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Demand Pooling in Omnichannel Operations

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Abstract. Both traditional retailers and e-tailers have been implementing omnichannel strategies such as buy online, pick up at store (BOPS). We build a stylized model to investigate the impact of the BOPS initiative on store operations from an inventory perspective. We consider two segments of customers, namely store-only customers who only make purchases offline and omni-customers who strategically choose between offline and online channels. We show that BOPS may either benefit or hurt the retailer depending on two fundamental system primitives: the store visiting cost and the online waiting cost. If the online waiting cost is relatively low and the store visiting cost is even lower, BOPS can induce omni-customers to migrate from online buying to BOPS, leading to *demand pooling* at the brick-and-mortar (B&M) store. Such demand pooling provides two benefits for the retailer: it reduces the overstocking cost, and after inventory reoptimization, it results in a higher fill rate at the B&M store, which benefits existing customers and potentially attracts more customers to the store. In contrast, if both store visiting and online waiting costs are relatively high with the latter even higher, introducing BOPS can result in *demand depooling* as a result of the migration of the omni-customers from offline purchasing to BOPS. This leads to a lower fill rate after inventory reoptimization, likely the result of a lower profit margin under BOPS, which turns away store-only customers and hurts the retailer.

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1. Introduction

Heated debates emerged a decade ago about where the future of retailing lies–online or offline channels? The answer seems more apparent now as the lines between digital and physical stores become blurrier. The future of retailing looks like a hybrid of physical stores and online ordering channels with each company striving to achieve the same goal from different starting points. Amazon and Walmart, for example, are each trying to become more like the other—Walmart by investing heavily in its technology and acquiring online retailers such as Jet and Bonobos and Amazon by opening physical bookstores and buying the physical supermarket Whole Foods.

The omnichannel environment presents equal opportunities for both "traditional" retailers (e.g., Walmart), which began business with physical stores, and "new" retailers (e.g., Warby Parker), which started out by selling online (Bell et al. 2014). However, finding ways to manage inventory at a local store, which may serve multiple streams of customers in a given omnichannel strategy, becomes a key challenge to retailers. On the one hand, inventory plays a vital role under different omnichannel strategies because of its effect on the service levels experienced by customers. To cater to both online and in-store shoppers at the same time, Target improved its brick-and-mortar (B&M) in-stock performance by 20% in the fourth quarter of 2015 (Chao 2016). On the other hand, inventory is often the most significant cost component for retailers (as a percentage of sales). As mentioned, one solution for traditional retailers is to use the merchandise in their stores, ideally after inventory reoptimization, to fulfill online orders; however, that strategy may not be as efficient as the centralized distribution centers that e-tailers use

(Kapner 2015). With more inventory at stores to meet the in-store pickup demand, retailers also face a risk of being stuck with excess inventory (Bose 2014).

In this paper, we study a representative omnichannel strategy, that is, buy online, pick up at store (BOPS). In fulfilling customer demand under BOPS, the B&M store plays the critical role of a mini-warehouse and pickup location. We build a stylized model for a retailer with two segments of customers: store-only customers who only consider purchasing the product at the B&M store and omni-customers who consider buying the product through all channels provided by the retailer. As a benchmark, we first analyze a BASE model in which no omnichannel strategy is implemented and online and offline channels are operated independently. Without considering the implication of inventory, it is intuitive that the introduction of a new omnichannel strategy expands the market while simultaneously cannibalizing the existing online and offline channels. However, the story can be very different if we consider the strategic interaction between the retailer's inventory decision and customers' purchasing behavior. Hence inventory is critical to determining whether BOPS might be a good strategy for a retailer.

Assuming that customers' online base surplus (i.e., valuation minus price) is higher than their offline base surplus[1] and that the profit margin of online sales is lower than that of offline sales,[2] we find that BOPS may either benefit or hurt the retailer depending on two fundamental system primitives: the store visiting cost and the online waiting cost. If store visiting and online waiting costs are both low with the former even lower[3], the introduction of BOPS can incentivize omni-customers to migrate from the online channel to BOPS, which not only gives local inventory information, but also provides a new purchase channel for omni-customers. Thus, BOPS can lead to *demand pooling* at the B&M store; that is, the local inventory can be used to fulfill orders from two customer segments. Demand pooling has two benefits for the retailer. First, it allows higher utilization of the local inventory and saves overstocking cost (referred to as the "utilization enhancement effect"). Second, after inventory reoptimization, it results in a higher fill rate at the B&M store (referred to as the "availability improvement effect"), which benefits the existing customers and potentially attracts more customers to visit. However, the opposite of demand pooling can also happen. If store visiting and online waiting costs are both high with the latter even higher,[4] BOPS can hurt the retailer as well as the customers. The damage is due to a *demand depooling* effect: those omni-customers who would shop offline in the BASE model now migrate to BOPS, in which the profit margin is lower than in the offline channel. After inventory reoptimization, the fill rate is reduced at the B&M store, which then deters the store-only and omni-customers from visiting the store. That is, although omni-customers who adopt BOPS are still mainly fulfilled by the B&M store, demand depooling occurs after inventory reoptimization because the profit margin of BOPS sales is lower than that of online sales. Therefore, BOPS may hurt both the retailer and those two segments of customers.

2. Literature Review

We study the joint management of online and offline channels under an omnichannel strategy and explore its pros and cons by considering the interactions of multiple channels through the endogenized inventory decisions. There are two closely related streams of literature: omnichannel and multichannel management. The more closely related is omnichannel management, which has recently gained traction. One part of this stream investigates the impact of omnichannels on customers' choice behavior among channels. For example, Konus et al. (2008) and De Keyser et al. (2015) use survey data to identify various segments of multichannel shoppers. Chintagunta et al. (2012) empirically quantify the relative transaction costs when households choose between the online and offline channels of grocery stores. These empirical papers provide a better understanding of customers' channel choice behavior and market segmentation. Another part of this stream of literature investigates the practical implications of implementing an omnichannel strategy. Gallino and Moreno (2014) empirically examine the impact of BOPS on a retailer's sales volume in both online and offline channels and find that the implementation of BOPS results in a reduction in online sales and an increase in store sales and traffic. Gallino et al. (2017) analyze the data from a leading U.S. retailer that introduced the ship-to-store option (BOSS) to customers and demonstrate that BOSS can increase sales dispersion among various products in the B&M stores. Bell et al. (2018) empirically show that offline showrooms not only increase online and overall sales, but also improve operational efficiency.

