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Collaborative Consumption: Strategic and Economic Implications of Product Sharing

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Recent technological advances in online and mobile communications have enabled collaborative consumption or product sharing among consumers on a massive scale. Collaborative consumption has emerged as a major trend as the global economic recession and social concerns about consumption sustainability lead consumers and society as a whole to explore more efficient use of resources and products. We develop an analytical framework to examine the strategic and economic impact of product sharing among consumers. A consumer who purchased a firm's product can derive different usage values across different usage periods. In a period with low self-use value, the consumer may generate some income by renting out her purchased product through a third-party sharing platform as long as the rental fee net of transaction costs exceeds her own self-use value. Our analysis shows that transaction costs in the sharing market have a nonmonotonic effect on the firm's profits, consumer surplus, and social welfare. We find that when the firm strategically chooses its retail price, consumers' sharing of products with high marginal costs is a win-win situation for the firm and the consumers, whereas their sharing of products with low marginal costs can be a lose-lose situation. Furthermore, in the presence of the sharing market, the firm will find it optimal to strategically increase its quality, leading to higher profits but lower consumer surplus.

Keywords: collaborative consumption; product sharing; pricing; sharing economy; peer to peer; quality
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1. Introduction

Consumers often buy or own products but do not fully utilize them. Product sharing among consumers, collaborative consumption, has emerged as a major trend in recent years as the global economic recession and social concerns about consumption sustainability lead consumers and society as a whole to explore more efficient use of resources and products. Recent technological advances in online, mobile communications have enabled collaborative consumption on a massive scale. Many websites, online communities, and social media platforms have helped to facilitate sharing among consumers in their local areas and sometimes even across states or countries for a wide range of products and services such as bicycles (Spinlister), boats (Boatbound, GetMyBoat), cars (RelayRides, Getaround), working or parking spaces (Citizen Space, JustPark), car rides (Lyft, Uber, Zimride), short-term rental (Airbnb, Roomorama), gardens (Shared Earth, Landshare), clothing, portable tools/appliances, electronics, and household items (Friends with Things, NeighborGoods).[1] In farmer communities in developing countries, the sharing of agricultural equipment is also common. Many product-sharing transactions involve the renters paying a fee to the product owners through a sharing platform. From the consumer's perspective, sharing underutilized products seems profitable and also environmentally responsible. How does product sharing affect the manufacturer? Though managers are wary of such sharing, anecdotal evidence shows that some firms are proactively responding to the emerging trend of collaborative consumption. For example, General Motors (GM) has worked with RelayRides to make it easier for owners to rent out their underused OnStar-enabled GM vehicles to offset the cost of ownership, by introducing features such as remote unlocking of doors by authorized renters using their smartphones (General Motors 2012).

This paper focuses on the consumer-to-consumer sharing of products (e.g., on RelayRides or NeighborGoods), *not* the peer-to-peer offering of services (e.g.,

[1] The rise of collaborative consumption is well documented in the book *What's Mine Is Yours* (Botsman and Rogers 2010).

on Uber).[2] Our model captures the idea that a consumer's usage value for a product may vary over time. In each usage period, a product owner can decide whether to use the product herself or to rent it out to others through a third-party product-sharing platform, and consumers who did not purchase the product can decide whether to rent the product from the product-sharing platform.[3] For each sharing transaction, the renting consumer pays a rental fee to the platform, which keeps a percentage of that rental fee as a service fee and gives the rest to the product owner. The product owner will endure two types of transaction costs when renting out her product—one that is proportional to the sharing price (e.g., the platform's fee) and one that is independent of the sharing price (e.g., costs of delivering and picking up the product). We develop an analytical framework with these key market features to study how a firm—the brand owner or manufacturer of the product—should strategically choose its retail price and product quality to respond to anticipated sharing by consumers. We examine the impacts of product sharing on the firm's profits, consumer surplus, and social welfare.

We highlight a few major findings from our analysis. First, transaction costs in the sharing market have a nonmonotonic effect on the firm's profits, consumer surplus, and social welfare. One may intuit that when product-sharing transaction costs (such as the platform's fee or the sharing coordination cost) are high, product owners will be less likely to offer the competing rental option to other consumers, who will be more likely to buy the firm's product, which should allow the firm to increase its price, leading to higher profitability, lower consumer surplus, and lower social welfare. Our analysis shows that the firm may actually be worse off when product-sharing transaction costs increase, because some product buyers with a high usage value in only one period will not be able to earn as much rental income from the sharing market and will no longer be willing to buy the product at the same price. In equilibrium, the firm's price will be lower, leading to *higher* consumer surplus and social welfare.

Second, if the firm strategically chooses the price of its product (of exogenous quality), product sharing among consumers can be either a lose-lose or a win-win situation for the consumers and the firm, depending on the firm's marginal cost. When the firm's marginal cost is low and the product-sharing transaction cost is not too high, the existence of the sharing market will induce the firm to significantly increase its price (from the otherwise low price in the absence of sharing), but the loss in unit sales results in lower total profits and fewer consumers using the product, even taking sharing into account. By contrast, when the firm's marginal cost is high, product sharing is a win-win for the firm and the consumers. This is because, for any given quality, the firm with a high marginal cost will save a lot of marginal costs of production by selling fewer units at higher prices, which many consumers are still willing to buy because of the potential rental income from the sharing market. Without the sharing market, many consumers who have high usage values only in one period will no longer be willing to buy the firm's high-cost product because of the forgone income from sharing.

Third, if the firm strategically chooses both its retail price and product quality in anticipation of consumers' sharing, then the sharing market will lead to higher quality and higher prices, increasing the firm's profit but lowering consumer surplus. The underlying reason is that those consumers with more variable usage values across different usage periods will be willing to pay more to buy the product since they can generate some income by renting out the product when their own usage value is low. This essentially increases those consumers' willingness to pay for product quality and hence gives the firm an incentive to raise its product quality in equilibrium. The firm's endogenous quality decision allows it to select a strategic price–quality pair to ensure higher profitability by extracting more surplus from customers who anticipate the potential income from product sharing.

We will analyze the robustness of our results and insights to several alternative modeling assumptions. First, we provide a benchmark analysis of the secondary (used goods) market, where between periods, consumers can sell their products. This helps us identify the difference between the used goods market and the product-sharing market. Second, we extend our two-period product-sharing model to an n-period model. Third, we allow for product depreciation over time. Fourth, we explicitly model the impact of the moral hazard problem in the sharing market, where the renter may use the product in abrasive ways that hurt the product owner's welfare. Fifth, we allow for product-sharing transaction costs for both the renter and the product owner. Furthermore, we also discuss how our results may be affected if the consumer's valuations are correlated across usage periods, or when there is a third-party rental agency, or if not all consumers are strategic and forward looking.

[2] Though we use consumer-to-consumer sharing as the context, our model applies equally to business-to-business sharing of products, e.g., the sharing of equipment among businesses or hospitals. The essence is that a firm/manufacturer's customers may rent out the product to its other potential customers during periods of low self-use value.

[3] For expositional convenience, we refer to the firm as "it" and a consumer as "she."

1.1. Related Literature

Consumers' social sharing (or piracy) of information goods has received considerable attention in the literature. It has been shown that strong protection against piracy may reduce social welfare (e.g., Besen and Kirby 1989, Johnson 1985, Liebowitz 1985, Novos and Waldman 1984) and that the consumer's sharing of information goods can actually benefit the firm because of the firm's strategic pricing to target sharing groups rather than individuals (e.g., Bakos et al. 1999, Galbreth et al. 2012), positive network externalities (e.g., Conner and Rumelt 1991, Takeyama 1994, Varian 2005), and reduced price competition as price-sensitive consumers will copy (Jain 2008). A small stream of literature also examines the impact of the consumer's illegal sharing of information goods on the firm's incentives to invest in quality (e.g., Lahiri and Dey 2013, Novos and Waldman 1984). Our research differs from the aforementioned literature in several ways. First, we focus on physical products, which cannot be costlessly duplicated by consumers and hence present no piracy issue that plagues digital products. In our model, the consumers must forgo their own use of the product for any period in which they rent it out to others. Second, we explicitly model the consumer's economic incentives to legally share a purchased product—unlike the case of information goods, the owners of a physical product typically have transferable usage rights and can share the product at their own discretion. We endogenously determine which segments of consumers will buy the product and which will rent from a product-sharing platform that facilitates sharing among consumers. Third, in investigating the economic impacts of the consumers' product sharing on the firm's pricing and quality decisions, we closely examine the critical roles played by the firm's marginal cost and the transaction costs (including the sharing platform's fees), which are neglected in that literature.

Our research complements the stream of literature on secondary markets for durable goods. Used goods in secondary markets are lower-quality, depreciated products that can cannibalize the demand of the firm's new or upgraded products (e.g., Bulow 1982, 1986; Chen et al. 2013; Coase 1972; Fudenberg and Tirole 1998; Waldman 1997). But a product's resale value in the secondary market can also increase the forward-looking consumer's valuation for the firm's product in its primary retail market, giving rise to a value-enhancement effect (e.g., Chevalier and Goolsbee 2009, Hendel and Lizzeri 1999, Miller 1974, Rust 1986). One central question in this stream of literature is whether the secondary market helps or hurts the firm. Anderson and Ginsburgh (1994) consider a two-period model, where consumers have heterogeneous tastes for new and used goods. They show that, given the quality level of new goods, if the used goods' quality level is high enough, the secondary market will benefit the firm; by contrast, if the quality level of used goods is low, the secondary market will hurt the firm. Hendel and Lizzeri (1999) use an infinite-horizon model to show that if the density function of consumers' taste distribution is nondecreasing, the firm will make higher profits when the used market is open. Johnson (2011) focuses on a two-period model but extends it to allow consumers' quality preferences to change over time. If the consumers' quality preferences in the two periods are correlated, the secondary market will benefit the firm, whereas if the consumers' quality preferences in the two periods are independent, the firm may prefer to close down the secondary market. Chen et al. (2013) provide both a theoretical analysis and an empirical analysis using U.S. automobile data. They show that a firm is more likely to benefit from opening the secondary market if its products are less durable. In addition, the theoretical literature on secondary markets has examined firms' strategic pricing and new product introduction decisions when facing competition from used goods (e.g., Fishman and Rob 2000; Waldman 1993, 1996b) and firms' optimal decisions on product durability (e.g., Anderson and Ginsburgh 1994, Hendel and Lizzeri 1999, Johnson 2011, Waldman 1996a). Waldman (2003) offers a detailed review of the research on secondary markets and durable goods.

