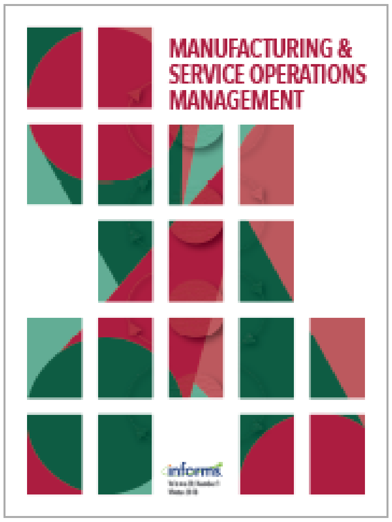

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Managing Competition from Within and Outside: Using Strategic Inventory and Network Externality to Combat Copycats

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Abstract. ***Problem definition*:** Prior studies have identified the role of downstream retailers' strategic inventory in mitigating double marginalization within decentralized supply chains. Our work adds to this literature by introducing two relevant features that naturally appear in a dynamic environment: *network externality* and *copycatting*. We demonstrate how strategic inventory and network externality can be used to manage competition from within and outside the supply chain. ***Methodology/results*:** We develop a game-theoretical model to capture the strategic interaction within a brand-name supply chain, which enjoys positive externalities from early-period sales but faces competition from copycats in later periods. We show that copycats, on the one hand, deter the retailer's strategic inventory by exerting external competition and on the other hand, can amplify the benefit of the retailer's strategic inventory in allaying internal double marginalization and enhancing the supply chain's external competitiveness. We further show that network externality, on the one hand, brings immediate gains to the supply chain's external battle with copycats and on the other hand, creates internal inefficiency in the form of cross-period double marginalization best exhibited under the supplier's *dynamic* contract. When network externality and strategic inventory are optimized jointly, we find that they are always complementary in increasing the supplier's payoff but can be substitutive to the retailer under a large inventory cost and weak network externality. ***Managerial implications*:** Our work provides firms ways of managing decentralized supply chains in the face of copycats. We propose strategic inventory and network externality to combat copycats and provide normative guidance on their operating mechanisms.

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Keywords: strategic inventory • network externality • copycats • supply chain • competition

1. Introduction

Anand et al. (2008) first introduced the notion of *strategic inventory* in decentralized supply chains. Using a two-period model with an upstream supplier (he) and a downstream retailer (she), Anand et al. (2008) studies two contractual formats of the supplier: a *commitment contract* that specifies the wholesale prices of both periods up front and a *dynamic contract* that allows the supplier to announce the wholesale price of each period at the beginning of that period. Anand et al. (2008) shows that under the dynamic contract, the retailer may deliberately hold inventory, even though there is no uncertainty on both the demand and supply sides. Such inventory is deemed strategic because it can effectively limit the supplier's prices in the later period, thereby alleviating double marginalization and creating potentially win-win outcomes for both supply chain players. In contrast, strategic inventory vanishes under the supplier's commitment contract. These observations enrich the conventional wisdom about inventory, and their implications can be applied to various industries, such as automobile dealerships, publishers, and video game console producers, as long as the supply chains concerned are decentralized and operate in a dynamic environment.

Awaiting the decentralized supply chains in the later period are, however, not only the profit battle from within but also, the threat from external *copycats*. As noticed in Pun and DeYong (2017), "Combining low prices with a streamlined business model, these firms wait for trends to develop and then move quickly to cash in on popular items. In this arena, Zara and Forever 21 are two of the most-often cited offenders of traditional sensitivities." Likewise, in the digital world, the great success of Nintendo Switch has prompted competitors, such as PSP and Mbox, to follow its creative path and compete in the same space. Raspberry Pi, the dominant player in the microcomputer industry, has led the trend and influenced its various competitors, such as Banana Pi, in their designs and productions.

This motivates us to examine the pricing and inventory incentives of a brand-name supply chain in anticipation of the entry of copycats in the later stage of its sales. Further, as motivated by the practice of the digital sector, we consider a *network externality* exclusive to the brand-name product. For instance, Nintendo Switch allows friends to connect under the multiuser mode. Raspberry Pi offers apps exclusively released on its platform, and there is positive feedback between the variety of these apps and their user size. In both cases, the network externality is *exclusive*; the multiuser mode only works for Nintendo users, and apps developed for Raspberry Pi may not be compatible with other non-Raspberry Pi operating systems. We thus focus on modeling an exclusive "installed-base" network externality (Katz and Shapiro 1992, Mitchell and Skrzypacz 2006, Chen et al. 2009).[1] It creates an additional utility for those who purchase the brand-name product in the later period.

Our analysis illustrates how decentralized supply chains can use strategic inventory and network externality, either separately or jointly, to combat copycats by managing intertwined internal and external competition. We start by analyzing a model that leverages the retailer's strategic inventory exclusively to combat copycats. Similar to Anand et al. (2008), we find that strategic inventory only exists under the supplier's dynamic contract. Moreover, we find that copycats deter the retailer's strategic inventory, and with highly competitive copycats, the retailer fully abandons strategic inventory, even though inventory holding is costless. We further show that the retailer's strategic inventory can alleviate double marginalization and that such effect not only persists in the presence of copycats but can materialize for a wider range of holding costs with moderately competitive copycats. This improves the internal efficiency and enhances the supply chain's external competitiveness relative to copycats. As a result, with moderately competitive copycats, both the supplier and retailer can become better off from strategic inventory regardless of the retailer's holding cost. In other words, although competition from copycats can deter the retailer from carrying strategic inventory, the same competition may also strengthen the effect of strategic inventory (provided that it exists) in mitigating internal competition while competing with copycats externally.

With network externality, the pricing incentives of the brand-name supply chain can drastically change. Although network externality brings immediate gains to the supply chain's external competition with copycats and encourages both supply chain players to seed "installed" customers, such incentives are partially distorted because of decentralization; if the retailer sets a low price to stimulate early sales, the supplier will exploit this opportunity and charge a high price in the later period. This in return reduces the retailer's incentive to create high sales in the first place. In other words, double marginalization occurs not only within each period as a result of the usual internal competition but also, across periods in ways of utilizing network externality. Nonetheless, network externality has some favorable implications too. By incentivizing the supplier to cut his early price, network externality cultivates the retailer's strategic inventory, and the elevated strategic inventory can partially alleviate the inefficiency because of cross-period double marginalization. This creates two opposing forces at play and makes the overall effect of network externality mixed.

An integral analysis of strategic inventory, network externality, and copycats highlights an intricate interplay between these key features best exhibited in the brand-name supply chain's contractual preferences. Anand et al. (2008) shows that in a model without network externality or copycats, the supplier always prefers a dynamic contract whenever the retailer holds strategic inventory. This has been a fixture in subsequent studies (e.g., Guan et al. 2019, Roy et al. 2019) but can be possibly overturned in the presence of network externality. Specifically, the amount of strategic inventory the retailer can afford is limited by her inventory cost. In our setting, the holding cost must be sufficiently small to enable a considerable amount of strategic inventory that is strong enough to outweigh the inefficiency of the dynamic contract in the form of cross-period double marginalization. The retailer's contractual preference is more elusive and depends intimately on the quality of copycats, the strength of network externality, and her holding cost. When strategic inventory and network externality are managed jointly, we find that they are always complementary in increasing the supplier's payoff but can be substitutive to the retailer under a large holding cost and weak network externality.

We extend our model to consider an *inclusive* network externality shared by both the brand-name and copycat products and *long-lived* customers who strategically decide the optimal timing of their purchases. Most insights in our main model with exclusive network externality and short-lived customers qualitatively extend, and we also uncover new mechanisms in each extension too. For example, with inclusive network externality, the retailer's strategic inventory has a slightly different pattern, and the dominance of the supplier's commitment contract is undermined by highly competitive copycats. With long-lived customers, the retailer has lower incentives of carrying strategic inventory but can still benefit from the supplier's dynamic contract even if she carries no strategic inventory.

1.1. Literature Review

Our paper contributes to the growing literature on strategic inventory in decentralized supply chains. Anand et al. (2008) first uncovers the role of the retailer's strategic inventory in mitigating double marginalization. Desai et al. (2010) confirms this idea by studying a forward-buying retailer, and Hartwig et al. (2015) presents empirical evidence to validate this idea. Strategic inventory is also known to hurt the supply chain profits when the retailer's holding cost is relatively large, and the literature has proposed various remedies to curb the retailer's strategic inventory (e.g., Arya and Mittendorf 2013, Arya et al. 2014). More recently, Roy et al. (2019) studies the effect of making the retailer's inventory invisible to the supplier and shows that this can lead to increased strategic inventory when the retailer's holding cost is relatively large. Guan et al. (2019) studies the effect of the retailer's strategic inventory on the supplier's channel decisions. Our paper contributes to this literature by introducing two relevant features that naturally appear in a dynamic environment, network externality and copycatting, and demonstrating their contrasting implications for the retailer's strategic inventory. Although it is widely acknowledged that the supplier's dynamic contract can improve the internal supply chain efficiency by generating strategic inventory, we show that such strength can be possibly overturned as a joint outcome of network externality and copycats.

Our paper also relates to the literature on copycats and more broadly, generic products following brand-name innovations (e.g., Frank and Salkever 1997, Brekke et al. 2013). This literature classifies copycats into two categories: deceptive ones and nondeceptive ones. With deceptive copycats, customers cannot distinguish between authentic and fake products before consumption (e.g., Qian et al. 2015, Gao 2018, Choi 2019). Our work falls into the second category of nondeceptive copycats, which have an identifiably inferior nature. With nondeceptive copycats, Cho et al. (2015) studies how to combat copycats that sell their faked products through an illicit distributor. Gao et al. (2017) studies the entry of nondeceptive copycats into luxury product markets. Yi et al. (2022) proposes anti-counterfeiting actions to combat copycats and examines who is in the best position within a brand-name supply chain to carry out such actions. Wu et al. (2021) studies the impact of copycats on the brand-name supply chain's distribution strategies. Our work is closely related to Pun and DeYong (2017), which studies a monopoly producer that faces competition from copycats in a dynamic setting. This is precisely a setting where strategic inventory and network externality can play critical roles, and we articulate these roles in this paper.

The third stream of literature on network externality (or termed network effects in some references) dates back to Katz and Shapiro (1992), which first describes this phenomenon as "each buyer receives greater benefits, the larger is the total number of buyers using compatible products, i.e. the larger is the installed base of the selected technology." Network externality has drawn a growing interest in the operations community. Candogan et al. (2012) studies a monopoly firm's optimal pricing when customers exhibit local network effects. Hu et al. (2015) examines the effect of network externality on a monopolist's marketing strategies under demand uncertainty. Wang and Wang (2017) characterizes firms' assortment decisions under a discrete choice model with network effects. Hu et al. (2020) studies firms' information disclosure strategies for network goods. Chen and Chen (2021) discusses the implications of network effects in a competitive setting. Notably, all these studies either consider a static model or rule out the retailer's inventory holding across periods, thus lacking an analysis of strategic inventory that is crucial in our paper.

2. Model

We consider a two-period model wherein a brand-name supply chain sells its products in both periods and there is potential entry of copycats in the second period.[2] The late entry of copycats is reflective of the fact that most copycats selectively imitate brand-name products that prove to be successful in their early sales (Pun and DeYong 2017). Further, copycats' imitation and production require time investment, which entails brand-name products exclusivity in their early sales. In this paper, we study two operational levers for the brand-name supply chain to combat copycats: strategic inventory and network externality.

We follow Anand et al. (2008) and assume that one-unit mass of customers arrive in each period, each demanding at most one unit of a product. Customers are short lived, with demands that can only be fulfilled in their arriving period.[3] Our focus on short-lived customers applies to *industrial* products. For example, Raspberry Pi has wide applications in marine and agriculture studies (e.g., monitoring of temperature and humidity) and quality control in manufacturing (e.g., inspection of defects). Customers in these contexts represent industrial entities (e.g., farms, observatories, and production plants). Mainly driven by industrial needs and purposes, the demands of these entities are often immediate and thus, cannot be postponed.

Customers in each period have heterogeneous valuations for the brand-name product, which we assume are uniformly distributed over $[0,1]$. The copycats, as a follower, have an inferior nature in their designs and productions (Pun and DeYong 2017, Yi et al. 2022), and we assume that a customer with valuation θ for the brand-name product has valuation $\beta\theta$ (with $\beta < 1$) for the copycat product. Thus, the parameter β measures the competitiveness of copycats and is coherently determined by their design and production technologies. We interchangeably refer to β as the "competitiveness" and "quality" of copycats, and we assume β is common knowledge to all stakeholders (Pun and DeYong 2017, Yi et al. 2022).