Existing analytical models of omnichannel management focus on investigating how omnichannel strategies affect a retailer's operational decisions and profitability. Cao et al. (2016) show that BOPS provides customers with a new purchasing option and, thus, can attract more customers, which may benefit the retailer. However, BOPS may be detrimental because of the profit margin loss from operating BOPS (when customers migrate from the offline channel, the purchase price could be lower, and there is an extra handling cost when customers migrate from either the offline or online channel). We identify a positive pooling effect and a negative depooling effect of

BOPS in addition to its market expansion effect and possible profit margin loss.

In this stream of analytical models, a trilogy by Gao and Su is closely related to our model. Gao and Su (2017b) study how retailers can effectively deliver online and offline information to omni-customers by comparing three information mechanisms: physical showrooms, virtual showrooms, and availability information disclosure. Different mechanisms result in different customer valuation revelations, leading to different channel choice behavior. In particular, they show that physical showrooms may prompt a retailer to lower the store inventory level because a segment of customers decides not to buy after learning via showrooming that their valuation turns out to be low. The reduced inventory level pushes the other segment of customers who have a high realized valuation to migrate to the online channel. As a result, in equilibrium, both segments migrate to the online channel as they are homogeneous ex ante. Such an interaction, via the B&M inventory, between the two *ex post* different segments of customers who are ex ante homogeneous is analogous to that between the two *ex ante* different segments of customers—omnichannel and store-only customers—in our paper.

Moreover, as we do, Gao and Su (2017a) also study an omnichannel strategy with the BOPS option and examine the impact of the BOPS initiative on store operations. One of their main findings is that BOPS may benefit or hurt the retailer, depending on the product characteristics. The benefits of BOPS are twofold. First, BOPS as an additional option enables the retailer to reach new customers (i.e., a market expansion effect) by inventory information disclosure. Second, BOPS can generate extra cross-selling revenue for the B&M store by inducing omni-customers to visit the store. On the other hand, Gao and Su (2017a) also reveal an adverse effect of BOPS, which may reduce the cross-selling revenue in the B&M store. That is, customers can learn the real-time inventory information via BOPS and will not visit the B&M store once the desired item is out of stock. Furthermore, they extend their results to the case in which there are two segments of customers —store-only and omni-customers— who proportionally share a random demand size. Our model has some similarity but two essential differences: (1) store-only customers in our model are strategic in the sense that they anticipate the in-store fill rate before heading out to the store, and (2) we separately model the sizes of the two segments using two random variables. These two differences enable us to identify another benefit of BOPS from the inventory perspective (even without the cross-selling effect), that is, the demand pooling effect, which leads to an increase in the fill rate of the B&M store after inventory reoptimization and then attracts more store-only customers to purchase. They also enable us to identify another drawback of BOPS, that is, the demand depooling effect, operating in the reverse direction of the pooling effect.

Finally, in the context of a service system, Gao and Su (2018) examine the effects of both online and offline self-ordering technologies on customer demand, employment levels, and the firm's profit. The authors investigate the interaction, through the staffing level, between employee-served (offline channel) and self-serving (online self-ordering channel) customers. In a drastically different context, we consider the interaction, through the local inventory, between store-only and omni-customers who can strategically choose the purchase channel as well as how their orders are fulfilled and obtain a different set of managerial insights.

3. Model Description

We consider a retailer that sells a product to customers through two channels: online and offline. As in Cao et al. (2016), we assume there are two types of customers: one intending to shop only offline, referred to as *store-only customers* and the other contemplating both the online and offline channels, referred to as *omni-customers*.[5] This classification is also consistent with several empirical studies. For example, De Keyser et al. (2015) demonstrate that the proportion of store-only customers is around 18% by survey data from a Dutch telecom retailer, whereas that of multichannel customers is about 52%. Such segmentation can be predicted by both demographics and psychographics (see Konus et al. 2008): store-only customers are those who are not tech-savvy and prefer traditional shopping or those who enjoy shopping in the physical stores, whereas omni-customers are those who prefer to try new and different products, seek new experiences, and are typically young and well educated.[6] We assume that the market sizes of omnichannel and store-only customers, denoted by D_m and D_s, respectively, follow the normal distributions with mean and variance, (μ_m, σ_m^2) and (μ_s, σ_s^2), respectively. To simplify the analysis, we also assume they have the same coefficient of variation, that is, $\sigma_m/\mu_m = \sigma_s/\mu_s$. Moreover, the market sizes of the two segments are assumed to be correlated with a general coefficient of ρ to show that our results are robust to any demand correlation between the two streams of customers.

The customer segmentation mentioned is based on the channel choices a customer faces when making a purchase decision. We refer to those customers who eventually choose to purchase offline (respectively, online) as the *offline* (*online*) demand. The online demand, if any, consists of omni-customers only, who would otherwise choose to purchase offline or exit the market, whereas the offline demand, if any, consists of store-only customers, omni-customers, or both.

The retailer can hold inventory in the local B&M store or the distribution center (DC). The offline demand can be satisfied only by the B&M inventory. In contrast, the online demand can be fulfilled by both sources, depending on the omnichannel strategy employed by the retailer and the resulting choices made by customers. In particular, we consider the following two strategies observed from the practice, with the former as a benchmark and the latter being a typical omnichannel strategy that is widely adopted in the retailing industry.

Independent online and offline channels (BASE): In the BASE model, the retailer uses the DC inventory to fulfill the online demand, and online and offline channels operate independently.

Buy online, pick up at store (BOPS): In the BOPS model, the retailer uses the B&M store inventory to satisfy those online customers who choose the local pickup option.

We assume that omni-customers who eventually choose BOPS first check online for the store inventory; if the store is out of stock, they then switch to the online channel with DC fulfillment if the utility of doing so is positive (see Gao and Su 2017a). For ease of exposition, we assume that the DC has *unlimited* inventory capacity. (Our main results also hold when the inventory level in the DC is endogenized.) This assumption is reasonable when the retailer can make an emergency replenishment from another DC or a supplier with a relatively short lead time compared with that from the DC to customers. As a result, the online purchases, regardless of how they are fulfilled, can be fully satisfied in time. Therefore, the retailer focuses on deciding how much inventory to stock in the B&M store before random demands are realized. In addition, customers are *lost* if they choose to visit the local store only to discover that their desired product is out of stock. The latter is consistent with the observation in Haddon (2018) that "when [walk-in] customers do not immediately find the items they want, 70% switch to another brand or store, or stop their order."

