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Internet book retailing and supply chain management: an analytical study of inventory location speculation and postponement

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Abstract

Internet retailing models support supply chains where consumer order locations are decoupled from inventory locations. In this setting, retailers dynamically consider inventory location speculation and postponement to fulfill their orders. Particularly, retailers can manage inventory to fulfill orders through two opposing strategies: in-stock inventory and drop-shipping. This paper extends the supply chain management literature by modeling Internet retailers' decisions to balance their offerings between these two strategies. The results show how retailers depend more on both of these strategies as their market share and product popularity increase. Thus, both inventory management strategies may be considered simultaneously to better manage Internet retailers' inventory.

Keywords: Inventory management; Electronic commerce; Postponement

1. Introduction

To take advantage of the Internet's capabilities, some retailers have developed entirely new business models, or completely redesigned their current ones. However, just as quickly as business

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innovators like Webvan.com and Kozmo.com burst on to the Internet scene, they have quickly disappeared. In their wake comes a better appreciation for the importance of business fundamentals, such as inventory management, to the success of Internet retailing. Indeed, retailers who have successfully used the Internet to manage their business operations have been able to find new ways to use their inventories and save costs. After all, like their off-line counterparts, Internet retailers are subject to costs associated with holding, ordering, purchasing, and shipping inventory.

Internet retailers must optimize inventory-replenishment decisions if they are to maximize their profits. Internet retailers, however, have a key distinction relative to traditional ones: they can postpone inventory location (and, consequently, ownership) to upstream supply chain echelons up until the arrival of consumer orders and drop-ship products to avoid stock outs. This functionality has allowed Internet retailers to draw inventory that is *owned* by entities upstream in the supply chain and *held* by those entities at their stocking locations in order to fulfill online consumer orders (Rabinovich and Evers, 2003).

Research on electronic commerce has placed little attention to studying how Internet retailers rely on inventory location postponement. Perhaps this is because prior research about the economics of electronic markets builds on the hypothesis that the Internet brings about greater price competition among firms (Bakos, 2001; Kauffman and Walden, 2000). The result may be perfect competition, where price equals marginal cost. Therefore, research on the economics of electronic commerce has concluded, somewhat simplistically, that all surviving firms in the industry are likely to have similar operational structures in order to have the same low marginal cost as their competitors; otherwise, these firms are likely to exit the market.

However, empirical research, including Bailey (1998), Brynjolfsson and Smith (2000), and Clemons et al. (2002), has found that there is still a significant amount of price dispersion among Internet firms. Therefore, these studies infer, Internet retailers have an ability to differentiate themselves in order to provide superior or inferior value to their consumers and garner a wide range of prices. This may include their ability to select different inventory management strategies.

This resonates with the work of Keeney (1999), Torkzadeh and Dhillon (2002), and Yang and Jun (2002), who measure the consumer's value of services provided through Internet commerce. Not surprisingly, all three studies underscore the value that consumers put on the inventory management performance of the firm. Consumers want to make sure they receive the products they ordered in a timely manner.

This article extends this prior research by examining how Internet retailers can differentiate themselves based on specific inventory management strategies. In so doing, it complements other studies that find a link between information technology and investment and increased supply chain performance. For example, Lee et al. (1999) show that investment in information technology may reduce stockouts and increase inventory turnover and Zhu and Kraemer (2002) find a positive linkage between e-commerce capability and an increase in the frequency of inventory turnover.

This research provides an understanding of how Internet firms can efficiently manage their supply chains through inventory location postponement or speculation. By developing an analytical model, this research describes how Internet retailers can strategically develop tradeoffs derived from either relying on postponement or speculation of inventory location to either upstream or downstream echelons in their supply chains. The results provide a measurement of efficiency gained through Internet adoption that can be compared to other research on product distribution improvements via product-transfer and inventory-management performance (Ballou, 1992; Bowersox and Closs, 1996). Furthermore, the research helps explain the rapid adoption and diffusion of a variety of inventory management strategies among Internet retailers (c.f., Rabinovich and Evers, 2003).

Although this research has broader implications, it is based on an analysis of the Internet book retailing industry. There are several reasons why Internet book retailing is a suitable industry to investigate. First, it is a fairly competitive industry, where firms sell homogenous goods, and industry profitability is highly dependent on order fulfillment and inventory replenishment operations (Collura and Applegate, 2000, 2001). Under this environment, firms are compelled to rely on internal capabilities and external relations with their suppliers in order to optimize their customer service and realize comparative advantages. Second, book retailing has become one of the largest and most reliable retailing segments on the Internet. Prior research has underscored this industry property as an important contributor to internal validity in research (Brynjolfsson and Smith, 2000). Third, the book industry has reached a high level of consolidation among wholesalers and publishers and is founded on long-lasting wholesaler–publisher relationships comprising significant transactional volumes (Milliot, 2001). Therefore, relative to retailers in other areas of Internet commerce, Internet book retailers exhibit better-defined postponement standards in their inventory management strategies. Fourth, the high uniformity in product volume and weight among stock-keeping units (SKUs) reduces the effects of exogenous inventory-cost determinants, with the exception of SKU value, popularity, and time in market. This property, combined with the fact that books are subject to short market demand cycles, provides a critical setting for the evaluation of inventory management strategies centered on location postponement and speculation decisions across the supply chain.

The remainder of the paper is structured as follows. Section 2 presents the theoretical foundation and academic motivation for the research on the book retailing industry on the Internet. Section 3 develops an analytical model to describe how Internet retailers choose between speculative (i.e., in-stock) and postponed (i.e., drop-shipped) inventory. Finally, Section 4 outlines the conclusions, implications, and future research opportunities from this research.

