Strategic Inventories under Supply Chain Competition

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Problem definition: We consider the effects of strategic inventory in the presence of chain-to-chain competition in a two-period model. *Academic/practical relevance:* Established findings suggest that strategic inventory may alleviate double marginalization and improve the efficiency of a decentralized distribution channel. However, none consider the role of strategic inventory under chain-to-chain competition. *Methodology:* We build a two-period model consisting of two competing supply chains, each with an upstream manufacturer and an exclusive retailer. The retailers compete on either price or quantity. We characterize the firms' strategies under the concept of Perfect Bayesian Equilibrium. We consider the cases where contracts are either observable or unobservable across supply chains. *Results:* (1) Strategic inventory still exists under chain-to-chain competition. Retailers may carry more inventory when the competition becomes fiercer, which further intensifies the supply chain competition. (2) Different from the existing findings, strategic inventory may backfire and hurt all the firms. Interestingly, the firms may benefit from a higher inventory holding cost. (3) Under supply chain competition, the prisoner's dilemma can arise if the competition intensity is intermediate; in other words, the manufacturers are better off without strategic inventory, and yet they cannot help allowing strategic inventory, which is the unique equilibrium. *Managerial implications:* Despite its appeal among firms of a single supply chain, the role of strategic inventory is altered or even reversed by chain-to-chain competition. Conventional wisdom on strategic inventory should be applied with caution.

Key words: Strategic inventory, chain-to-chain competition, double marginalization

1. Introduction

1.1. Background and Motivation

Forward buying refers to retailers' activity of purchasing units during a particular period, holding some of them in inventory, and then selling them in subsequent periods (Desai et al. 2010). It has been a long-time business practice. The empirical literature provides evidence of forward buying in various categories, including bathroom tissue, coffee, detergents, and paper towels (Bell et al. 1999). Likewise, Armstrong (1991) also finds empirical support of forward buying in such product categories as disposable diaper and ground caffeinated coffee.

Anand et al. (2008) first identify the strategic role of such inventory held by the retailer in coordinating supply chains. They find that in a two-period dyadic supply chain, the retailer may build up *strategic inventory* (SI) at the end of the first period to limit the manufacturer's market power in the second period. Interestingly, this strategic use of inventory alleviates double marginalization and improves both the manufacturer's and the retailer's profit. Under different settings, a number of subsequent studies (Desai et al. 2010, Arya and Mittendorf 2013, Hartwig et al. 2015) have all confirmed the similar role of strategic inventory in a decentralized supply chain. In particular, Hartwig et al. (2015) conduct an experimental study to show that decision makers indeed use inventory strategically as the theory prescribes.

While these findings are very insightful, one missing feature amongst all existing research on strategic inventory is supply chain competition, which appears to be prevalent in this modern economy. As a matter of fact, the product categories (e.g., detergents, coffee, paper towels, and diapers) of the earlier cited empirical literature on forward buying are all rather competitive with many brands and retailers. As Taylor (2003), Barnes (2006), and Ha and Tong (2008) thoroughly discussed, nowadays business competition is all about supply chain versus supply chain. The financial performance of a firm, be it a manufacturer or a retailer, hinges on the performance of the supply chain it belongs to. Examples of chain-to-chain competition abound. A canonical example of this can be seen when competing car manufacturers distribute their cars through exclusive dealers. Another example can be seen in the relationship between electronics manufacturers and exclusive distributors/retailers; for example, customers frequently purchase through Panasonic shops and Samsung shops that operate independently from the original manufacturers (e.g., Panasonic in Japan and Samsung in Korea). Sanitaryware brands such as Toto and Jacob Delafon typically sell their products through regional distributors, and likewise many garment brands sell their products through third-party exclusive retailers.

To fill the gap between the academic literature and business practice, we attempt in this paper to study the role of strategic inventory in the presence of chain-to-chain competition. In addition to

the fact that chain-to-chain competition is ubiquitous and should be factored into the picture, this paper follows a natural rationale: conventional wisdom on strategic inventory should be applied with caution. Strategic inventory primarily facilitates *internal coordination* within a supply chain, but it is not a priori clear whether this internal coordination is overwhelmingly beneficial when facing *external competition*.

In compliance with Anand et al. (2008), we consider a two-period model in which two retailers sell (imperfect) substitutes that are sourced from their exclusive manufacturers. The retailers can purchase excessive goods in the first period and carry them through to the second period. In the basic model, we consider a situation where the supply contracts and transaction details within a supply chain are *not observable* to the rival supply chain and where the retailers compete on price. Unobservable contract is typical in practice. Consider two competing automotive manufacturers and their exclusive dealers in a region. Contract terms such as wholesale prices and order quantities are often not observable to the rival firms, although they are mostly known within the chain. As robustness checks, we also study the scenario where contracts are observable across chains and the scenario where the retailers engage in quantity competition.

1.2. Summary of Our Findings

Based on these model characteristics, we make a number of observations. First, we replicate the existing wisdom by showing that the retailers still hold strategic inventory under supply chain competition. Strategic inventory could lead to lower wholesale prices in the second period, thereby alleviating double marginalization. This establishes the close connection between the existing literature and our setup. However, in addition to double marginalization alleviation, strategic inventory also has a *competition intensification effect*. By stocking excessive inventory in the first period, a retailer faces a lower wholesale price in the second period, which intensifies the competition between the two retailers. Note that when competition is not fierce, strategic inventory could alleviate the first-period competition. However, this effect is immaterial compared with the competition intensification effect in the second period.

Along this line, the more substitutable the goods are, the more strategic inventory the retailers will carry and the fiercer the competition between the supply chains will be. When competition is mild, the double marginalization alleviation effect overweighs the competition intensification effect; consequently, strategic inventory improves the firms' profits. However, when competition is fierce, the competition intensification effect starts to take over, which leads to lower equilibrium profits for all firms.

Second, we compare the results with those in the no inventory (NI) case, which refers to the scenario in which the retailer cannot carry inventory. In Anand et al. (2008), the manufacturers always prefer to operate with strategic inventories. This insight is further confirmed by Desai et al. (2010), Arya and Mittendorf (2013), and Roy et al. (2019) in different contexts. However, in the presence of supply chain competition, we show that *the manufacturers can strictly prefer to eliminate strategic inventories.* This occurs when competition is relatively fierce because the competition intensification effect now overshadows double marginalization alleviation and strategic inventory backfires on both the retailers and the manufacturers. It is also worth mentioning that while firms benefit from strategic inventory only when competition is mild, strategic inventory always improves social welfare.

Third, we consider the case where the manufacturers can choose whether to allow retailers to carry strategic inventories. For example, a manufacturer can eliminate strategic inventory by implementing a vendor-managed inventory (VMI) system and delivering to its retailer only the needed amount for the current period. In e-commerce, drop shipping is a common arrangement between the manufacturer and retailer. Similarly, with drop shipping, the retailer does not physically handle the products or carry inventory. The manufacturers' choices of eliminating strategic inventory are long-term decisions, and, once made, cannot be changed in the short run. We find that in equilibrium the manufacturers choose to eliminate strategic inventory when competition is fierce. This happens because NI could help the retailers shield themselves from the fierce competition caused by strategic inventory, which in turn also benefits the manufacturers. However, holding strategic inventory remains a pure-strategy equilibrium when competition is less fierce, even though it may hurt the manufacturers' profits. This constitutes a form of the "prisoner's dilemma": when the competition is intermediate, it is very difficult for either manufacturer to escape from this unfortunate outcome.

Finally, to check the robustness of our findings, we extend the basic model in two directions. We consider a case in which the contract terms between a manufacturer and its downstream retailer are observed by the other supply chain, and find that our results continue to hold. We also investigate a scenario in which the retailers compete on quantity (as opposed to price). We find that the main insights remain qualitatively unchanged under quantity competition.

Taken together, these results help us build an understanding of strategic inventory in competitive markets.