The product-sharing market has some conceptual similarity to a secondary market for used goods in that both have a cannibalization effect and a value-enhancement effect on the firm. However, our research offers new insights not shown in the extant literature on secondary markets. First, we show that product sharing among consumers will increase the firm's profits if the firm strategically chooses its product quality in addition to price. One can think of product quality in two dimensions—the initial baseline quality (e.g., the speed of microprocessors or the resolution of a touchscreen for a firm's smartphone product) and the rate of depreciation of that quality over time (i.e., the durability of the product). Our paper focuses on the former product-quality decision rather than the latter durability decision examined in the extant literature (e.g., Anderson and Ginsburgh 1994, Chen et al. 2013). Second, if the product quality is exogenous, we find that whether the product-sharing market improves or reduces the firm's profit critically depends on the firm's marginal cost. When the firm's marginal cost is high, product sharing will be a win-win situation for the firm and the consumers; by contrast, when the firm's marginal cost is low, product sharing may become a lose-lose situation for the firm and the consumers. This finding also complements the secondary-market literature, which has shown whether the secondary market benefits or hurts the firm depends on the distribution of consumer preferences and the durability of the firm's product (see Anderson and Ginsburgh 1994, Hendel and Lizzeri 1999, Johnson 2011, Chen et al. 2013). None of this literature has examined the critical role played by the firm's marginal cost of production.

Besides the differences in findings, there is also an important conceptual difference between the secondary used goods market and the product-sharing market. A resale transaction in the used goods market involves the *permanent* transfer of product ownership from the seller to the buyer, whereas a sharing transaction in the product-sharing market involves a *temporary* transfer of use right from the product owner to the renter only for the particular sharing period (e.g., one afternoon, one day, one week) and the owner still owns the product's continuation value for future periods (i.e., any future usage value and the salvage value). An important consequence is that the product's future continuation value has a very significant effect on the equilibrium price in the secondary used goods market but not on the equilibrium product-sharing prices in the sharing market. This difference has ramifications on the transaction costs (e.g., the platform's percentage fees) in the two markets. It helps explain why in reality a consumer who needs to use a product will not buy and sell a used product frequently on a period-by-period basis but may have multiple rental or sharing transactions.

Our paper also contributes to the extant literature on bundling of products. One main finding of this literature (e.g., Adams and Yellen 1976, Schmalensee 1984) is that a multiproduct monopolist can increase its profits by selling bundles of two products if the consumers' valuations for the two products are negatively correlated. Similarly, Bakos and Brynjolfsson (1999) show that bundling a large number of unrelated information goods can improve a firm's profit relative to selling the goods separately. When a product can be used in multiple periods, we can consider the product as a bundle of the consumer's product usage over all periods. Hence, in this sense, the literature on the consumer's rent-or-buy decision and the firm's selling-or-leasing decision (e.g., Agrawal et al. 2012, Desai 1999, Desai and Purohit 1998, Hendel and Lizzeri 2002, Huang et al. 2001, Johnson and Waldman 2003) is also related to bundling. Note that these streams of literature examine a firm's optimal bundling–unbundling or selling–leasing strategies, where consumers decide whether to buy or rent the product/bundle from the firm. By contrast, in our product-sharing setting, the firm sells the product (which is a bundle of the product's usage in all time periods) to the consumers, but these consumers can decide whether to buy the product from the firm or rent the product from the sharing market, where the firm's own customers (i.e., the buyers or owners of the product) may offer their purchased product during periods in which they have low self-use values for the product. That is, in our framework, the firm's own customers may indirectly compete with the firm itself by renting out the purchased product to other consumers, and the consumers' purchase decisions depend on both their own usage values for the product and the potential rental income they may generate from the sharing market. We study the firm's optimal strategic responses, in terms of its pricing and quality decisions, to the consumer's product-sharing behaviors. We find that consumers' sharing of low-cost products (such as information goods) is a lose-lose situation for the consumers and the firm, whereas the consumers' sharing of high-cost products is a win-win situation. The transaction costs for product sharing are shown to have a nonmonotonic effect on the firm's profit and the consumer's surplus.

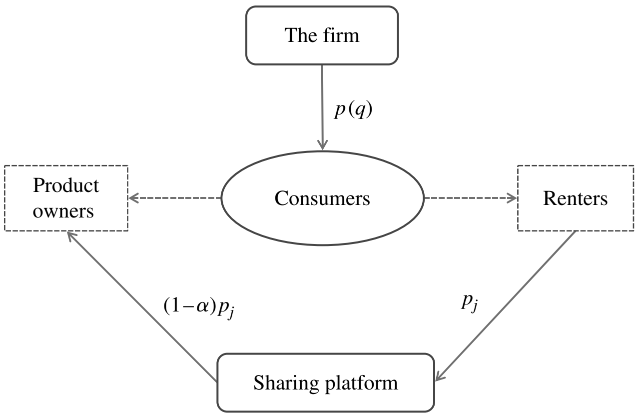
2. Model

A monopolist firm produces a product of quality q at a constant marginal cost of c. The monopolist sells the product at price p to consumers, each of whom buys at most one unit and can derive usage value from the product in n time periods. Note that the consumer's product sharing is a short-term event. For example, car owners typically rent out their cars on RelayRides on a daily basis, but car manufacturers do not dynamically change their prices on a daily basis even when they respond to the existence of the product-sharing market by pricing strategically or even changing their product quality (e.g., General Motors added new features to their cars to facilitate consumers' easier and more reliable car sharing on RelayRides). So, to reduce analytical complexity, we focus on the fairly reasonable case where the firm will strategically choose its price but will not dynamically adjust that price from one sharing period to another.

At the end of the n usage periods, the product has some salvage value ε (e.g., it can be sold in a secondary used goods market). Each consumer's per-period usage value from the product may vary over time. Consumer i's usage values v_{ij} for $j = 1, 2, \ldots, n$ depend on the product's quality (q) and her willingness to pay for quality (θ_{ij}); we assume $v_{ij} = q\theta_{ij}$, where θ_{ij} is uniformly distributed in the consumer population: $\theta_{ij} \sim \mathrm{U}[0, 1]$. Without loss of generality, we normalize the total number of consumers to one. This type of model for quality and consumer heterogeneity has been widely adopted in the economics and marketing literature since Mussa and Rosen (1978). For expositional clarity/succinctness, we assume $n = 2$ for the main model.[4] That is, the consumer can derive usage

[4] Section 5 offers some discussion of an n-period model, with the detailed analysis given in part II of the online appendix (available as supplemental material at https://doi.org/10.1287/mnsc.2016.2647).

Figure 1 **Model Structure**



value from the product in two usage periods, $j = 1, 2$; two periods are enough to capture the key market characteristic that a consumer's usage value can vary across time and that during a period of low usage value, she can earn some income by renting out her product through a sharing platform. If the consumer rents out her product, she will earn a rental fee for that period but needs to pay the platform a percentage fee, denoted by an $\alpha \in [0, 1)$ fraction of the rental fee. Typically in practice, the sharing platform collects the rental fee from the renter, keeps a fixed α fraction of that fee as a service charge, and will give the remaining fraction $(1-\alpha)$ to the product owner. We model two types of transaction costs endured by the product owner when renting out her product—one that is proportional to the sharing price (e.g., the platform's fee) and one that is independent of the sharing price (e.g., costs of delivering and picking up the product, or the accelerated product maintenance cost due to moral hazard of the renter). From here on, unless stated otherwise, we use the term "transaction cost" to refer to the latter and "platform fee" to refer to the former.[5] Let $t \geq 0$ denote the transaction cost for each sharing transaction. The market structure is illustrated in Figure 1.

It is important to point out that, in contrast to the typical case of information goods, in our model, when the product owner rents out her product in a period, she forgoes her own use of the product for that period (i.e., she will get zero usage value in that period). Also in clear contrast to the case of a used goods resale transaction, in a product-sharing transaction, the product owner—the consumer who bought the product before—still owns the product's future continuation value (e.g., any future usage value and the salvage value ε) after the transaction. The sharing transaction is only for the product's usage right for one usage period, after which the product will be returned to the original owner.

Consumer's Strategic Options. Consumers are forward-looking; at the time of their product-purchase decision, they rationally anticipate the possibility of sharing or renting the product in the sharing market. Let p_j denote the sharing price in period j in the sharing market. Each consumer i can choose one of the eight (not-clearly-dominated) options listed below with the corresponding surplus, denoted by U_i:[6]

i. Buy the product and use it in both periods: $U_i = v_{i1} + v_{i2} - p + \varepsilon$.

ii. Buy the product, use it in period 1, and rent it out in the sharing market in period 2: $U_i = v_{i1} + (1-\alpha)p_2 - t - p + \varepsilon$.

iii. Buy the product, rent it out in the sharing market in period 1, and use it in period 2: $U_i = v_{i2} + (1-\alpha)p_1 - t - p + \varepsilon$.

iv. Do not buy the product but rent it in both periods: $U_i = v_{i1} - p_1 + v_{i2} - p_2$.

v. Do not buy the product but rent it only in period 1: $U_i = v_{i1} - p_1$.

vi. Do not buy the product but rent it only in period 2: $U_i = v_{i2} - p_2$.

vii. Buy the product (as a speculator) and rent it out in both periods: $U_i = (1-\alpha)p_1 - t + (1-\alpha)p_2 - t - p + \varepsilon$.

viii. Neither buy nor rent the product (i.e., the outside option): $U_i = 0$.

Market-Clearing Mechanism. With a sharing market, consumers may choose any of the above eight options. In each product usage period, some consumers may rent out their purchased products while others may rent a product from the product-sharing market. In equilibrium, the supply and the demand for product sharing will be equal.[7] In each period j, there will be a market-clearing price (p_j) that works to match the supply and demand; a consumer needs to pay p_j to rent the product from the market, and a consumer who rents out her product will receive a fee of $(1-\alpha)p_j$ while the platform keeps αp_j as its service fee.

[5] Section 5 provides a more explicit model of moral hazard and considers the possibility that both the product owner and the renter have transaction costs. The detailed analyses for these models are given in parts IV and V of the online appendix.

[6] It is suboptimal for consumers to buy the product in the second period since the retail price is the same across the two periods.

[7] The firm is assumed to play no direct role in the product-sharing market. In reality, in many markets, the firms (manufacturers) themselves do not offer hour-to-hour or day-to-day rentals of their products. This may be because the firm's transaction cost for managing the renting of its products is much higher than that for consumers. For example, a consumer with an Xbox console can rent it to others in her local area on a daily or weekly basis much more efficiently than Microsoft, the producer of the Xbox, since the company would have many logistical issues (e.g., because of the lack of physical presence in the consumer's local area or city). Indeed, in reality, on these product-sharing platforms (or the firms' stores), we typically do not see the firms themselves offering to rent their products on a day-to-day basis; for example, we do not see General Motors offering hourly rental of their cars on car-sharing websites or at its own dealerships. We discuss the third-party rental agency in Section 5.