In the BASE model, we assume that store-only customers and omni-customers who purchase offline have equal chances of being satisfied by the local inventory as the retailer has no way of differentiating the two segments of customers when they visit the B&M store. In contrast, BOPS enables the retailer to tell omni-customers from store-only customers and to implement different fulfillment priorities. Alishah et al. (2016) show that the optimal inventory allocation policy aims to satisfy the store-only customers first. Based on this, we assume that store-only customers have a higher fulfillment priority than omni-customers who purchase from BOPS and are also satisfied from the local inventory. That is, the retailer satisfies store-only customers first and then satisfies the BOPS demand as much as possible by using the remaining inventory in the B&M store. This assumption, adopted by Govindarajan et al. (2020) as well, is consistent with the notion that store-only customers tend to represent a higher profit margin or a greater loss of goodwill in the event of a stockout than omni-customers, who tend to have more purchase options. In reality, customers from different segments may come in sequentially, and the retailer could use a sophisticated inventory rationing policy. Nevertheless, our model serves as a good approximation of the practical situation in which the retailer reserves inventory for store-only customers.

We denote by c_o and c_b the unit fulfillment costs of the DC and the B&M store, respectively. The fulfillment cost includes the procurement cost, the logistics cost incurred in shipping from the DC to the customer's doorstep, and the inventory holding and handling costs at the DC or B&M store. We assume that $c_o \le c_b$, which is consistent with the observation that the inventory holding and handling costs at the B&M store are much higher than those at the DC (Kapner 2015).

Given the retailer's channel strategy, customers choose the purchase option that maximizes their expected utility, which consists of at most three elements—the expected base surplus of consuming the product, the store visiting cost, and the online waiting cost—and is expressed as

$$\mathbb{E}[\text{utility}] = \mathbb{E}[\text{base surplus}] - \text{store visiting cost (if any)} - \text{online waiting cost (if any)}.$$

Expected Base Surplus

Customers' expected base surplus = fill rate × (base valuation − selling price), where the fill rate is based on customers' belief or actual information about the in-stock probability. The selling prices for online and offline channels, denoted by p_o and p_b, are assumed to be exogenous. For simplicity, we assume that customers are homogeneous in their valuation of the product in the online and offline channels, denoted by v_o and v_b, respectively. The comparison of v_o and v_b can go either way. On the one hand, customers can accurately value the offline product after inspection, and online customers without firsthand experience may risk having only partial knowledge on which to base their valuation. Thus, customers may view the online product as being inferior to its offline counterpart, that is, $v_o < v_b$ (Chiang et al. 2003). On the other hand, customers may find online purchases more appealing because of the abundant review information and easy comparison shopping available online, which can lead to $v_o \ge v_b$. Moreover, the fill rate for the online channel is equal to one because we assume that its demand can always be fulfilled, whereas the offline demand may face a stockout risk, depending on the inventory level in the B&M store.

Store Visiting Cost

Customers who visit the B&M store incur a positive visiting cost k, which might depend on the average driving distance. From the retailer's perspective, k can be a measure of the density of its B&M stores. Here, a lower value of k means a higher density of B&M stores. For simplicity, we assume that this cost is identical for all customers.

Online Waiting Cost

The online waiting cost, denoted by t, is the (perceived) waiting cost associated with processing and delivery of online orders as opposed to no waiting if the customers can buy the product offline. From the retailer's perspective, the higher the value of t, the less delivery efficiency the retailer has. From the customers' perspective, t can also be interpreted as a measure of their patience level, depending on the type of product. For instance, people may be less patient with the delivery of perishable products than with that of durable ones.

The sequence of the game between the retailer and customers is as follows. Under a specific channel strategy, the retailer first forms a belief in the proportion(s) of customers who will purchase offline and then decides the inventory level in the B&M store. Customers who cannot observe the inventory level in the B&M store form a belief about the fill rate, and when the BOPS option is available, omni-customers can determine whether their online purchase is available for local pickup. Based on the belief/information, customers choose the option that yields the highest, nonnegative, expected utility among all available purchase options or choose to exit the market generating zero surpluses. Throughout the paper, we adopt the notion of rational expectation (RE) equilibrium (see, e.g., Su and Zhang 2008, Cachon and Swinney 2009). The RE equilibrium (REE) requires that beliefs must be consistent with actual outcomes. Here, the retailer's belief must be identical to the actual proportion(s) of customers who purchase offline, whereas customers' beliefs about the fill rate of the offline channel must agree with the actual expected in-stock probability. We denote the base surpluses from online and offline channels by u_o and u_b, respectively, without considering the fill rate of the offline channel. Hence, $u_o = v_o - p_o$ and $u_b = v_b - p_b$. For ease of exposition, we make the following two assumptions with one on the demand side about customer utilities and the other on the supply side about the profit margins.

Assumption 1. $u_o \geq \max(t, u_b)$.

Assumption 1 requires that customers' base surplus from the online channel (i.e., $u_o - t$) is nonnegative, ensuring that the online channel is always a potential choice. It holds when the online waiting cost is relatively low. Assumption 1 also requires the online base surplus to be higher than the offline base surplus. This assumption is merely for ease of exploration; with it relaxed, our main insights on demand (de) pooling still hold (see Online Appendices B and C).

Let $\Phi(\cdot)$ be the cumulative distribution function of a standard normal distribution and $\Phi^{-1}(\cdot)$ its inverse function. Then, we define

$$\epsilon^* \equiv \Phi^{-1}(1 - c_b/p_b) \quad \text{and}$$
$$\Delta \equiv \left(\sqrt{\sigma_s^2 + \sigma_m^2 + 2\rho\sigma_s\sigma_m} - \sigma_s\right) \int_{-\infty}^{\epsilon^*} \epsilon \, d\Phi(\epsilon)/\mu_m,$$

where ϵ^* corresponds to the critical fractile for a newsvendor and Δ measures a scaled risk associated with going to the B&M store because of its limited inventory.

Assumption 2. $p_o - c_o \leq p_b - c_b + \Delta$.

Assumption 2 rules out the existence of multiple non–Pareto-dominant equilibria. We note that this assumption can be less restrictive than $p_o - c_o \leq p_b - c_b$, adopted by Gao and Su (2017a), when $\Delta \geq 0$. The condition $\Delta \geq 0$ can hold when the two streams of demand are sufficiently negatively correlated (noting that $\int_{-\infty}^{\epsilon^*} \epsilon d\Phi(\epsilon) < 0$). If $\Delta < 0$, for example, when $\rho \geq 0$, Assumption 2 implies that the profit margin of online sales is sufficiently lower than that of offline sales. Moreover, when Assumption 2 is relaxed, the same insights hold for at least one of the equilibria.