2. Theory

This study's theoretical perspective builds on research considering speculative inventory management policies, as well as literature on inventory location postponement. Internet retailers may dynamically choose their sourcing locations for inventory between their own warehouses and those of their vendors. This is because the arrival of online consumer orders does need to coincide, at any given time or location, with inventory offered for sale by Internet retailers.

This setting differs from decisions in traditional retail environments, where inventory replenishment decisions are centered on either inventory location speculation *or* postponement. Consequently, existing inventory models in supply chain management must be integrated so that an Internet retailer can dynamically choose between these two options.

The remainder of this section reviews and integrates research on inventory management policies centered on speculative inventory and inventory postponement. Through this review and integration, this section develops a theoretical perspective that motivates the subsequent analytical modeling of an Internet retailer's inventory management decisions spanning multiple echelons of the supply chain.

2.1. Managing inventory through speculative and location postponement policies: review of extant knowledge

The literature on inventory speculation includes a class of problems that involves the analysis of a firm's inventory order quantities, under conditions of uncertainty and spoilage. Since a firm must forecast and anticipate the need of its buyers, a speculation strategy involves a great amount of uncertainty. Specifically, positive or negative differences between market demand and stock volumes accumulated by firms can respectively lead to important underage and overage costs, in a single-stage (i.e., *newsvendor*) environment (Nahmias, 1982; Raafat, 1991). This problem is amplified when there are seasonal effects and trend variations caused by unexpected market events. Under these circumstances, supply chain members have been compelled to rely on large volumes of cycle and safety stock as a way to exploit scale economies on the supply side and address uncertainty on the demand-side of their businesses, respectively. As these large volumes of inventory sit in the firms' facilities, the firms incur inventory-holding costs and face a possible depreciation of the value in that inventory. As defined by traditional research on newsvendor environments, the value of the inventory may even drop to zero by the end of the inventory order cycle. Moreover, This loss in value may ultimately trigger inventory returns between firms and their suppliers (Kandel, 1996; Pasternack, 1985).

A more attractive alternative to the use of speculative (i.e., in-stock) inventory may involve the use of drop-shipping to fulfill customer orders from inventory located at facilities controlled and owned by the firms' suppliers. This alternative may prove particularly valuable when products are subject to demand uncertainty, obsolescence, and perishability (Abad, 1996; Cobbaert and Van Oudheusden, 1996; Luo, 1998).

Firms have traditionally used drop-shipping and other strategies based on inventory location postponement to lower inventory holding costs and depreciation. Location postponement (also referred to as time postponement) involves delaying the location of finished inventory until after demand materializes downstream in the supply chain. This differs from form postponement, where a firm may put the components of a finished good in inventory to delay the assembly of those components to the customized specifications of the consumer.

Through location postponement, inventory can stay in a centralized location where it may be sent to many possible destinations (within the same or at different supply chain echelons), upon the arrival of demand for the product. In the past, researchers have studied inventory location postponement in the context of inventory centralization strategies. Analytical models by Eppen (1979), Evers and Beier (1993), Maister (1976), and Zinn et al. (1989) as well as applications by Zinn and Bowersox (1988) showed that postponing inventory at a centralized location until demand for the inventory is received yields reductions in safety stock, while holding service levels constant. Furthermore, prior research has considered inventory location postponement in the context of emergency transshipments, wherein inventory at a location is shifted to an alternate site to satisfy demand arriving at the alternate site, only when stock is unexpectedly unavailable at the alternate site (Evers, 2001). Krishnan and Rao (1965) pioneered research on inventory location postponement and emergency transshipments, in particular, by modeling a system with negligible replenishment and transshipment times and under no holding, storage, and transportation costs. Krishnan and Rao's work was extended by Tagaras (1989) and Tagaras and Cohen (1992) who assessed positive effects of emergency transshipments on inventory availability and accounted for deterministic lead times in modeling transshipments, respectively. More recently, Evers (1996, 1997) showed that the portfolio-effect model, which is based on the square-root law, is applicable to the analysis of emergency transshipments when an unlimited number of inventory locations are considered.

In a *retailing* context, the ability of a merchant to directly ship a product from a warehouse to a customer constitutes an example of inventory location postponement. In this model, a retailer is able to ship a single good directly from a warehouse, which it may or may not own, to the consumer. In the mail order industry and in Internet retailing, all products are directly shipped to a consumer from warehouses owned by the retailers or their vendors without the products ever being on the shelves of a location adjacent to the customer.

For the retailer, it matters whether the products come from their own warehouses or their suppliers' warehouses. Internet retailers wishing to reduce the risks associated with owning all inventory may choose to employ an inventory postponement strategy. This approach allows retailers to postpone the purchase of incoming material until demand is known, eliminating the risk of holding obsolete inventory in stock and the opportunity costs from having capital tied up in inventory on the balance sheet.

Nevertheless, there are drawbacks associated with postponing the location of inventory. First, there is a risk of lost sales when demand exceeds a vendor's capacity to make inventory available within a given lead-time, or when a competing retailer's decision to speculate on incoming inventory is more attractive to customers. Second, the costs of transportation and material handling activities may increase with smaller order batches in a postponement strategy (Xu et al., 1994). Clearly, the higher cost of lost sales must be balanced with a lower inventory investment and, therefore, lower inventory carrying costs. Despite these drawbacks, an inventory postponement strategy does have the potential to reduce costs for firms, including Internet retailers (Bucklin, 1965; Pagh and Cooper, 1998; Zinn and Bowersox, 1988).