Timing of Events. The timing of events in the core model is as follows. First, the firm chooses its retail price p. Second, consumers decide whether to buy the product. Third, in each usage period, consumers who bought the product before decide whether to use it themselves or to rent it out in the sharing market, while consumers who did not buy the product decide whether to rent it from the sharing market, which clears at some endogenously determined equilibrium price p_j, at which there is no excess demand or supply for sharing. Note that after each sharing transaction, the product is returned from the renter to the original product owner, who will obtain the salvage value (ε) at the end of the last usage period. Note also that the platform's percentage fee (α) is taken as given; this is because, in practice, the sharing platform's percentage fee is the same across different products. If we endogenize α in our model, it would imply that the platform optimizes its percentage fee on an *individual* product basis, charging a different percentage for different products, which clearly does not reflect reality. In reality, the sharing platforms charge a fixed percentage fee across different products, and that percentage is typically between 10% (e.g., on Spinlister) to 25% (e.g., on RelayRides). Nonetheless, our numerical study shows that the main results from our core model remain qualitatively the same even if the platform endogenously chooses its percentage fee.[8]

3. Analysis

In this section, we assume that the firm has developed the product, which has a quality level of q with a marginal cost of production c. The question is how the firm should optimally price its product in response to anticipated product sharing among consumers. Section 4 will examine the case in which the firm strategically chooses both its quality and price in anticipation of the consumers' product sharing. Key notations in this paper are summarized in Table 1.

The firm's profit is given by $\pi(p, q) = (p - c)d(p, q)$, where $d(p, q)$ denotes the firm's demand given its retail price p and product quality q. Note that in our model if $c < \varepsilon$, the firm will make infinite profit by producing infinite units of its product to get the salvage value. Furthermore, if $c \geq 2q + \varepsilon$, the firm will not produce the product since it will not be able to profitably sell any unit of the product. So we will focus on the nontrivial parameter range of $c \in [\varepsilon, 2q + \varepsilon)$. Note that $d(p, q) = 0$ if $p \geq 2q + \varepsilon$ and that the firm's profit will be negative if $p < c$. So to find the firm's optimal pricing, we need to examine only the case of $p \in [c, 2q + \varepsilon)$.

[8] The numerical study with the platform endogenously choosing its percentage fee is provided in part VI of the online appendix.

Table 1 Summary of Notations

Symbol	Description
$j = 1, 2$	Product usage periods
p	Retail price of the product
q	Quality of the product
c	The firm's marginal cost of production
$v_{ij} = q\theta_{ij}$	Consumer i's usage value for the product in period j, where $\theta_{ij} \sim \mathrm{U}(0, 1)$
p_j	The market clearance price for the secondary sharing market in period j
t	Product-sharing transaction cost (per period of sharing)
α	The platform's percentage fee
ε	The salvage value
$d(p, q)$	Firm's market demand given its retail price p and product quality q
U_i	Consumer i's utility
π	The firm's profit
sw	Social welfare
cs	Total consumer surplus
^{N}	This superscript indicates the case without sharing or collaborative consumption
^{S}	This superscript indicates the case with sharing or collaborative consumption
$_q$	This subscript indicates the case where the firm strategically chooses its quality

3.1. No Product-Sharing Market (N)

Let us first consider the benchmark case of a no product-sharing market. This case can happen, for example, if the transaction cost for sharing is prohibitively high (e.g., $t \geq q$).

As illustrated in Figure 2, consumers are uniformly distributed on the $q \times q$ square; given the firm's retail price p, only consumers with a total usage value of $v_{i1} + v_{i2} \geq p - \varepsilon$ will buy the product. The firm's demand function conditional on p and q is easily computed below depending on whether $p - \varepsilon \leq q$ or $p - \varepsilon > q$:

$$d^N(p, q) = \begin{cases} 1 - \dfrac{(p-\varepsilon)^2}{2q^2} & \text{if } 0 \leq p - \varepsilon \leq q, \\[2ex] \dfrac{1}{2}\left(2 - \dfrac{p-\varepsilon}{q}\right)^2 & \text{if } q < p - \varepsilon < 2q. \end{cases}$$

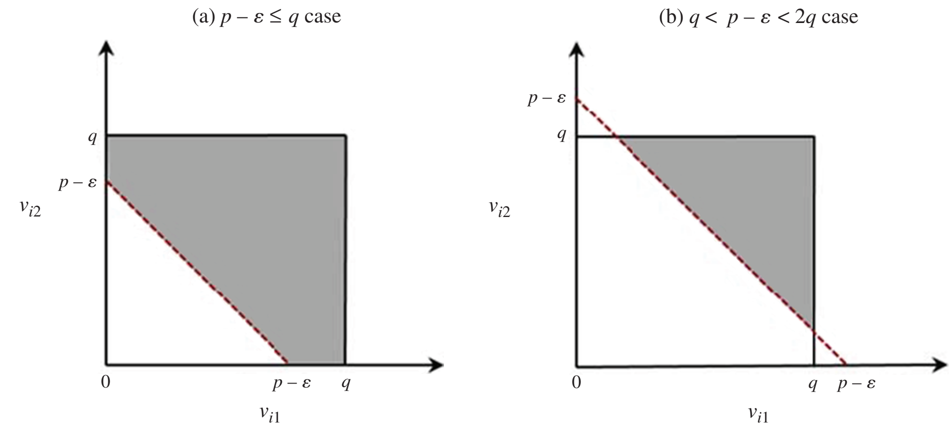
To reduce notational clutter, we define $\tilde{c} \equiv (c - \varepsilon)/q$ and use a superscript N to indicate the equilibrium outcome in this benchmark case of a no sharing market. One can show that the firm's optimal retail price is

$$p^N = \begin{cases} \dfrac{\tilde{c} + \sqrt{\tilde{c}^2 + 6}}{3} q + \varepsilon & \text{if } 0 \leq \tilde{c} < \dfrac{1}{2}, \\[2ex] \dfrac{2 + 2\tilde{c}}{3} q + \varepsilon & \text{if } \dfrac{1}{2} \leq \tilde{c} < 2. \end{cases}$$

The firm's demand at this optimal price is given by

$$d^N = \begin{cases} \dfrac{6 - \tilde{c}^2 - \tilde{c}\sqrt{\tilde{c}^2 + 6}}{9} & \text{if } 0 \leq \tilde{c} < \dfrac{1}{2}, \\[2ex] \dfrac{2(2 - \tilde{c})^2}{9} & \text{if } \dfrac{1}{2} \leq \tilde{c} < 2. \end{cases}$$

Figure 2 (Color online) Consumer Purchase Decision in the Absence of a Sharing Market



The firm's optimal profit is given by

$$\pi^N = \begin{cases} \dfrac{\tilde{c}^3+(\tilde{c}^2+6)\sqrt{\tilde{c}^2+6}-18\tilde{c}}{27}q & \text{if } 0 \le \tilde{c} < \dfrac{1}{2}, \\[2ex] \dfrac{2(2-\tilde{c})^3}{27}q & \text{if } \dfrac{1}{2} \le \tilde{c} < 2. \end{cases}$$

The total consumer surplus and social welfare are given by

$$cs^N = \begin{cases} \left[1+\dfrac{2\tilde{c}^3+(2\tilde{c}^2-24)\sqrt{\tilde{c}^2+6}-18\tilde{c}}{81}\right]q & \text{if } 0 \le \tilde{c} < \dfrac{1}{2}, \\[2ex] \left[\dfrac{4}{3}+\dfrac{8(1+\tilde{c})^3}{81}-\dfrac{4(1+\tilde{c})^2}{9}\right. \\[2ex] \qquad \left. -\dfrac{2\tilde{c}(2-\tilde{c})^2}{9}-\dfrac{2(2-\tilde{c})^3}{27}\right]q & \text{if } \dfrac{1}{2} \le \tilde{c} < 2 \end{cases}$$

and

$$sw^N = \begin{cases} \left[1+\dfrac{5\tilde{c}^3+(5\tilde{c}^2-6)\sqrt{\tilde{c}^2+6}-72\tilde{c}}{81}\right]q \\[2ex] \quad \text{if } 0 \le \tilde{c} < \dfrac{1}{2}, \\[2ex] \left[\dfrac{4}{3}+\dfrac{8(1+\tilde{c})^3}{81}-\dfrac{4(1+\tilde{c})^2}{9}-\dfrac{2\tilde{c}(2-\tilde{c})^2}{9}\right]q \\[2ex] \quad \text{if } \dfrac{1}{2} \le \tilde{c} < 2. \end{cases}$$

It is easy to verify that p^N increases in $\tilde{c}$, whereas d^N, π^N, cs^N, and sw^N all decrease in $\tilde{c}$.

3.2. Product-Sharing Market (S)

We now examine the case in which there exists a product-sharing market. We consider only the nontrivial case of $t \in [0, (1-\alpha)q)$, since if $t \ge (1-\alpha)q$, there will be no sharing transactions in equilibrium, and the results will be the same as if no sharing market exists.

Let us first determine the subgame equilibrium for the sharing market given the firm's price p. One can show that at a low enough price with $p-\varepsilon \le t/(1-\alpha)$, consumers will buy the product from the firm and no consumers will rent the product from the sharing market. By contrast, at a high price with $(2-\alpha)q - t < p-\varepsilon < 2q$, no consumers will be able to benefit from buying and then renting out the product. In summary, there will be transactions in the sharing market only if $t/(1-\alpha) < p-\varepsilon \le (2-\alpha)q - t$. This result suggests that the firm can interrupt the product-sharing market by adjusting its retail price (but that may not be optimal). Lemma 1 shows the firm's demand function and the subgame equilibrium market-clearing prices in the sharing market (when transactions exist).