Customers purchasing the brand-name product in the second period enjoy an additional utility in the form of an *exclusive* network externality. For example, Raspberry Pi offers programs exclusively released on its platform that are incompatible with other competitors' operating systems, such as Banana Pi and Orange Pi. For Raspberry Pi, a high volume of early adoptions will stimulate a large number of programs exclusively developed for its various applications, either open sourced or licensed by software producers, which in return, will increase its appeal to prospect users. In other words, there is positive feedback between Raspberry Pi's programs and their user size, hinting at an "installed-base" network externality (Mitchell and Skrzypacz 2006).

Formally, with s_1 denoting the first-period sales of the brand-name product, the gross valuation of a second-period customer for the brand-name product is $\theta + \gamma s_1$, where γ measures the strength of network externality. Our model thus captures the classic viewpoint of installed-base network externality (Katz and Shapiro 1992, Mitchell and Skrzypacz 2006, Chen et al. 2009); early "installed" customers can be used to "seed" future sales through network externality. Customers' valuations of the copycat product remain $\beta\theta$ and are unaffected by the exclusive network externality.[4]

The brand-name product is sold through a decentralized supply chain composed of an upstream supplier (he) and a downstream retailer (she). We follow Anand et al. (2008) and consider two contractual formats of the supplier. Under the *commitment contract*, the supplier announces the wholesale prices of both periods before the selling season, whereas under the *dynamic contract*, the supplier announces the wholesale price of each period at the beginning of that period. Under both contracts, the retailer incurs a unit cost h for carrying inventory across periods. We specify the sequence of events under each contract as follows.

Commitment Contract. (1) The supplier announces wholesale prices of each period (w_1, w_2). (2) The retailer determines order sizes (q_1, q_2) and prices of the brand-name product (p_1, p_2) in each period. (3) Copycats observe p_2 and set price p_C for the copycat product. In steps (2) and (3), we assume that the retailer has the first-mover advantage in the price competition with copycats in the second period (Yi et al. 2022).

Dynamic Contract. (1) The supplier announces the first-period wholesale price w_1. (2) The retailer orders q_1 and sets price p_1 in the first period. (3) The supplier observes retailer's q_1 and p_1 and then, announces the second-period wholesale price w_2. (4) The retailer orders q_2 and sets price p_2 in the second period. (5) Copycats observe p_2 and set price p_C.

Anand et al. (2008) analyzes these two contracts in a model without copycats or network externality and shows that the retailer has incentives to carry inventory under the supplier's dynamic contract. Anand et al. (2008) terms such inventory as *strategic inventory* as it is carried in order to bring down the supplier's second-period price.

In this paper, we illustrate how strategic inventory and network externality can be used to combat copycats, either individually or jointly, by managing an intertwined internal and external competition.

2.1. Model Without Strategic Inventory or Network Externality

To fix ideas, we first present a model without strategic inventory or network externality. This develops a benchmark that isolates copycats from both operational levers. This model can be obtained by setting $h = \infty$ and $\gamma = 0$. Using this model, we establish an equivalence between the supplier's two contractual formats.

Proposition 1. *When there is no network externality ($\gamma = 0$) among brand-name users and the retailer's holding cost is prohibitively high ($h = \infty$), the supplier's, retailer's, and copycats' optimal decisions are summarized in Table 1. In particular, the supplier's commitment and dynamic contracts lead to the same equilibrium outcomes.*

The equivalence between the supplier's two contractual formats can be understood by noting that both

Table 1. Optimal Decisions Without Strategic Inventory or Network Externality

Wholesale prices (w_1, w_2)	$\left(\frac{1}{2}, \frac{1-\beta}{2-\beta}\right)$
Sales (s_1, s_2, s_C)	$\left(\frac{1}{4}, \frac{1}{4}, \frac{3}{4(2-\beta)}\right)$
Retailer's prices (p_1, p_2)	$\left(\frac{3}{4}, \frac{3(1-\beta)}{2(2-\beta)}\right)$
Copycats' price p_C	$\frac{3\beta(1-\beta)}{4(2-\beta)}$
Profits (π_S, π_R, π_C)	$\left(\frac{4-3\beta}{8(2-\beta)}, \frac{4-3\beta}{16(2-\beta)}, \frac{9\beta(1-\beta)}{16(2-\beta)^2}\right)$

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the supplier's and retailer's optimal decisions are time-independent. Specifically, the high holding cost precludes the retailer's strategic inventory that can otherwise twist the supplier's pricing incentives. The nonexistent network externality also precludes pricing incentives to generate strong early sales. Collectively, they lead to time-independent demands.

Both the supplier's and retailer's profits decrease with the quality of copycats. The entry of copycats essentially creates shadow competition against the brand-name supply chain in the later period, and as their quality increases, they encroach more heavily on the brand-name market. Both the supplier and retailer have to cut their prices to defend their market share; their profits thus dwindle.

We next incorporate strategic inventory and network externality into our analysis and demonstrate how they can be managed, either individually or jointly, to combat copycats.

3. Managing Strategic Inventory in the Presence of Copycats

We start by analyzing how to utilize strategic inventory to combat copycats. We assume the retailer has a finite holding cost h, and we impose $\gamma = 0$ to isolate the effect of strategic inventory from network externality.

Anand et al. (2008) characterizes the supplier's and retailer's optimal decisions in this model without copycats ($\beta = 0$) and finds that the retailer only carries inventory under the supplier's *dynamic contract* when her holding cost $h < 0.25$. Anand et al. (2008) also compares the supplier's two contractual formats and shows that the supplier always benefits from the retailer's strategic inventory (and thus, prefers the dynamic contract), whereas the retailer benefits from strategic inventory (and thus, prefers the dynamic contract) only when her holding cost is even smaller, $h < 21/152 \approx 0.14$.

Anand et al. (2008) attributes their findings to the *contract-space-expansion* effect of the retailer's strategic inventory. Specifically, by carrying inventory, the retailer sources for her second period from both the supplier and her first-period inventory, likely at different prices. Thus, strategic inventory expands the price space of the second-period vertical contract. This alleviates double marginalization and always benefits the supplier. In contrast, the retailer has to incur holding costs for carrying inventory; she gets better off only when her holding cost h is sufficiently small.

3.1. Impact of Copycats

We next extend the analysis of Anand et al. (2008) to markets with copycats. We characterize equilibrium outcomes in such markets.

Proposition 2. *Suppose there is no network externality among brand-name users* ($\gamma = 0$).

i. *Under the commitment contract, the optimal decisions of the supplier, retailer, and copycats are the same as those in Table* 1 and *Proposition* 1.

ii. *Under the dynamic contract, the supplier's, retailer's, and copycats' optimal decisions are summarized in Table* 2. *There exists a cutoff value of holding cost* h_1 *below which the retailer carries inventory; the cutoff* $h_1 > 0$ *for all* $\beta < (\sqrt{73} - 5)/6$, *and* h_1 *is decreasing in* β.

Despite the entry of copycats, the retailer does not carry inventory under the supplier's commitment contract. This can be understood by noting that if the

Table 2. Dynamic Contract Without Network Externality

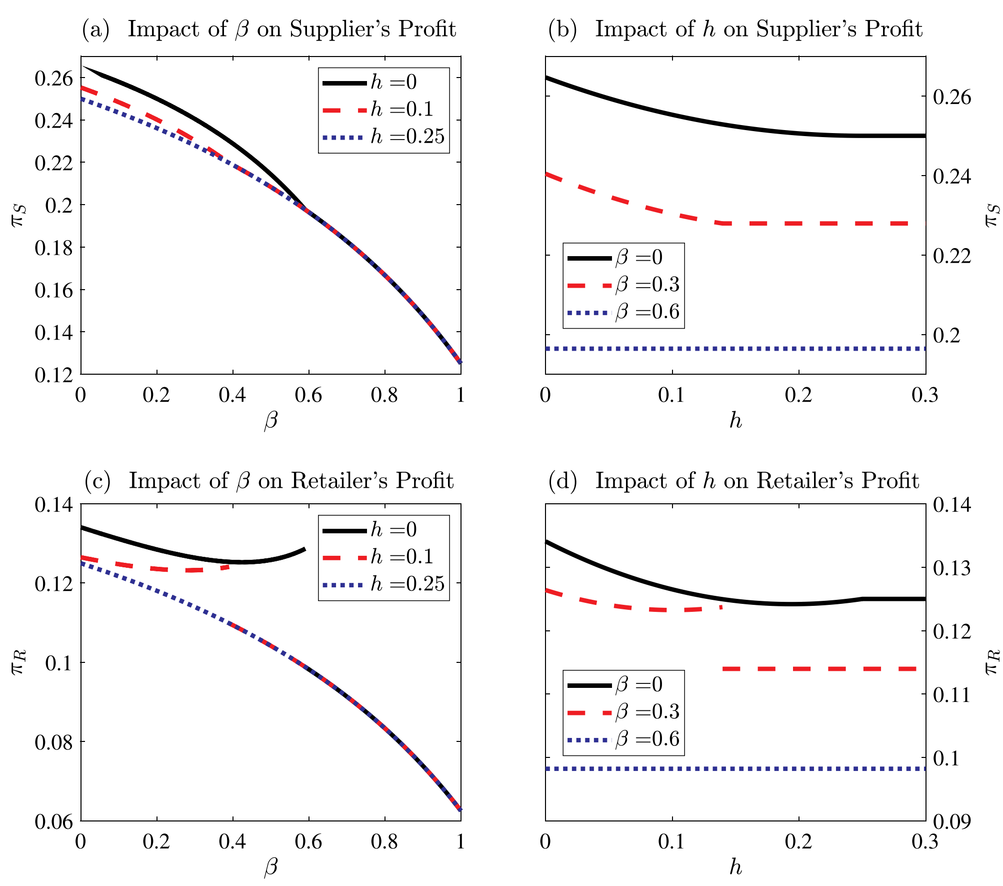
Condition I	$\beta < (\sqrt{73} - 5)/6$ and $0 \le h < h_1 \triangleq \frac{1-\beta}{(2-\beta)(4-3\beta)}\left(2 - \beta - \frac{\beta}{2}\sqrt{\frac{17-13\beta}{1-\beta}}\right)$
Wholesale prices (w_1, w_2)	$\left(\frac{9(1-\beta)-h(2-\beta)}{17-13\beta},\ \frac{2}{13}\left(4h + 3 - \frac{3(h+4)}{17-13\beta}\right)\right)$
Retailer's orders (q_1, q_2)	$\left(\frac{13-11\beta}{2(17-13\beta)} - \frac{h(7\beta^2-23\beta+18)}{2(1-\beta)(17-13\beta)},\ \frac{3(2-\beta)}{2(17-13\beta)} - \frac{h(2-\beta)(5-4\beta)}{2(1-\beta)(17-13\beta)}\right)$
Inventory I	$\frac{1}{17-13\beta}\left(\frac{5-7\beta}{2} - \frac{h(4\beta^2-13\beta+10)}{1-\beta}\right)$
Sales (s_1, s_2, s_C)	$\left(\frac{(2-\beta)(h+4)}{2(17-13\beta)},\ \frac{11-10\beta}{2(17-13\beta)} - \frac{h(4\beta^2-13\beta+10)}{2(1-\beta)(17-13\beta)},\ \frac{1}{17-13\beta}\left(\frac{13-16\beta}{2-\beta} + \frac{h(5-4\beta)}{1-\beta}\right)\right)$
Retailer's prices (p_1, p_2)	$\left(\frac{1}{2}\left(1 + \frac{9(1-\beta)-h(2-\beta)}{17-13\beta}\right),\ \frac{1}{13}\left(4h + 16 - \frac{3(h+4)}{17-13\beta}\right) - \frac{1}{2-\beta}\right)$
Copycats' price p_C	$\frac{\beta}{26}\left(4h + 16 - \frac{3(h+4)}{17-13\beta}\right) - \frac{\beta}{2(2-\beta)}$
Supplier's profit π_S	$\frac{1}{2(17-13\beta)}\left(9(1-\beta) - 2h(2-\beta) + \frac{h^2(3\beta^2-10\beta+8)}{1-\beta}\right)$
Retailer's profit π_R	$\frac{118h-155+\beta(350-357h)+\beta^2(309h-290)+\beta^3(87-80h)}{2(13\beta-17)^2(\beta-2)} + \frac{h^2(97\beta^3-437\beta^2+638\beta-304)}{4(13\beta-17)^2(\beta-1)}$
Copycats' profit π_C	$\frac{\beta}{8(1-\beta)(2-\beta)^2}\left(\frac{2(2-\beta)}{13}\left(4h + 3 - \frac{3(h+4)}{17-13\beta}\right) + 1 - \beta\right)^2$
Condition II	(a) $\beta \ge (\sqrt{73} - 5)/6$ or (b) $\beta < (\sqrt{73} - 5)/6$ and $h \ge h_1$
Optimal decisions	Same as Table 1

supplier commits to wholesale prices (w_1, w_2) before the selling season, the retailer then compares $w_1 + h$ with w_2 to determine her sourcing strategy for the second period. If $w_2 > w_1 + h$, then she only sources from her first-period inventory. The supplier earns w_1 per unit from this inventory, and he can be better off by cutting w_2 to $w_1 + h$. Doing so will prompt the retailer to source the same amount in the second period but at price $w_2 = w_1 + h$. This improves the supplier's profit. Thus, in optimality, the supplier always sets $w_2 \le w_1 + h$ to eliminate the retailer's inventory. This constraint can hold with or without copycats; in fact, the entry of copycats further drives down the supplier's w_2, allowing this constraint to hold more generally. Because the retailer's strategic inventory does not exist under this contract, the resulting equilibrium outcomes mimic those in Table 1.