Next, we use $U_{X,Y}^Z$ to denote customers' expected utility, where X represents the type of customers, Y specifies the fulfillment channel, and Z reflects the model setting. Specifically, $X \in \{m, s\}$, where m denotes omni-customers and s represents store-only customers; $Y \in \{b, o, ob\}$, where b and o represent the traditional offline and online channels, respectively, and ob means the BOPS channel; and $Z \in \{B, P\}$, where B and P correspond to the BASE and BOPS settings, respectively.

4. Model Analysis

In this section, we analyze two different types of omnichannel strategies, namely BASE and BOPS, and characterize the Pareto-dominant RE equilibrium under each strategy.

4.1. Separate Online and Off-line Channels (BASE)

As mentioned, customers who purchase via the offline channel may face a stockout. Without knowing the exact inventory in the B&M store, customers first form a belief $\hat{\zeta}$ on the in-stock probability before making their purchase decision. Based on this belief, customers' utilities from offline and online channels, respectively, can be expressed as

$$U_{s,b}^B = U_{m,b}^B = \hat{\zeta} u_b - k, \quad U_{m,o}^B = u_o - t. \tag{1}$$

Store-only customers purchase the product if $U_{s,b}^B \geq 0$; otherwise, they exit the market. Assumption 1 ensures that $U_{m,o}^B$ is always nonnegative. Hence, omni-customers never choose to exit the market. In particular, omni-customers purchase the product from the offline channel if and only if $U_{m,b}^B \geq U_{m,o}^B$ and from the online channel if and only if $U_{m,o}^B > U_{m,b}^B$.

Next, we consider the retailer's decision problem. First, the retailer anticipates that a fraction $\hat{\phi}_m$ of omni-customers and a fraction $\hat{\phi}_s$ of store-only customers purchase through the offline channel, and thus, the aggregated offline demand is $\hat{\phi}_m D_m + \hat{\phi}_s D_s$. Given that customers do not have inventory information for the B&M store in BASE, as mentioned, we assume that those omni-customers who visit the store and experience a stockout will not switch back to the online purchase and, hence, will be lost. This is in contrast to the BOPS case in which omni-customers can check the local inventory before heading to the store and, in the event of a stockout, can easily switch to online purchase with DC fulfillment. The remaining fraction $(1 - \hat{\phi}_m)$ of omni-customers choose to purchase through the online channel as its utility is always nonnegative. That is, the online demand can be expressed as $(1 - \hat{\phi}_m) D_m$. Therefore, the retailer's expected profit function can be expressed as

$$\pi_B(q) = \underbrace{p_b \mathbb{E}[\min(\hat{\phi}_m D_m + \hat{\phi}_s D_s, q)] - c_b q}_{\text{Profit from Offline Channel}} + \underbrace{(p_o - c_o)\mathbb{E}[(1 - \hat{\phi}_m) D_m]}_{\text{Profit from Online Channel}}. \tag{2}$$

The first two terms and the last term in (2) represent the expected profits from the offline and online channels, respectively. Without loss of generality, we normalize the unit salvage value to zero. Given the beliefs $\hat{\phi}_m$ and $\hat{\phi}_s$, the retailer chooses the order quantity q to maximize the expected total profit. Unlike the classic newsvendor problem, here in equilibrium, the demand also depends on the fill rate, which, in turn, depends on the order quantity. To derive the RE equilibrium, we must characterize how the retailer's order quantity and the market size affect the fill rate of the B&M store and then the customer belief. According to Deneckere and Peck (1995), this fill rate is given by $\mathbb{E}[\min\{D, q\}]/\mathbb{E}[D]$, where D and q represent the random demand and the inventory level in the B&M store, respectively.

We first explore how demand aggregation affects the fill rate by comparing two scenarios that could possibly sustain in an RE equilibrium. In scenario I, only store-only customers choose the offline channel, that is, $(\hat{\phi}_m, \hat{\phi}_s) = (0, 1)$, and in scenario II, both store-only customers and omni-customers purchase offline, that is, $(\hat{\phi}_m, \hat{\phi}_s) = (1, 1)$. Let q_s and q_{sm} be the optimal order quantity maximizing (2) under scenarios I and II, respectively. Consequently, the corresponding fill rates can be calculated as $\zeta_s = \mathbb{E}[\min(D_s, q_s)]/\mathbb{E}[D_s]$ and $\zeta_{sm} = \mathbb{E}[\min(D_m + D_s, q_{sm})]/\mathbb{E}[D_m + D_s]$.

Lemma 1. $\zeta_{sm} \geq \zeta_s$.

Lemma 1 shows that demand aggregation from different customer streams (scenario II) leads to a higher fill rate of the B&M store than just a single stream of store-only customers (scenario I). This result indicates the potential benefit of demand pooling, which we explore later for BOPS. With Lemma 1, the following proposition characterizes the RE equilibrium for the BASE model.

Proposition 1 (REE in BASE). *At the RE equilibrium, the inventory level in the B&M store and customers' channel choices in the offline channel are as follows:*

i. *If* $k \leq \zeta_{sm} u_b - (u_o - t)$, $q^B = q_{sm}$ *and* $(\phi_s^B, \phi_m^B) = (1, 1)$.

ii. *If* $\zeta_{sm} u_b - (u_o - t) < k \leq \zeta_s u_b$, $q^B = q_s$ *and* $(\phi_s^B, \phi_m^B) = (1, 0)$.

iii. *If* $k > \max(\zeta_s u_b, \zeta_{sm} u_b - (u_o - t))$, $q^B = 0$ *and* $(\phi_s^B, \phi_m^B) = (0, 0)$.

A fraction $(1 - \phi_m^B)$ *of omni-customers purchase through the online channel.*

Proposition 1 shows that, if the store visiting cost is low enough, both store-only customers and omni-customers choose to purchase through the offline channel. If the store visiting cost is in an intermediate range, omni-customers switch to the online channel because the utility of purchasing online is higher than offline, whereas store-only customers stick to the offline channel as the associated utility is still positive. If the store visiting cost is high enough, no customers visit the B&M store. Moreover, those omni-customers who do not choose the offline channel purchase online because of Assumption 1.

4.2. Buy Online, Pick Up at Store (BOPS)

Now, we analyze the BOPS model, in which the retailer can use the B&M store inventory to fulfill orders from both store-only customers and omni-customers who choose BOPS. As in the BASE model, store-only customers can either purchase through the offline channel or exit the market, depending on the utility $U_{s,b}^P = \hat{\zeta} u_b - k$, where $\hat{\zeta}$ is the belief about the fill rate in the B&M store. However, when BOPS is a viable option, omni-customers face a choice of one of four alternatives: purchase online with DC fulfillment, purchase offline, choose BOPS, or exit the market.