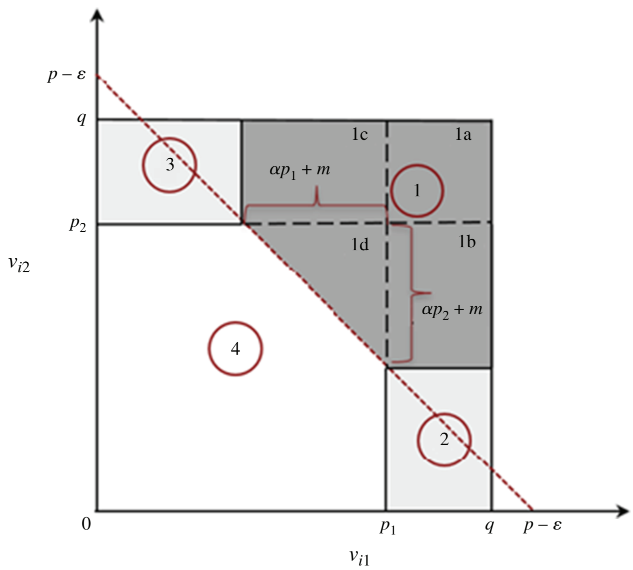
Lemma 1. *In the subgame following the firm's pricing decision, the firm's demand is given by*

$$d^S(p,q) = \begin{cases} 1-\dfrac{(p-\varepsilon)^2}{2q^2} & \textit{if } 0 \le p-\varepsilon \le \dfrac{t}{1-\alpha}, \\[2ex] 1-\dfrac{\alpha}{2(2-\alpha)}\dfrac{(p-\varepsilon)^2}{q^2}-\left(\dfrac{1-\alpha}{2-\alpha}+\dfrac{1}{2-\alpha}\dfrac{t}{q}\right) \\[2ex] \quad \cdot \dfrac{p-\varepsilon}{q}+\dfrac{1}{2-\alpha}\dfrac{t}{q} \\[2ex] \qquad\qquad \textit{if } \dfrac{t}{1-\alpha} < p-\varepsilon \le (2-\alpha)q-t, \\[2ex] \dfrac{1}{2}\left(2-\dfrac{p-\varepsilon}{q}\right)^2 & \textit{if } (2-\alpha)q-t < p-\varepsilon < 2q. \end{cases}$$

Product-sharing transactions exist in equilibrium only if $t/(1-\alpha) < p-\varepsilon \le (2-\alpha)q - t$ and the equilibrium market-clearing prices in the sharing market are $p_1 = p_2 = (p-\varepsilon+t)/(2-\alpha)$.

Given that the firm's price (p) and the product-sharing prices (p_j) are in the relevant ranges for sharing transactions to exist, we can divide all consumers into four segments based on their usage values in the two usage periods, as illustrated in Figure 3. Consumers in segment 1 (i.e., 1a, 1b, 1c, and 1d) will buy the product

Figure 3 (Color online) Consumer Decisions in the Presence of a Product-Sharing Market



from the firm and use it themselves in both periods. Consumers in segment 2 will use the product in the first period but not in the second period; they are indifferent between (a) buying the product and renting it out in the second period and (b) not buying the product but renting it from the sharing market in the first period. Similarly, consumers in segment 3 will use the product in the second period but not in the first period; they are indifferent between (a) buying the product and renting it out in the first period and (b) not buying the product but renting it from the sharing market in the second period. Consumers in segment 4 will not use the product in either period, and they will find it unprofitable to buy or rent out the product (as a pure rental intermediary). Note that, for a market-clearing equilibrium, we do not need to specify exactly which consumers in segments 2 and 3 will buy the product, who will use it in one period and rent it out in the other period, nor who among them will only rent the product from the sharing market. We need only match the aggregate sharing demand and supply from the two segments to determine the equilibrium sharing prices.

Comparing Figure 3 with Figure 2, we see clearly that product sharing makes a difference in reshaping the firm's demand. First, a consumer with a total usage value lower than $p-\varepsilon$ will not buy the product when no sharing market exists but may buy the product when the sharing market exists. This is because she anticipates a net positive benefit from renting the product out when her own usage value is low. Her net benefit from renting out her product in period j, net of her transaction cost (t), the platform's fee (αp_j), and her opportunity cost (the self-use value she forgoes, v_{ij}), is given by $(1-\alpha)p_j - v_{ij} - t$. Because of this anticipated benefit from sharing, consumers in segments 2 and 3 below the line $v_{i1}+v_{i2}=p-\varepsilon$, as illustrated in Figure 3, may now buy the product at price p, whereas they will not buy it when the sharing market does not exist. That is, the consumer's product sharing can increase the firm's demand.

Second, a consumer with a total usage value higher than $p-\varepsilon$ will buy the product when no sharing market exists but may no longer buy the product when the sharing market exists. This is because she can rent the product from the sharing market. In particular, consumers in segments 2 and 3 that are above the line $v_{i1}+v_{i2}=p-\varepsilon$ will buy the product at price p if there is no sharing market, but they may now rent the product from the sharing market instead. That is, product sharing can also reduce the firm's demand.

Having examined the equilibrium of the sharing market given the firm's price p, we now consider the firm's strategic pricing decision and the overall equilibrium outcome. We will focus on the equilibrium outcome in the parameter region where sharing transactions exist.[9] To reduce notational clutter, we define $\tilde{t} \equiv t/q$ and use a superscript S to indicate the equilibrium outcome for the current case with product sharing. One can show that the firm's optimal price is given by

$$p^S = \Big(\sqrt{[2(1-\alpha+\tilde{t})-\alpha\tilde{c}]^2+6\alpha[(2-\alpha+\tilde{t})+(1-\alpha+\tilde{t})\tilde{c}]} \\ -[2(1-\alpha+\tilde{t})-\alpha\tilde{c}]\Big)\cdot\frac{1}{3\alpha}q+\varepsilon.$$

The firm's demand at optimal pricing is given by

$$d^S = -\frac{\alpha}{2(2-\alpha)}\frac{(p^S-\varepsilon)^2}{q^2}-\left(\frac{1-\alpha}{2-\alpha}+\frac{1}{2-\alpha}\tilde{t}\right) \\ \cdot\frac{p^S-\varepsilon}{q}+\frac{1}{2-\alpha}\tilde{t}+1.$$

The firm's profit is $\pi^S=(p^S-c)d^S$. Social welfare is the sum of all the values created in the market less all the associated costs; one can simplify it to

$$sw^S = \frac{1}{3(2-\alpha)^3q^2}\{-\alpha(6+(-6+\alpha)\alpha)(p^S-\varepsilon)^3 \\ +3(-1+\alpha)[2+(-3+\alpha)\alpha+4\tilde{t}](p^S-\varepsilon)^2q$$

[9] Essentially, this means that we will focus on the parameter range

$$t<t^*=\begin{cases}\tilde{t}_Aq & \text{if } 0\le c<\dfrac{q}{2},\\ \tilde{t}_Cq & \text{if } \dfrac{q}{2}\le c<2q,\end{cases}$$

where

$$\tilde{t}_A=\frac{(1-\alpha)[\tilde{c}-(1-\alpha)+\sqrt{\tilde{c}^2+(1-\alpha)(6-2\alpha)\tilde{c}+3\alpha^2-14\alpha+17}]}{4-\alpha}$$

and $\tilde{t}_C$ is the solution of equation $sw^S=sw^N$. When t is larger than that threshold, there will be no transaction in the product-sharing market in equilibrium, which is not interesting.

$$+6\tilde{t}[2+\alpha(-3+\alpha+\tilde{t})](p^S-\varepsilon)q^2$$
$$+[4\tilde{t}^3+(3\alpha-6)\tilde{t}^2-3\alpha^3+18\alpha^2-36\alpha+24]q^3\}$$
$$-\tilde{c}d^S q.$$

The total consumer surplus is computed by subtracting the firm's profit and the platform's total fees from the social welfare; one can simplify it to

$$cs^S = sw^S - \pi^S - \alpha\frac{(p^S-\varepsilon)/q+\tilde{t}}{2-\alpha}\left[1-\frac{(p^S-\varepsilon)/q+\tilde{t}}{2-\alpha}\right] \cdot\left[(1-\alpha)\frac{(p^S-\varepsilon)/q+\tilde{t}}{2-\alpha}-\tilde{t}\right]q.$$

As in the case without any sharing market, we find that p^S increases in $\tilde{c}$, whereas d^S, π^S, cs^S, and sw^S all decrease in $\tilde{c}$.

3.3. Impact of Collaborative Consumption

We have analyzed the firm's strategic pricing decision and the equilibrium outcomes for the two cases based on whether the product-sharing market exists. We can now examine the impact of consumer-to-consumer product sharing on the firm's price, profit, the consumer's surplus, and social welfare. We study how two key factors—transaction costs (t and the platform's fee) and the firm's marginal cost (c)—affect the economic impact of collaborative consumption.

Proposition 1. *As the product-sharing transaction cost (t) increases, the firm's optimal retail price p^S will decrease, but the impacts of t on π^S, sw^S, and cs^S are nonmonotonic.*

The proofs of all propositions in this paper are provided in the appendix.

One may intuit that when the transaction cost for product sharing increases, the firm should raise the price of its product since its customers will be less likely to offer the competing rental option to other consumers, making these consumers more likely to buy the product. However, as Proposition 1 shows, a higher transaction cost for sharing will induce the firm to drop its price. To delineate the intuition, let us use a concrete example, documented in Table 2 (with $q=1$, $c=0.1$, $\alpha=0.1$, and $\varepsilon=0$), to first see the effect of the sharing market and then study what happens as the transaction cost increases. Without the sharing market, the firm's optimal price is $p^N\approx 0.85$. When the sharing market exists (e.g., under $t=0$), some consumers will switch from buying to renting the product from the sharing market. If the firm keeps its price at p^N, the firm's demand will drop from $d^N\approx 0.64$ to $\tilde{d}\approx 0.58$, and its profit will drop from $\pi^N\approx 0.48$ to $\tilde{\pi}\approx 0.43$. The firm will find it suboptimal to lower its price to retain those lost customers, because customers with a high usage value in one period but a very low usage value in another period will still rent out the product when they have a low self-use value, which will cannibalize the firm's sales. So the firm will find it optimal to raise its price to $p^S\approx 1.02 > p^N$, in an attempt to capture at least some of the product's value enhanced by the sharing market. As we see in Table 2 (with $t=0$), if the firm optimally raises its price from p^N to $p^S\approx 1.02$, its demand will drop further to $d^S\approx 0.49$, but its profit will improve from $\tilde{\pi}\approx 0.43$ to $\pi^S\approx 0.4503$, even though its profit is still lower than if the sharing market did not exist. As the sharing transaction cost increases, the product's value enhanced by the sharing market will decrease, and the cannibalization from the sharing market will also decrease; the firm's optimal price increase (from $p^N\approx 0.85$) will become lower ($p^S|_{t=0.1}\approx 0.98 < p^S|_{t=0}\approx 1.02$). A higher transaction cost for sharing will lead to a lower retail price, because with an increased transaction cost, some product buyers with a high usage value in one period but a low usage value in another period will not be able to earn as much rental income and hence will no longer be willing to buy the product at the same price. To compensate and retain some of these buyers, the firm will find it optimal to reduce its retail price when the sharing transaction cost increases. So, put differently, our result implies that *lower* frictions or transaction costs in the sharing market increase the consumer's incentives for product sharing but can induce the firm to *raise* rather than lower its price.