In contrast, the retailer has an incentive to carry inventory under the supplier's dynamic contract. Because $w_1 > w_2$ (i.e., the procurement cost is higher in the first period), such inventory should be interpreted as strategic inventory too (Anand et al. 2008). The entry of copycats further creates a cutoff holding cost h_1 that separates regions with and without strategic inventory: under fixed β, strategic inventory exists for holding cost below h_1 and vanishes otherwise. Because the cutoff h_1 decreases with β, this suggests that the retailer's incentives of carrying strategic inventory decrease with the quality of copycats. In particular, with highly competitive copycats, $\beta > 0.59$, the retailer does not carry inventory even if inventory holding is costless (i.e., $h_1 = 0$).

Although the supplier's profit under the dynamic contract is continuous in both h and β, the retailer's profit may have a *discontinuity* at the boundary $h = h_1$ (except for the special case without copycats; i.e., $\beta = 0$ and cutoff $h_1 = 0.25$). See Figure 1 for the supplier's and retailer's profits under representative β and h. This discontinuity is driven by the supplier's strategic choice between two different strategies: one that tolerates the retailer's strategic inventory and the other that eliminates strategic inventory. Which strategy is more profitable to the supplier depends on both β and h. Under fixed $h < 0.25$, the brand-name product has weaker second-period sales as β increases, and thus, the benefit of strategic inventory in reducing w_2 is most pronounced under small β. The supplier thus has to tolerate the retailer's strategic inventory under small β but sees it as less of a concern under large β. Likewise, under fixed

Figure 1. (Color online) Supplier's and Retailer's Profits Without Network Externality: Dynamic Contract



$\beta < 0.59$, the supplier makes a similar switch as h increases. In both cases, the retailer's profit takes a downward jump at the boundary $h = h_1$ (see Figure 1(c) and (d)). The supplier's profit, in contrast, is always continuous in h and β, even at the cutoff $h = h_1$: the supplier actively seeks a switch between two strategies, and they generate the same profit for the supplier at $h = h_1$.

Unlike the commitment contract under which both the supplier's and retailer's profits decrease with the quality of copycats β (see Table 1), this parameter has subtle effects, especially on the retailer's profit, under the dynamic contract. The supplier's profit continues to decrease with β under the dynamic contract (Figure 1(a)), but the effect of β on the retailer's profit is more elusive. A high β adversely affects the sales of the brand-name product and at the same time, lowers the supplier's wholesale prices in both periods. Which effect is dominant for the retailer depends on the value of β. Under fixed and small h (Figure 1(c)) ($h \in \{0, 0.1\}$), the first effect dominates for β slightly above zero, and this hurts the retailer's profit. The second effect dominates as β increases, and this allows the retailer's profit to increase. As β further increases and crosses the boundary, commitment and dynamic contracts become equivalent, prompting the retailer's profit to decrease with β again.

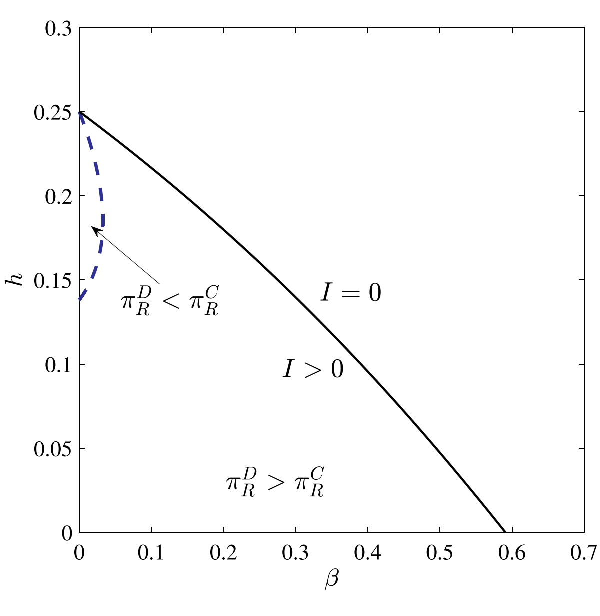
Likewise, although an increased holding cost h always reduces the supplier's profit (Figure 1(b)), its effect on the retailer's profit is rather mixed (Figure 1(d)). Specifically, the retailer's profit first decreases with h; then, it increases, takes a downward jump at the boundary $h = h_1$, and stays a constant afterward. To explain, note that a high holding cost, on the one hand, reduces the retailer's strategic inventory and allows the supplier's w_2 to increase and on the other hand, drives down the supplier's w_1. The first effect dominates for h slightly above zero, and this hurts the retailer's profit. As h increases, the second effect starts to dominate and increases the retailer's profit. The supplier switches to a different strategy as h hits the boundary h_1, and this results in a plummet in the retailer's profit. As h further increases, the dynamic contract is equivalent to the commitment contract, and they both generate a constant profit for the retailer.

Strategic inventory can mitigate double marginalization within the brand-name supply chain. The elevated internal efficiency then enhances the supply chain's external competitiveness relative to copycats. To illustrate this better, we compare the supply chain profits under the supplier's two contractual formats (recall that strategic inventory does not exist under the supplier's commitment contract; see Proposition 2(i)) and summarize our findings as follows. First, the supplier continues to benefit from the retailer's strategic inventory in markets with copycats. Second, the retailer can benefit from strategic inventory for a wider range of holding costs. In particular, with $\beta > 0.032$, the retailer always does better under the dynamic contract whenever she carries strategic inventory. (Recall that the same does not hold in absence of copycats, $\beta = 0$.) See Figure 2 for illustrations of the retailer's contractual preference, where we use superscripts "D" and "C" to denote dynamic and commitment contracts, respectively.

The findings suggest that the effect of strategic inventory in mitigating internal competition not only persists in the presence of copycats but in fact, can be strengthened by copycats, and the enhanced internal efficiency further lends support to the supply chain's external competition with copycats. In other words, although competition from copycats can deter the retailer's strategic inventory, it may also amplify the effect of strategic inventory (provided that it exists) in ameliorating internal efficiency while competing with copycats externally.

With slightly competitive copycats, $\beta < 0.032$, the retailer's contractual preference exhibits a somewhat different pattern: the retailer benefits from strategic inventory (and thus, prefers the dynamic contract) only when her holding cost is either sufficiently small or sufficiently large. To understand this result, recall that for $\beta < 0.59$, the retailer's profit under the dynamic contract is nonmonotone with respect to h. It first decreases with h; then, it increases, takes a downward jump at the boundary $h = h_1$, and remains a constant afterward. Recall also that the last constant is equal to the retailer's profit under the commitment contract. Thus, the space of h where the retailer prefers the dynamic contract depends on the size of the downward jump. This jump has size 0 in markets without copycats ($\beta = 0$) but gets wider as β increases. For β slightly above zero, this jump has a very tiny size,

Figure 2. (Color online) Commitment vs. Dynamic Contract Without Network Externality: Retailer's Profit



and so, the profit under the commitment contract outperforms the lowest profit under the dynamic contract (attained under an intermediate h). In this case, the dynamic contract is preferred when h is either sufficiently large or sufficiently small. For β above 0.032, the downward jump has a considerable size, allowing the retailer's profit under the dynamic contract to unambiguously dominate that under the commitment contract.

4. Managing Network Externality in the Presence of Copycats

In this section, we study how to manage cross-period network externality in the presence of copycats. We impose $h = \infty$ to isolate the effect of network externality from strategic inventory. We also impose $\gamma \le \frac{2(1-\beta)}{2-\beta}$ to restrict the strength of network externality.[5] This latter assumption is not very restrictive when the copycat product has low to medium quality. For example, with $\beta = 0.5$, this assumption requires $\gamma < 2/3$: the feasible γ can induce more than half of the highest intrinsic valuation of the brand-name product provided full market coverage in the first period. We present the equilibrium outcomes in such markets in the next result.

Proposition 3. *Suppose the retailer cannot hold inventory* ($h = \infty$) *and* $\gamma \le \frac{2(1-\beta)}{2-\beta}$.

i. *Under the commitment contract, the supplier's, retailer's, and copycats' optimal decisions are summarized in Table 3.*

ii. *Under the dynamic contract, the supplier's, retailer's, and copycats' optimal decisions are summarized in Table 4.*

iii. *Both the supplier and retailer are better off under the commitment contract.*

Unlike the retailer's strategic inventory that combats copycats through allayed internal competition, the exclusive network externality enhances product values and brings immediate gains to the brand-name supply chain's external competition. The use of such network externality, however, must be exercised with caution as it alters the pricing incentives of the brand-name supply chain and creates undesired internal inefficiency. Unlike Proposition 1, which establishes an equivalence between the supplier's two contractual formats under $h = \infty$, these two contracts are no longer equivalent in the presence of network externality. This is because both the supplier and retailer have incentives to cultivate first-period "installed" customers to "seed" future sales. Such incentives, however, are partially distorted because of decentralization best exhibited under the supplier's dynamic contract. Under this contract, if the retailer attempts high sales s_1 by charging a low p_1, the supplier will exploit this opportunity and charge a high w_2 accordingly. This hurts the retailer's incentives to create high sales in the first place. In other words, double marginalization because of internal competition occurs not only within each period in the profit battle within a supply chain but also, across successive periods in ways of utilizing network externality. The commitment contract, in contrast, enforces static prices (w_1, w_2) and precludes dynamic w_2 that changes with the retailer's chosen p_1. This alleviates cross-period double marginalization and leads to unanimous benefits for both supply chain players.

The pitfall of the dynamic contract can be further observed as follows. One can verify that the supplier's first-period prices under two contracts satisfy $w_1^D \le w_1^C$. That is, the supplier sets his first-period price w_1 low under the dynamic contract to target high sales s_1. However, anticipating the supplier's greed in the second period, the retailer charges a higher price p_1 under the dynamic contract and ends up with lower first-period sales, $s_1^D \le s_1^C$, leading to a weaker network externality. Nevertheless, the supplier charges a higher second-period price under the dynamic contract $w_2^D \ge w_2^C$, further aggravating double marginalization in this period.

Thus, compared with the dynamic contract, the commitment contract can effectively alleviate the inefficiency from cross-period double marginalization; see our formal result established in Proposition 3(iii). To illustrate this further, we plot in Figure 3 the supplier's and retailer's profit gaps between two contracts under representative $\gamma \in \{0.1, 0.3\}$. We observe increased gaps between two contracts, in both absolute and relative terms, as the quality of copycats increases. In other words, fierce competition from copycats can in effect exacerbate the inefficiency of the dynamic contract in utilizing network externality. To motivate our analysis next, recall from Section 3 that the dynamic contract can also induce the retailer's strategic inventory under a finite holding cost, which may provide a remedy for its undesired internal inefficiency. We explore this issue in the next section.