Moreover, as in Gao and Su (2017a), we assume that omni-customers can always check the inventory via BOPS before going to the store. This means that BOPS plays the role of disclosing inventory information. Hence, given that the offline inventory information is taken into account, omni-customers' utilities of purchasing from different channels are given by

$$U^P_{m,b} = u_b - k, \quad U^P_{m,o} = u_o - t, \quad U^P_{m,ob} = u_o - k. \quad (3)$$

Given that $u_o \geq t$ (see Assumption 1), omni-customers always earn a nonnegative utility from the online channel, and thus, they never choose to exit the market. Figure 1 illustrates the omni-customers' decision tree. Specifically, an incoming omni-customer always checks the inventory availability at the B&M store first via BOPS. If the B&M store is out of stock, this omni-customer purchases from an online channel or leaves the market, depending on the customer's utility $U^P_{m,o}$. If the inventory is available, the customer compares utilities from each option, given in (3), to choose the one that maximizes the customer's utility and generates a nonnegative surplus.

As $u_o \geq u_b$ (see also Assumption 1), an omni-customer always prefers the BOPS channel over purchasing offline. Therefore, the omni-customer chooses either the online channel or the BOPS channel. In particular, the customer chooses the BOPS channel if $U^P_{m,ob} \geq U^P_{m,o}$ (i.e., $k \leq t$) and, otherwise, the online channel. Overall, $\mathbf{1}_{\{k\leq t\}} D_m$ and $\mathbf{1}_{\{k>t\}} D_m$ represent the numbers of omni-customers who prefer BOPS and those who prefer the online channel, respectively, where $\mathbf{1}_{\{\cdot\}}$ is an indicator function.

Next, we derive the sales volumes from different channels. Notably, omni-customers' channel choices only depend on parameters that are assumed to be common knowledge. Therefore, unlike in the BASE model, the retailer can predict omni-customers' decisions with only a belief $\hat{\phi}_s$ about the proportion of store-only customers who would purchase through the offline channel. Recall that we assume the store-only customers to have fulfillment priority. After fulfilling orders from the store-only customers, the B&M store has the remaining inventory at the level of $(q - \hat{\phi}_s D_s)^+$. Given that the number of omni-customers who prefer the BOPS channel is $\mathbf{1}_{\{k\leq t\}} D_m$, the sales volume of BOPS is $\min(\mathbf{1}_{\{k\leq t\}} D_m, (q - \hat{\phi}_s D_s)^+)$. The sales volume in the online channel includes the online demand $\mathbf{1}_{\{k>t\}} D_m$ and the unsatisfied BOPS demand $(\mathbf{1}_{\{k\leq t\}} D_m - (q - \hat{\phi}_s D_s)^+)^+$. Therefore, given the belief $\hat{\phi}_s$, the retailer's expected profit can be expressed as

$$\begin{aligned}\pi_P(q) = {} & \underbrace{p_b \mathbb{E}[\min(\hat{\phi}_s D_s, q)]}_{\text{Revenue from Store-Only Customers}} \\ & + \underbrace{p_o \mathbb{E}\Big[\min\Big(\mathbf{1}_{\{k\leq t\}} D_m, (q - \hat{\phi}_s D_s)^+\Big)\Big]}_{\text{Revenue from BOPS Channel}} - c_b q \\ & + \underbrace{(p_o - c_o)\mathbb{E}\Big[\mathbf{1}_{\{k>t\}} D_m + \Big(\mathbf{1}_{\{k\leq t\}} D_m - (q - \hat{\phi}_s D_s)^+\Big)^+\Big]}_{\text{Profit from Online Channel}}.\end{aligned} \quad (4)$$

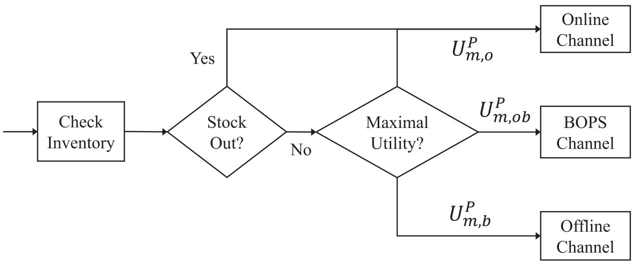
In (4), the first term represents the expected revenue from store-only customers, the second term is the revenue from omni-customers who purchase through the BOPS channel, the third term is the inventory procurement cost of the B&M store, and the last term is the profit from those omni-customers who purchase through the online channel with DC fulfillment.

To better understand the effect of BOPS on the fill rate of the B&M store, we first consider a special case of $k \leq t$, in which omni-customers always choose to purchase via BOPS if available. We denote by q_p the optimal order quantity that maximizes (4) with $\hat{\phi}_s = 1$. The corresponding fill rate for store-only customers is given by $\zeta_p = \mathbb{E}[\min(D_s, q_p)]/\mathbb{E}[D_s]$. The following lemma illustrates how the BOPS strategy might affect the fill rate of the off-line channel.

Lemma 2. *$q_{sm} \geq q_p \geq q_s$ and $\zeta_p \geq \zeta_s$. Moreover, ζ_{sm} can be greater or less than ζ_p.*

Recall that q_s and ζ_s (see Lemma 1) are the retailer's optimal order quantity and the corresponding fill rate of the offline channel in the BASE model when just the store-only customers purchase offline. With the BOPS strategy, the B&M store inventory can be used to fulfill orders from both store-only and BOPS customers. Therefore, BOPS decreases the overstocking risk for the local store inventory. This incentivizes the retailer to order more local inventory, which, in turn, leads to a higher fill rate, that is, $q_p \geq q_s$ and $\zeta_p \geq \zeta_s$, thereby benefiting store-only customers in the parameter subspace in which the B&M store sells only to store-only customers. However, in the parameter subspace in which omni-customers who used to shop offline have now switched to BOPS, the resulting fill rate for store-only customers could decrease or increase after inventory reoptimization. This is because, compared with BASE, BOPS leads to a lower understocking cost because unsatisfied omni-customers

Figure 1. The Decision Tree of Omni-Customers Under the BOPS



who choose BOPS are recaptured by the online channel. This incentivizes the retailer to order less and reduce the overall fill rate at the B&M store under BOPS. However, as store-only customers have higher fulfillment priority under BOPS than under BASE, in which they share the inventory with omni-customers, even if the inventory level may be lower under BOPS, it is still possible for the fill rate for store-only customers under BOPS to be higher.