2.2. Integrating inventory speculation and postponement research

Although the literature on the speculative newsvendor problem and the literature on inventory postponement are fairly well understood, there has been little integration of both areas of work. Perhaps this is because in many industries, firms are likely to select either one strategy or the other to manage their inventory. However, there are a growing number of firms—exemplified by Internet retailers—that can dynamically choose between the two. For example, Amazon.com may decide to source a book from its own warehouse for an order one minute, and then from a vendor's warehouse the next. Amazon.com is able to do this because the sourcing location is completely immaterial to the consumer. When trying to determine whether to speculate or do location postponement dynamically, the formulation of the problem becomes one of cost minimization. This is a main thrust of this paper.

Only recently, have a handful of researchers extended these findings to a supply-chain setting and Internet-enabled operations. Concentrating on inventory and product-release operations, Rabinovich and Evers (2003) show that inventory centralization and market demand growth affect positively the level of cost-effective service received by online shoppers. Rabinovich and Evers (2003) also show that under increasing demand levels, Internet retailers can provide optimal service to consumers by fulfilling orders through inventories located at their own facilities and avoid relying on inventories held elsewhere in the supply chain. In turn, Rabinovich and Shenbagaraman (2004) showed that under inventory location speculation regimes, emergency transshipments reduce stockout occurrences without expanding safety- and cycle-stocks at the inventory locations supporting the fulfillment of online consumers orders. Moreover, these benefits are maximized when inventory locations fulfill demand that is uniformly balanced across markets assigned to each location. Netessine and Rudi (2003) demonstrated that inventory location postponement arrangements lower inventory-holding costs, relative to overall inventory investment, when there is an increase in the number of online retailers participating in these arrangements or when the retailers face an increase in market demand variability.

Prior research has underscored an additional element of uncertainty that every Internet retailer must contend with: the ability of each of the retailer's suppliers to fulfill an order satisfactorily. Specifically, Keeney (1999) interviewed over 100 consumers to help determine what they value from Internet retailers. This study found that Internet retailers must "assure reliable delivery" to successfully attract orders. Torkzadeh and Dhillon (2002) extended this finding through survey research and found that consumers highly value Internet retailer's ability to minimize shipping errors. Since the location postponement strategy relies on an expected level of service by each supplier, there must be a significant amount of trust between each supplier and the Internet retailer. To facilitate this trust, there may be a close coordination between the Internet retailer and the supplier to share information on the supplier's stock levels. This is important because the retailer understands that inventory held by the supplier is a limited resource. Furthermore, the retailer is highly uncertain as to the quantity of products available and the time necessary to deliver those products, when the products reside in the supplier's inventory instead of its own. If the supplier cannot deliver, then the retailer cannot fulfill the consumers order. This condition would ultimately negate the retailer the option of dynamically choosing between speculation and location postponement strategies.

To minimize the uncertainty of postponing inventory location to upstream echelons in their supply chains, some retailers have implemented inventory consignment programs. The most traditional consignment arrangement is the one in which a supplier has ownership of the goods that are found in a retailer's inventory location. Only when consumers buy the inventory does the retailer send payment back to the supplier. At any time, a retailer may send inventory back to the supplier. A reverse consignment is also possible whereby a retailer may ask a supplier to hold its inventory at the supplier's location until a later point in time.

Although both consignment strategies are possible in Internet retailing, the traditional consignment approach is seldom used and the reverse consignment is almost never used. This is not to say that consignment arrangements are not present in offline environments. Consignment arrangements exist in the electronics manufacturing and health care industries (Ackerman, 1986; Ballard, 1987; Benefield, 1985; Fenton and Sanborn, 1987; Gerber, 1987; Hackett, 1993; Valentini and Zavanella, 2003).

2.3. Contextual setting

The retailing of books over the Internet provides a critical context in which drawbacks associated with inventory speculation are considerably high. Since book publishers are subject to long manufacturing runs that stem from large fixed costs in setting up printers and associated software, retailers often keep up to six months demand for a book title in inventory. Another reason why they keep such a large amount of inventory is that the book production for a given title often involves only one run or edition, giving retailers little flexibility in their inventory reordering policies. This relatively large amount of stock is likely to change in value during the inventory's cycle time because of the uncertainty regarding the popularity of each book title. Therefore, the spoilage drawbacks in the speculative newsvendor model are very similar to the problems experienced by these Internet book retailers.

Moreover, the insights that can be obtained from investigating retailing book markets on the Internet are generalizable to other settings. Many of the successful Internet retailing markets, such as computer software and hardware, electronics, and compact discs have inventory management problems similar to the ones experienced by Internet retailing markets focused solely on books. In all of these markets an Internet retailer can practice inventory location postponement. However, in relying on drop-shipping, retailers in all of these markets must be concerned about possible order fulfillment problems occurring upstream in their supply chains (i.e. at their vendors' echelons). For instance, in deciding whether to drop-ship, a retailer must consider each of its vendors' scale of operation and the resulting costs from ordering drop-shipments from the vendors' facilities. Also, the engines of electronic commerce that allow for real-time tracking of product popularity that have been initially used for measuring book popularity are being increasingly used for other products. For example, Amazon.com has transported its ability to track book popularity to its computer software and hardware, electronics, and compact discs markets. This is not surprising; popularity is a critical factor in determining a retailer's inventory holding costs and, consequently, the choice of where to source an item—either through in-stock or drop-shipping—in Internet markets beyond book retailing.