Table 3. Commitment Contract Without Strategic Inventory

Wholesale prices (w_1, w_2)	$\left(\frac{1}{2}, \frac{1-\beta}{2-\beta}\right)$
Sales (s_1, s_2, s_C)	$\left(\frac{(1-\beta)(\gamma+2)}{8(1-\beta)-\gamma^2(2-\beta)}, \frac{1}{4}\left(1+\frac{\gamma(2-\beta)(\gamma+2)}{8(1-\beta)-\gamma^2(2-\beta)}\right), \frac{3}{4(2-\beta)} - \frac{\gamma(2+\gamma)}{4[8(1-\beta)-\gamma^2(2-\beta)]}\right)$
Retail prices (p_1, p_2, p_C)	$\left(1-\frac{(1-\beta)(\gamma+2)}{8(1-\beta)-\gamma^2(2-\beta)}, \frac{3(1-\beta)}{2(2-\beta)}+\frac{\gamma(1-\beta)(\gamma+2)}{2[8(1-\beta)-\gamma^2(2-\beta)]}, \frac{3\beta(1-\beta)}{4(2-\beta)}-\frac{\gamma\beta(1-\beta)(\gamma+2)}{4[8(1-\beta)-(2-\beta)\gamma^2]}\right)$
Profits (π_S, π_R, π_C)	$\left(\frac{(1-\beta)[4-3\beta+\gamma(2-\beta)]}{(2-\beta)[8(1-\beta)-\gamma^2(2-\beta)]}, \frac{(1-\beta)[4-3\beta+\gamma(2-\beta)]}{2(2-\beta)[8(1-\beta)-\gamma^2(2-\beta)]}, \frac{\beta(1-\beta)[12(1-\beta)-2\gamma^2(2-\beta)-\gamma(2-\beta)]^2}{4(2-\beta)^2[8(1-\beta)-\gamma^2(2-\beta)]^2}\right)$

Table 4. Dynamic Contract Without Strategic Inventory

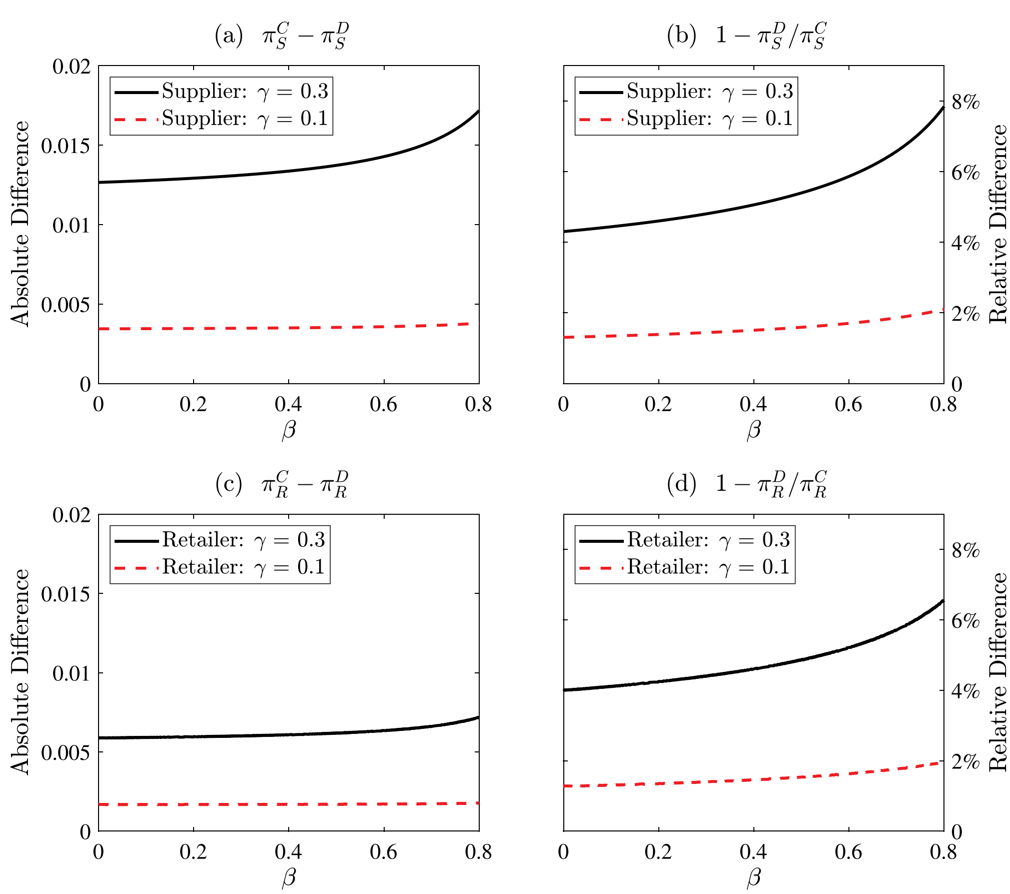
Wholesale prices (w_1, w_2)	$\left(\frac{\gamma+24}{32}-\frac{(1-\beta)(3\gamma+8)}{2[16(1-\beta)-\gamma^2(2-\beta)]},\ \frac{1-\beta}{2-\beta}\left(\frac{1}{4}+\frac{2[6(1-\beta)+\gamma(2-\beta)]}{16(1-\beta)-\gamma^2(2-\beta)}\right)\right)$
Sales (s_1, s_2, s_C)	$\left(\frac{(1-\beta)(3\gamma+8)}{2[16(1-\beta)-\gamma^2(2-\beta)]},\ 1/4+\frac{\gamma(2-\beta)(3\gamma+8)}{16[16(1-\beta)-\gamma^2(2-\beta)]},\ \frac{3}{4(2-\beta)}-\frac{\gamma(3\gamma+8)}{16[16(1-\beta)-\gamma^2(2-\beta)]}\right)$
Retailer's prices (p_1, p_2)	$\left(1-\frac{(1-\beta)(3\gamma+8)}{2[16(1-\beta)-\gamma^2(2-\beta)]},\ \frac{3(1-\beta)}{2-\beta}\left(\frac{1}{8}+\frac{(1-\beta)+\gamma(2-\beta)}{16(1-\beta)-\gamma^2(2-\beta)}\right)\right)$
Copycats' price p_C	$\frac{\beta(1-\beta)}{2(2-\beta)}\left(\frac{15}{8}-\frac{\gamma(2-\beta)+6(1-\beta)}{16(1-\beta)-\gamma^2(2-\beta)}\right)$
Supplier's profit π_S	$\frac{1-\beta}{2(2-\beta)}\left(\frac{17-13\beta+3\gamma(2-\beta)}{16(1-\beta)-\gamma^2(2-\beta)}-\frac{1}{16}\right)$
Retailer's profit π_R	$(1-\beta)\left[\frac{7}{128(2-\beta)}+\frac{1}{16(1-\beta)-\gamma^2(2-\beta)}\left(\frac{3\gamma+4}{8}+\frac{2(1-\beta)[3\gamma(2-\beta)+17-13\beta]}{(2-\beta)[16(1-\beta)-\gamma^2(2-\beta)]}\right)\right]$
Copycats' profit π_C	$\frac{\beta(1-\beta)[16\gamma-15\beta\gamma^2+192\beta+30\gamma^2-192-8\beta\gamma]^2}{256(2-\beta)^2[16(1-\beta)-\gamma^2(2-\beta)]^2}$

5. Jointly Managing Strategic Inventory and Network Externality

In this section, we study a general model with combined strategic inventory, network externality, and copycats. Recall from Proposition 2(ii) that the retailer carries no inventory under the supplier's dynamic contract when copycats are highly competitive ($\beta > 0.59$). Then, how does the presence of network externality affect the retailer's strategic inventory? Recall also that strategic inventory and network externality can both be used to combat copycats by managing intertwined internal and external competition. Then, if optimized jointly, how will they affect the supply chain performance in its competition with copycats?

These two questions are tightly connected because as we will illustrate shortly, not only the existence but also, the *amount* of strategic inventory will critically determine the supply chain performance, with the latter

Figure 3. (Color online) Commitment vs. Dynamic Contract Without Strategic Inventory: Profit Comparison



amount being highly sensitive to the strength of network externality. To answer the first question, we fix $h \in \{0, 0.3\}$ and plot the equilibrium outcomes in Figure 4. We find robust patterns in both cases: the presence of network externality strengthens the retailer's incentives of carrying strategic inventory. For example, with $\gamma = 0.33$, the retailer holds inventory under $h = 0$ even when copycats are extremely competitive, $\beta = 0.79$. (Recall that the same copycats will fully deter the retailer from carrying inventory absent the network externality.) Likewise, when $h = 0.3$, the retailer holds inventory under network externality as long as copycats are not excessively competitive. (Recall that under $h = 0.3$, strategic inventory does not exist for all $\beta > 0$ absent the network externality.)

To understand these results, recall that the brand-name supply chain has incentives to stimulate early sales to reap the most benefits of network externality. This brings down the supplier's first-period price, and the retailer takes this opportunity to stock more inventory. Thus, network externality cultivates the retailer's strategic inventory under the dynamic contract. Nevertheless, recall from Section 4 that the dynamic contract also suffers an elevated inefficiency from cross-period double marginalization. Thus, the overall assessment of this contract is mixed, as we demonstrate.

5.1. Commitment vs. Dynamic Contracts

Indeed, the profitability of the dynamic contract depends on *how much* strategic inventory is carried in equilibrium. To glean insights, we start by considering a market without copycats.

Proposition 4. *Suppose there are no copycats ($\beta = 0$) and $\gamma \leq 1$.*

i. *Under the commitment contract, the supplier's and retailer's optimal decisions are the same as those in Table 3* and *Proposition 3*(i).

ii. *Under the dynamic contract, the supplier's and retailer's optimal decisions are summarized in Table 5. The retailer will carry inventory if and only if $h < h_2$.*

iii. *There exists $h_R < h_S < h_2$ such that the supplier prefers the dynamic contract if and only if $h < h_S$ and the retailer prefers the dynamic contract if and only if $h < h_R$.*

Part (i) shows that the supplier's commitment contract is independent of the retailer's holding cost h. Similar to our reasoning in Section 3, the supplier sets $w_2 \leq w_1 + h$ to eliminate the retailer's strategic inventory. This constraint is trivially satisfied for all $h \geq 0$ as long as the network externality is not overwhelmingly strong.

Part (ii) establishes how network externality affects the retailer's inventory incentives. The presence of network externality creates three distinct regions under the supplier's dynamic contract: an "inventory" (IV) region $h < h_2$, an "inventory-threat" (IT) region $h_2 < h < h_3$, and a "no-inventory-threat" (NI) region $h \geq h_3$. The retailer carries inventory in the first region and abandons inventory in the other two. Recall from Proposition 2(ii) that only IV and NI regions exist absent the network externality. There, IV and NI regions are separated by a boundary h_1, and commitment and dynamic contracts are equivalent for h above h_1 in the NI region. Now, with network externality, a new IT region emerges and is sandwiched by two new boundaries h_2 and h_3. The first boundary h_2 separates regions with and without

Figure 4. (Color online) Strategic Inventory Under Dynamic Contract

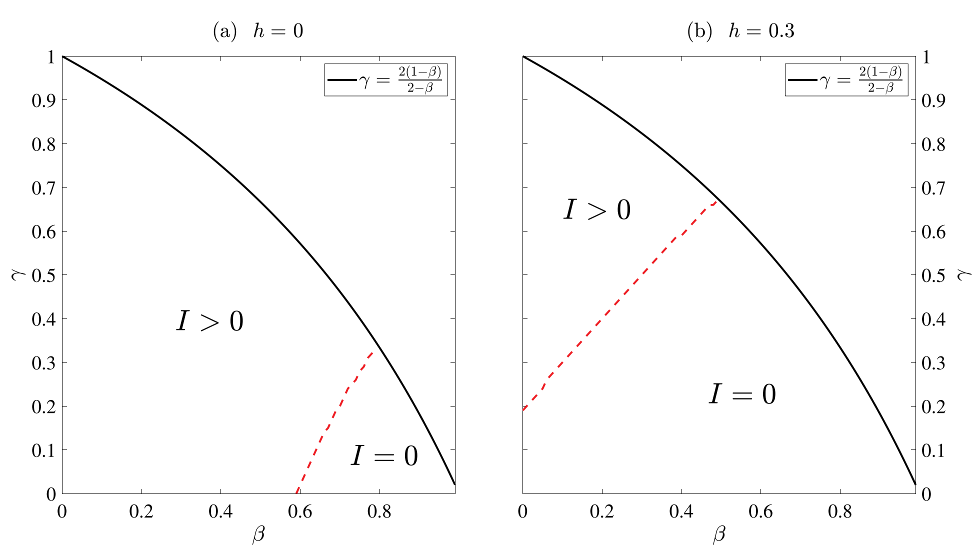


Table 5. Dynamic Contract with Strategic Inventory and Network Externality but Not with Copycats