According to Proposition 1, because of the firm's strategic pricing, a change in the transaction cost t can have a nonmonotonic effect on the firm's profit, social welfare, and the total consumer surplus. So the sharing platform's effort to reduce the transaction cost for sharing may not always benefit the consumers or the firm. As the transaction cost decreases, product owners are more likely to share their products to earn higher rental income (net of the transaction cost and the platform

Table 2 **Example with a Low-Cost Product** ($q=1$, $c=0.1$, $\alpha=0.1$, $\varepsilon=0$)

		Retail price	Demand	Profit	Consumer surplus
Without sharing market		$p^N\approx 0.85$	$d^N\approx 0.64$	$\pi^N\approx 0.48$	$cs^N\approx 0.25$
With sharing market	$t=0$	Keep p^N	$\tilde{d}\approx 0.58$	$\tilde{\pi}\approx 0.43$	$\tilde{cs}\approx 0.320$
(keeping p^N)	$t=0.1$	Keep p^N	$\tilde{d}\approx 0.59$	$\tilde{\pi}\approx 0.44$	$\tilde{cs}\approx 0.317$
With sharing market	$t=0$	$p^S\approx 1.02$	$d^S\approx 0.49$	$\pi^S\approx 0.4503$	$cs^S\approx 0.23$
(strategic pricing)	$t=0.1$	$p^S\approx 0.98$	$d^S\approx 0.51$	$\pi^S\approx 0.4502$	$cs^S\approx 0.24$

fee), but the firm's strategic increase of its price will not only reduce the customer's net sharing benefit but also force some customers who only use the product themselves (e.g., in segment 1d in Figure 3) to drop out of the market. Hence, consumer surplus and social welfare in the market can drop.

Note that t is a product-sharing transaction cost that is independent of the sharing price, whereas the sharing platform's percentage fee represents a transaction cost that is directly proportional to the sharing price. By similar analysis and intuition, we easily obtain the corollary that a decrease of the sharing platform's percentage fee (i.e., α) may not always benefit the consumers or the firm. In summary, frictions in the sharing market (e.g., the product-sharing transaction cost t and the platform percentage fee) have a nonmonotonic effect on the firm's profit and the total consumer surplus.

Corollary. *A decrease of the platform's percentage fee may not benefit the consumers or the firm.*

Some questions naturally arise. When is the firm likely to *benefit* from the consumers' product sharing? Under what situations will the sharing market *increase* consumer surplus and social welfare? Does product sharing necessarily affect the consumer and the firm in opposite ways? Note that if the sharing platform's percentage fee is excessively high (i.e., $\alpha > 1 - t/q$), there will be no sharing transactions in equilibrium. For the rest of this paper, we assume that the platform's percentage fee is not too high; more specifically, $\alpha < \alpha^*$ for some $\alpha^* < 1 - t/q$. Our analysis shows that the firm's marginal cost and the transaction cost for sharing play an important role in determining the effects of the product-sharing market.

Proposition 2. *When the firm's marginal cost c and the product-sharing transaction cost t are low, the existence of the sharing market will reduce both the firm's profit and the total consumer surplus (i.e., a lose-lose situation). Or, put mathematically, there exist $c_1 \in (\varepsilon, q/2+\varepsilon)$ and $t_1 \in (0, t^*]$ such that $\pi^S < \pi^N$ and $cs^S < cs^N$ if $c < c_1$ and $t < t_1$.*

Proposition 2 shows that when the firm's marginal cost is low and the transaction cost is not high, product sharing among consumers will hurt the firm. Again, let us use the example in Table 2 to delineate the intuition. Without a sharing market, the firm's optimal strategy for a low-cost product is to set a low price to have a large number of consumers buy the product (from Table 2, the optimal retail price and demand are $p^N \approx 0.85$ and $d^N \approx 0.64$). However, when the sharing market exists, even if the firm still charges the same low price p^N, the firm's demand will drop from d^N to $\tilde{d} \approx 0.59$ in the case of $t = 0.1$ and from d^N to $\tilde{d} \approx 0.58$ in the case of $t = 0$. The firm with a low-cost product will tend to have fewer consumers buying its product than when no sharing market exists, because there will be high availability of the (low-cost) products in the sharing market and some consumers will switch from buying to renting the product. That is also why when the transaction cost for sharing is lower, the firm's demand will drop more. Anticipating consumers' sharing, the firm will find it optimal to raise the price to capture some of the product's value enhanced by the sharing market; e.g., when $t = 0$, the firm's optimal price increases from $p^N \approx 0.85$ to $p^S \approx 1.02$, resulting in a further drop in demand to $d^S \approx 0.49$. Overall, as shown in Table 2, the firm's increased price is not enough to offset the reduction in demand, resulting in a lower profit than when no sharing market exists.

Furthermore, as Proposition 2 shows, in the case of a low-cost product, the sharing market with a low transaction cost will also reduce consumer surplus. This is because the firm will significantly increase its price, leading to lower unit sales and fewer consumers using the product than when no sharing market exists. As we see in Table 2, without the sharing market, the firm's optimal price is $p^N \approx 0.85$, the total quantity sold is $d^N \approx 0.64$, and consumer surplus is $cs^N \approx 0.25$. When the sharing market exists, if the firm keeps its price at p^N, consumers will benefit from product sharing although fewer consumers will buy (e.g., when $t = 0.1$, consumer surplus increases to $\tilde{cs} \approx 0.317 > cs^N$, though $\tilde{d} \approx 0.59 < d^N$). If the firm optimally raises its price from p^N to $p^S \approx 0.98$, the unit sales will drop further to $d^S \approx 0.51$, reducing the consumer surplus to $cs^S \approx 0.24 < cs^N$. As the transaction cost for product sharing decreases (say, $t = 0$), the impact of product sharing will strengthen, and the firm's optimal price increase will become larger, leading to much lower unit sales and hence reducing consumer surplus even further (e.g., $p^S|_{t=0} \approx 1.02 > p^S|_{t=0.1} \approx 0.98$, $d^S|_{t=0} \approx 0.49 < d^S|_{t=0.1} = 0.51$, $cs^S|_{t=0} \approx 0.23 < cs^S|_{t=0.1} \approx 0.24$). This finding shows that for products with low marginal costs of production, product sharing is a lose-lose situation for both the firm and the consumers. Can the product-sharing market *benefit* the firm or the consumers?

Proposition 3. *When the firm's marginal cost is high, the existence of the product-sharing market will benefit the firm and increase the consumer surplus (i.e., a win-win situation). Or, put mathematically, there exists $c_2 \in (q/2+\varepsilon, 2q+\varepsilon)$ such that $\pi^S > \pi^N$ and $cs^S > cs^N$ if $c > c_2$.*

Proposition 3 shows that when the firm's marginal cost of production is high, product sharing among consumers is a win-win situation for the firm and the consumers. When the sharing market does not exist, the firm's optimal strategy for its high-cost product is to charge a high price, and in equilibrium, only a small number of consumers will buy the product. With the sharing market, the firm has an incentive to increase its retail price. However, this is quantitatively different

Table 3 **Example with a High-Cost Product** ($q=1$, $c=0.95$, $\alpha=0.1$, $\varepsilon=0$, $t=0$)

	Retail price	Demand	Profit	Consumer surplus
Without sharing market	$p^N \approx 1.30$	$d^N \approx 0.25$	$\pi^N \approx 0.09$	$cs^N \approx 0.06$
With sharing market (strategic pricing)	$p^S \approx 1.44$	$d^S \approx 0.27$	$\pi^S \approx 0.13$	$cs^S \approx 0.07$

from the case of a low-cost product—the firm's optimal price in the absence of sharing is already high, the magnitude of the price increase as a result of consumers' product sharing is not as dramatic for high-cost products. We see that, for example, in the case of $t=0$, $p^S/p^N \approx 1.2$ for the low-cost product with $c=0.1$ (in Table 2), whereas $p^S/p^N \approx 1.1 < 1.2$ for the high-cost product with $c=0.95$ (in Table 3). Furthermore, for high-cost products, the firm can save a lot of marginal costs of production by selling fewer units at higher prices, which many consumers are willing to pay because of the potential earnings from renting out the product in the sharing market. Thus, the firm is better off. This finding suggests that a firm with high marginal costs of production may have incentives to promote or improve the sharing market to encourage consumers' product sharing even if the firm does not directly profit from the sharing market, because it can indirectly benefit by strategically raising its price to extract some value created by the sharing market.

Note that without the sharing market, only a small number of consumers will buy and use the high-cost product because of its high price. When a product-sharing market exists, some consumers with high usage values only in one period who otherwise will not buy the product will now buy the product even though the price is higher. This is because they anticipate the potential income from renting out the product during the period with low self-use value. This market-expansion effect is relatively stronger for products with high marginal costs—more consumers can use (buy or rent) the product when the sharing market exists. For example, for the low-cost product in Table 2 (with $c=0.1$ and $t=0$), the firm will sell *fewer* units after strategically increasing its price; i.e., $d^S \approx 0.49 < d^N \approx 0.64$ with $p^S \approx 1.02 > p^N \approx 0.85$. By contrast, for the high-cost product in Table 3 (with $c=0.95$ and $t=0$), the firm will sell *more* units even after it strategically increases its price; i.e., $d^S \approx 0.27 > d^N \approx 0.25$ with $p^S \approx 1.44 > p^N \approx 1.30$. As a result, the consumers' product sharing will increase the total consumer surplus (and also social welfare).

In summary, our analyses suggest that the consumer's sharing of high-cost products (such as high-tech products, cars, or agricultural equipment in developing countries) is overall beneficial for both the consumers and the firm. By contrast, the sharing of products with very low marginal costs (such as digital products or information goods) may be bad for both the consumers and the firm. These findings are consistent with the anecdotal observations that firms in industries with high marginal costs tend to encourage or facilitate sharing (e.g., GM) and firms selling information goods tend to discourage or curb consumers' sharing.

4. Strategic Quality Decision

With the booming and maturing of sharing markets, one may expect that firms will over time become more strategic when they design their products in anticipation of the consumers' product sharing. In this section, we explore such a situation, where the firm responds to the anticipated product sharing among consumers by strategically choosing not only its price but also its product quality. How will such strategic behaviors by the firm influence the market outcome and the impact of the consumer's product sharing? We address this research question by extending the core model to allow for the firm's endogenous quality decision.

The firm's marginal cost of production typically depends on the quality level of the product. For example, a luxury model of a car will cost the manufacturer more to make than an economy model. For analytical tractability, we use the commonly adopted quadratic cost function: $c = k_1 q^2$. To simplify later analytical expressions, instead of expressing the product's salvage value as some fraction of the cost (c) of producing the product, we write the product's salvage value as $\varepsilon = k_2 q^2$, where $k_2 < k_1$; i.e., the salvage value is a k_2/k_1 fraction of the marginal cost of the product.