The Internet also allows retailers to decouple inventory locations from consumer order locations in markets that involve a variety of durable products (e.g., software, computers, DVDs, etc.), not just books. This is because Internet shopping events depend on consumers' accessing information on the product they want to buy, as opposed to accessing the product itself and a successful transaction completion in these markets is independent of orders and inventory coinciding at a particular time and place (Brynjolfsson and Smith, 2000; Rabinovich and Evers, 2003). That is, in markets where consumer purchases for durable goods are made through the Internet, the value of inventories is expected to be minimally dependent on the inventories' physical location at the time consumer purchases take place. As a result, exchanges with consumers are virtually unlimited by the coupling of consumer order arrivals and inventories at specific times and locations (Lampel and Mintzberg, 1996; van Hoek, 2001). The placement of inventory at locations, such as retail stores, before demand materializes can be regulated to obtain an optimal balance among lead times, holding costs, and inventory excess and shortage costs in the supply chain.

This functionality leaves Internet retailers with the power to decide where and how to source inventory across the supply chain to fulfill consumer orders. Retailers may opt not to decouple consumer-order and inventory locations and adopt an inventory management strategy that solely relies on in-stock inventory. In this case, retailers absorb inventory-holding costs by locating inventory in their own facilities prior to the arrival of consumer orders and by internally sourcing inventory from within their organizations to fulfill those orders.

On the other hand, Internet retailers may decide to decouple consumer-order locations from their own inventory locations and adopt an inventory management strategy that relies solely on drop-shipped inventory. Under this condition, retailers keep no inventory and, instead, rely on stocking capabilities at upstream supply-chain entities, e.g. wholesalers, to drop-ship products once consumer demand materializes. This strategy may result in considerable inventory-holding cost savings for the Internet retailers, but may prevent the retailers from lowering their ordering costs through bulk inventory reordering and replenishment operations from their suppliers.

In the context of book retailing operations over the Internet, this paper studies conditions conducive to realizing an optimal balance between a reliance on drop-shipped inventory and a reliance on in-stock inventory. Reliance on either inventory type is part of a decision-making process that involves not only in-stock and drop-shipped inventory, but also inventory stock outs by Internet retailers. This study constitutes an initial attempt to analyze optimization alternatives and determinants in an electronic-commerce setting within the single-stage inventory literature.

To that end, Section 3 develops an analytical model that extends prior work on two-stage ordering models with capacity constraints (Fisher and Raman, 1996) and with supply cost differences (Donohue, 2000). The model develops an optimal cost balance that trades off reliance on speculative or in-stock inventory with drop-shipped inventory. This balance may be a clear win for the book industry. More books are sold, more consumers are satisfied, and, potentially, underage and overage inventory costs are minimized, as unnecessary inventory and product movements across the supply chain are reduced. Furthermore, supply quantities ordered by a given Internet retailer may be optimized with the elimination of contract inefficiencies stemming from double marginalization (Donohue, 2000; Spengler, 1950).

3. Analytical model

The analytical model examines the inventory management decisions by an Internet book retailer during an inventory order cycle. Consistent with the book industry's environment, the objective of the Internet retailer is to minimize inventory costs and concurrently maximize consumer order fill rates during the order cycle, based on its decisions on in-stock and drop-shipped inventory reliance.

The model assumes that the Internet retailer operates under fixed-order conditions. This assumption is not unrealistic in the book industry, where retailers source inventory from vendors through preset agreements that are invariant over time. Furthermore, the model assumes an average demand rate and lead-time during future order cycles. This assumption enables generalizable model conditions and applicability to Internet retailers selling mass-market and durable goods, such as books and music CDs. These goods maintain their form and quality for extended periods of time and are subject to high volumes of consumer orders. Under these circumstances, market demand for these durable products will renew itself and remain constant for extended order cycles.

It is also assumed that each stock keeping unit, or SKU (i.e., a book title, j), has a popularity rank (α_j) that helps the Internet retailer forecast the amount of products it expects to sell during a future order cycle. In turn, this gives the retailer an indication of how many products to buy if it is trying to ensure quantity matching of inventory and sales. Values for α_j range from 0 (most popular SKUs) to infinity (least popular SKUs).

Popularity rank measures like the one described above are not uncommon among Internet retailers. For example, Amazon.com maintains measurements of popularity ranks for book titles sold through its Internet site. These sales rankings show how a given book title is *currently* selling at Amazon.com. The lower the ranking's number, the higher the sales for a particular SKU. Furthermore, the sales-ranking measures at Amazon.com are updated regularly. In every category (e.g., books and CDs), the top 10,000 best sellers are updated each hour to reflect sales over the preceding 24 hours. The next 100,000 are updated daily. The rest of the list is updated monthly.

Demand during a future order cycle, in turn, is assumed to be dependent on the popularity rank of the product observed immediately before the cycle. The demand function is given in Eq. (1). The relationship between demand and popularity rank is assumed to be exponential, as opposed to linear, in nature. This assumption follows from the expectation that demand will diminish marginally with decreases in the popularity ranking of products with highly infrequent demand. It is consistent with findings in the Internet book retailing industry (Rabinovich and Evers, 2003). The market demand for book j is defined as:

$$D_j = \mathrm{e}^{(1-\alpha_j)} \tag{1}$$

For a given Internet retailer, i, it is assumed that its product demand during a future order cycle is a portion of its overall market share (determined by m_i). The higher the retailer's market share, the greater the demand levels captured during a future order cycle (refer to Eq. (2)). The demand for book j from retailer i is defined as:

$$d_{ij} = m_i D_j \tag{2}$$

The cost function follows typical total cycle cost functions for classical inventory reorder policies for fixed order sizes (Tersine, 1994). Consequently, the Tersine (1994) notation is used for a description of the costs associated with ordering and holding inventory. Eq. (3) presents the total cost function under the assumed market demand, lead time, and product characteristics presented above. The cost function for retailer i for book j is defined as:

$$C_{ij} = c_{ij}d_{ij} + \mathrm{TC}_{ij} + \mathrm{HC}_{ij} \tag{3}$$

where $c_{ij}d_{ij}$ is the product costs; TC_{ij} is the expected transaction costs due to inventory reordering and replenishment in that period; and HC_{ij} is the holding cost. Table 1 summarizes the variables in the model.