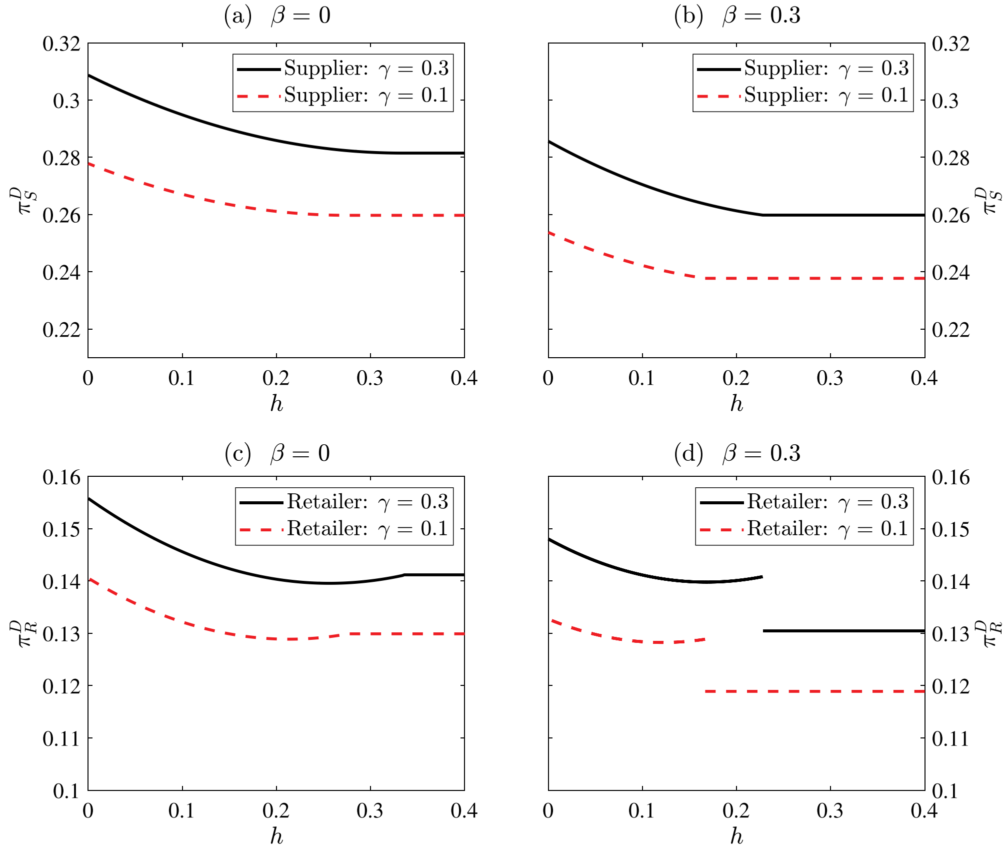
Inventory region (IV)	$h < h_2 \triangleq \frac{8(2\gamma+5)(\gamma+2)}{320-32\gamma-30\gamma^2+\gamma^3}$
Wholesale prices (w_1, w_2)	$\left(\frac{9(9h+2)}{\gamma+34}-\frac{5h}{2},\ \frac{6(9h+2)}{\gamma+34}-h\right)$
Retailer's order quantities (q_1, q_2)	$\left(\frac{h-2}{2(\gamma-2)}-\frac{2(9h+2)}{\gamma+34}+\frac{h}{4},\ \frac{3(9h+2)}{\gamma+34}-\frac{h}{2}\right)$
Inventory I	$\frac{h-2}{4(\gamma-2)}-\frac{h}{2(\gamma+2)}-\frac{63h+14}{4(\gamma+34)}+\frac{h}{4}$
Sales quantities (s_1, s_2)	$\left(\frac{h-2}{4(\gamma-2)}-\frac{9h+2}{4(\gamma+34)}+\frac{h}{2(\gamma+2)},\ \frac{h-2}{4(\gamma-2)}-\frac{h}{4}-\frac{h}{2(\gamma+2)}+\frac{45h+10}{4(\gamma+34)}\right)$
Retail prices (p_1, p_2)	$\left(1+\frac{9h+2}{4\gamma+136}-\frac{h}{2\gamma+4}-\frac{h-2}{4\gamma-8},\ \frac{h\gamma}{4(\gamma+2)}-\frac{3h}{2}+\frac{h-2}{4(\gamma-2)}+\frac{29(9h+2)}{4(\gamma+34)}\right)$
Retailer's profit	$\frac{h^2}{4(\gamma+2)}-\frac{(h-2)^2}{16(\gamma-2)}+\frac{3h^2}{16}+\frac{9(9h+2)^2}{(\gamma+34)^2}-\frac{387h^2+140h+12}{16(\gamma+34)}$
Supplier's profit	$\frac{(9h+2)^2}{8(\gamma+34)}-\frac{(h-2)^2}{8(\gamma-2)}-\frac{h^2}{8}$
Inventory-threat region (IT)	$h_2 \le h < h_3 \triangleq \frac{(\gamma+2)(\gamma^2+16\gamma+32)}{32(8-\gamma^2)}$
Wholesale prices (w_1, w_2)	$\left(\frac{16h-h\gamma^2-6\gamma-12}{(\gamma+2)(\gamma-8)},\ \frac{8+4\gamma(h+1)}{(\gamma+2)(8-\gamma)}\right)$
Inventory I	0
Sales quantities (s_1, s_2)	$\left(\frac{4h}{5(\gamma+2)}-\frac{4h+5}{5(\gamma-8)},\ \frac{2(4h+5)}{5(8-\gamma)}-\frac{2h}{5(\gamma+2)}\right)$
Retail prices (p_1, p_2)	$\left(\frac{\gamma^2-5\gamma-14+8h}{(\gamma+2)(\gamma-8)},\ \frac{12+6\gamma(h+1)}{(\gamma+2)(8-\gamma)}\right)$
Retailer's profit	$\frac{16\gamma(1+h)-(h+1)\gamma^3-(4h^2+2h-1)\gamma^2+64h^2+32h+20}{(\gamma+2)^2(\gamma-8)^2}$
Supplier's profit	$\frac{14(4h+5)^2}{25(\gamma-8)^2}-\frac{16h^2}{25(\gamma+2)^2}+\frac{24h(4h+5)}{125(\gamma-8)}-\frac{h(96h-5)}{125(\gamma+2)}$
No-inventory-threat region (NI)	$h \ge h_3$
Wholesale prices (w_1, w_2)	$\left(\frac{\gamma}{32}+\frac{3}{4}+\frac{3\gamma+8}{4(\gamma^2-8)},\ \frac{1}{8}-\frac{\gamma+3}{\gamma^2-8}\right)$
Inventory I	0
Sales quantities (s_1, s_2)	$\left(\frac{3\gamma+8}{4(8-\gamma^2)},\ \frac{1}{16}-\frac{\gamma+3}{2(\gamma^2-8)}\right)$
Retail prices (p_1, p_2)	$\left(1+\frac{3\gamma+8}{4(\gamma^2-8)},\ \frac{3}{16}-\frac{3(\gamma+3)}{2(\gamma^2-8)}\right)$
Retailer's profit	$\frac{7}{256}-\frac{3\gamma^3+4\gamma^2-48\gamma-100}{16(\gamma^2-8)^2}$
Supplier's profit	$\frac{6\gamma+17}{8(8-\gamma^2)}-\frac{1}{64}$

inventory, and the second boundary h_3 splits the no-inventory region into two subregions differentiated by whether the retailer's potential to hold inventory creates a threat to the supplier. Further, for h above h_3 in the NI region, the equivalence between the commitment and dynamic contracts fails to hold. These results collectively point to an intricate perspective of network externality in affecting strategic inventory.

We plot the supplier's and retailer's profits in a market *without* copycats in Figure 5(a) and (c) by fixing $\gamma \in \{0.1, 0.3\}$. We find that the supplier's profit is always continuous and decreasing in h, whereas the retailer's profit is nonmonotone with respect to h. We also plot the supplier's and retailer's profits in a market *with* copycats in Figure 5(b) and (d), where we identify, in addition to the nonmonotonicity, a discontinuity in the retailer's profit, as reminiscent of one of our key findings in Section 3. Thus, although network externality and copycats can both affect the supplier's pricing incentives toward the retailer's strategic inventory, only copycats can drive sharp transitions in the retailer's profits.

Part (iii) establishes the supply chain players' contractual preferences in a market without copycats. Recall from Section 4 that the dynamic contract is dominated by the commitment contract under $h = \infty$. This dominance extends to IT and NI regions where holding costs remain large. This dominance, however, can be reversed in the IV region. Specifically, in this region, the dynamic contract is inferior to the commitment contract under intermediate holding costs, and the reversal is true under small holding costs. Recall that the dynamic contract can induce the retailer's strategic inventory that mitigates internal competition and meanwhile, suffers an inefficiency in utilizing network externality. The result suggests that, to offset the latter efficiency, the retailer must carry a considerable amount of strategic

Figure 5. (Color online) Dynamic Contract with Strategic Inventory, Network Externality, and Copycats: Supplier's and Retailer's Profits



inventory. In other words, *the act of carrying strategic inventory does not guarantee the superiority of the dynamic contract under network externality; a sufficient amount of strategic inventory does.* Thus, for the dynamic contract to be favorable, the retailer's holding cost must be even smaller for strategic inventory to exist to a considerable level.

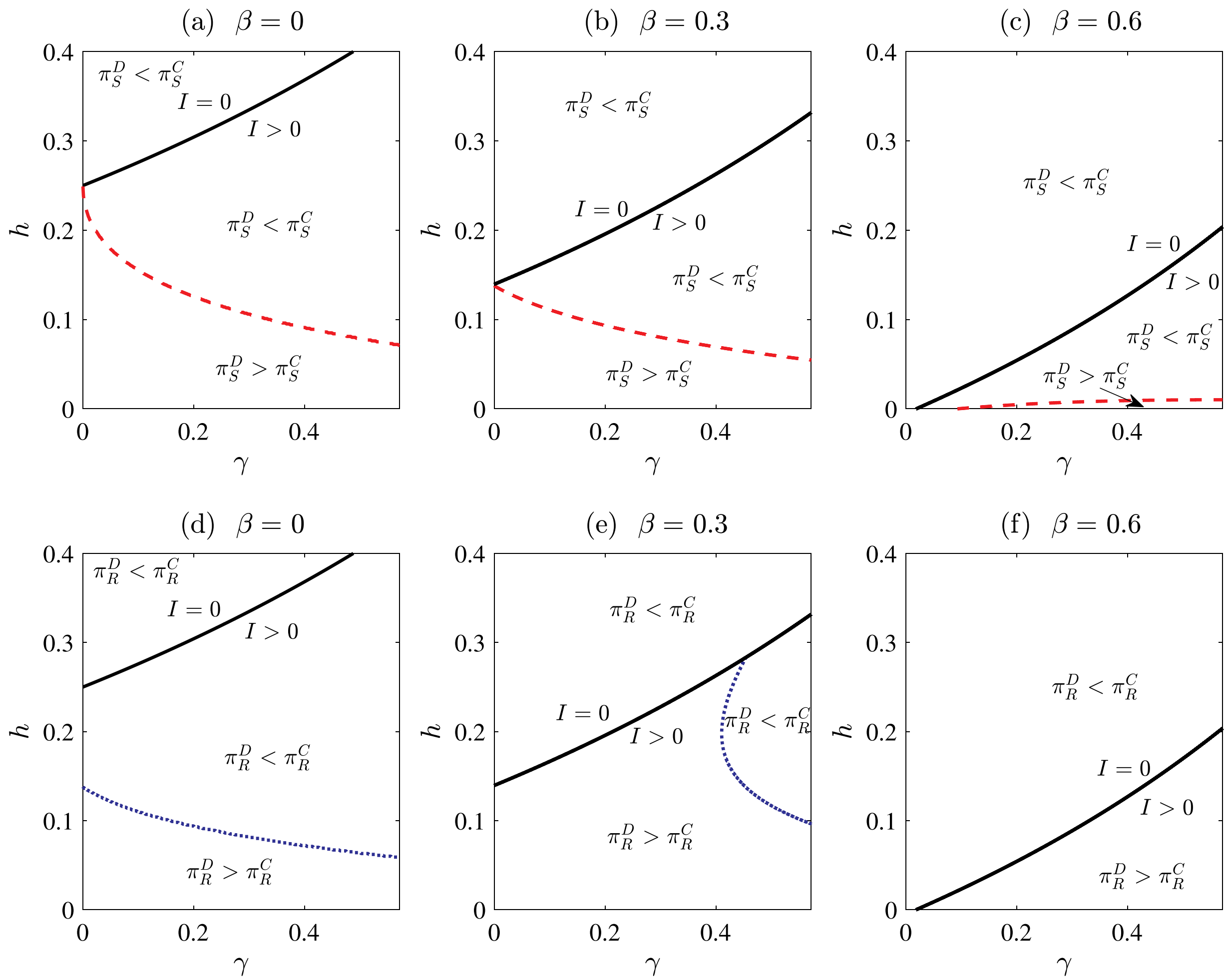
Part (iii) further identifies two thresholds of holding costs. The retailer's threshold h_R is lower than the supplier's h_S as the holding cost is solely borne by the retailer. For h above h_S but below h_2, the retailer carries inventory but only a limited amount that is insufficient to fully allay the inefficiency of the dynamic contract because of cross-period double marginalization. The commitment contract is the dominant contract for both supply chain players in this region.

