the adverse effect of advance demand information on the seller's profit does not rely on a premium preorder price. Instead, it only hinges upon the possibility that the product may be available at a future low price, no matter when the price will be dropped (it can be after the product release).

Proposition 6. *Consider the mixed arrival model. If $z_L < 0$, there exists a $\tilde{\mu}$ such that Π^p increases in ρ if and only if $\mu_{1H} \le \tilde{\mu}$. If $z_L \ge 0$, then Π^p always increases in ρ.*

Next we consider the case with price guarantee. The analysis for mixed arrivals is more involved because the seller needs to set multiple prices and refunds. To simplify analysis, we assume that for any customer, the refund is based on the purchasing price and the final price of the product. There are two possible final prices in stage 3: v_L if the seller lowers the price to satisfy the low-type customers, or v_H if the seller does not serve the low-type customers at all. The seller needs to determine two refunds η_1 and η_2 in stages 1 and 2, respectively, where η_1 is the refund to the preorder customers in stage 1 and η_2 is the refund to the high-type customers in stage 2, if the final price is reduced to v_L.

Again, we find that even under price guarantees, the seller's total profit may decrease with ρ in certain circumstances. In particular, the price guarantee mitigates the negative effect of ρ on the margin from the high-type customers, but it introduces a new negative effect of ρ on the profit from the low-type customers. Together with Proposition 6, this finding confirms the robustness of the key insight from the basic model: In the preorder strategy, more accurate demand information may hurt a seller's profit regardless of the use of price guarantees.

7.3. Proportional Rationing Rule

In this extension, we examine the robustness of our key results under the proportioning rationing rule. To facilitate discussion, we define the probability of product availability in the second period, contingent on the preorder demand $\mu_H + \sigma_H x$, to be (the superscript pr stands for proportional rationing):

$$\xi^{pr}(x) = \mathbb{E}\left[\frac{\min(Q(x), \tilde{X}_L(x))}{\tilde{X}_L(x)}\right], \tag{14}$$

where $\tilde{X}_L(x)$ is the updated low-type demand.

Lemma 5. *$\xi^{pr}(x)$ is increasing in ρ if and only if $x \ge -\rho\lambda_L$.*

In the preorder strategy (without price guarantee), a high-type customer's belief of product availability is given by $\mathbb{E}[\xi^{pr}(X)]$. Lemma 5 shows that $\xi^{pr}(x)$ is increasing in ρ when the realization of high-type demand is large. Through extensive numerical experiments, we find that its expectation $\mathbb{E}[\xi^{pr}(X)]$ is always increasing in ρ. This implies that under the proportional rationing, again, more advance demand information leads to a lower preorder price in the preorder strategy.

In the price guarantee mechanism, for a given price reduction threshold $\hat{x} < 0$, the probability that the product is available at the low price ($p_2 = v_L$) in the second period is $\hat{\xi}^{pr}(\hat{x}) = \mathbb{E}[\xi^{pr}(x) \mid x \le \hat{x}]\Phi(\hat{x})$. From Lemma 5, $\hat{\xi}^{pr}(\hat{x})$ is decreasing in ρ if $\rho < -\hat{x}/\lambda_L$; this suggests that the negative effect of advance demand information on the preorder price may be reversed with a price guarantee when ρ is small.

The above results indicate that advance demand information has a similar effect on the seller's first-period profit with or without price guarantee as under the θ-rationing rule. Note that the choice of the rationing rule does not affect the seller's second-period profit. Therefore, the main results about the effect of ρ on the seller's overall profit continue to hold under the proportional rationing rule.

8. Conclusion

This paper studies the prevailing preorder practice in which a seller accepts consumer orders before the release of a product. Consumers who are eager to obtain the product will benefit from preorder because it guarantees immediate product availability on release. Preorder is also beneficial to the seller because it allows the seller to gauge market demand from preorder sales, and to charge distinct prices to different consumer segments. In this paper, we develop a modeling framework to analyze the preorder strategy a seller may use to sell a perishable product in a short selling season. The market consists of two consumer segments, those who arrive in the preorder season with valuation v_H and those in the regular selling season with valuation v_L, respectively. There is a correlation between these two random demand segments, which we use to measure the accuracy of advance demand information. To the best of our knowledge, this modeling framework is the first to simultaneously incorporate the following three important elements: seller's inventory and pricing decisions, consumers' forward-looking behavior, and advance demand information.

The value of advance demand information has been widely studied in the operations literature. Most studies emphasize the benefit of advance demand information, i.e., it helps improve a firm's inventory decision when facing uncertain market demand. However, we find that the seller's profit may *decrease* with the accuracy of advance demand information obtained from the preorder sales. Specifically, the seller will benefit from more accurate advance demand information only if the low-type valuation is sufficiently large or the high-type demand is relatively small. This result is due to a possible conflict between advance demand information and price discrimination: Accurate demand information may increase product availability in the regular selling period, which hinders the seller from charging a high price to the high-type customers in the *preorder season*.