1.3. Related Literature

Our paper contributes to the growing literature concerning the strategic use of inventories. The idea of strategic inventory was originally proposed by Anand et al. (2008). In their seminal work, Anand et al. consider a decentralized distribution channel in which a retailer may opt to carry additional inventory after the first period to convince the manufacturer to lower its wholesale price in the second period. There are no uncertainties in the model and the use of inventories is purely strategic. They show that strategic inventory could alleviate double marginalization and improve both the manufacturer's and the retailer's profits. Moreover, the manufacturers always prefer to operate with strategic inventories.

Following Anand et al. (2008), Desai et al. (2010) use strategic inventory to explain the practice of forward buying. They consider competition at either the upstream or the downstream, but not chain-to-chain competition, and their focus is on channel configuration. Therefore, their insights are different. In their two retailers – one manufacturer model, a retailer could free ride on the rival retailer's strategic inventory, and as competition becomes fiercer, strategic inventory level decreases. This is in direct contrast to our finding. Moreover, they assume that the contract between one retailer and the manufacturer is observed by the rival retailer, whereas we assume contracts are not observable across supply chains. In their two manufacturers – one retailer model, the retailer is always better off with strategic inventory, which intensifies the competition between the upstream manufacturers. In our model, strategic inventory can backfire on the retailers' profit when competition is fierce. Arya and Mittendorf (2013) show that manufacturer-to-consumer rebates can further improve the performance of strategic inventory. In particular, they find that with consumer rebates, carrying strategic inventories is preferred to the elimination of inventories (i.e., NI) by the manufacturer, retailer, and consumers alike. Arya et al. (2014) demonstrate that, in the presence of strategic inventory, a firm's decision to cede procurement choices to its individual divisions can help moderate inventory levels and provide a natural salve on supply chain frictions. Recently, Roy et al. (2019) consider the case where the manufacturer cannot observe the retailer's level of strategic inventory. They show that this can lead to more or less strategic inventory, depending on the level of holding cost. They also find that the manufacturer would prefer not to have visibility into the retailer's operations, which would permit it to observe the inventory, while the retailer would prefer for the manufacturer to have observability only when the holding cost is sufficiently low. Guan et al. (2019) show that a retailer could carry strategic inventory to limit the encroachment of its upstream manufacturer and that both firms may benefit from the coexistence of strategic inventory and supplier encroachment.

It is worth noting that excess inventory may arise due to other strategic concerns. For example, Lai et al. (2011) and Lai et al. (2012) show that, in the presence of short-term valuation concerns, firms (or firm managers) may have an incentive to overstock to signal their market value to the capital market.

This paper is also closely related to the literature on chain-to-chain competition. Beginning with McGuire and Staelin (1983), this classical problem has been extensively studied in operations management, marketing, and economics (e.g., Ha and Tong 2008, Carr and Karmarkar 2005, Villas-Boas 2007). While McGuire and Staelin (1983) implicitly assume that all contracts are public information in the market, Coughlan and Wernerfelt (1989) show that the channel equilibrium is completely different when such contracts are not observed by rival firms. Corbett and Karmarkar (2001) consider entry decisions and post-entry decisions in a multi-tier serial supply chain. Ha and Tong (2008), Ha et al. (2011) and Ha et al. (2017) focus on the value of information sharing within a supply chain under chain-to-chain competition. In particular, they assume that contract types are observable but that contract terms are not observable to firms in the rival supply chain. In this connection, Shin and Tunca (2010) study the effect of observability in supply chains. They show that forecast observability (i.e., the observability of forecast investments) amplifies both the overinvestment in forecasting and the ensuing supply chain efficiency.

Finally, there is a large body of literature on inventory competition; for example, see Cachon (2001), Netessine and Rudi (2003), Gaur and Park (2007), Zhao and Atkins (2008), and Nagarajan and Rajagopalan (2009). However, this literature largely studies the competition of two firms and focuses on the operational role of inventory; that is, to prevent stock-out. In contrast, we consider the strategic role of inventory under chain-to-chain competition.

1.4. Organization of this Paper

The rest of the paper is organized as follows. Section 2 presents the model, which is analyzed and discussed in Section 3. Section 4 considers the equilibrium strategies when the manufacturers could choose between strategic inventory operations and no inventory operations. Section 5 extends the model to consider observable contracts and quantity competition. The paper is concluded in Section 6. All the proofs are relegated to the online appendix.

2. Model

Our model consists of two competing supply chains, indexed by $i \in \{1,2\}$ and $j = 3 - i$, each with an upstream manufacturer (he) and a downstream retailer (she). The two retailers sell imperfect substitutes and compete on price, each sourcing from an exclusive manufacturer, which does not supply to the other retailer.

Market demand. There are two periods in the model, $t = 1, 2$. In period t, the retail demand for product i is[1]

$$D_{it} = 1 - p_{it} + \theta(p_{jt} - p_{it}), \tag{1}$$

where $\theta > 0$ reflects the extent of competition between the two supply chains. This parameter captures the degree of substitutability both between the products and between the retailers. When θ is larger, competition will be fiercer. Throughout this paper, as in (1), we use the first subscript to represent supply chain indices and the second subscript to represent period indices. This demand structure has been used in the literature (e.g., Desai et al. 2010). The manufacturers' marginal production costs are symmetric, constant and are normalized to zero.

It is noteworthy that some literature (e.g., McGuire and Staelin 1983) uses a different demand function to model supply chain competition, i.e., $D_{it} = 1 - p_{it} + tp_{jt}$, where $t \in [0, 1)$ captures the intensity of competition. This model is equivalent to our model in the sense that

$$D_{it} = 1 - (1 - t)p_{it} + t(p_{jt} - p_{it}).$$

Let $\hat{p} = (1 - t)p$ and $\theta = \frac{t}{1-t}$, we have $D_{it} = 1 - \hat{p}_{it} + \theta(\hat{p}_{jt} - \hat{p}_{it})$, where θ can be any positive number. For example, $t = 0.8$ corresponds to $\theta = 4$.

Inventory carryover. So far, the model is standard and is commonly used in the literature (cf. McGuire and Staelin 1983). We assume, à la Anand et al. (2008), that the retailers could purchase excessive goods during period $t = 1$, carry the goods in their retail inventory, and sell them during period $t = 2$. The unit inventory holding cost is h per period.

Timing and decisions. We analyze a four-stage game, with two stages in each period. In the first stage, the two manufacturers simultaneously decide their first-period wholesale prices, w_{i1} and w_{j1}. In the second stage, the two retailers simultaneously decide their retail prices p_{i1} and p_{j1}. They also decide Q_{i1} and Q_{j1}, the quantities that they order from their upstream manufacturers. Note that the order Q_{i1} may exceed the actual demand D_{i1}. If so, the excessive goods, $I_i = (Q_{i1} - D_{i1})^+$ are carried forward to the second period by retailer i.

In the third stage, the two manufacturers simultaneously decide their second-period wholesale prices, w_{i2} and w_{j2}. In the fourth stage, the retailers decide their retail prices p_{i2} and p_{j2}, and then they decide Q_{i2}, Q_{j2}, the quantities that they order from their upstream manufacturers. Retailer i

[1] Although we chose such a simplified linear demand form to make the results easier to understand, the whole analysis holds for a general linear demand function. That is, given $D_{it} = a - bp_{it} + cp_{jt} (c < b)$, we can rewrite it as $\hat{D}_{it} = 1 - \hat{p}_{it} + \theta(\hat{p}_{jt} - \hat{p}_{it})$ by rescaling $\hat{D} = \frac{D}{a}$, $\hat{p} = \frac{b-c}{a}p$, and $\theta = \frac{c}{b-c}$.

uses both I_i, her inventory carryover, and Q_{i2}, the new orders she places in period 2, to satisfy the demand.

Information structure. Our model slightly differs from the traditional literature on supply chain competition (cf. McGuire and Staelin 1983) in its information structure. We assume that the contract terms and transaction details within a supply chain are *not observed* by firms of the rival supply chain. In other words, firms of supply chain j do not observe w_{it} or Q_{it}, and subsequently, they do not observe I_i either. We make this assumption of unobservability for the following reasons. First, as pointed out by the literature, unobservable contracts are more realistic because contract terms within a supply chain are typically not observed by rival firms (see Coughlan and Wernerfelt 1989, Gavazza and Lizzeri 2009, Hart et al. 1990, Ha et al. 2011, Li and Liu 2020, McAfee and Schwartz 1994, Rey and Tirole 2007, or Segal 1999, for example). Second, our main findings remain qualitatively unchanged under observable contracts (see Section 5.1). Third, the analysis of unobservable contracts is cleaner and more tractable. As such, we choose to study unobservable contracts in the main model.