Under the dynamic contract, although the boundary h_2 for strategic inventory to exist is increasing in γ, both the thresholds h_S and h_R are decreasing in γ; see Figure 6(a) and (d). To explain the latter, note that the effects of a stronger network externality are twofold. A stronger network externality, on the one hand, induces more strategic inventory by pushing down the supplier's w_1 and on the other hand, exacerbates the inefficiency of the dynamic contract under network externality. The latter inefficiency gets stronger as γ increases, and to overcome it, the retailer's holding cost should further decrease to secure a good level of strategic inventory.

Markets with copycats, $\beta > 0$, are more complex to analyze. We numerically compute the equilibrium outcomes for $\beta \in \{0.3, 0.6\}$ and plot the supply chain players' contractual preferences in Figure 6. Recall from Section 3 that copycats deter the retailer's strategic inventory, the essential element that the dynamic contract relies on to restore its efficiency. Thus, as expected, the boundary of holding costs that separates regions with and without inventory shifts downward as the quality of copycats increases. Recall also from Section 4 that copycats exacerbate the inefficiency of the dynamic contract under network externality. At first thought, this would suggest that the dynamic contract is less favorable to both supply chain players in the face of copycats. This intuition, however, only applies to the supplier. Indeed, we observe reductions in holding costs for the supplier to prefer the dynamic contract as copycats become more competitive.

The retailer's contractual preference in the presence of copycats, however, is more elusive. To elaborate, recall that the retailer's profit under the dynamic contract is

Figure 6. (Color online) Commitment vs. Dynamic Contract with Strategic Inventory, Network Externality, and Copycats



nonmonotone with respect to her holding cost h. Recall also that the competition from copycats creates a discontinuity in her profit. It first decreases with h; then, it increases, takes a downward jump, and stays a constant afterward. The last constant corresponds to the retailer's profit under the dynamic contract without strategic inventory and is always lower than the retailer's profit under the commitment contract (see Proposition 3(iii)). Thus, the space of holding costs where the retailer prefers the dynamic contract depends on both the size of the downward jump and how much this contract is inferior to the commitment contract under $h = \infty$.

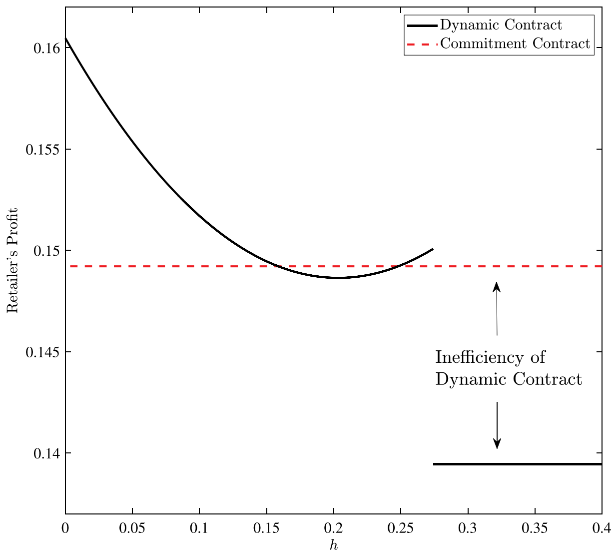
The size of the downward jump increases with β (it has size 0 when $\beta = 0$). For small β (Figure 6(d)), this jump has a very tiny size, and the commitment contract can outperform the dynamic contract by a significant margin under large h. In this case, the dynamic contract is favorable to the retailer only when the holding cost is sufficiently small.

For intermediate β (Figure 6(e)), the downward jump widens and dominates the gains of the commitment contract under small γ. In this case, the dynamic contract is dominant in all space of h whenever the retailer carries strategic inventory. As γ increases, the value of the commitment contract increases too but only in a restrictive manner that is insufficient to fully match the size of the downward jump. In this case, the dynamic contract is preferred when the holding cost is either very small or very large; see Figure 7 for an illustration of such a case under $\beta = 0.3$ and $\gamma = 0.43$, where the retailer's profits under commitment and dynamic contracts are observed to cross twice. As γ further increases, the gains of the commitment contract can outperform the size of the downward jump. This makes the dynamic contract favorable to the retailer under small holding costs only.

For large β (Figure 6(f)), the downward jump further widens, and its magnitude exceeds the benefits of the commitment contract. This time, the retailer prefers the dynamic contract whenever she carries strategic inventory.

To summarize, the retailer's contractual preference is jointly determined by three factors: the quality of copycats, which affects the value of strategic inventory

Figure 7. (Color online) Commitment vs. Dynamic Contract with Strategic Inventory, Network Externality, and Copycats: Retailer's Profit, $\beta = 0.3, \gamma = 0.43$



(Section 3); the strength of network externality that governs the inefficiency of the dynamic contract (Section 4); and the level of holding cost that determines the amount of strategic inventory she can afford.

5.2. Are Network Externality and Strategic Inventory Substitutes or Complements in Combatting Copycats?

We next study the joint effects of strategic inventory and network externality in combatting copycats. Specifically, we examine whether strategic inventory and network externality, each aiming to increase the supply chain players' payoffs by managing intertwined internal and external competition, are complementary or substitutive in doing so when optimized jointly in the face of copycats.

We focus on the supplier's dynamic contract with non-degenerated strategic inventory. Let $\pi_i(h,\gamma)$ denote supply chain player i's profit under holding cost h and network externality with strength γ. Define the profit difference

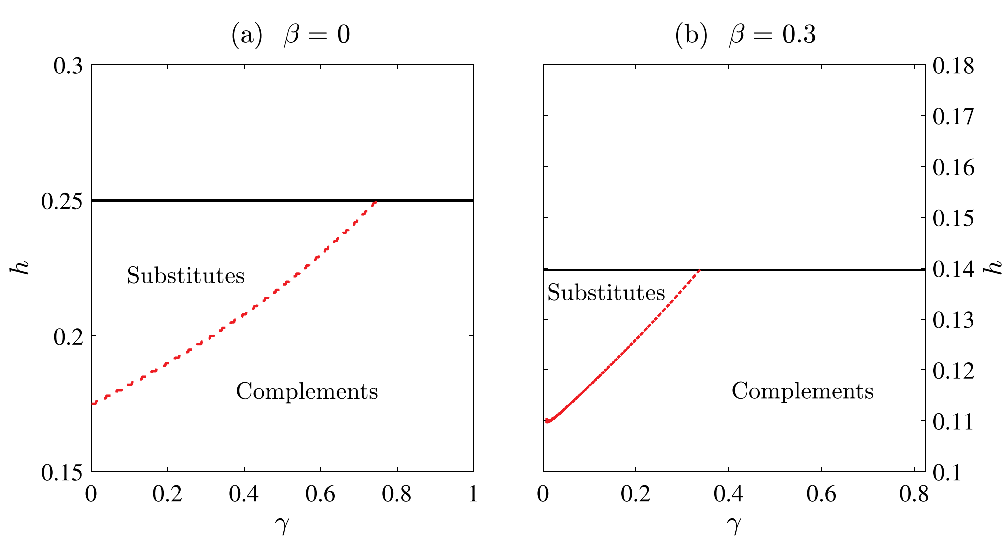
$$\Delta_i(h,\gamma) := \pi_i(h,\gamma) + \pi_i(\infty,0) - \pi_i(h,0) - \pi_i(\infty,\gamma),\ i \in \{S,R\},$$

where $\pi_i(h,0), \pi_i(\infty,\gamma)$, and $\pi_i(\infty,0)$ represent player i's profits in a market with strategic inventory but no network externality (Section 3), a market with network externality but no strategic inventory (Section 4), and a market with neither of them (Section 2.3), respectively. With this definition, network externality and strategic inventory are complementary to player i if Δ_i is positive and are substitutive otherwise. We focus on holding costs $h \le h_1$, where h_1 is defined in Proposition 2. This implies that the retailer carries strategic inventory even when $\gamma = 0$ and continues to do so for all $\gamma > 0$.

We find that $\Delta_S > 0$ for all $h \le h_1$ and $\beta < 0.59$. This suggests that network externality and strategic inventory are always complementary in increasing the supplier's payoff.

The sign of Δ_R (thus, the retailer's gains from jointly using network externality and strategic inventory) is mixed and depends on all parameters of β, h, and γ. We plot in Figure 8 two cases of $\beta \in \{0, 0.3\}$. In both cases, network externality and strategic inventory are substitutive to the retailer under small γ and large h, and they are complementary otherwise. In other words, there are synergies of jointly using network externality and strategic inventory under a low holding cost and strong

Figure 8. (Color online) Joint Effect of Strategic Inventory and Network Externality on the Retailer



network externality. To explain these synergies, note that a strong network externality lowers the supplier's first-period price and leads to increased strategic inventory. Such effect gets strengthened under a low holding cost, both ensuring strategic inventory to exist to a high level. In contrast, under a large holding cost and low to medium network externality, the retailer can only afford a limited amount of strategic inventory that is insufficient to fully allay the inefficiency of the dynamic contract. In this case, network externality and strategic inventory have substitutive effects on the retailer's profit.

6. Extensions

Our main model has focused on short-lived customers whose demands must be satisfied in their arriving period. It has also assumed an exclusive network externality that uniquely exists among brand-name users. We relax these assumptions and consider two extensions in this section. We consider in Section 6.1 an inclusive network externality shared by both the brand-name and copycat products. We consider in Section 6.2 an extension of long-lived customers whose demands can be postponed.

6.1. Inclusive Network Externality

Our main model assumed an exclusive network externality that uniquely exists among brand-name users. This can be a natural consequence of the brand-name product's hardware/software configurations that deny compatibility with all other competitors, as in the case of Raspberry Pi. Network externality can take other forms in other circumstances too. For example, it can exert influence by promoting public awareness through word of mouth or cultivating a trend or user habit through early adoptions. This latter network externality has an *inclusive* nature and is likely to benefit both the brand-name and copycat products.

We thus consider an inclusive network externality shared by both the brand-name and copycat products in this extension. Following our main model, we assume that the brand-name product is sold in both periods and that copycats enter the market in the second period. With s_1 denoting the first-period sales of the brand-name product, a second-period customer with intrinsic valuation θ has a gross valuation $\theta + \gamma s_1$ for the brand-name product and gross valuation $\beta(\theta + \gamma s_1)$ for the copycat product. Thus, the amount of network externality each product can enjoy is proportional to its quality. In other words, although network externality is inclusive to both products, the brand-name product has a better advantage in utilizing it.