An effective way of resolving such a conflict between advance demand information and price discrimination is to offer a price guarantee: the seller promises to compensate early purchasers in case the price is lowered later. Interestingly, we find that the seller's profit may still *decrease* in the accuracy of advance demand information, even when the seller would benefit from more advance demand information if the price guarantee were not offered. The explanation of this result is as follows. Although price guarantees can mitigate (and in some situations may even reverse) the effect of the above conflict, they introduce another adverse effect of advance demand information: With price guarantees, a seller will lower the price to profit from low-type consumers only when the preorder demand is relatively low, but low preorder demand implies weak low-type demand as well (when the two demand segments are positively correlated). As a result, the use of price guarantees excludes situations where the seller can enjoy a great profit *in the regular season* from low-type consumers, and such an adverse effect is stronger when the advance demand information is more accurate.

Therefore, contrary to conventional wisdom, we have demonstrated that advance demand information can be detrimental to firms when facing forward-looking consumers: (1) It may hurt the seller's profit in the preorder season through its negative effect on the preorder price. (2) In the presence of price guarantees, it can also hurt the seller's profit in the regular season through its negative effect on the regular-season demand. Because of such negative effects of advance demand information, the seller needs to carefully decide whether to accept preorders and whether to provide price guarantees with preorders. We find that the seller's strategy choice depends critically on the relative market sizes of the two types of consumers. To be specific, the preorder option should be used without a price guarantee if the high-type segment is relatively small, but with a price guarantee if the high-type segment is relatively large, and no preorder may be optimal for the cases in between.

This research can be extended in a couple of directions. First, a more sophisticated consumer valuation model can be introduced. For instance, consumers may update their uncertain valuations based on preorder sales (e.g., a highly sought-after product during the preorder season provides a positive signal about the product value). Incorporating information updating for the consumers in addition to demand updating for the seller is an interesting direction for future research. Second, this paper focuses on a monopolist's selling strategy. A natural extension is to consider the preorder strategy in a duopoly setting. It would be interesting to study how competition affects the firms' strategy choice and the associated pricing and inventory decisions.

Electronic Companion

An electronic companion to this paper is available as part of the online version at http://dx.doi.org/10.1287/msom.1120.0398.

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References

Alexandrov A, Lariviere MA (2012) Are reservations recommended? *Manufacturing Service Oper. Management* 14(2): 218–230.

Aviv Y, Pazgal A (2008) Optimal pricing of seasonal products in the presence of forward-looking consumers. *Manufacturing Service Oper. Management* 10(3):339–359.

Berndtson C (2010) Apple sells out iPad preorder inventory as launch nears. *CRN* (March 29), http://www.crn.com/.

Boyacı T, Özer Ö (2010) Information acquisition for capacity planning via pricing and advance selling: When to stop and act? *Oper. Res.* 58(5):1328–1349.

Cachon GP, Swinney R (2009) Purchasing, pricing, and quick response in the presence of strategic consumers. *Management Sci.* 55(3):497–511.

Carnoy D (2009) Amazon drops price of Kindle 2 to $299. *CNET* (July 8), http://news.cnet.com/.

Chu L, Zhang H (2011) Optimal preorder strategy with endogenous information control. *Management Sci.* 57(6):1055–1077.

Coursey D (2010) Apple iPad price cut: Blunder or brilliance? *PCWorld* (February 8), http://www.pcworld.com/.

Dana J (1998) Advance-purchase discounts and price discrimination in competitive markets. *J. Political Econom.* 106(2):395–422.

Darlin D (2010) Applause, please, for early adopters. *New York Times* (May 9) BU6.

Elmaghraby W, Keskinocak P (2003) Dynamic pricing in the presence of inventory considerations: Research overview, current practices, and future directions. *Management Sci.* 49(10):1287–1309.

Elmalghraby W, Gulcu A, Keskinocak P (2008) Designing optimal preannounced markdowns in the presence of rational customers with multiunit demands. *Manufacturing Service Oper. Management* 10(1):126–148.

Eppen GD, Iyer AV (1997) Improved fashion buying with Bayesian updates. *Oper. Res.* 45(6):805–819.

Falcon J (2009) Sony admits early adopter "tax" on PSP Go! *Game Stooge.com* (June 30), http://www.gamestooge.com/.

Fisher M, Raman A (1996) Reducing the cost of demand uncertainty through accurate response to early sales. *Oper. Res.* 44(1):87–99.

Gallego G, Özer Ö (2001) Integrating replenishment decision with advance demand information. *Management Sci.* 47(10):1344–1360.

Gallego G, Özer Ö (2003) Optimal replenishment policies for multiechelon inventory problems under advance demand information. *Manufacturing Service Oper. Management* 5(2):157–175.

Goldstein P (2009) Nokia N900 goes on preorder in U.S. *Fierce Wireless.com* (September 4), http://www.fiercewireless.com/.