Next, we formally characterize the RE equilibrium under BOPS.

Proposition 2 (REE Under BOPS). *At the RE equilibrium, the retailer's optimal inventory level in the B&M store and customers' optimal channel choices are as follows:*

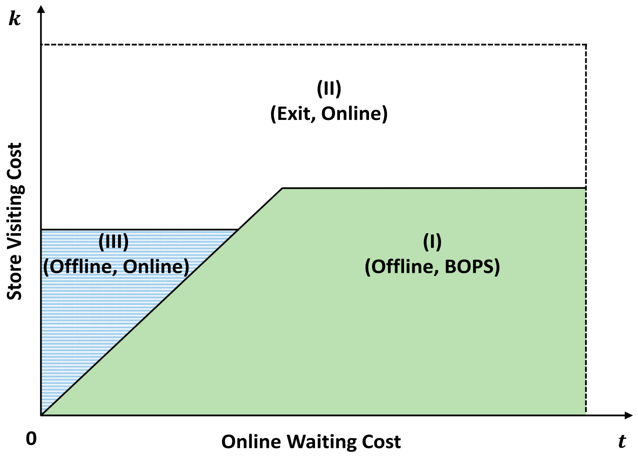
i. *If* $k \le \min(t, \zeta_p u_b)$, $q^P = q_p$, $\phi_s^P = 1$, *and omni-customers choose BOPS (and spill over to the online channel in the event of stockout).*

ii. *If* $t < k \le \zeta_s u_b$, $q^P = q_s$, $\phi_s^P = 1$, *and omni-customers purchase through the online channel.*

iii. *If* $k > \max(\min(t, \zeta_p u_b), \zeta_s u_b)$, $q^P = 0$, $\phi_s^P = 0$, *and omni-customers purchase through the online channel.*

Figure 2 illustrates the RE equilibrium in different parameter regions depending on the store visiting cost k and the online waiting cost t. We discuss the equilibrium by considering two cases: $k \ge t$ and $k < t$, which correspond to two separate regions divided by the 45° line in Figure 2. In the former case ($k \ge t$), wherein the store visiting cost is higher than the online waiting cost, omni-customers always choose the online channel. As the store visiting cost increases, store-only customers switch from originally choosing the offline channel (area III) to exiting the market (see the part of area II above the 45° line). In the latter case ($k < t$), omni-customers may prefer BOPS over the online channel. When the store visiting cost k is below a threshold (area I), store-only customers prefer to shop offline (as opposed to exiting the market). In this case, it is beneficial for the retailer to serve both demand streams through the B&M store. However, when the store visiting cost exceeds the threshold (see the part of area II below the 45° line), store-only customers exit the market. This also affects the incentive of the retailer to serve omni-customers. With only omni-customers, it is more profitable for the retailer to serve them through the online channel instead of BOPS because the same price is charged but $c_o \le c_b$. Therefore, even though omni-customers may prefer BOPS, the retailer shuts down this channel to force these customers to buy online. This highlights how the interaction of the store-only and omni-customers could influence the optimal omnichannel design; see further discussion in the following section.

Figure 2. (Color online) Customer Choice Behavior Under BOPS



Note. $(\cdot,\cdot)$ represents the equilibrium, at which the former and latter arguments denote the equilibrium channel choices of store-only customers and omni-customers, respectively.

5. Strategy Comparison: BOPS vs. BASE

The introduction of the BOPS strategy may yield the following effects, which are essentially two sides of the same coin.

Demand Pooling Effect

Compared with the BASE model, the introduction of BOPS may motivate omni-customers who purchase online under BASE to switch from the online channel to BOPS as the latter option provides a higher surplus. As a result, demand pooling occurs in the sense that the retailer uses the local inventory to serve both BOPS and store-only customers. Lemma 2 shows that demand pooling can lead to a higher fill rate (i.e., $\zeta_p \ge \zeta_s$), which, in turn, attracts more store-only customers ex ante and satisfies more of them ex post and, thus, can benefit the retailer.

Demand Depooling Effect

The demand depooling effect is the opposite of the demand pooling effect. Consider that, under BASE, omni-customers may prefer purchasing offline as it provides a higher surplus than that from the online channel, for example, when the store visiting cost is low. When BOPS becomes a viable option, omni-customers have a strong incentive to switch from offline to BOPS because the store visiting cost applies to both the offline purchase option and BOPS, but BOPS generates more surplus under Assumption 1. Though the store inventory serves both BOPS and store-only customers, the profit margin under BOPS can be sufficiently lower than that of the offline channel under Assumption 2.[7] Hence, the introduction of BOPS can incentivize the retailer to reduce the in-store inventory level, leading to a lower fill rate, which turns away store-only customers ex ante or ex post and, thus, can hurt the retailer.

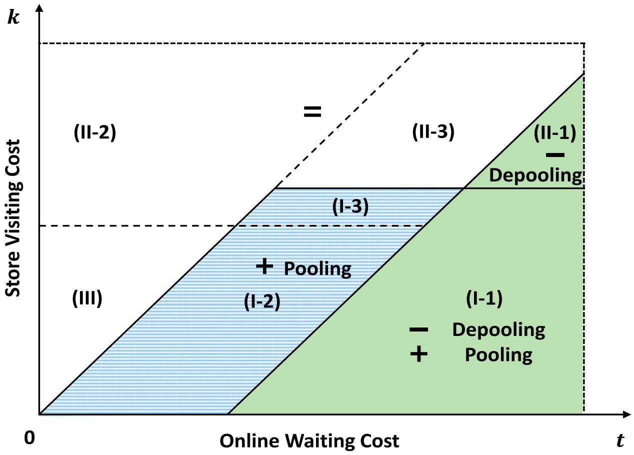
With the REE under BASE and BOPS characterized in Propositions 1 and 2, we now formally compare the two strategies for the retailer; see Figure 3 for an illustration. For areas III, II-2, and II-3, the two strategies have the same profitability. We explain this in two separate cases: (i) areas III and II-2 (in which $k \geq t$) and (ii) area II-3 (in which $k < t$). Although the outcomes are identical, the reasons behind those results are different. In the former regions, that is, where the store visiting cost is higher than the online waiting cost ($k \geq t$), the omni-customers do not choose the BOPS channel. That is, BOPS does not affect customers' channel choices and makes no difference to the retailer's optimal decision. We turn our attention to area II-3. In the BASE model, store-only customers choose to exit the market, whereas omni-customers choose the online channel. With BOPS, omni-customers prefer BOPS over the online channel because the store visiting cost is lower than the online waiting cost ($k < t$). In comparison, store-only customers would still prefer to exit the market. As the fulfillment cost of the online channel is lower than that of BOPS, serving only the BOPS demand by using the B&M store inventory is not profitable for the retailer; hence, the retailer shuts down the BOPS channel, for example, by disclosing no local inventory. As a result, the market equilibrium is the same as in the BASE model.