As in Anand et al. (2008), there is no demand uncertainty in our model. As these authors noted, this assumption helps isolate the strategic interactions between the manufacturers and the retailers via inventories, without muddying the waters through other effects that are not the focus of this paper. Anand et al. (2008) suggest that strategic inventory could alleviate double marginalization in a supply chain and, therefore, could improve the profits of both the upstream and the downstream firms. As we will show in this paper, in the presence of supply chain competition, strategic inventory not only alleviates double marginalization but also intensifies the competition between the two supply chains. The exact implication of strategic inventory hinges on the magnitudes of these two effects.

3. Analysis

In this section we will analyze the channel equilibrium in the basic model. Given that contract terms are not observed by firms of the rival supply chain, we characterize the firms' strategies under the concept of Perfect Bayesian Equilibrium (PBE). It is noteworthy that PBE does not impose restrictions on beliefs off the equilibrium path. This gives rise to multiple equilibria. Here we assume *passive beliefs* — beliefs are not updated upon observing a deviance, an assumption commonly made in the literature (Gavazza and Lizzeri 2009, Hart et al. 1990, Ha et al. 2011, Li and Liu 2020, McAfee and Schwartz 1994, Segal 1999, Rey and Tirole 2007). For example, when observing an unexpected wholesale price w_{i1}, retailer i does not change her belief of w_{j1}. Similarly, when observing an unexpected retail price p_{j1}, retailer i does not change her belief of w_{j1}.

Table 1 Equilibrium strategies

	SI ($h \leq \frac{1}{4+\theta}$)	SI ($h > \frac{1}{4+\theta}$) or NI
w_{i1}	$\frac{36-2h(4-\theta)}{68+19\theta}$	$\frac{2}{4+\theta}$
p_{i1}	$\frac{104+55\theta-2h(1+\theta)(4-\theta)}{(2+\theta)(68+19\theta)}$	$\frac{3}{4+\theta}$
D_{i1}	$\frac{(1+\theta)(32+19\theta+2h(4-\theta))}{(2+\theta)(68+19\theta)}$	$\frac{1+\theta}{4+\theta}$
I_i	$\frac{(1+\theta)(20+7\theta)(1-h(4+\theta))}{(2+\theta)(68+19\theta)}$	0
w_{i2}	$\frac{24+40h+14h\theta}{68+19\theta}$	$\frac{2}{4+\theta}$
p_{i2}	$\frac{92+43\theta+2h(1+\theta)(20+7\theta)}{(2+\theta)(68+19\theta)}$	$\frac{3}{4+\theta}$
D_{i2}	$\frac{(1+\theta)(44+19\theta-2h(20+7\theta))}{(2+\theta)(68+19\theta)}$	$\frac{1+\theta}{4+\theta}$
Π_i	$\frac{4(1+\theta)(306-34h(4-\theta)+h^2(272+\theta(136+21\theta)))}{(68+19\theta)^2}$	$\frac{4(1+\theta)}{(4+\theta)^2}$
π_i	see Online Appendix	$\frac{2(1+\theta)}{(4+\theta)^2}$

It is worth mentioning that there are other beliefs such as *symmetric beliefs* and *wary beliefs* that are used when studying unobservable contracts in a supply chain (McAfee and Schwartz 1994). These beliefs are less appealing in our model because (1) our model consists of two independent manufacturers, whereas the existing literature focuses on a single upstream manufacturer, and (2) in our model, a deviation in retail price can result from the off-equilibrium behavior by either the manufacturer or the retailer, which is indistinguishable to the rival supply chain. Due to these issues, we adopt passive beliefs for our analysis.

3.1. Equilibrium Characterization

The detailed analysis has been relegated to the online appendix. The equilibrium strategies are described in Table 1. We also compare the results to those in a no inventory (NI) system, where a manufacturer only delivers whatever its downstream retailer can sell.

Strategic inventory. From the results in Table 1, we observe that the firms still hold strategic inventory under supply chain competition. Moreover, we have the following proposition.

PROPOSITION 1. *Under chain-to-chain competition, we have the followings:*

(i) *If and only if* $h < \frac{1}{4+\theta}$, *strategic inventory exists in equilibrium.*

(ii) *When $\theta < \hat{\theta}$, strategic inventory increases in the intensity of competition, otherwise, strategic inventory decreases in the intensity of competition, where $\hat{\theta}$ solves*[2]

$$h = \frac{1552 + 1144\hat{\theta} + 229\hat{\theta}^2}{8928 + 11920\hat{\theta} + 6254\hat{\theta}^2 + 1484\hat{\theta}^3 + 133\hat{\theta}^4}.$$

The rationale for a retailer to hold strategic inventory under chain-to-chain competition remains the same: it induces the upstream manufacturer to reduce the second-period wholesale price, which leaves more room for the retailer's profit margin. In the presence of market competition, it also provides the retailer with more pricing flexibility to compete. Collectively, incorporating supply chain competition does not eliminate strategic inventory. Nevertheless, the retailer will hold strategic inventory only if holding inventory is not too costly.

A similar logic applies to understanding the impact of competition on strategic inventory. When competition becomes fiercer (i.e., θ increases), the second-period demand D_{i2} becomes more sensitive to the selling price p_{i2}. As the selling price is influenced by the wholesale price w_{i2}, the retailer has a stronger incentive to induce a lower wholesale price in order to remain competitive in the market. Mathematically, this arises because

$$\frac{\partial D_{i2}}{\partial w_{i2}} = \frac{\partial D_{i2}}{\partial p_{i2}} \cdot \frac{\partial p_{i2}}{\partial w_{i2}} = -\frac{1}{2}(1+\theta) < 0.$$

Holding strategic inventory turns out to be an effective way to lower the wholesale price and boost the demand, and it is more effective when θ is large. On the other hand, when θ is large, the fierce competition erodes the retailer's second-period margin $p_{i2} - w_{i2}$, and the retailer is less interested in carrying strategic inventories. When θ is low, the former effect dominates, and strategic inventory is increasing in θ; whereas when θ is high, the latter effect dominates, and strategic inventory is decreasing in θ.

3.2. Comparison with NI

Proposition 1 indicates the essence of strategic inventory. However, one question remains unaddressed: Is strategic inventory profitable in competitive markets? To answer this question, we will compare our results with the benchmark in which strategic inventory is absent. We derive the firms' equilibrium profits in the absence of strategic inventory and summarize the equilibrium results in Column NI of Table 1.

Price competition. Does strategic inventory intensify or alleviate the price competition between the two supply chains? To address this issue, we compare the equilibrium prices under SI and under NI. The results are summarized in the following corollary.

[2] Note that for given h, there is a unique $\hat{\theta}$ since the right-hand side of the equation is monotonically decreasing in $\hat{\theta}$. In particular, $h = 0$ implies $\hat{\theta} = \infty$, i.e., strategic inventory always increases in the intensity of competition.

COROLLARY 1. *Compared to the case of NI, we have that in equilibrium,*

(i) *the first-period wholesale and retail prices are higher under SI when $\theta < 4$, and lower otherwise.*

(ii) *the second-period wholesale and retail prices are always lower under SI.*

Corollary 1 illustrates that strategic inventory always intensifies the second-period competition. As both retailers carry strategic inventory, the manufacturers will charge lower wholesale prices in the second period to motivate the retailers to buy. As a result, the second-period retail prices go down and competition becomes fiercer than under NI.

Now consider the effect of strategic inventory on first-period price competition. Here two forces play against each other. On the one hand, as discussed by Anand et al. (2008), the manufacturers have an incentive to raise the first-period wholesale prices to discourage their own retailers from carrying inventories. On the other hand, both manufacturers have a tendency to encourage the retailers to carry inventory to gain a competitive advantage in the second period over the competing chain. Consequently, when θ is small, the first force dominates and the retailers face higher wholesale prices and thus charge higher retail prices, which reduces the intensity of first-period competition. When θ is large, i.e., the competition between the two supply chains is fierce, the second force prevails; as a result, the manufacturers charge lower prices and in turn, the competition is fiercer in both periods than under NI.