Two cases are subsequently developed to assess four propositions. Case 1 is a more constrained model, where the firm is ordering in advance the inventory it needs to satisfy future demand during the cycle. Case 2 is a more general case, where the retailer seeks to address demand uncertainty by ordering in advance an inventory amount that could be lower than what its future demand might be and then rely on drop-shipping for the remainder of its inventory.

Thus, two order quantity cases pertaining to the cost function in Eq. (3) are considered below. In Case 1, the Internet retailer orders a lot size greater than or equal to its d_{ij}. In this case, the

Table 1
List of variables

Symbol	Name	Description
Firm variables (firm i)		
m_I	Market share	The market share for retailer i
k_i	Drop-shipping cost	The cost of ordering one unit to be drop-shipped to the consumer
f_i	Ordering cost	The fixed cost for placing an order
h_i	Holding cost	The cost of holding one unit of stock in inventory
Title variables (title j)		
α_j	Popularity	The popularity rank for product j
D_j	Demand	The total demand for product j
Didactic variables		
s_{ij}	In-stock quantity	The in-stock inventory quantity for product j for firm i
q_{ij}	Order quantity	The quantity of product j ordered by firm i
c_{ij}	Cost	The cost per product for item j by retailer i
p_{ij}	Drop-shipped quantity	The total number of products j drop-shipped by retailer i
d_{ij}	Cycle demand	The demand for product j for firm i during the cycle

retailer adopts a reliance on in-stock inventory strategy and fulfills future demand with inventory placed in its own stock-keeping locations prior to the arrival of consumer orders. In Case 2, the retailer orders a lot size smaller than its d_{ij}. In this case, the retailer adopts a reliance on drop-shipped inventory strategy to fulfill future consumer orders placed through its website.

3.1. Case 1: In-stock inventory reliance under imperfect demand information

In Case 1, the retailer places an order quantity (q_{ij}) greater than or equal to the expected demand during the order cycle. From Eq. (4), the order quantity is in excess of d_{ij} by s_{ij}, with $s_{ij} = [0, \infty)$.

With this inequality between cycle demand and order quantity in the cycle, the number of orders per cycle is expected to be less than one in the long run. Ordering costs are given by Eq. (5), where f_i is the fixed cost for placing an inventory order. Holding costs are proportional to the inventory levels over the order cycle and the cost of keeping one unit of inventory in stock during the cycle (h_i). From Eq. (6), the levels of inventory and holding costs during the order cycle will increase as a result of the additional number of units ordered.

$$q_{ij} = d_{ij} + s_{ij} = m_i D_j + s_{ij} = m_i \mathrm{e}^{(1-\alpha_j)} + s_{ij} \tag{4}$$

$$\mathrm{TC}_{ij} = \frac{f_i d_{ij}}{q_{ij}} \tag{5}$$

$$\mathrm{HC}_{ij} = \frac{h_i q_{ij}}{2} \tag{6}$$

The value of q_{ij} in Eq. (4) is substituted in Eqs. (5) and (6). In turn, the resulting TC_{ij} and HC_{ij} in Eqs. (5) and (6) are substituted in the cost function in Eq. (3). This cost function is minimized with respect to s_{ij}. The value of s_{ij} that minimizes total costs during the cycle is given by Eq. (7):

$$s_{ij} = \sqrt{\frac{2f_i m_i \mathrm{e}^{(1-\alpha_j)}}{h_i}} - m_i\,\mathrm{e}^{(1-\alpha_j)} \quad \text{when}\, \frac{2f_i}{h_i} > m_i\,\mathrm{e}^{(1-\alpha_j)}; \quad 0 \text{ otherwise} \tag{7}$$

3.2. Case 2: Drop-shipped inventory reliance under imperfect demand information

In Case 2, the retailer uses drop-shipping to supplement its orders once its inventory is depleted. The retailer places an order quantity smaller than the expected demand during a future order cycle. From Eq. (8), the order quantity is lower than or equal to d_{ij} by p_{ij}, with $p_{ij} = [0, \infty)$. In this case, the reordering costs are exactly f_i. There is always one and only one order placement for each cycle in the future (Eq. (9)). The holding costs follow the same logic as in Case 1. Obviously, the levels of inventory during a future order cycle will be on the low side as a result of the reduced number of units ordered in advance (Eq. (10)). Furthermore, these costs are determined by drop-shipping costs necessary to fulfill consumer orders with inventory not owned by the Internet retailer and not located at the retailer's stock-keeping locations. As indicated in the second term of Eq. (10), these drop-shipping costs are directly a function of costs incurred by the Internet retailer when ordering one unit of inventory to be drop-shipped to the consumer (k_i).

$$q_{ij} = d_{ij} - p_{ij} = m_i D_j - p_{ij} = m_i\,\mathrm{e}^{(1-\alpha_j)} - p_{ij} \tag{8}$$

$$\mathrm{TC}_{ij} = f_i \tag{9}$$

$$\mathrm{HC}_{ij} = \frac{h_i q_{ij}^2}{2(q_{ij} + p_{ij})} + \frac{k_i p_{ij}^2}{2(q_{ij} + p_{ij})} \tag{10}$$