Next, we compare the two strategies for the remaining parameter space that is below the 45° line (i.e., $k < t$). We first characterize the area in which BOPS benefits the retailer as follows.

Proposition 3 (Demand Pooling Effect). *If the online waiting cost is relatively low and the store visiting cost is even lower as shown in areas I-2 and I-3 of Figure 3, that is,* $\zeta_{sm}u_b - u_o + t < k \leq \min(t, \zeta_p u_b)$, *BOPS benefits the retailer.*

In this scenario, with BOPS introduced, omni-customers switch from the online channel to BOPS as the latter provides a higher surplus. As a result, *demand pooling* occurs in the sense that the retailer uses the local inventory to serve both BOPS and store-only customers. Two benefits are associated with demand pooling. First, for the original inventory level, it allows higher utilization of the perishable inventory and saves overstocking cost when the visiting cost is low enough (area I-2). This phenomenon is called the *utilization enhancement effect*. Second, in anticipation of the pooled demand, the retailer reoptimizes the local inventory and sets a higher fill rate at the local store (areas I-2 and I-3). This is called the *availability improvement effect*, which creates a win–win–win situation that benefits the retailer and store-only and omni-customers. In particular, the improved product availability locally under BOPS not only reduces the loss of sales to store-only customers ex post, but also can attract more of them (those customers who would otherwise shop elsewhere) ex ante to visit the store and lead to a market expansion for the retailer (area I-3).

Figure 3. (Color online) BOPS over BASE



Thus, we provide here an alternative rationale for the application of BOPS—demand pooling. This is in contrast to Cao et al. (2016), who show that the BOPS channel could cannibalize the existing offline channel. Our finding is consistent with the empirical observation by Gallino and Moreno (2014), who argue that the implementation of BOPS is associated with an increase in store sales and traffic. We explain this observation from the perspective of demand pooling in addition to the benefit of information release by BOPS that is introduced in Gao and Su (2017a). In practice, on the one hand, in order to capture the benefits of the pooling effect, traditional offline retailers, such as Walmart, Best Buy, Target, and IKEA, which have already built a strong B&M store network, now also use their offline stores as e-commerce warehouses (see, e.g., Chaudhuri 2016, Gottfried 2016, Nash 2016, Ziobro 2016). On the other hand, dominant e-tailers such as Amazon and TMall Alibaba in China are now opening more B&M stores, hoping to capture store-only customers in addition to their existing customers, who might adopt the BOPS option. For example, Amazon has started opening a convenience-style Go store and is slated to open large multifunction stores with curbside pickup capability (Stevens and Safdar 2016).

However, introducing BOPS may backfire and turn away existing store-only customers, thus having a detrimental impact on both the retailer and customers. This demand depooling effect is illustrated by the following extreme scenario in which the whole segment of store-only customers are "forced" out ex ante.

Proposition 4 (Demand Depooling Effect). *If both the store visiting cost and the online waiting cost are relatively high with the latter even higher as in area II-1 of Figure 3,* *that is,* $\zeta_p u_b < k \leq \zeta_{sm} u_b - u_o + t$, *store-only customers exit the market after BOPS is implemented, and BOPS hurts the retailer.*

In this scenario, both store-only and omni-customers in the BASE model choose the offline channel (which implies that omni-customers prefer the offline channel to online). If BOPS becomes a viable option, omni-customers have a strong incentive to switch from the offline channel to BOPS because the store visiting cost applies to both the offline purchase option and BOPS, but BOPS generates more customer surplus because $u_o \geq u_b$ (see Assumption 1). Under Assumption 2, which holds, for example, when online sales have a lower margin than offline sales, the B&M store has an incentive to reduce the fill rate after BOPS is implemented. The lower fill rate makes the offline option no longer attractive to store-only customers, and as such, they prefer to exit the market. In turn, such demand depooling would hurt the retailer. Proposition 4 is an extreme case in which all store-only customers are turned away ex ante. Proposition 5 presents a middle ground in which store-only customers could be turned away unsatisfied ex post because of a lower fill rate.

The demand depooling effect is consistent with practical observations. For example, to combat the potential decrease in the fill rate at the B&M store after introducing BOPS, Target does not offer some of its most heavily advertised items through BOPS (Ziobro 2015), whereas Toys "R" Us scaled back some online marketing and eliminated other online deals entirely during the Christmas of 2016 in fear of shorting store-only customers on popular products (Ziobro 2016).

The effects of demand pooling and depooling of BOPS are two sides of the same coin and may be in play simultaneously as the following result implies.

Proposition 5 (Both Effects in Play)**.** *If the store visiting cost is low and the online waiting cost is high as in area I-1 of Figure 3, that is,* $k \leq \min(\zeta_p u_b, \zeta_{sm} u_b - u_o + t)$, *both demand pooling and depooling effects apply. In that area, there exists* $\delta_S(c_o)$ *such that*

i. *If the online price is low, that is,* $p_o < \delta_S(c_o)$, *the demand depooling effect dominates, and BOPS hurts the retailer.*

ii. *If the online price is high, that is,* $p_o \geq \delta_S(c_o)$, *the demand pooling effect dominates, and BOPS benefits the retailer.*

Proposition 5 shows that, when the store visiting cost is low and the online waiting cost is high as in area I-1 of Figure 3, the effects of demand pooling and depooling of BOPS are in play simultaneously. For such a case in equilibrium under the BASE, both store-only and omni-customers choose to visit the B&M store to make a purchase, and the retailer sets up a relatively high fill rate at ζ_{sm}. Now, we dissect the migration process of omni-customers after the introduction of BOPS into two parts to illustrate how the two effects of demand pooling and depooling apply simultaneously:

Omni-Customers Migrate to BOPS

Under Assumption 2, the retailer has an incentive to store less inventory at the B&M store, which may deter store-only customers from visiting the store ex ante or leave more store-only customers unsatisfied ex post. This is the depooling effect.

Omni-Customers Pick up at Store

After checking the inventory via BOPS, a fraction of omni-customers come to pick up their purchases, which are taken from the local inventory. With the same pool of local inventory serving store-only customers and some omni-customers, the retailer may have an incentive to increase the fill rate of the offline channel. This is the pooling effect.