Note that the transaction cost (t) for sharing can be related to the product's value, which depends on the quality of the product. For example, other things being equal, the product owner will assess a higher (moral hazard) cost for accelerated product depreciation or maintenance when sharing an expensive high-quality car than when sharing a low-quality economy car. This can be due to, for instance, the anticipated higher cost of maintenance services for the high-quality car (e.g., changing its high-performance tires or brakes) or other risks associated with sharing. For simplicity, we assume that $t = \tau q$, where τ represents the transactional friction of sharing.[10] Note that the extended game builds on the core model analyzed in the earlier

[10] Note that in this extension we model only the sharing transaction cost related to the product's value. There can also exist transaction costs that are independent of the product's value, such as costs of delivering and picking up the product. Analytical solutions for the model including both types of transaction costs become very cumbersome, but our qualitative insights and intuitions remain the same. Hence, we have chosen to present the simplified model in the current extension.

sections; the only difference is that the firm will now strategically choose both p and q to maximize its profit. We use a subscript q for the variables to indicate the current, endogenous-quality case.

4.1. No Product-Sharing Market (N)

We first examine the benchmark case with no product-sharing market. Define $k \equiv k_1 - k_2$. With similar analysis to that in the core model, we can obtain the firm's optimal price and quality: $p_q^N = 1/(2k) + \varepsilon$ and $q_q^N = 1/(2k)$, with a corresponding demand of $d_q^N = \frac{1}{2}$ and profit of $\pi_q^N = 1/(8k)$. The total consumer surplus is $cs_q^N = 1/(12k)$, and social welfare is $sw_q^N = 5/(24k)$.

4.2. With a Product-Sharing Market (S)

We now analyze the market outcome when a sharing market exists. Note that if the transaction cost is extremely high (i.e., when $\tau \geq 1$), there will be no sharing transactions and the market outcome will be the same as the benchmark case with no sharing market. So we will focus only on the case with $\tau < 1$. With similar analysis to that of the core model, it can be shown that the firm's optimal quality is given by

$$q_q^S = \frac{3\alpha - 3 - 3\tau + \sqrt{9\tau^2 + 2(9-\alpha)\tau - 7\alpha^2 + 14\alpha + 9}}{8k\alpha}.$$

Its optimal price is given by

$$p_q^S = \frac{3\alpha - 3 - 3\tau + \sqrt{9\tau^2 + 2(9-\alpha)\tau - 7\alpha^2 + 14\alpha + 9}}{4\alpha} q_q^S + \varepsilon.$$

The firm's demand at optimal pricing is

$$d_q^S = 1 - \frac{\alpha(p_q^S - \varepsilon)^2}{2(2-\alpha)(q_q^S)^2} - \frac{(1-\alpha+\tau)(p_q^S - \varepsilon)}{(2-\alpha)q_q^S} + \frac{\tau}{2-\alpha}.$$

The firm's profit is $\pi_q^S = [p_q^S - k(q_q^S)^2]d_q^S$, and social welfare is given by

$$\begin{aligned} sw_q^S = {} & \frac{1}{3(2-\alpha)^3(q_q^S)^2}\{\alpha[(6-\alpha)\alpha - 6](p_q^S - \varepsilon)^3 \\ & -3(1-\alpha)[2+(\alpha-3)\alpha+4\tau](p_q^S-\varepsilon)^2 q_q^S \\ & +6\tau[2+\alpha(\alpha+\tau-3)](p_q^S-\varepsilon)(q_q^S)^2 \\ & +[4\tau^3+3(\alpha-2)\tau^2-3(\alpha^3-6\alpha^2+12\alpha-8)](q_q^S)^3\} \\ & -k(q_q^S)^2 d_q^S. \end{aligned}$$

The total consumer surplus is computed by subtracting the firm's profit and the platform's total fees from the social welfare:

$$\begin{aligned} cw_q^S = {} & sw_q^S - \pi_q^S - \alpha\frac{(p_q^S-\varepsilon)/q_q^S+\tau}{2-\alpha}\left[1 - \frac{(p_q^S-\varepsilon)/q_q^S+\tau}{2-\alpha}\right] \\ & \cdot\left[(1-\alpha)\frac{(p_q^S-\varepsilon)/q_q^S+\tau}{2-\alpha} - \tau\right] q_q^S. \end{aligned}$$

4.3. Impact of Collaborative Consumption

Next we examine the economic impact of the product-sharing market by comparing the market outcomes in the case with the sharing market versus those in the case without. Since no consumers will share the product if $\tau \geq 1 - \alpha$ (in which case whether the sharing market exists makes no difference), we will focus on the nontrivial parameter region of $\tau \in [0, 1-\alpha)$.

Proposition 4. *There exists some $\alpha^{**} > 0$ such that if $\alpha < \alpha^{**}$, the product-sharing market will*

(i) *increase the firm's equilibrium quality, i.e., $q_q^S > q_q^N$;*

(ii) *increase the firm's profit but reduce consumer surplus, i.e., $\pi_q^S > \pi_q^N$ and $cs_q^S < cs_q^N$; and*

(iii) *increase (reduce) social welfare if the transaction cost is low (high)—put mathematically, $\exists\, \tau_1 \in (0, 1-\alpha)$ such that $sw_q^S > sw_q^N$ if $\tau \in [0, \tau_1)$ and $sw_q^S < sw_q^N$ if $\tau \in (\tau_1, 1-\alpha)$.*[11]

Proposition 4 shows that the consumer's product sharing gives the firm a strategic incentive to increase product quality. With the sharing market, those consumers with a high usage value in one period and a low usage value in another period will be willing to pay more for the product since they can earn some rental income from the sharing market when their own usage value is low. This in effect increases those consumers' willingness to pay for quality and hence gives the firm an incentive to raise its product quality in equilibrium. However, the increase in product quality does not lead to an increase in consumer surplus. In fact, because the firm will strategically raise its retail price to target a smaller number of customers, the existence of the sharing market will reduce the total consumer surplus even though some consumers with very high valuation for quality will become better off (as a result of the quality increase). By choosing its product quality and price strategically, the firm will make more profits when the sharing market exists. This result is different from the case where the firm strategically chooses only its price. The potential positive effect of product sharing on consumer surplus (shown in Proposition 3) goes away and the firm is always better off when it strategically chooses both its product quality and price. This difference mainly comes from the fact that, in anticipating the consumers' product sharing, the firm's endogenous quality decision allows it to strategically select a price–quality pair (or, equivalently, a price–cost pair, since the firm's marginal cost is a function of quality) to ensure higher profitability by extracting more surplus from customers. Proposition 4 also shows that the sharing

[11] Note that $\alpha < 1 - \tau$ is a *sufficient* condition for $q_q^S > q_q^N$ (and also for $p_q^S > p_q^N$ and $d_q^S < d_q^N$). In addition, our numerical study shows that Proposition 4, parts (ii) and (iii) hold if there exist sharing transactions; i.e., $\alpha < 1 - \tau$. That is to say, $\alpha^{**} = 1 - \tau$.

market increases social welfare when the transaction cost is low but not when the transaction cost is high. This finding suggests that it can be overall socially beneficial to reduce the transaction cost in the sharing market.

5. Alternative Models and Assumptions

In this section, we analyze and discuss the robustness of our insights to several alternative modeling assumptions. First, in part I of the online appendix, we first provide a benchmark analysis of a secondary used goods market to show how the product-sharing market differs from the secondary market. We assume that instead of the sharing market, there exists a secondary market for used goods, where between periods consumers can sell their products. There is an important conceptual difference between the secondary used goods market and the product-sharing market. A resale transaction in the secondary market involves the *permanent* transfer of product ownership (from the seller to the buyer), whereas a sharing transaction in the product-sharing market involves a *temporary* transfer of use right (from the product owner to the renter) only for the particular sharing period. Therefore, the product's future continuation value (including its future salvage value) will affect the equilibrium price in the secondary used goods market but not in the product-sharing market. This has important ramifications on the transaction costs in the markets—for example, the product's salvage value will increase the used goods resale transaction cost that is proportional to the transaction price (e.g., the platform's percentage fees). In reality, the transaction costs that are transaction-price dependent may also include sales tax or sales commissions. In our framework, if there is no transaction cost that is proportional to the transaction price (i.e., $\alpha = 0$) *and* if there are no differences in other transaction costs between the two types of markets, then the secondary used goods market will result in the same outcome as the product-sharing market. However, if there exists some transaction cost proportional to the transaction price (i.e., $\alpha > 0$), the secondary used goods market and the product-sharing market will be different. More specifically, even in our two-period model, we see that in the sharing market, the product's salvage value ε simply shifts the firm's retail price by ε in its demand function. Consequently, if the product's salvage value ε and its unit cost c change by the same amount, all the equilibrium results in our sharing model will be the same except that the equilibrium retail price will shift by ε. When ε and c do not change by the same amount, our equilibrium outcomes will depend on $c-\varepsilon$, and ε will not *qualitatively* change our results except shifting the parameter regions for those results. By contrast, in the secondary market, ε plays a more critical role in the firm's demand function, not merely shifting the retail price by ε. When $\varepsilon > (1-\alpha)/\alpha$, the results under the secondary market will be *qualitatively* different from our findings under the sharing market. For example, the existence of the sharing market will be a win-win situation for the firm and the consumers when the firm's marginal cost (or $c-\varepsilon$) is high and a lose-lose situation when the marginal cost is low. By direct contrast, the existence of a secondary used goods market will be a win-win situation for the firm and the consumers when the marginal cost (or $c-\varepsilon$) is *low* and a lose-lose situation when the marginal cost is *high*. Our analysis helps explain why, in reality, a consumer who needs to use a product will not buy and sell the used product frequently on a period-by-period basis but may have frequent rental or sharing transactions. Also, because the product's future continuation value has different effects on transaction costs across the two types of markets, we conjecture that the platform's percentage fee (if endogenized) will be much lower in the secondary used goods market than in the product-sharing market. The anecdotal evidence seems to support this intuition. For example, the percentage fee is approximately 4% in a secondary used goods market such as eBay (its "final value" selling fee for most product categories), but the percentage fee is typically 10% (e.g., on Spinlister) to 25% (e.g., on RelayRides) in the product-sharing market. We leave it to future research to analytically contrast the optimal platform fees and contracts between these different types of consumer-to-consumer markets.

Second, we extend our two-period product-sharing model to an n-period model. For analytical tractability, we assume that consumers learn their usage in each period at the beginning of that period. That is, when deciding whether to buy a product from the firm in the first period, consumers know their first-period usage value (i.e., v_{i1}), but for later periods $j = 2, \ldots, n$, they know only the distribution of their usage value; i.e., $v_{ij} \sim \mathrm{U}[0, q]$. We find that our main results remain qualitatively the same. Product sharing is a win-win situation for the firm and the consumers when the firm's marginal cost is high and a lose-lose situation when the marginal cost is low. Furthermore, the firm will find it optimal to increase its quality when the sharing market exists. The detailed analysis of this n-period model is given in part II of the online appendix.