The value of q_{ij} in Eq. (8) is substituted in Eq. (10). In turn, the resulting TC_{ij} and HC_{ij} in Eqs. (9) and (10) are substituted in the cost function in Eq. (3). This cost function is minimized with respect to p_{ij}. The value of p_{ij} that minimizes total costs during the cycle is given by Eq. (11):

$$p_{ij} = \frac{h_i m_i\,\mathrm{e}^{(1-\alpha_j)}}{h_i + k_i} \tag{11}$$

3.3. Analysis of propositions

One notable aspect of the results in Eqs. (7) and (11) is the dependence that in-stock and drop-shipped inventory reliance during future order cycles have on SKU popularity rank (α_j) and market demand levels (m_i), under optimal cost conditions. The remainder of this section analyzes the nature of these relationships through the use of partial derivatives of Eqs. (7) and (11) with respect to the parameters α_j and m_i.

Insights from the partial derivatives are supplemented by numerical examples using values for h_i (\$1) and k_i (\$1) proportional to the lowest discounted prices for mass-market books. Furthermore, the examples use a value for f_i (\$100) proportional to the stock reordering costs for a retailer offering mass-market books. Finally, the examples adopt market share values, m_i, of 50% and 90%. These values are indicative of Internet book retailers with differential levels of market power.

Proposition 1. *As product popularity increases, reliance on in-stock inventory increases.*

Using the result from Case 1 (Eq. (7)), $\frac{\partial s_{ij}}{\partial \alpha_j}$ is examined:

$$\frac{\partial s_{ij}}{\partial \alpha_j} = m_i \mathrm{e}^{(1-\alpha_j)} - \frac{1}{2}\sqrt{\frac{2 f_i m_i e^{(1-\alpha_j)}}{h_i}} \tag{12}$$

Because an increase in α_j signifies a decrease in product popularity and $s_{ij} \geqslant 0$, the result in Eq. (12) implies that:

$$1 - \ln\left(\frac{f_i}{2m_i h_i}\right) < \alpha_j \quad \text{then Proposition 1 is true} \tag{13}$$

$$1 - \ln\left(\frac{f_i}{2m_i h_i}\right) > \alpha_j \quad \text{then Proposition 1 is false} \tag{14}$$

From Eqs. (13) and (14), the causal relationship between α_j and s_{ij} is defined by a concave function, where there is an identifiable maximum described above. This is illustrated in the numerical example in Fig. 1, where product popularity increases as α_j moves to the left from the lower popularity levels on the right-hand side of the α_j axis and leads to a progressively greater reliance on in-stock inventory up until:

$$\alpha_j = 1 - \ln\left(\frac{f_i}{2m_i h_i}\right) \tag{15}$$

At that point, increases in product popularity lead to a progressively lower reliance on in-stock inventory to meet average future order cycle demand.

Proposition 2. *As product popularity increases, reliance on drop-shipped inventory increases.*

Taking the derivative of the solution for Case 2 (Eq. (11)) with respect to α_j, it is shown that:

$$\frac{\partial p_{ij}}{\partial \alpha_j} = \frac{-h_i m_i \mathrm{e}^{(1-\alpha_j)}}{h_i + k_i} \tag{16}$$

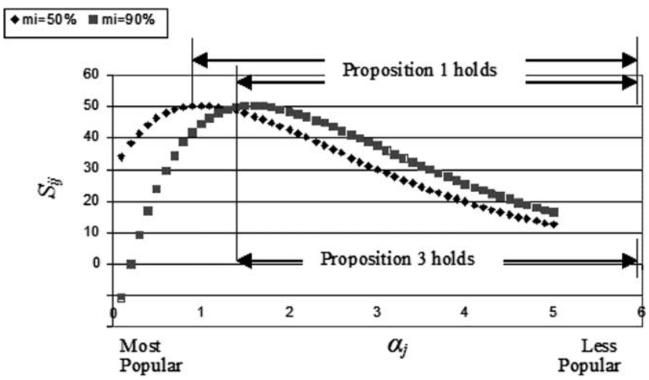

Fig. 1. Numerical example to support Propositions 1 and 3.

$\frac{\partial p_{ij}}{\partial \alpha_j}$ is always negative because every variable in Eq. (16) takes on a positive number. Thus, decreases in product popularity—represented by increases in α_j—lead to a progressively lower reliance on drop-shipping levels.

From Eq. (16), Proposition 2 follows. Fig. 2 presents the graphical results from a numerical example based on the values outlined above.

Proposition 3. *As market share increases, reliance on in-stock inventory increases.*

Following Eqs. (13) and (14), Proposition 3 holds if in-stock inventory decreases as α_j goes up. Thus, with α_j measuring product popularity ranks and $s_{ij} \geqslant 0$,

$$1 - \ln\left(\frac{f_i}{2m_i h_i}\right) < \alpha_j \quad \text{then Proposition 3 is true} \tag{17}$$

$$\text{If } 1 - \ln\left(\frac{f_i}{2m_i h_i}\right) > \alpha_j \quad \text{then Proposition 3 is false} \tag{18}$$

These results indicate that for high levels of market share, reliance on in-stock inventory during future order cycles becomes a declining function on popularity for a greater range of popularity levels. This is because $1 - \ln(\frac{f_i}{2m_i h_i})$ goes to infinity as market share increases, thereby covering a greater range of popularity levels.