Huang T, Van Mieghem JA (2009). Are you willing to click? Advance demand information and price discrimination under strategic consumer behavior. Working paper, Northwestern University, Evanston, IL.

Jack S (2007) iPhone early adopters: How do you feel about the $399 iPhone? *MacDailyNews.com* (September 5), http://www.macdailynews.com/.

Jerath K, Netessine S, Veeraraghavan SK (2009) Revenue management with strategic customers: Last-minute selling and opaque selling. *Management Sci.* 56(3):430–448.

Keizer G (2009). AT&T, Best Buy sell out of iPhone 3G S preorder supplier. *Computerworld* (June 15), http://www.computerworld.com/.

King C (2009). Price drop on Nokia N900 at Amazon.com. *Pocketables.com* (September 18), http://www.pockettables.net/.

Lai G, Debo LG, Sycara K (2010) Buy now and match later: Impact of posterior price matching on profit with strategic consumers. *Manufacturing Service Oper. Management* 12(1):33–55.

Levin Y, McGill J, Nadiak M (2007) Price guarantees in dynamic pricing and revenue management. *Oper. Res.* 55(1):75–97.

Levin Y, McGill J, Nadiak M (2009) Dynamic pricing in the presence of strategic consumers and oligopolistic competition. *Management Sci.* 55(1):32–46.

Liu Q, van Ryzin GJ (2008) Strategic capacity rationing to induce early purchases. *Management Sci.* 54(6):1115–1131.

Macarthy A (2007) Retailers criticize HMV over PS3 preorder deal. *Gamesquad.com* (February 7), http://www.gamersquad.com/.

Martin M (2006) No Wii until 2007 without a preorder, warns retail. *GameIndustry.biz* (July 12), http://www.gamesindustry.biz/.

McCardle K, Rajaram K, Tang CS (2004) Advance booking discount programs under retail competition. *Management Sci.* 50(5):701–708.

Mersereau AJ, Zhang D (2012) Markdown pricing with unknown fraction of strategic customers. *Manufacturing Service Oper. Management* 14(3):355–370.

Moe W, Fader PS (2002) Using advance purchase orders to forecast new product sales. *Marketing Sci.* 21(3):347–364.

Nair H (2007) Intertemporal price discrimination with forward-looking consumers: Applications to the U.S. market for console video-games. *Quant. Marketing Econom.* 5(3):239–292.

Özer Ö (2003) Replenishment strategies for distribution systems under advance demand information. *Management Sci.* 49(3):255–272.

Özer Ö, Wei W (2004) Inventory control with limited capacity and advance demand information. *Oper. Res.* 52(6):988–1000.

Pham A (2001) GameCube sold faster than Xbox, Toysrus says. *Los Angeles Times* (October 9), http://articles.latimes.com/2001/oct/09/business/fi-54925.

Png IPL (1991) Most-favored-customer protection versus price discrimination over time. *J. Political Econom.* 99(5):1010–1028.

Prasad A, Stecke KE, Zhao X (2011) Advance selling by a newsvendor retailer. *Production Oper. Management* 20(1):129–142.

Su X (2007) Inter-temporal pricing with strategic customer behavior. *Management Sci.* 53(5):726–741.

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

Su X, Zhang F (2009) On the value of commitment and availability guarantees when selling to strategic consumers. *Management Sci.* 55(5):713–726.

Swinney R (2011) Selling to strategic consumers when product value is uncertain: The value of matching supply and demand. *Management Sci.* 57(10):1737–1751.

Talluri KT, van Ryzin GJ (2004) *The Theory and Practice of Revenue Management* (Springer, New York).

Tang CS, Rajaram K, Alptekinoglu A, Ou J (2004) The benefits of advance booking discount programs: Model and analysis. *Management Sci.* 50(4):465–478.

Tenerowicz S (2010) Walmart drops preorder price of myTouch 3G Slide to $129.99. *Androidguys.com* (May 29), http://www.androidguys.com/2010/05/29/.

Tofel KC (2010) 3 reasons Apple's iPad won't see a price drop. *GigaOM.com* (March 7), http://gigaom.com/.

Wall Street Journal (2002) Apple gets record preorders for its iMac desktop PC (January 29) B6.

Weng ZK, Parlar M (1999) Integrating early sales with production decisions: Analysis and insights. *IIE Trans.* 31(11):1051–1060.

Xie J, Shugan SM (2001) Electronic tickets, smart cards, and online prepayments: When and how to advance sell. *Marketing Sci.* 20(3):219–243.

Yin R, Aviv Y, Pazgal A, Tang CS (2009) Optimal markdown pricing: Implications of inventory display formats in the presence of strategic customers. *Management Sci.* 55(8):1391–1408.

Yu M, Kapuscinski R, Ahn H-S (2007) Advance selling with limited capacity and customers' dependent valuations. Working paper, University of Michigan, Ann Arbor.

Zhao X, Stecke KE (2010) Pre-orders for new to-be-released products considering consumer loss aversion. *Production Oper. Management* 19(2):198–215.