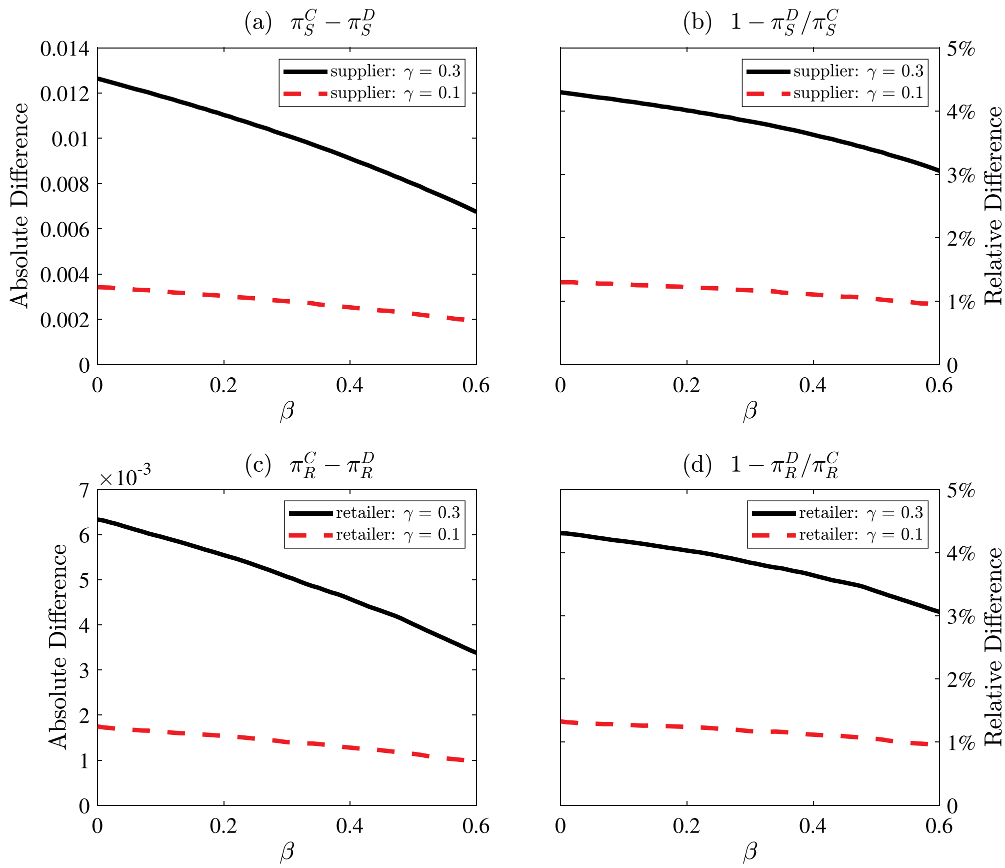
We replicate our analysis in Sections 4 and 5 for this extension and summarize our key findings. First, the dynamic contract continues to suffer an internal inefficiency under the inclusive network externality. This is because cross-period double marginalization rooted in the supplier's second-period greed persists as long as network externality can increase the distinction of the brand-name product in its external competition with copycats. Once again, this makes the commitment contract the dominant contract absent strategic inventory.

Recall from Section 4 that the dominance of the commitment contract gets strengthened with highly competitive copycats under an exclusive network externality. We find that the opposite is true under an inclusive network externality; see Figure 9 for the profit gaps under the inclusive network externality for $\gamma \in \{0.1, 0.3\}$. To understand this contrast, note that differentiation of inclusive network externality is closely tied to quality differentiation. Thus, a high β reduces both quality and network externality differentiation. This reduces the supply chain's incentives to stimulate early sales and thus, alleviates cross-period double marginalization that hurts the dynamic contract most. As a result, the profit gaps between two contracts decrease with β under the inclusive network externality.

Inclusive network externality also induces a slightly different pattern of the retailer's strategic inventory. See Figure 10 for two cases of $h \in \{0, 0.3\}$, where we restrict the strength of network externality $\gamma \leq 1 - \beta$ to simplify analysis. We find robust patterns in both cases. First, inclusive network externality continues to expand the parameter space where the retailer holds strategic inventory. Although inclusive network externality creates only limited incentives to stimulate early sales, such incentives persist (compared with the case of no network externality) and prompt the supplier to cut w_1. This allows strategic inventory to exist for a wider range of the retailer's holding costs. Second, the boundaries that separate regions with and without strategic inventory are nonmonotone with respect to β. (Recall that these boundaries in Figure 4 are increasing in β under an exclusive network externality.) For example, under $h = 0.3$ and intermediate γ, the retailer carries strategic inventory when β is either relatively small or relatively large β. To explain, note that a small β allows the brand-name product to be sufficiently differentiated from copycats through network externality, and the supplier exploits this differentiation to generate high sales in the first period. This allows the supplier's w_1 to decrease and thus, stimulates the retailer's strategic inventory. A large β, in contrast, reduces both quality and network externality differentiation, and it is crucial that the retailer should fully utilize strategic inventory to restore internal efficiency and increase external competitiveness. Thus, with highly competitive copycats, the role of strategic inventory under the inclusive network externality is similar to our finding in Section 3.

We plot the supplier's and retailer's contractual preferences in Figure 11 when strategic inventory, inclusive network externality, and copycats are all present. Similar

Figure 9. (Color online) Commitment vs. Dynamic Contract Without Strategic Inventory: Inclusive Network Externality



to our finding in Section 5, we observe that the mere existence of strategic inventory does not guarantee the profitability of the dynamic contract; a sufficient amount of strategic inventory does. For both the supplier and the retailer, the holding cost must be sufficiently small to induce a good level of strategic inventory that is strong enough to fully allay the inefficiency of the dynamic contract.

Figure 10. (Color online) Strategic Inventory Under Dynamic Contract: Inclusive Network Externality

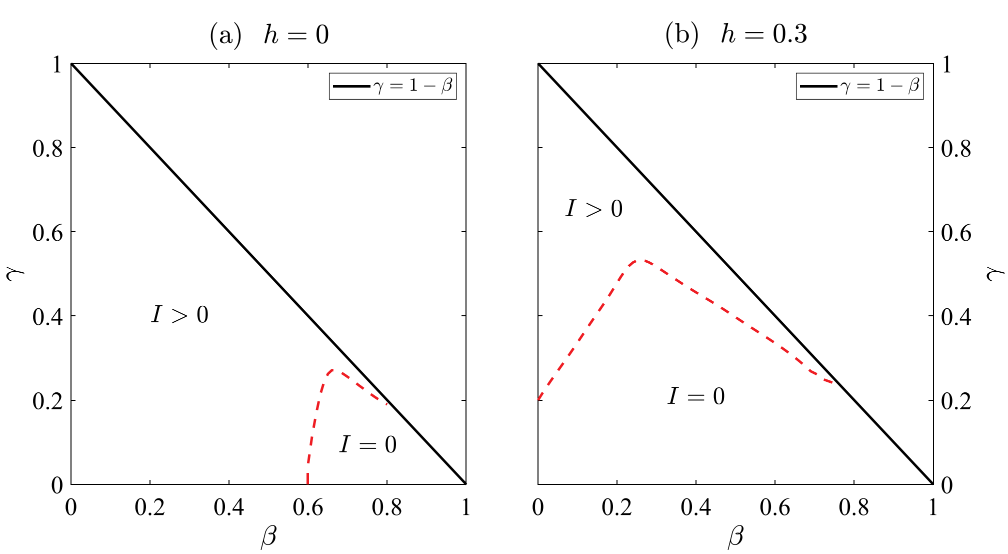
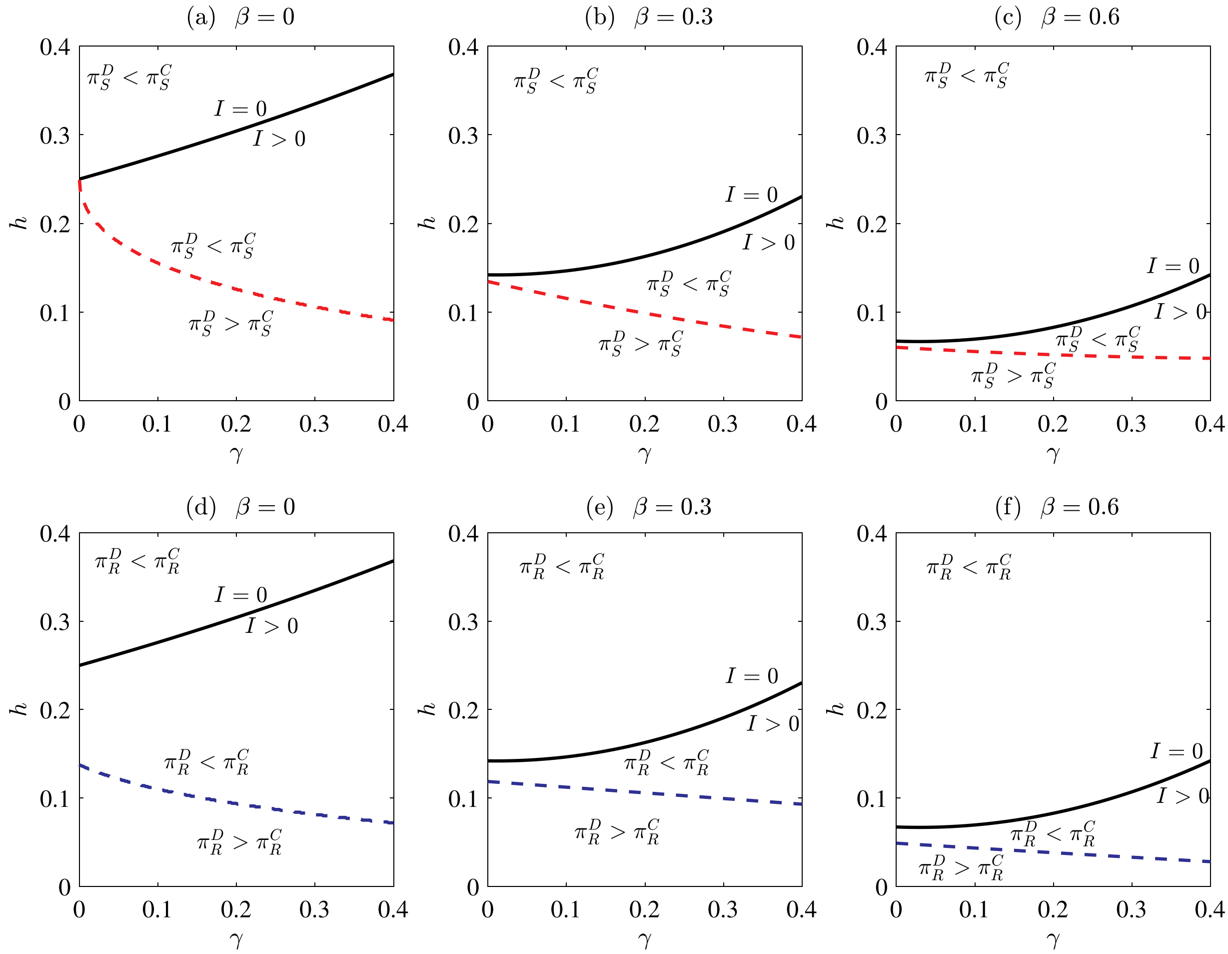


Figure 11. (Color online) Commitment vs. Dynamic Contract Under Strategic Inventory, Inclusive Network Externality, and Copycats



6.2. Long-Lived Customers

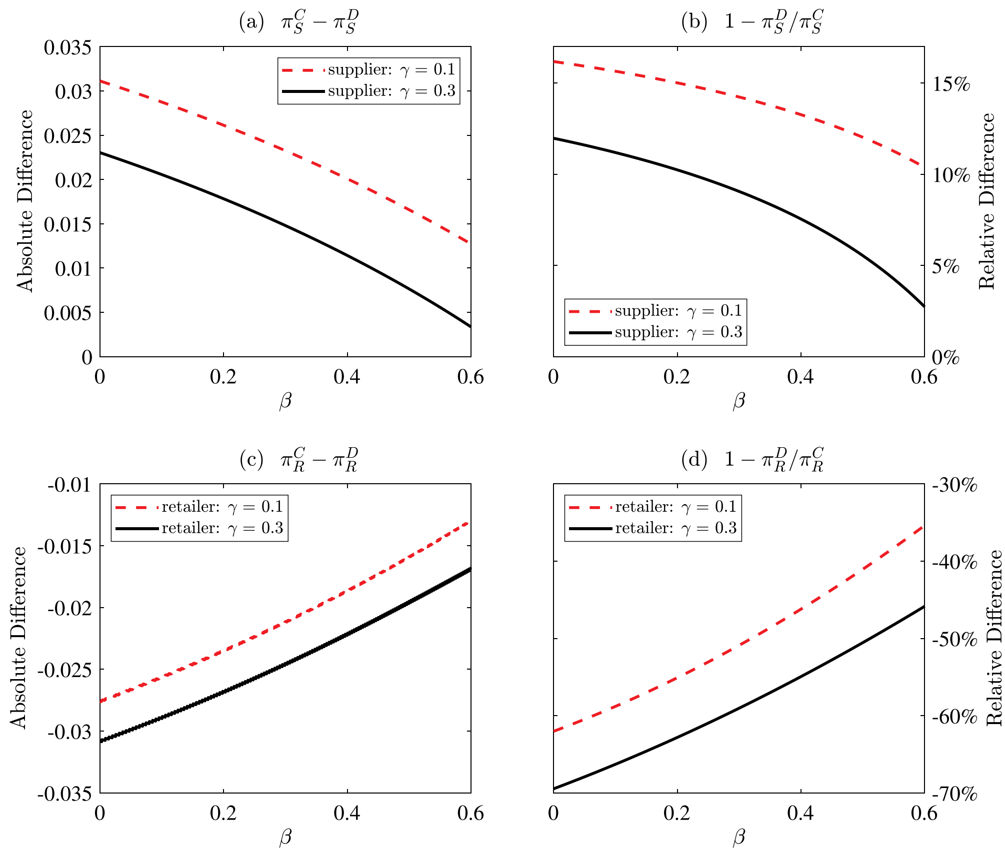
Our main model assumed that one-unit mass of short-lived customers arrive in each period and that their demands can only be satisfied in their arriving period. This applies to industrial products for which customers have immediate demands that cannot be postponed. We consider in this extension an alternative model with long-lived customers who may postpone their purchases for better prices. This model fits into product categories such as consumer discretionary (e.g., fashion clothing and electronics). We follow Kabul and Parlaktürk (2019) and assume that one-unit mass of customers arrive in the first period. Each customer demands at most one unit of a product and strategically decides the optimal timing of her purchases, if any.