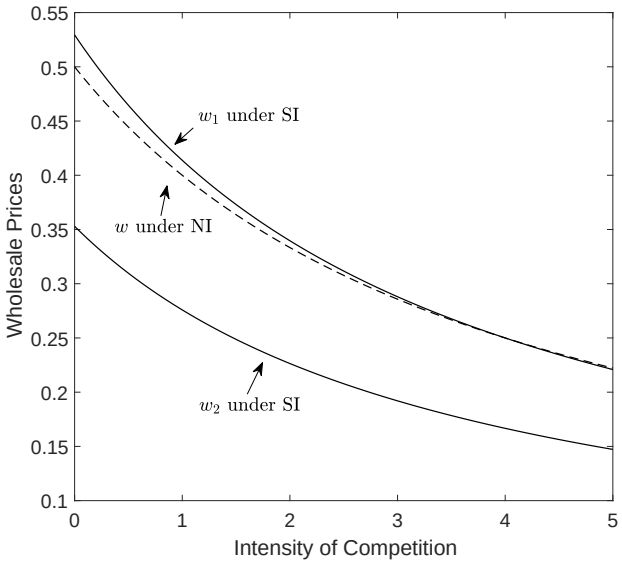


Figure 1 **SI and wholesale prices ($h = 0$)**

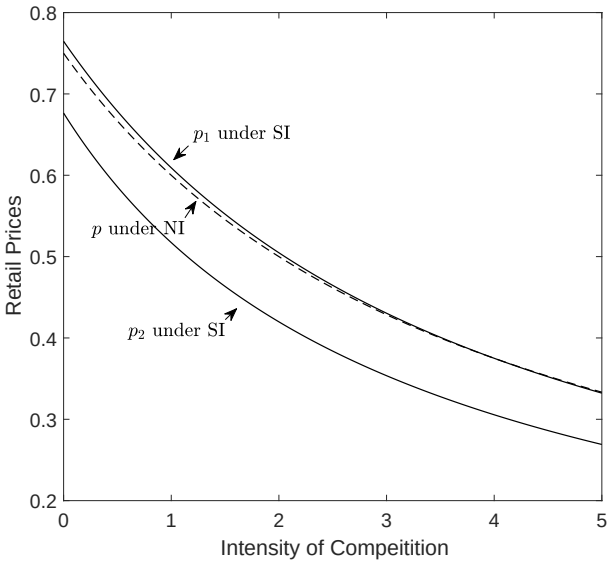


Figure 2 **SI and retail prices ($h = 0$)**

In Figures 1 and 2 we show the effect of strategic inventory on the equilibrium prices. From the figures, we can see that, when θ is small, the first-period prices are higher under SI, thereby

reflecting the softening of competition. However, this effect quickly diminishes as θ increases. When θ is large, competition is fiercer in both periods. It is worth noting that, relative to the NI setting, the first-period wholesale price decreases faster in θ. As θ increases, the competition between the two supply chains becomes fiercer. Each individual supply chain would benefit more from holding strategic inventory on its own side to be competitive in the second period. As such, a manufacturer is more willing to lower his first-period wholesale price (relative to his wholesale price in the NI setting) to encourage his downstream retailer to stock more. As such, the first-period wholesale price in the SI setting decreases faster in θ.

Profit comparisons. Comparing the firms' profits under different strategies yields the following proposition.

PROPOSITION 2. *Suppose that $h < \frac{1}{4}$. Under chain-to-chain competition, there exists $0 \leq \theta_0 < \frac{1}{h} - 4$ such that strategic inventories leave all firms strictly worse off when $\theta_0 < \theta < \frac{1}{h} - 4$. (When $h \geq \frac{1}{4}$ or $\theta \geq \frac{1}{h} - 4$, strategic inventories are not carried in equilibrium.)*

We now consider the case of $h = 0$, which allows us to characterize the conditions more succinctly. We have the following corollary.

COROLLARY 2. *Suppose that $h = 0$, we have the following results.*

(i) *When $\theta \geq 1.308$, strategic inventories always leave the manufacturers worse off;*

(ii) *When $\theta \geq 2.021$, strategic inventories always leave the retailers worse off;*

(iii) *When $\theta \geq 1.505$, strategic inventories always leave the supply chain profits worse off.*

Proposition 2 indicates that, unlike the monopoly case ($\theta = 0$), in a competitive market strategic inventory may reduce both the retailers' and the manufacturers' profits. To visualize this, in Figures 3 and 4 we supplement Proposition 2 by plotting the manufacturers' and the retailers' profits under the SI and NI setting (setting $h = 0$). When $\theta = 0$, the model degenerates to the familiar Anand et al. (2008) model of monopoly markets, where strategic inventory leads to 5.9% and 7.3% profit improvement for the manufacturer and the retailer, respectively. However, when θ is large, strategic inventory leads to substantial *profit losses*. For example, when $\theta \to \infty$, the two products are perfect substitutes and strategic inventory can lead to 15.2% and 11.6% profit losses for the manufacturers and the retailers, respectively.[3] Clearly, the profit advantage of strategic inventory hinges on the intensity of the competition.

[3] When $\theta \to \infty$, all firms make zero profits with or without strategic inventory, but the relative profit improvement is still positive.

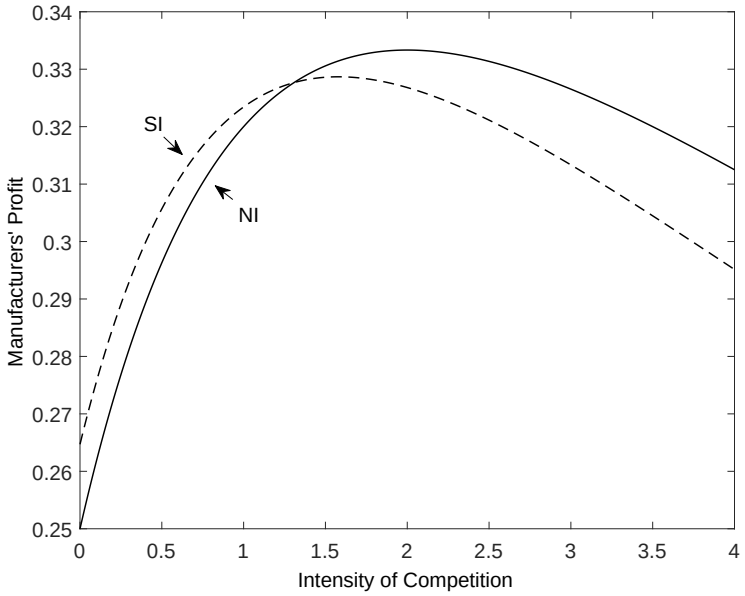


Figure 3 The benefit of strategic inventory to the manufacturers ($h = 0$)

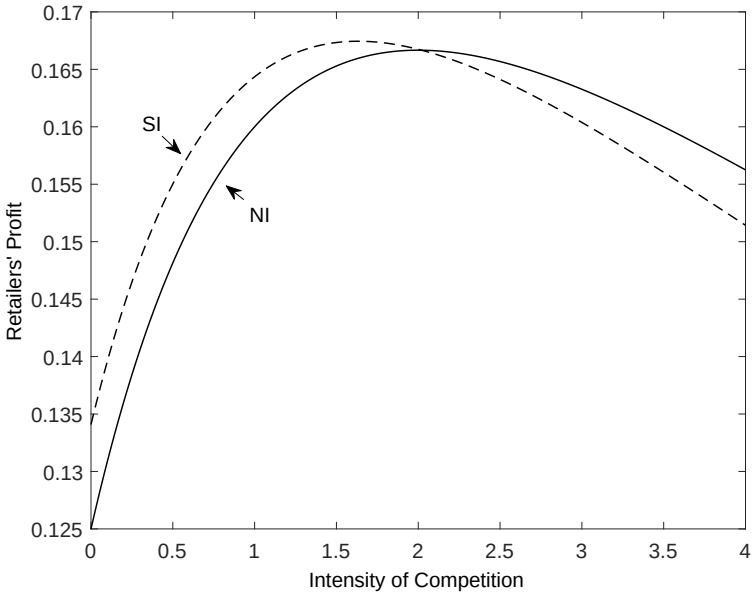


Figure 4 The benefit of strategic inventory to the retailers ($h = 0$)

Why does fierce competition reduce the profitability of strategic inventory? To answer this question, note first that in the absence of competition, strategic inventory has the sole effect of alleviating double marginalization. This *double marginalization alleviation effect* is unambiguously positive. The presence of competition brings a second effect to strategic inventory: it reduces (intensifies) the first-period chain-to-chain competition when θ is small (large), and also inten-

sifies second-period chain-to-chain competition, as shown in Figures 1 and 2. Competition is so fierce in the second-period that strategic inventory has an overall *competition intensification effect*[4]. This competition intensification effect backfires on both the retailers' and manufacturers' profits.