Proposition 4. *Market-share growth leads to greater reliance on drop-shipped inventory.*

For Case 2, Proposition 4 is always true, as shown in Eq. (19):

$$\frac{\partial p_{ij}}{\partial m_i} = \frac{h_i \mathrm{e}^{(1-\alpha_j)}}{h_i + k_i} \tag{19}$$

This result is illustrated in the numerical application. From Fig. 2, an expansion in market share increases reliance on drop-shipped inventory to meet future average demand in the order cycle, regardless of α_j.

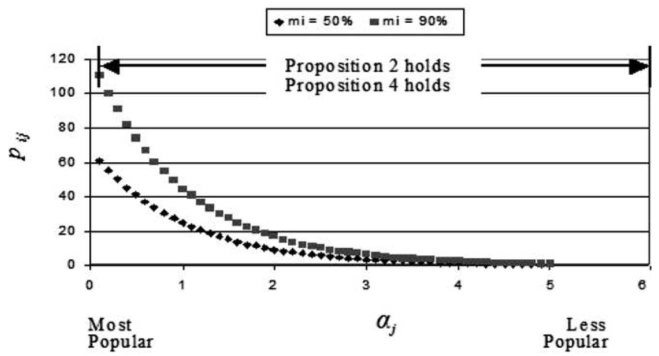

Fig. 2. Numerical example to support Propositions 2 and 4.

The insights gleaned from Propositions 1–4 may be best understood in the contextual setting of Internet book retailing. Amazon.com and BarnesandNoble.com, two of the largest Internet book retailers, are often faced with the challenge of how to manage their inventory based upon product popularity. In fact, both firms keep track of book popularity dynamically. They share this information with customers to help direct them to popular products. Moreover, they use this information to help set the price for their products. Perhaps most importantly, they also use this information to determine their inventory location postponement strategy.

Following Propositions 1 and 2, it is likely that both Amazon.com and BarnesandNoble.com will increase their reliance on in-stock inventory and drop-shipping as product popularity goes up. However, the conditional nature of Propositions 1 and 3 indicates that both firms may treat some of their most popular products uniquely. For example, when Amazon.com sells blockbuster releases of the *Harry Potter* books, they handle sufficient volume to warrant a special inventory policy. Specifically, Amazon.com usually chooses to work closely with its vendors and the United States Postal Service to ensure that it can use drop-shipping to handle the volume and delivery timing of such a popular product.

The dynamics of Propositions 3 and 4 may be best understood through a comparison of Amazon.com and BarnesandNoble.com. Since Amazon.com has a larger market share than BarnesandNoble.com, it will rely more heavily on in-stock inventory to meet demand for SKUs that are not on top of the popularity charts. BarnesandNoble.com is a smaller player than Amazon.com and cannot afford to carry in-stock inventory volumes for non-popular items at levels comparable to those at Amazon.com. After all, because of its smaller scale, BarnesandNoble.com faces a greater risk of not selling in-stock inventory for SKUs facing demand that is exponentially lower than that for best-selling items in the market.

But, what about those SKUs with a commanding popularity lead over other books in the market? For those items, Amazon.com and BarnesandNoble.com can afford to rely more heavily on drop-shipping, as inventory costs outweigh drop-shipping costs for such heavily requested items. The leading retailer, however, will need to ensure a greater access to drop-shipped inventory, relative to that of its competitor, to secure a seamless fulfillment service to consumers. Otherwise, its market share will be undermined. This is why Amazon.com will rely more heavily on drop-shipped inventory than BarnesandNoble.com for best-selling items facing demand levels that are exponentially greater than other books in its website.

3.4. Sensitivity analysis

A sensitivity analysis was performed to assess the robustness of the findings from the numerical analysis of the propositions. The firm variables of holding costs (h_i), drop-shipping costs (k_i), reordering costs (f_i), and market share (m_i) are mean estimates of an Internet book retailer. However, there is sufficient heterogeneity among firms to warrant an investigation of how firm differences may impact the findings.

Two of the propositions are *not* conditional on the four firm variables and hold true for all possible values. Proposition 2, which states that as product popularity increases, reliance on drop-shipped inventory increases, is true for all possible non-negative values of h_i, k_i, and m_i. By examination of Eq. (16), increasing holding costs, decreasing drop-shipping costs, and increasing market share all strengthen the relationship of increasing popularity leading to more reliance on drop-shipped inventory. Proposition 4, which states that market share growth leads to greater reliance on drop-shipped inventory is also true for all non-negative values of h_i and k_i. By examination of Eq. (19), an increase in holding costs and a decrease in drop-shipping costs strengthen the link between market share and reliance on drop-shipped inventory, as stipulated in Proposition 4. A sensitivity assessment of the model, available by the authors upon request, confirms this result.

The remaining two propositions are conditional on the four firm variables h_i, k_i, f_i, and m_i. An analysis of holding costs, h_i, shows that lowering holding costs increases reliance on in-stock inventory. Reliance on in-stock inventory increases with popularity until the point of maximum reliance shown in Eq. (13). As holding costs decrease, the point of maximum reliance shifts to include increasingly popular products. This can be demonstrated by analyzing the left hand side of Eq. (13) and Fig. 1, where a decrease in holding costs shifts the point of maximum reliance on in-stock inventory to the left—towards the most popular goods. Results from a sensitivity analysis on the numerical model (available by the authors upon request) concurred with this finding. Therefore, there is a larger range over which Proposition 1 holds as inventory holding costs go down. A similar analysis of Proposition 3 showed that decreasing holding costs lead to a larger range of popularity over which Proposition 3 holds.