Third, our core model has not explicitly considered any depreciation of the product over time. If we allow for product depreciation, e.g., the product quality is q for the first period but $q(1-\Delta)$ for the second period, where Δ represents the rate of depreciation over time, we find that in equilibrium, Δ will lower both the firm's retail price and the second-period sharing price. The analytical solutions for such a model become very cumbersome, but our main qualitative insights and intuitions remain the same as long as Δ is not too large. Hence, we have presented the simplified model (with $\Delta = 0$) as the main model and provided the detailed analysis for the case of $\Delta > 0$ in part III of the online appendix.

Fourth, the sharing market has a salient moral hazard problem—the consumer renting another's product may use it more abusively or carelessly than the product's owner does. For example, the renter may drive a rented car much less carefully with fast acceleration, hard braking, or not slowing down on uneven or speed-bumped roads. In our core model, the transaction cost t can be interpreted as a reduced-form moral hazard cost that is imposed on the product owner who rents out her product. For example, we can set t to be the expected cost to the product owner, which is the damage or accelerated depreciation d multiplied by the probability w of such damage occurring. We have also analyzed a more explicit model of moral hazard in the sharing market. More specifically, we assume that for each period the product is rented out, its quality will decrease by δq ($\delta < 1$) and its salvage value will decrease by m ($<\varepsilon$). In reality, the renters may not be able to readily observe the quality degradation of a previously rented product (i.e., whether a product has been rented out before). We analyze two cases. First, we analyze the case where the quality degradation of a previously rented product (as a result of the renter's moral hazard) is observable. Second, we examine the case where the renter does not directly observe the quality degradation of a previously rented product but will infer an expected degradation in quality of $\tilde{\delta} q$ with $\tilde{\delta} \leq \delta$, which in equilibrium will be fulfilled (from the early-period outcome). Our analysis shows that all our results remain qualitatively the same whether the renters observe the quality degradation caused by moral hazard. The only difference with our core model is that no sharing transaction occurs in the first period; i.e., in equilibrium, only consumers with high first-period usage value will buy the product. These consumers will use the product themselves in the first period and rent it out in the second period if their self-usage value is low. The detailed analysis of this moral hazard model is given in part IV of the online appendix. We acknowledge that this analysis is based on a two-period model for analytical tractability. In a general n-period model with moral hazard, the analysis for the sharing market becomes analytically intractable because there will be different quality variations of the products in the sharing market.

Fifth, our core model assumes that the product owner bears all transaction costs for sharing. But in reality, both the product owner and the renter have some transaction costs; for example, the renter may also have to incur some costs for picking up and returning the rented product. In part V of the online appendix, we analyze a product-sharing model with both parties having some transaction costs: the product owner incurs a cost t_1 and the renter incurs a cost t_2 for each sharing transaction. We show that this model extension is equivalent to our core model with the product owner's transaction cost t replaced by $t_1 + (1-\alpha)t_2$. Note that the total transaction cost $t_1 + t_2$ is not perfectly or fully internalized through the sharing price—the effective total transaction cost is *smaller* than the direct sum. So, when the renter shares some of the total transaction cost, product-sharing transactions will be more likely to occur. The underlying reason for this effect hinges on the fact that the renter's transaction cost tends to reduce the product-sharing price, which lowers the platform fee paid by the product owner, making sharing more likely.

Besides analyzing the above five formal models, we would also like to briefly discuss how our results may be affected if some other model assumptions are relaxed. First, we have implicitly assumed that consumers know ex ante (at the time of purchase) their usage valuation for each period. Actually, this assumption is not necessary; e.g., if consumer i has her usage values v_{i1} and v_{i2} switched between two periods, it will make no difference in our analysis as long as the consumer learns her usage value for each period at the beginning of that period. The assumption we make is only that the consumer's usage value in the population is uniformly distributed in each period. In addition, we have assumed that the consumer's usage values across different periods are not correlated. Note that if the consumers' usage values are perfectly positively correlated (e.g., each consumer has the same usage values across all periods), in equilibrium, there will not be any product sharing among consumers. In a model in which the consumers' valuations are partially correlated across different periods, we expect our main results and intuitions to hold qualitatively the same as long as there is enough valuation heterogeneity across consumers and across periods such that product sharing will occur in the market. The effects of product sharing will be moderated by positive correlation and enhanced by negative correlation between the consumer's usage values.

Second, note that our model explicitly allows consumers to work as a third-party rental company, which buys the product from the manufacturer/firm and rents it out in all periods. However, we have assumed that such a rental company acquires the product at the same price as consumers do, which leads to no speculators or pure rental agencies in equilibrium. In practice, a rental company might be able to buy the product at cheaper prices than consumers can, or perhaps it has lower transaction costs than do consumers. In that situation, the product-sharing price in the market will tend to be lower, and hence we expect that both the value-enhancement and cannibalization effects of consumer-to-consumer sharing will be moderated. The intuition and trade-off from our analysis will still be relevant. As we observe in reality, even in markets with product rental agencies, consumer-to-consumer product sharing is still flourishing.

Finally, our model assumes that all consumers are forward-looking and fully anticipate the possibility of product sharing. The opposite assumption is that consumers are all myopic; i.e., their purchase decisions are based only on their current-period utility, and when deciding whether to buy the product, they will not consider the potential income from product sharing in the future. In that extreme case, obviously, the firm's pricing and quality decisions will be the same as if the product-sharing market does not exist. However, since product owners can ex post decide to rent the product out during usage periods with low self-use values, the consumer surplus will be higher than in the case of forward-looking consumers—interestingly, consumers are better off being myopic than being strategic and forward-looking. In a model in which some consumers are myopic, we expect our main results and intuition to stay qualitatively the same as long as a large enough fraction of consumers are strategic, though the quantitative effects will be moderated.

6. Conclusions

Collaborative consumption has emerged as a major trend in recent years as the global economic recession has put financial pressure on consumers and as social concerns about consumption sustainability bring the society's attention to effective use of resources and products. Advances in mobile communication technologies and online product-sharing platforms have helped to facilitate product sharing among consumers on an unprecedented scale. Consumers share a wide range of products from bicycles, cars, and video game consoles to clothing, portable tools, and household appliances. We have provided an analytical model that captures the idea that a consumer's own usage value for her purchased product may vary over time. In a period of low self-use value, the product owner can forgo her product use and rent it out to others through a third-party sharing platform. For each sharing transaction, the renting customer pays a rental fee and the product owner pays the platform a percentage fee. We model two types of transaction costs for product sharing—one that is proportional to the sharing price (e.g., the platform's fee) and one that is independent of the sharing price (e.g., costs of delivering and picking up the product). We have examined the consumer's purchasing and sharing decisions, and we investigated how a brand owner or manufacturer of the product should strategically choose its price and product quality to respond to the anticipated product sharing among consumers. Our analysis shows that the firm's marginal cost of production and the transaction costs in the product-sharing market play a critical role in determining the market outcome.

We have shown several main findings. First, transaction costs in the sharing market, such as the transaction cost or the platform's percentage fee, have a nonmonotonic impact on the firm's profit, consumer surplus, and social welfare. Second, if the firm strategically chooses its price (taking quality as given), then product sharing among consumers can be either a lose-lose or a win-win situation for the firm and the consumers. It is a lose-lose situation when the firm's marginal cost is low and the transaction cost is not too high. By contrast, it is a win-win situation if the firm's marginal cost is high. Third, if the firm strategically chooses both its price and product quality in anticipation of the sharing market, consumer-to-consumer product sharing will lead to higher quality but even higher prices, increasing the firm's profit but lowering consumer surplus.

We conclude by pointing out some caveats and potential directions for future research. First, we have analyzed only a monopoly market. We expect that if the firm has competitors, its ability to extract consumer surplus from the product's value enhanced by the sharing market will be moderated, depending on the level of competition and product differentiation among competitors. So consumers will be more likely to benefit from sharing whereas the firms' gains from sharing may be very limited. Second, we have assumed that the firm plays no direct role in the sharing market. As the sharing economy grows, the firm itself may enter the sharing market. For example, BMW has recently entered into the U.S. car-sharing market and launched a new car-sharing service called ReachNow (Loizos 2016). Our future research will focus on the trade-off that a firm faces when directly entering into the sharing market. Third, we have not explicitly modeled any uncertainty in the sharing market. In essence, the consumer is assumed to be risk neutral and makes her decision based on the average of the anticipated revenue from product-sharing transactions. We have also focused on search goods rather than experience goods, whose quality may not be fully observed by the consumers prior to purchase. We will leave it to future research to study the effects of uncertainty in the sharing market and uncertainty in the firm's product quality. Fourth, we have assumed an exogenous proportional fee by the sharing platform, in line with the observed reality, where the platform's percentage fee does *not* vary across different products or product categories. However, it might be of interest to examine what happens if the platform charges different fee percentages based on some product characteristics (e.g., a lower percentage for high-end products to encourage the sharing of such products). Such studies may provide strategic recommendations different from the platforms' current strategies of not adjusting fee percentages based on products or product categories. Price discrimination issues by the sharing platform are outside the scope of this paper but deserve their own theoretical study in future research. Fifth, we have assumed that the firm sells its product directly to consumers; future research may explore how channel structures affect sharing. For example, Jiang and Tian (2016) study the effect of product sharing on channel members, similar to what Shulman and Coughlan (2007) do for the used goods market. Finally, collaborative consumption in the sharing economy is a fast-growing trend; we have studied consumer-to-consumer *product* sharing but not peer-to-peer *service* offerings such as Uber. When consumers share their purchased products (e.g., tools, cars), the manufacturers and the retailers of those products will be affected and can strategically change their decisions, which is the focus of our research. By contrast, when consumers offer their time or services (e.g., a consumer on TaskRabbit assembles IKEA furniture for another consumer), typically there is no strategic upstream supplier (manufacturer or retailer). In those situation, the labor market and the traditional service providers may be affected by the peer-to-peer service platforms. Theoretical research and empirical research on both types of collaborative consumption are of great managerial and academic interest.

Supplemental Material

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Appendix

Proof of Lemma 1. First, we will show the following lemma.