Therefore, when competition is weak, the double marginalization alleviation effect dominates, and overall strategic inventory improves the profits of both manufacturers and retailers. As θ grows, the competition intensification effect starts to take over and eventually dominates the double marginalization alleviation effect. Therefore, strategic inventory can either benefit or hurt firms, depending on the magnitudes of these two effects. In a similar vein, the effect of strategic inventory on total channel profit hinges on the intensity of competition between the two chains.

While the previous literature has suggested that strategic inventory alleviates the issue of double marginalization, and that firm profits decrease with market competition, our results find an interaction between these two effects, namely, strategic inventory intensifies market competition and leaves the firms worse off when competition is fierce enough. Such an interaction effect is new and has not been covered in the literature.

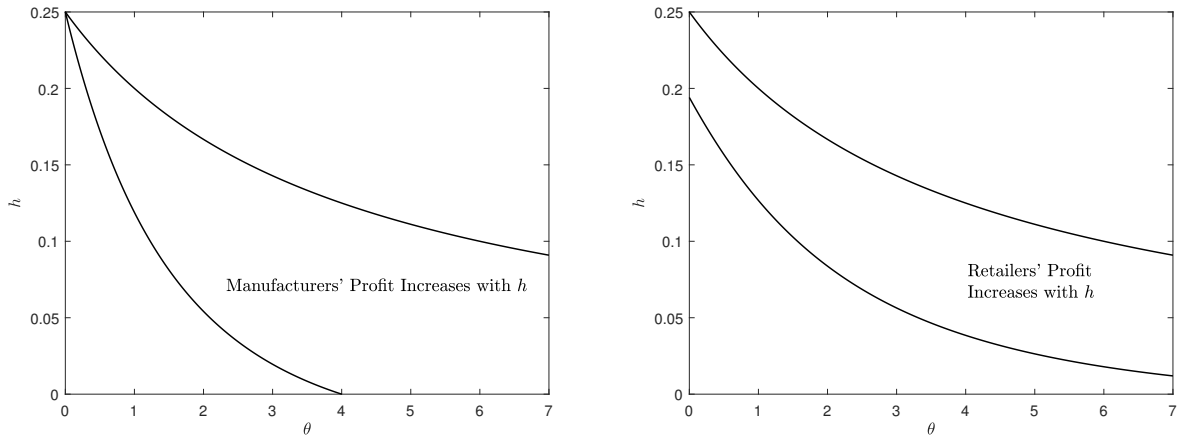
It is noteworthy that although both the manufacturers and the retailers prefer SI (NI) to NI (SI) when competition is low (high), their interests toward strategic inventory are not perfectly aligned. For example, when $h = 0$, the manufacturers (retailers) are worse off (better off) with strategic inventories when $1.308 \leq \theta \leq 2.021$. This is because the benefit of double marginalization alleviation is not created equal for the supply chain members — the retailers benefit more from the double marginalization alleviation effect. Moreover, when $h > 0$, the cost of carrying strategic inventory is borne by the retailers alone, which makes SI less profitable for the retailers.

Welfare implication. Finally, in regard to social welfare, we have the following corollary.

COROLLARY 3. (i) *When $\theta < 1.512$, strategic inventory always improves social welfare.* (ii) *When $\theta > 1.512$, strategic inventory improves social welfare when h is small enough.*

The intuition for Corollary 3 is as follows. Strategic inventory has two effects on social welfare. First, strategic inventory alleviates double marginalization and improves supply chain efficiency. This effect benefits social welfare because prices are lower and demand is higher. Second, strategic inventory brings about a dynamic inefficiency into the system as inventory holding cost is incurred. This effect hurts social welfare. When competition is less fierce or inventory holding cost is not too high, the former effect dominates the latter and social welfare is higher. When competition is fierce and inventory holding cost is high, however, there is substantial cost incurred in carrying strategic inventory. As a result, the latter effect dominates and social welfare is worse off.

[4] That is, the second-period prices are much lower under SI. The first-period prices are only slightly higher under SI when θ is small.



(a) Manufacturers' Profit

(b) Retailers' Profit

Figure 5 The effect of h on the firms' profit

3.3. Inventory Holding Cost

Anand et al. (2008) show that in a monopoly supply chain, the manufacturer's profit is always decreasing in the inventory holding cost h. The rationale is that a higher inventory holding cost reduces the strategic inventory and the benefit of double marginalization alleviation. Does the same result hold under supply chain competition? We analyze the effect of an increase in h on the manufacturers' and the retailers' profits, and summarize the results in the following proposition.

PROPOSITION 3. (i) *In equilibrium, the manufacturers' profit is strictly increasing in h when*

$$\frac{17(4-\theta)}{272+136\theta+21\theta^2} \leq h \leq \frac{1}{4+\theta}.$$

(ii) *In equilibrium, the retailers' profit is strictly increasing in h when*

$$\frac{1888+1424\theta+242\theta^2-35\theta^3}{9728+11456\theta+5344\theta^2+1148\theta^3+98\theta^4} \leq h \leq \frac{1}{4+\theta}.$$

Proposition 3 suggests that, in contrast to the monopoly case, under supply chain competition both the manufacturers' and the retailers' profits can increase in h. The rationale is the following. When h is high, an increase in h reduces strategic inventory, which consequentially alleviates the competition between the two chains. Moreover, increasing h can also save the costs associated with carrying strategic inventories (i.e., $I_i \cdot h$ decreases in h when h is high). As a result, both the manufacturers and the retailers may benefit from a higher inventory holding cost. The regions that the firms' profits increase with h are illustrated in Figure 5.

It is worth mentioning that we assume that supply chain i observes h_j, the inventory holding cost of supply chain j. This assumption is reasonable when the two retailers use similar facilities and technologies to store the products. Nonetheless, it may be possible that supply chain i does not observe h_j, and vice versa. While we are not able to solve a model with unobserved inventory holding cost, we expect our insights to continue to hold: Under supply chain competition, the role of strategic inventory is two-fold. On the upside, it improves the internal coordination within a supply chain. On the downside, it intensifies the competition between the two supply chains. When the competition is fierce enough, the latter effect can dominate the former effect and leave competing firms worse off.

4. Endogenizing the Choice between SI and NI

So far, in our model both retailers are left to decide whether to carry inventory from period to period. However, as we have seen, when the competition is fierce, strategic inventory backfires and hurts all of the firms. Therefore, the firms may have incentives to disallow strategic inventory in their supply chains.

To prevent retailers from holding strategic inventory, manufacturers may adopt a vendor-managed inventory (VMI) system. As Anand et al. (2008) point out, under VMI, the manufacturers manage the retailer's inventories and it virtually eliminates strategic inventories in vertical contracts. Notably, VMI is a long-term decision and requires a sizeable investment and commitment. Therefore, once made, such an arrangement often becomes known to the firms of the rival supply chain. In e-commerce, drop shipping remains a common arrangement between the manufacturer and retailer (Lofgren 2020). With drop shipping, the retailer simply forwards customer orders to the manufacturer, who delivers the orders directly to customers and is paid a predetermined price by the retailer (Khouja 2001). Because the retailer does not handle the products physically, drop shipping eliminates strategic inventory as well. Notably, the choice of drop shipping is a long-term decision and can also be easily observed by other firms. Based on the discussion above, the manufacturers can credibly commit to eliminating strategic inventories in the first place.