The impact of lower holding costs on in-stock reliance is not surprising. As the cost of holding a product in inventory decreases, it is likely that a retailer will carry this product in inventory, instead of relying on drop-shipping. Amazon.com's expansion of their warehouses may be an example of this. As its order volume increased and its variety of SKUs expanded, the opportunity cost of keeping a given item in stock, within its limited warehousing space, increased. Essentially, this might have boosted holding costs and compelled Amazon.com to reduce its reliance on in-stock inventory. By building new warehouses, Amazon.com was able to reduce its holding costs and increase its reliance on in-stock inventory.

An analysis of ordering costs, f_i, shows that a reliance on in-stock inventory is directly aligned with the value of f_i. Reliance on in-stock inventory increases with popularity until the maximum point derived in Eq. (13). However, as f_i increases, this maximum point shifts to include increasingly popular books. This insight can be gleaned from an inspection of the inequality in Eq. (13). As f_i increases, α_j can be reduced (i.e., product popularity increases) and Proposition 1 will still hold. This insight is confirmed through the numerical model in Fig. 1 and sensitivity analyses, where an increase in ordering costs shifts the maximum point in the in-stock reliance curve to the left—toward more popular products. A similar analysis on Proposition 3 showed that as reordering costs increase, there is a larger range of product popularity over which Proposition 3 holds.

The finding that an increase in ordering costs leads to an increase in in-stock reliance may be considered surprising at first. Since it is more costly to order inventory, a retailer may choose to drop-ship a product instead of relying on in-stock inventory. However, a firm is actually more inclined to rely on in-stock inventory because it will place larger orders to keep items in inventory and offset high inventory ordering costs. Consider the time when Amazon.com was faced with a potential increase in ordering costs from its wholesaler, Ingram. Over five years ago, Ingram was the target of a takeover by Amazon.com's competitor, Barnes & Noble. Barnes & Noble would have likely increased Amazon.com's ordering costs and Amazon.com would have had no choice but to rely more intensely on its own inventory, instead of Ingram's to fulfill its consumer orders.

This eventuality, however, never occurred because Barnes & Noble's bid for Ingram was blocked on antitrust grounds.

4. Conclusion

The rise of the Internet enables sellers to leverage their supply chains in a way that allows them to reduce their inventory management costs without jeopardizing consumer service levels. This paper helps Internet retailers in this endeavor by providing analytical insights into the dynamics of inventory postponement and speculation as a function of product popularity and Internet retailer market share. To that end, the paper reviews and integrates research on inventory management policies centered on speculative inventory and inventory postponement. Moreover, the paper develops an analytical model to study inventory management decisions of Internet book retailers under two strategies: in-stock inventory reliance and drop-shipped inventory reliance, both under imperfect demand information. Furthermore, the models use a demand function that endogenizes Internet-retailer market share and SKU popularity rank—a measure used by many Internet retailers as a pricing and inventory gauge.

Overall, the analytical results in the paper suggest that reliance on in stock and drop-shipped inventory to fulfill Internet orders from consumers may be considered simultaneously. Thus, as products become more popular and Internet retailers increase their market share, they could rely more heavily on both forms of inventory management strategies to achieve an optimal inventory management performance. This finding coincides with developments in the industry, where dominant players have simultaneously pursued both in-stock and drop-shipping reliance strategies through the development of privately owned warehouses and the consolidation of inventory management relationships with upstream supply chain partners.

The results from the analytical model also offer detailed insights into the general finding that growth in product popularity leads to an increased reliance on in-stock inventory. Specifically, the results suggest that under optimal inventory management performance conditions, this general finding may be altered for the most popular items, depending on the relationship between the Internet retailer's ordering or transaction costs and the product of the retailer's market share and holding costs. Thus, Internet retailers with large market shares and low ordering-cost levels may seek a lower reliance on in-stock inventory in order to absorb unexpected surges in product demand for their most popular SKUs. Put differently, Internet retailers may rotate the inventory for their most popular SKUs while simultaneously keeping a minimal level of in-stock inventory on hand. This capability is significantly amplified for Internet retailers exhibiting high transaction-efficiencies and in dominant market positions.

Several research extensions build on this paper's findings. First, the analytical model assumes that Internet retailers make ordering decisions based on expected demand during their future order cycles. Further research may consider multiple levels of stochastic demand and their effects on retailers' inventory management decisions studied in this paper. Under Poisson-arrival conditions, typical of Internet-retailing environments (Rabinovich and Evers, 2003), the inclusion of stochastic demand conditions may lead to more efficient inventory management decisions for those products with higher popularity levels. This is because demand variability is reduced as demand popularity increases. Thus, the ability to match demand with inventory availability increases as popularity for a given item expands.

Second, the results from this paper suggest that decreases in ordering or transaction costs lead to decreased levels of in-stock inventory, while holding retail market share and product-popularity levels constant. Future research may consider variable levels of market share while analyzing in-stock inventory effects from ordering costs. It may be that increased market levels lower ordering costs as a result of scale economies. In this case, given the negative effect of ordering costs on in-stock inventory levels, market share will have an indirect and negative effect on in-stock inventory levels, holding everything else constant.

Third, the paper considers marginal costs to be constant for all books and firms, irrespective of popularity and market-share levels. Research extensions may analyze the effects that differential marginal costs, as determined by popularity and market-share levels, have on inventory management decision in the Internet environment studies in this paper. Thus, for instance, it is expected that market-share expansions will lead to reductions in marginal cost that will, in turn, favor in-stock inventory holding decisions over drop-shipping decisions.

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