With the cost parameters in area I-1, in equilibrium, both depooling and pooling effects apply, and the fill rate at the local store may be lower or higher than that in BASE (see Lemma 2). The pooling effect benefits the retailer, which reduces the understocking risk by using the inventory of both channels; that is, BOPS strategy can serve *all* of those omni-customers who are *partially* served in the BASE model. This is because, in BASE, unsatisfied omni-customers who visit the local store and experience stockout are lost, whereas under BOPS, they are served either by the local inventory (if available) or by the DC inventory. However, the depooling effect that turns away store-only customers ex ante or ex post could offset the pooling effect. The overall impact of demand depooling and pooling depends on the online price. In particular, if the online price is above a certain threshold, the downside of demand depooling is limited and the benefit of demand pooling is more significant; then, the combined effect of BOPS is positive for the retailer and vice versa.

6. Discussion and Conclusion

Owing to the complexity of the problem, we adopt a simplified model to flush out the fundamental insights. Hence, examining whether these insights are robust is critical. We fully investigate a set of extensions of the model in Online Appendices D and E and discuss two of them here.

6.1. Cross-Selling Effect

Customers who visit the B&M store (whether they experience a stockout or not) are likely to purchase other products, which is the so-called *cross-selling effect*. Denote by r the expected cross-selling revenue brought by each customer who visits the store for the initially desired product. A positive cross-selling effect, that is, $r > 0$, could influence the retailer's inventory decision, which then, in turn, affects the customers' channel choice behavior. We discover the following.

First, the retailer can be more willing to adopt BOPS with cross-selling than without. For example, when the online waiting cost is relatively high but lower than the store visiting cost, without cross-selling ($r = 0$), store-only customers choose to exit the market and omni-customers turn to the online channel. As a result, the retailer has no incentive to stock any inventory at the local store. However, if the cross-selling effect is strong enough ($r \geq c_b - c_o$), it is beneficial for the retailer to stock some local inventory to entice omni-customers to make store visits via BOPS.

Second, the pooling effect is more likely to occur. Consider the situation in which, under BOPS without cross-selling, omni-customers switch from the online channel to BOPS, resulting in the pooling effect from the combined streams of store-only and omni-customers. With cross-selling, the stockout cost increases from $p_b - c_b$ to $p_b - c_b + r$. Thus, the retailer has an incentive to further increase the inventory level and the fill rate at the B&M store, which enhances the pooling effect.

Third, the negative effect of depooling could be strengthened. When the store visiting cost is high but lower than the online waiting cost, omni-customers who, under BASE, prefer visiting the B&M store migrate to BOPS (for both cases of $r = 0$ and $r > 0$), resulting in a lower fill rate in the B&M store under BOPS because $p_o \leq p_b$. Consequently, store-only customers are deterred from visiting the store, and in turn, the retailer suffers because of this depooling effect, not to mention the additional loss of cross-selling revenue from store-only customers.

6.2. Recourse Behavior of Omni-Customers

In the BASE model, when store-visiting omni-customers experience a stockout, they are assumed to be lost. Now, we relax this assumption. Suppose that those omni-customers who experience a stockout in store switch to the online channel. Compared with the lost sales case, the pooling/depooling effect could be strengthened or weakened. As the explanations for the impact of the recourse behavior on pooling and depooling effects are similar, here we only discuss its impact on the pooling effect.

Consider the situation under BASE in which, without the recourse behavior, omni-customers choose the online channel, and store-only customers exit the market. Here, without the recourse behavior, BOPS may trigger a pooling effect (i.e., the retailer uses the local inventory to serve both BOPS and store-only customers, resulting in a higher fill rate). However, the higher utility from the recourse behavior may incentivize omni-customers to switch from the online channel to the offline under BASE. That is, with the recourse behavior of omni-customers, both omni-customers and store-only customers can choose the offline channel under BASE. Then BOPS does not necessarily lead to a pooling effect; that is, the recourse behavior may lessen the pooling effect.

On the other hand, consider the situation in which, without the recourse behavior of omni-customers, both store-only and omni-customers choose the offline channel under BASE; here, BOPS may not trigger a pooling effect. The recourse behavior of omni-customers reduces the lost-sales cost at the B&M store. As a result, under BASE, the retailer orders less inventory for the B&M store, resulting in a lower fill rate, which forces omni-customers to choose the online channel. Consequently, the introduction of BOPS under the recourse behavior may bring omni-customers to visit the store, resulting in a pooling effect; that is, the recourse behavior could amplify the pooling effect.

6.3. Concluding Remarks

BOPS, as an omnichannel strategy, has been widely adopted by traditional B&M retailers (e.g., Walmart) and e-tailers (e.g., Amazon). From the inventory perspective, we develop a stylized model to investigate the impact of BOPS on store operations. We find that BOPS can be a double-edged sword for the retailer: it may either benefit or hurt the retailer depending on two fundamental system primitives, the store visiting and online waiting costs.

Many directions are worthy of further exploration. For example, our analysis suggests that omnichannel strategies tend to benefit the retailer when the online waiting cost is relatively low and the store visiting cost is even lower. However, it is difficult for retailers to push both capabilities to the desired level in a short time. Then, the cooperation between traditional offline retailers and e-tailers may be another effective way to enjoy the benefit of deploying omnichannel strategies quickly. Therefore, how to design an effective cooperation mechanism that benefits both sides may prove a vital problem for those online and offline firms who are also competitors.

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Endnotes

[1] Our main insights qualitatively carry over when this assumption is relaxed. The analysis is available upon request.

[2] A weaker condition is adopted later (see Assumption 2). Even if this weaker assumption is relaxed, the same insights hold for at least one of the equilibria.

[3] See, for example, areas I-2 and I-3 in Figure 3 for an illustration.

[4] See, for example, area II-1 in Figure 3 for an illustration.

[5] Gao and Su (2017a) only consider omni-customers. The introduction of store-only customers allows us to better study the interaction of multiple customer segments from the inventory perspective. Without store-only customers, our model is reduced to theirs.

[6] Though our model does not consider web-only customers, the modeling of such a segment would not change our insights. This is because our model focuses on the potential conflict of the offline inventory being shared by both store-only customers and omni-customers. This inventory would not be shared with web-only customers.

[7] If the profit margin of online sales is higher than that of offline sales, Assumption 2 requires that the two demand segments have a sufficiently high negative correlation, which leads to a sufficiently high fill rate under BASE and a relatively lower fill rate under BOPS as the omni-customers can be recaptured by the online channel in the event of a stockout.

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