In this section, we consider whether the manufacturers will choose to *eliminate* strategic inventory. For the ease of exposition, we will use the term NI to refer to the elimination of inventories and we will use the term strategic inventory (SI) to refer to the use of strategic inventory. As we have seen, manufacturers benefit from strategic inventory when competition is less fierce and may be hurt otherwise. Would a manufacturer then choose to commit to NI when a pure NI system is more beneficial?

To answer this question, we cannot directly compare the two systems (SI vs NI) because we must allow each manufacturer to determine whether he should adopt NI or SI. In the game-theoretic setting, we add a stage zero to the basic model in which the manufacturers simultaneously choose between NI and SI. If a manufacturer chooses NI, then his downstream retailer will carry zero strategic inventory in the subsequent stages. Alternatively, if he chooses SI, then his downstream retailer is free to carry any amount of strategic inventory. We assume that, as discussed earlier, once made, the manufacturers' choices become public knowledge in the market. Moreover, to focus on strategic incentives, we assume that there is no cost difference between SI and NI strategies.

We solve the model when the two supply chains adopt asymmetric inventory strategies and summarize the results in Table 2 of the Online Appendix. The case in which both supply chain adopt SI or NI is presented in Table 1. When the inventory holding cost $h = 0$, we have the following proposition.

PROPOSITION 4. *Suppose that $h = 0$. When the manufacturers can choose between NI and SI, the following equilibria are identified.*

(i) *When $\theta \leq 6.867$, there is a pure-strategy equilibrium where both manufacturers choose SI.*

(ii) *When $\theta \geq 6.650$, there is a pure-strategy equilibrium where both manufacturers choose NI.*

We have previously shown that for $\theta \geq 1.308$ a pure NI system dominates a pure strategic inventory system. However, from Proposition 4, for $\theta \leq 6.650$ a manufacturer can make greater profits through strategic inventory so long as his rival chooses an NI operation. Thus, for $\theta \leq 6.650$ the pure NI system is not an equilibrium. The problem of choosing between NI and strategic inventory operations when $1.308 \leq \theta \leq 6.650$ is a classical *prisoner's dilemma* game. This suggests that when the competition is at the intermediate level, it is very difficult for either party to escape from this unfortunate outcome. In essence, the fact that strategic inventory is prevalent does not mean that it benefits everyone. It could be an undesirable situation that firms cannot help falling into.

For a relatively high intensity of competition ($6.650 \leq \theta \leq 6.867$), both the pure NI system and the pure strategic inventory system can be sustained as equilibrium strategies, and the former is a preferred equilibrium (by both the manufacturers and the retailers) in that it Pareto dominates the latter. This dominant equilibrium is appealing and, therefore, is a natural equilibrium to select. In Figure 6, we plot their equilibrium profits. We can see that there is a discontinuity in the manufacturers' profit at $\theta = 6.650$, where they switch from (SI, SI) to (NI, NI). This regime switch showcases the manufacturers' strategic concerns about the retailers' inventory carryover.

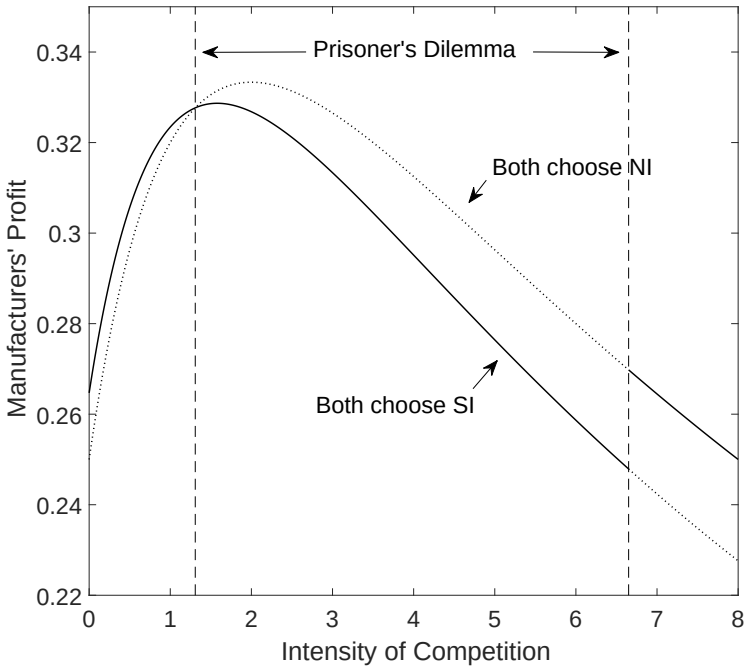


Figure 6 **Manufacturers' profits when they freely choose between NI and SI. Solid lines denote the equilibrium profits.**

Interestingly, Figure 6 also shows that manufacturers may benefit from an increase in the intensity of competition. This phenomenon occurs around the regime switch; that is, when θ is slightly below the threshold 6.650.[5] As competition becomes fiercer, the manufacturers are induced to choose NI instead of SI. This eliminates the retailers' flexibility (of using strategic inventory) and may substantially alleviate the downside of enhanced competition intensity. Consequently, the manufacturers can benefit.

Finally, we conducted numerical analysis for positive h and find out that the prisoner's dilemma also appears. This result is illustrated in Figure 7. In the area "prisoner's dilemma", the manufacturers are better off when they both choose NI, yet they cannot help choosing SI in equilibrium.

5. Extensions

In this section we examine two extensions of the basic model. First, we consider a case where the contracts within a chain are observable to the other chain. We then consider the scenario where the retailers compete on quantity instead of on price.

[5] The manufacturers' profit also increases in θ when $\theta < 1.579$. Within this regime, competition alleviates double marginalization and improves the manufacturers' profit.

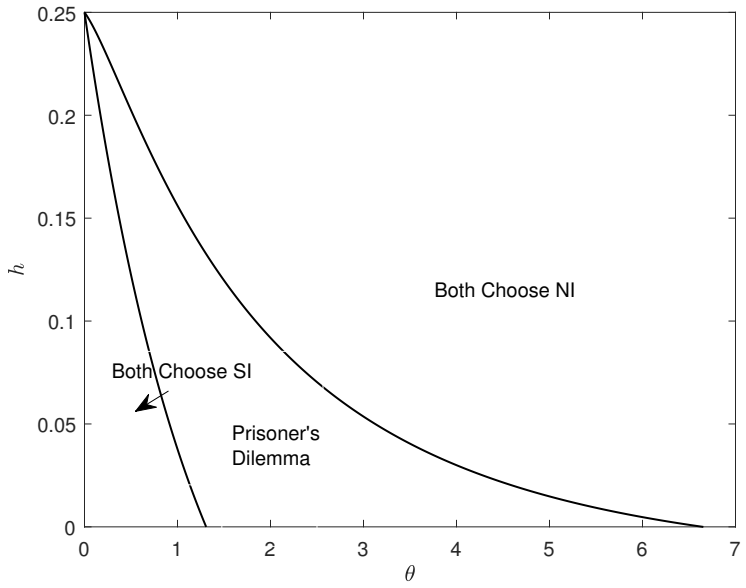


Figure 7 **Prisoner's dilemma and inventory holding cost.**

5.1. Observable Contracts

So far, our model assumes that the contract terms and transactions of a supply chain are not observed by firms in the other supply chain. Although unobserved contracts are more realistic, in certain cases this information may be observed.

Motivation for cross-chain observability. For example, the warehouse of a retailer may be monitored, observed, or spied on by her rivals. On certain online platforms, the retailers are required to disclose their inventory levels and, hence, inventory levels become public information. In addition, policy discussions in the European Union and the United States have led to legislation to mandate intermediaries to disclose their private information (see Inderst and Ottaviani 2012 and Janssen and Shelegia 2015). There is also a large body of literature, including both analytical and empirical studies, that implicitly assumes that supply chain contracts are public information in the market (McGuire and Staelin 1983, Tsay and Agrawal 2000, Corbett and Karmarkar 2001, Carr and Karmarkar 2005, Villas-Boas 2007).