As in Kabul and Parlaktürk (2019), customers incur costs for delayed purchases and consumption. A customer with valuation θ in the first period has valuation $\delta\theta$ (with $\delta < 1$) in the second period. The parameter δ thus measures the customer's patience level in postponing her consumption. Accordingly, the customer's intrinsic valuations of the brand-name and copycat products in the second period are $\delta\theta$ and $\beta\delta\theta$, respectively. Further, there is an exclusive network externality that differentiates brand-name products from copycats; the customer's gross valuation of the brand-name product in the second period is $\delta\theta + \gamma s_1$.

To facilitate a fair comparison with our main model, we study two contractual formats of the supplier by fixing the retailer's pricing strategy to be a *dynamic* one.[6] That is, the retailer only announces her price of each period at the beginning of that period. In this case, rational customers, upon observing the retailer's first-period price, have to deduce the retailer's second-period price as well as the copycats' price to make informed purchase decisions.

Note that the retailer's second-period price depends intimately on her first-period inventory, but this inventory is not observed by customers. Thus, customers must form beliefs about this inventory and use this

Figure 12. (Color online) Commitment vs. Dynamic Contract Without Strategic Inventory: Long-Lived Customers, $\delta = 0.7$



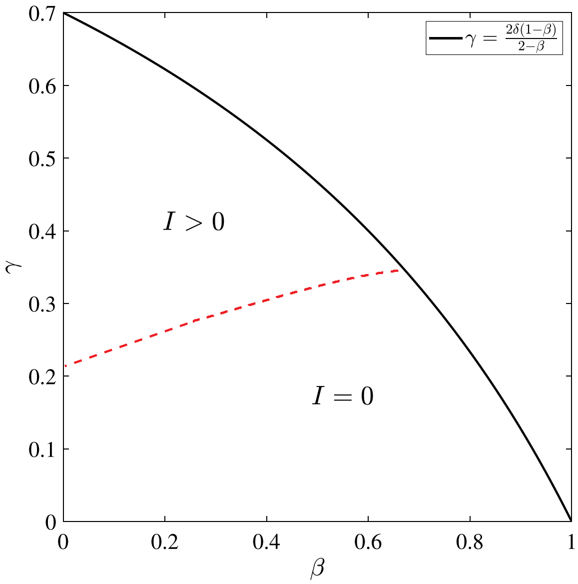
belief to deduce the retailer's and copycats' second-period prices. In equilibrium, customers' belief must be consistent with the retailer's true inventory level that maximizes her aggregate profits. We replicate our analysis in Sections 3–5 for this new model and summarize our key findings.

In absence of network externality ($\gamma = 0$), we find that the retailer does not carry inventory under both the supplier's commitment and dynamic contracts. This is consistent with Kabul and Parlaktürk (2019, proposition 2) established for markets without copycats ($\beta = 0$) under a zero holding cost ($h = 0$). Thus, the presence of long-lived customers reduces the retailer's incentives of carrying strategic inventory even in markets without copycats. This is because customers have discounted valuations in the second period, and this restricts the retailer's gains from using strategic inventory to bring down the supplier's w_2. Such benefits are further undermined by copycats, making the retailer more reluctant to carry inventory.

With costly inventory holding ($h = \infty$), the supplier continues to suffer an inefficiency under the dynamic contract because of cross-period double marginalization, but unlike Section 4, this inefficiency gets allayed as the quality of copycats increases; see Figure 12(a) and (b). This is because network externality enhances the second-period valuations of the brand-name product, which on the one hand, gives the brand-name product a competitive advantage over copycats and on the other hand, stimulates customers' strategic waiting. This latter behavior is widely known to hurt an integrated producer but can sometimes benefit players in decentralized supply chains, and Lin et al. (2018) shows that within the supply chain, the supplier is more likely to benefit from customers' strategic waiting. Applying this logic to our context, as copycats become more competitive, the supplier is in a better position to pull the pricing lever to counteract the inefficiency of the dynamic contract. We also find that the retailer can benefit from the dynamic contract even if she carries no inventory. Such benefits are driven by the fact that the retailer's large order size in the first period (even without strategic inventory) can bring down the supplier's second-period price.

When all three features are present, we plot in Figure 13 the retailer's strategic inventory for the case of $h = 0$. Similar to our finding in Section 5, network externality cultivates the retailer's strategic inventory. However, in the case of $h = 0.3$, we find that the retailer does not carry any inventory for all $\gamma < \frac{2\delta(1-\beta)}{2-\beta}$. (To contrast, recall from Figure 4(b) that the retailer may carry inventory with

Figure 13. (Color online) Strategic Inventory Under Dynamic Contract: Long-Lived Customers, $\delta = 0.7, h = 0$



short-lived customers for $h = 0.3$.) This again points to the retailer's reduced incentives of carrying strategic inventory in the context of long-lived customers.

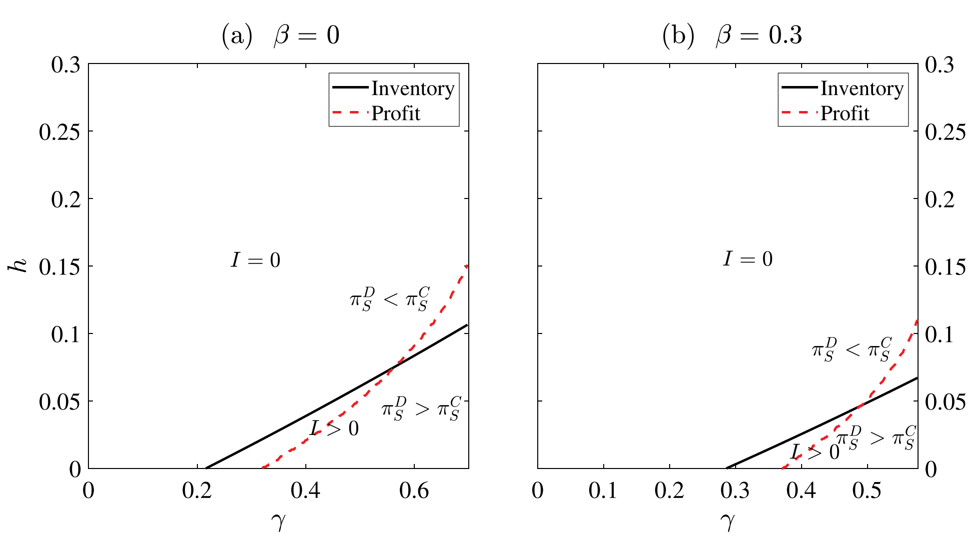
With long-lived customers, we also find that the retailer generally prefers the supplier's dynamic contract. Such a preference, as said, is driven by the fact that the retailer's large order size in the first period can bring down the supplier's second-period price under the dynamic contract even if she carries no inventory (that is, the retailer sells all her first-period inventories in that period). This can be explained by noting that with long-lived customers, those with high valuations purchase in the first period, and the remaining customers with low valuations wait until the next period. If the retailer sells a larger volume in the first period, those who remain in the second period will have lower average valuations. Anticipating this, the supplier has to lower w_2 to stimulate more sales in the second period. In this sense, the retailer's large order size in the first period can trigger wholesale price discounts even if the retailer carries no inventory. This effect vanishes when the supplier commits to static prices under the commitment contract. As a result, the retailer can be better off under the dynamic contract.

The supplier's contractual preference, in contrast, is more elusive. We plot in Figure 14 the supplier's preference for the cases of $\beta \in \{0, 0.3\}$. In both cases, the boundaries of holding costs that separate regions with and without the retailer's inventory increase with the strength of network externality. Below these boundaries, there is a sizable region that induces a considerable amount of strategic inventory. The supplier prefers the dynamic contract in this space under a large γ and small h, similar to our finding in Section 5. Above the boundaries, there is a no-inventory region under a large γ and intermediate h where the supplier prefers the dynamic contract too. In this region, although the retailer carries no inventory, the threat of carrying inventory along with a large order size in the first period prompts the supplier to cut w_2. This effect gets more pronounced under a large γ, making the dynamic contract more favorable to the supplier for a wider range of holding costs.

7. Conclusion

Our work was motivated by Raspberry Pi, a dominant player in the microcomputer industry that faces competition from copycats, such as Banana Pi and Orange Pi, that offer inferior and low-priced alternatives. Raspberry Pi operates a two-tier supply chain and leverages

Figure 14. (Color online) Commitment vs. Dynamic Contract with Long-lived Customers: Supplier's Preference, $\delta = 0.7$



an exclusive network externality to differentiate itself from inferior competitors. We developed a two-period dynamic model to capture these features and demonstrated how to use strategic inventory and network externality to combat copycats. Our results provided full-spectrum recommendations for supply chain players' pricing and inventory decisions.

From the retailer's perspective, strategic inventory is adopted under the supplier's dynamic contract, and it shall be abandoned when there is strong competition from copycats. As the competition from copycats intensifies, she may champion the supplier's dynamic contract for a wider range of holding costs. Nonetheless, if the product she resells exhibits a strong network externality, she should be cautious about the supplier's dynamic contract. Further, if customers can postpone their purchases, then she should be aware of the competition not only from copycats but also, from her future self; in this case, reducing the use of strategic inventory turns out to be a better option.

From the supplier's perspective, he should be aware that the retailer's strategic inventory is cultivated by network externality but discouraged by copycats. If the product he produces exhibits an exclusive network externality confined within this product (e.g., because of technological barriers), then he should take into account the retailer's inventory incentives; he should adopt a dynamic contract only when the retailer's holding cost is sufficiently small. He should continue to do so even if the network externality of his product is shared with copycats. Finally, with long-lived and strategic customers, the supplier may offer a dynamic contract to protect the retailer from competing with her future self, and this effect persists even if the retailer carries no strategic inventory.

Our work can be extended in multiple directions. We focused on modeling installed-base network externality driven by early adoptions, mainly motivated by applications in the digital world. However, network externality can take other forms: for example, in conspicuous goods markets for which there are opposing network implications for early and late adopters (e.g., Amaldoss and Jain 2005). Extending our analysis to incorporate different types of network externality constitutes an interesting direction for future study.

We also acknowledge that there are other realistic factors not captured in our model, such as competition, demand uncertainty, and product line designs. Extending our framework to incorporate these factors would be another valuable endeavor for future research.

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Endnotes

[1] Mitchell and Skrzypacz (2006, p. 622) suggests that the source of the installed-base benefit can be either "the availability of many complementary products and services (e.g., add-ons, applications, repair service, publications) or directly the number of other users (e.g., in case of a communication product)."

[2] One can broadly interpret the copycats as a low-quality entrant in the second period, whose late entry entails the brand-name product exclusivity in the first period.

[3] We consider in Section 6.2 an extension of long-lived customers who consider both immediate and delayed purchases to maximize their payoffs.

[4] We consider in Section 6.1 an extension of *inclusive* network externality shared by both the brand-name and copycat products.

[5] If γ is too large, it is possible that the retailer will exploit the strong network externality and set zero price in the first period to cover the entire market. We rule out this case and focus on partial market coverage in the first period.

[6] If the retailer's pricing strategy is a static one (i.e., the retailer commits to (p_1, p_2) in the first period), then under the supplier's dynamic contract, the supplier always sets his second-period price w_2 equal to the retailer's p_2. This leads to a zero profit for the retailer from her second-period sourcing. We choose not to consider this less interesting case and focus on the retailer's dynamic pricing strategy instead.

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