This motivates us to consider the *observed* case in this section. We revisit the basic model by assuming that all of the contracts are public information in the market. As the game features perfect information, we simply use backward induction to find out the subgame perfect equilibrium. To obtain tractable results, we assume that $h = 0$, which corresponds to the case where the inventory holding cost is negligible.[6] The following proposition says that strategic inventory still exists

[6] Numerical studies suggest that all our results go through under a small inventory holding cost.

in the observable case.

PROPOSITION 5. *In the observable case, strategic inventory exists in equilibrium. Moreover, compared to the unobserved case, in the observed case:*

(i) *The retailers stock less inventory;*

(ii) *Both the manufacturers and the retailers make higher profits.*

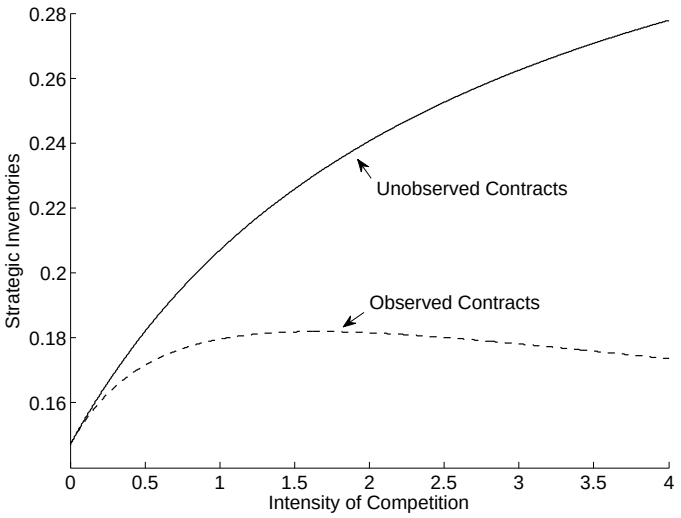


Figure 8 Strategic inventory in the observed and unobserved case

We again use a figure to visualize the findings on the effect of inventory observability. In Figure 8 we compare the equilibrium inventory levels in the observed case with the unobserved case. Proposition 5 suggests that strategic inventory again arises when the contract terms are observed by rival firms. The rationale is similar: strategic inventory facilitates the internal coordination of a supply chain. Interestingly, the retailers stock less inventory when the contract terms are observable. This result arises because in the observed case, when retailer i stocks more inventory (i.e., $\hat{I}_i$ increases, where we use hat to represent the observed case), the rival manufacturer j, facing a competitive disadvantage, will respond by undercutting its second-period price $\hat{w}_{j2}$, which intensifies supply chain competition, i.e., $\frac{\partial \hat{w}_{j2}}{\partial \hat{I}_i} < 0$. In anticipation of this, retailer i stocks less inventory in the observed case to avoid such "retaliation" from the rival chain.[7] As both retailers carry less inventory, the supply chain competition becomes less fierce, resulting in higher profits.

Do the firms benefit from strategic inventory? Again, we compare the firms' profits to the NI case, and summarize the results in the following proposition.

[7] In contrast, in the unobserved case, we have $\frac{\partial w_{j2}}{\partial I_i} = 0$ because I_i is not observed by manufacturer j.

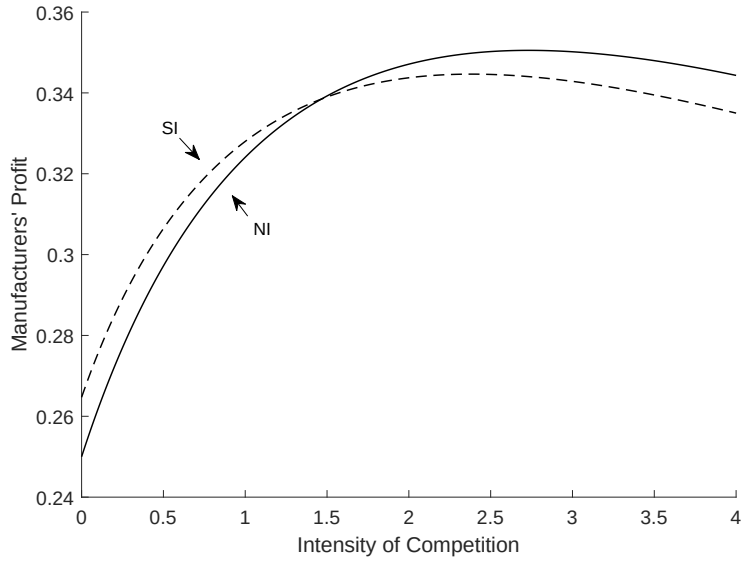


Figure 9 The benefit of strategic inventory to the manufacturers (observed case)

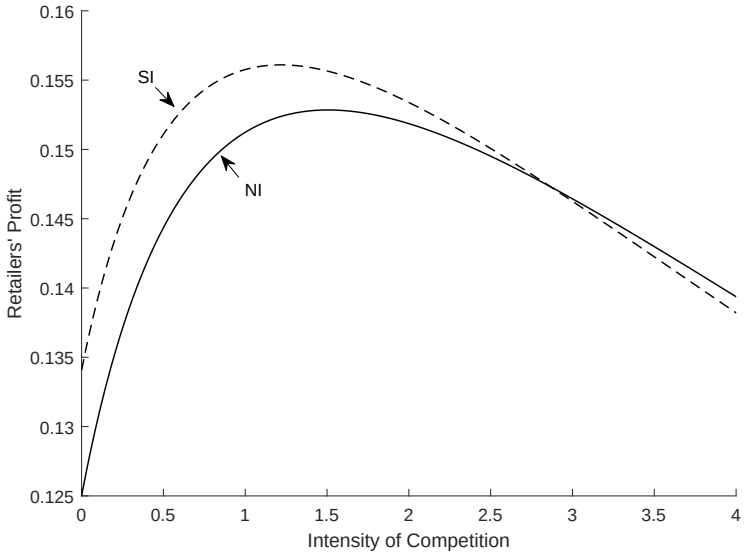


Figure 10 The benefit of strategic inventory to the retailers (observed case)

PROPOSITION 6. *Under chain-to-chain competition, when the contracts are observable, we have:*

(i) *The manufacturers benefit from strategic inventory if and only if* $\theta \leq 1.466$*;*

(ii) *The retailers benefit from strategic inventory if and only if* $\theta \leq 2.865$*;*

(iii) *The total supply chains benefit from strategic inventory if and only if* $\theta \leq 1.773$*.*

Proposition 6 replicates the main finding of the basic model that, under supply chain competition, both the manufacturers and retailers are worse off with strategic inventory when the

competition between the supply chains is fierce enough. The results are illustrated in Figures 9 and 10. Again, these results arise because, as competition becomes fiercer, the double marginalization alleviation effect of strategic inventory is dominated and overshadowed by the effect of competition intensification, which finally backfires on the firms' profits.

5.2. Quantity Competition

The basic model assumes that the two supply chains compete on price. In certain cases, the supply chains can also compete on quantity. In this subsection, we consider the case in which the supply chains compete on quantity.

To model quantity competition, we assume that the inverse demand function takes the following specification, which is commonly assumed in the literature:

$$p_{it} = 1 - Q_{it} - \gamma Q_{jt}, \tag{2}$$

where $0 \leq \gamma \leq 1$ reflects the extent of competition between the two supply chains. When $\gamma \to 0$, the demands for the two products are unrelated and there is no competition between the two products, whereas when $\gamma \to 1$, the two products are perfect substitutes. We maintain the setup of the basic model except that the retailer i now chooses the quantity to offer to the market in period t, Q_{it} (as opposed to the price p_{it} studied in the basic model).

We relegate the analysis to the appendix and present the result in Table 2. From Table 2, we can see that strategic inventory arises under quantity competition. In the basic model, we find that under price competition, strategic inventory always leaves firms worse off when the competition is fierce enough (see Proposition 2). Does the same results hold under quantity competition? The following proposition summarizes the result.

PROPOSITION 7. *Consider the case of quantity competition. When h is small, i.e., $h \leq 0.0378$, no matter how fierce the competition is, strategic inventories always leave both the manufacturers and the retailers better off.*

Note that Proposition 7 says that no matter how fierce the competition is, the firms are better off with SI when $h \leq 0.0378$. The threshold for the firms to benefit from SI is higher when competition is less fierce. For example, when $\gamma = 0.5$, both firms are better off with SI as long as $h \leq 0.0913$.[8]

Proposition 7 is in stark contrast to Proposition 2, which says that for all h, strategic inventories leave both the manufacturers and the retailers worse off when the competition is fierce enough.

[8] Similar results also hold when contracts are observable. We can show that under quantity competition, when contracts are unobservable, both firms are better off with SI as long as $h \leq 0.2042$.

Table 2 Equilibrium strategies for quantity competition

	SI ($h \leq \frac{1}{4+\gamma}$)	SI ($h > \frac{1}{4+\gamma}$) or NI
w_{i1}	$\frac{36-2h(4-\gamma)}{68+19\gamma}$	$\frac{2}{4+\gamma}$
Q_{i1}	$\frac{32+19\gamma-2h(4-\gamma)}{(2+\gamma)(68+19\gamma)}$	$\frac{1}{4+\gamma}$
p_{i1}	$\frac{104+55\theta-2h(4-\gamma)(1+\gamma)}{(2+\gamma)(68+19\gamma)}$	$\frac{3}{4+\gamma}$
I_i	$\frac{(1-h(4+\gamma))(20+7\gamma)}{(2+\gamma)(68+19\gamma)}$	0
w_{i2}	$\frac{24+40h+14h\gamma}{68+19\gamma}$	$\frac{2}{4+\gamma}$
Q_{i2}	$\frac{44+19\gamma-2h(20+7\gamma)}{(2+\gamma)(68+19\gamma)}$	$\frac{1}{4+\gamma}$
p_{i2}	$\frac{92+43\gamma+2h(1+\gamma)(20+7\gamma)}{(2+\gamma)(68+19\gamma)}$	$\frac{3}{4+\gamma}$
Π_i	$\frac{4(306-34h(4-\gamma)+h^2(272+136\gamma+21\gamma^2))}{(68+19\gamma)^2}$	$\frac{4}{(4+\gamma)^2}$
π_i	see Online Appendix	$\frac{2}{(4+\gamma)^2}$

Notably, in both observed and unobserved cases, the role of strategic inventory is two-fold. First, it has a double marginalization alleviation effect, which benefits the firms. Second, it has a competition intensification effect, which hurts the firms. However, as well established in the literature, competition is less fierce under quantity competition than under price competition (Singh and Vives 1984), which means that the competition intensification effect is less salient under quantity competition. As such, under quantity competition, the double marginalization alleviation effect always dominates the competition intensification effect, and therefore, the firms are always better off under SI.

It is worth noting that the above results only hold in the case of two competing chains. When there are three or more supply chains that compete on quantity, strategic inventory can make the manufacturers and the retailers worse off. For example, consider the case with four competing supply chains, with $h = 0$ and $\gamma = 1$. Straightforward analysis shows that strategic inventory leads to a 4.03% profit loss to the manufacturers and a 1.77% profit loss to the retailers. This is in line with our previous analysis: As the number of supply chains increases, the competition between the supply chains becomes fiercer. Accordingly, strategic inventory plays a more important role in intensifying market competition, which overshadows its effect in alleviating double marginalization. As a result, the firms can get hurt by strategic inventories.

Next, we examine how the firms' profits change with h. The following proposition summarizes the result.

PROPOSITION 8. *Consider the case of quantity competition.*

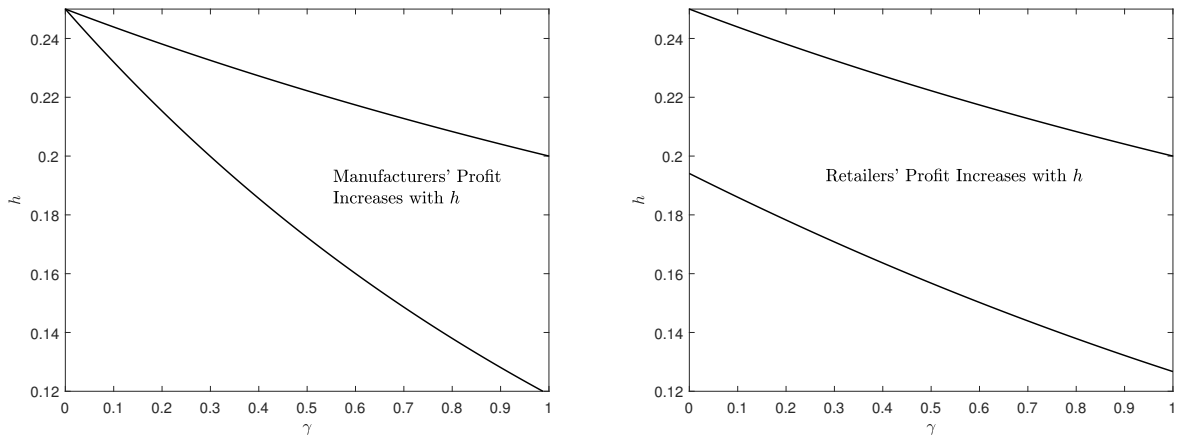
(i) *In equilibrium, the manufacturers' profit is strictly increasing in h when*

$$\frac{17(4-\gamma)}{272+136\gamma+21\gamma^2} \leq h \leq \frac{1}{4+\gamma}.$$

(ii) *In equilibrium, the retailers' profit is strictly increasing in h when*

$$\frac{1888+1424\gamma+242\gamma^2-35\gamma^3}{9728+11456\gamma+5344\gamma^2+1148\gamma^3+98\theta^4} \leq h \leq \frac{1}{4+\gamma}.$$

Proposition 8 replicates Proposition 3, suggesting that under quantity competition, a higher inventory holding cost can leave both the manufacturers and retailers better off. Again, this finding occurs because as h increases, less strategic inventory will be carried by the retailers, which can reduce the competition between the supply chains, working to the benefits of all firms. This result is illustrated in Figure 11.



(a) Manufacturers' Profit

(b) Retailers' Profit

Figure 11 The effect of h on the firms' profit under quantity competition

6. Concluding Remarks

This paper analyzes the role of strategic inventory in competitive markets. We have found that in addition to the double marginalization alleviation effect, strategic inventory also has a competition intensification effect. By and large, the retailers not only consider strategic inventory to

be a tool to secure lower wholesale prices, but also as a way to commit to a competitive pricing strategy. We relate the relative strength of these two effects to the extent of the competition. We find that when supply chain competition is fierce, strategic inventory intensifies the competition and hurts all of the firms. Importantly, this implies that manufacturers can strictly prefer to not carrying strategic inventories. This is in stark contrast to the existing literature, including Anand et al. (2008), Desai et al. (2010), Arya and Mittendorf (2013), and Roy et al. (2019).

We further allow manufacturers to commit to the elimination of strategic inventory. Essentially both the manufacturers and the retailers prefer to have strategic inventory in the supply chains when the competition is less fierce and prefer NI otherwise. However, for the firms, a sort of prisoner's dilemma can take place: they commit to strategic inventory due to competition, even though an NI system is more profitable to all of the firms. Finally, we extend our analysis to the cases of observable contracts and quantity competition and show that all our insights in the basic model continue to hold.

Our results underline the importance of supply chain competition on the effects of strategic inventory. However, our model can be extended in a number of directions. In our model, there is no demand uncertainty and inventory only plays a strategic role. One may consider the role of strategic inventory in the competitive market in the presence of demand uncertainty. Although the main implications from this study are expected to hold in the presence of demand uncertainty, it would be of interest to explore whether additional insights may arise. In addition, in our model, the observability of vertical contracts is exogenously given. One may endogenize the process and examine the incentives for a supply chain to disclose its contract terms in a credible way.

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