Lemma A. *Given the firm's retail price p, if in equilibrium there exist product-sharing transactions, then in equilibrium, $p_1 = p_2$ and $(1-\alpha)p_1 + p_2 - t = p - \varepsilon$ (and $p_1 + (1-\alpha)p_2 - t = p - \varepsilon$).*

Proof. We first prove that $p_1 = p_2$ if there are product-sharing transactions in equilibrium. It is equivalent to prove that it cannot be an equilibrium if $p_1 > p_2$ or $p_1 < p_2$. Consider the case where $p_1 > p_2$. If $p_1 + (1-\alpha)p_2 - t > p - \varepsilon$, option iv is dominated by option i (i.e., $v_{i1} + v_{i2} - p + \varepsilon > v_{i1} - p_1 + v_{i2} - p_2$) and option v is dominated by option ii (i.e., $v_{i1} + (1-\alpha)p_2 - t - p + \varepsilon > v_{i1} - p_1$). That is, no consumer will rent from the sharing market in period 1. But if $p_1 + (1-\alpha)p_2 - t \le p - \varepsilon$, then $(1-\alpha)p_1 + p_2 - t < p - \varepsilon$ (since $p_1 > p_2$), which implies that option iii is dominated by option vi (i.e., $v_{i2} + (1-\alpha)p_1 - t - p + \varepsilon < v_{i2} - p_2$). Meanwhile, no consumers will choose option vii since $(1-\alpha)p_1 - t + (1-\alpha)p_2 - t - p + \varepsilon < 0$. So no consumers (product owners) will rent the product out in period 2. Therefore, we conclude that $p_1 > p_2$ cannot constitute an equilibrium for the product-sharing market. Similarly, one can show that $p_1 < p_2$ cannot constitute an equilibrium, either. Altogether, we conclude that $p_1 = p_2$ must be true if there are sharing transactions in equilibrium. This result of an equal market-clearing price across the two periods is very intuitive since the demand and the supply in the sharing market are the same (symmetric) across the two periods.

Now we prove that $(1-\alpha)p_1 + p_2 - t = p - \varepsilon$ (i.e., $p_1 + (1-\alpha)p_2 - t = p - \varepsilon$) if there are product-sharing transactions in equilibrium. This is equivalent to proving that it cannot constitute an equilibrium if $(1-\alpha)p_1 + p_2 - t > p - \varepsilon$ (i.e., $p_1 + (1-\alpha)p_2 - t > p - \varepsilon$) or $(1-\alpha)p_1 + p_2 - t < p - \varepsilon$ (i.e., $p_1 + (1-\alpha)p_2 - t < p - \varepsilon$). First, suppose $(1-\alpha)p_1 + p_2 - t > p - \varepsilon$; i.e., $p_1 + (1-\alpha)p_2 - t > p - \varepsilon$. Then, option v is dominated by option ii (i.e., $v_{i1} + (1-\alpha)p_2 - t - p + \varepsilon > v_{i1} - p_1$), option vi is dominated by option iii (i.e., $v_{i2} + (1-\alpha)p_1 - t - p + \varepsilon > v_{i2} - p_2$), and option iv is dominated by option i (i.e., $v_{i1} + v_{i2} - p + \varepsilon > v_{i1} - p_1 + v_{i2} - p_2$). In summary, if $(1-\alpha)p_1 + p_2 - t > p - \varepsilon$ or $p_1 + (1-\alpha)p_2 - t > p - \varepsilon$, all consumers will prefer buying the product from the firm rather than renting it from the sharing market; i.e., there will be no sharing transactions. Second, suppose $(1-\alpha)p_1 + p_2 - t < p - \varepsilon$; i.e., $p_1 + (1-\alpha)p_2 - t < p - \varepsilon$. Then, option v dominates option ii (i.e., $v_{i1} + (1-\alpha)p_2 - t - p + \varepsilon < v_{i1} - p_1$), option vi dominates option iii (i.e., $v_{i2} + (1-\alpha)p_1 - t - p + \varepsilon < v_{i2} - p_2$), and no one will choose option vii (i.e., $(1-\alpha)p_1 - t + (1-\alpha)p_2 - t - p + \varepsilon < 0$). In summary, if $(1-\alpha)p_1 + p_2 - t < p - \varepsilon$ or $p_1 + (1-\alpha)p_2 - t < p - \varepsilon$, no consumers will buy the product to rent it out in the sharing market; i.e., there will be no transactions in the sharing market. Thus, if there are transactions in the sharing market, we must have $(1-\alpha)p_1 + p_2 - t = p - \varepsilon$ (i.e., $p_1 + (1-\alpha)p_2 - t = p - \varepsilon$) in equilibrium. This completes the proof of Lemma A.

We now prove Lemma 1. Note that if there are product-sharing transactions in period i, we must have $(1-\alpha)p_i -$

$t > 0$; i.e., $p_i > t/(1-\alpha)$. If $0 \le p - \varepsilon \le t/(1-\alpha) < p_i$, consumers will strictly prefer buying the product from the firm rather than renting it from the sharing market, and the firm's demand is easily computed: $d^S(p, q) = 1 - (p-\varepsilon)^2/(2q^2)$.

If $(2-\alpha)q - t < p - \varepsilon < 2q$, for option ii, consumer i's surplus is $v_{i1} + (1-\alpha)p_2 - t - p + \varepsilon \le q + (1-\alpha)q - t - p + \varepsilon < 0$; for option iii, the surplus is $v_{i2} + (1-\alpha)p_1 - t - p + \varepsilon \le q + (1-\alpha)q - t - p + \varepsilon < 0$; and for option vii, her surplus will be $(1-\alpha)p_1 - t + (1-\alpha)p_2 - t - p + \varepsilon \le (1-\alpha)q - t + (1-\alpha)q - t - p + \varepsilon < 0$. That is, no one will buy the product and then rent it out in the sharing market (i.e., there will be no sharing transactions), and the firm's demand is given by $d^S(p, q) = \frac{1}{2}(2 - (p-\varepsilon)/q)^2$.

Now we consider the case that $t/(1-\alpha) < p - \varepsilon \le (2-\alpha) \cdot q - t$. From Lemma A, if there are sharing transactions in equilibrium, we must have $p_1 = p_2$ and $(1-\alpha)p_1 + p_2 - t = p - \varepsilon$ (i.e., $p_1 + (1-\alpha)p_2 - t = p - \varepsilon$). If a consumer chooses option vii, her surplus will be $(1-\alpha)p_1 - t + (1-\alpha)p_2 - t - p + \varepsilon < -t < 0$, so no consumers will work as pure speculators. Next, we consider consumers' preferences over the other seven options. For ease of analysis, as illustrated in Figure 3, we divide all consumers into four segments based on the consumer's valuation in the two usage periods:

- *Segment* 1: Consists of four subsegments—1a: $v_{i1} \ge p_1$, $v_{i2} \ge p_2$; 1b: $v_{i1} \ge p_1$ and $(1-\alpha)p_2 - t \le v_{i2} < p_2$; 1c: $(1-\alpha) \cdot p_1 - t \le v_{i1} < p_1$ and $v_{i2} \ge p_2$; and 1d: $v_{i1} < p_1$, $v_{i2} < p_2$, and $v_{i1} + v_{i2} \ge p - \varepsilon$.
- *Segment* 2: $v_{i1} \ge p_1$ and $v_{i2} < (1-\alpha)p_2 - t$.
- *Segment* 3: $v_{i1} < (1-\alpha)p_1 - t$ and $v_{i2} \ge p_2$.
- *Segment* 4: $v_{i1} < p_1$, $v_{i2} < p_2$ and $v_{i1} + v_{i2} < p - \varepsilon$.

First, clearly, consumers in segment 1a will use the product in both periods. For option i, consumer i's surplus is $v_{i1} + v_{i2} - p + \varepsilon = (v_{i1} - (1-\alpha)p_1) + (v_{i2} - p_2) + t > 0$; for option iv, the surplus is $(v_{i1} - p_1) + (v_{i2} - p_2)$. So consumers in segment 1a will choose option i. Second, consumers in segments 1b and 2 will use the product in the first period. For option i, consumer i's surplus is $v_{i1} + v_{i2} - p + \varepsilon = (v_{i1} - p_1) + (v_{i2} - (1-\alpha)p_2) + t$; for option ii, the surplus is $v_{i1} + (1-\alpha)p_2 - t - p + \varepsilon = v_{i1} - p_1 > 0$; and for option v, the surplus is $v_{i1} - p_1 > 0$. When $v_{i2} - (1-\alpha)p_2 + t \ge 0$, option i gives the highest surplus; when $v_{i2} - (1-\alpha)p_2 + t < 0$, both options ii and v are the optimal choice. So consumers in segment 1b will choose option i, while consumers in segment 2 will choose ii or v. Third, similarly, consumers in segment 1c will choose option i, whereas consumers in segment 3 will choose option iii or vi. Fourth, clearly, consumers in segment 1d will not rent the product from the sharing market in any period. For option i, consumer i's surplus is $v_{i1} + v_{i2} - p + \varepsilon > 0$; for option ii, the surplus is $v_{i1} + (1-\alpha) \cdot p_2 - t - p + \varepsilon = v_{i1} - p_1 < 0$; and for option iii, the surplus is $v_{i2} + (1-\alpha)p_1 - t - p + \varepsilon = v_{i2} - p_2 < 0$. So consumers in segment 1d will choose option i. Finally, consumers in segment 4 will not use the product in either period, and they also find it unprofitable to buy the product and rent it out in the sharing market. In summary, consumers in segment 1 (i.e., 1a, 1b, 1c, and 1d) will choose to buy and use the product themselves in both periods. For consumers in segments 2 and 3, the best option is not unique. However, we know that in the first period, all consumers in segment 2 will use the product but consumers in segment 3 will not; in the second period, all consumers in segment 3 will use the product but consumers in segment 2 will not. That is, the demand in the sharing market is "segment 2" in the first period and "segment 3" in the second period. Note that the supply for the sharing market in each period comes from the products that consumers in segments 2 and 3 buy from the firm. Since in equilibrium the product-sharing demand in each period should be equal to the supply in each period, we obtain that, in equilibrium, half of all consumers in segments 2 and 3 will buy the product and the other half will rent from the product-sharing market. From Lemma A, by symmetry, we get $p_1 = p_2 = (p - \varepsilon + t)/(2-\alpha)$. Thus the firm's total demand is easily computed by summing up all consumers in segment 1 (including subsegments 1a, 1b, 1c, and 1d) and half of the consumers in segments 2 and 3: $d^S(p, q) = (1 - p_1/q) \cdot (1 - p_2/q) + (\alpha p_2/q + t/q)(1 - p_1/q) + (\alpha p_1/q + t/q)(1 - p_2/q) + \frac{1}{2}(\alpha p_2/q + t/q)(\alpha p_1/q + t/q) + (1 - p_1/q)((1-\alpha)p_2/q - t/q)$. Plugging in $p_1 = p_2 = (p - \varepsilon + t)/(2-\alpha)$, we have $d^S(p, q) = 1 - (\alpha/(2(2-\alpha)))((p-\varepsilon)^2/q^2) - ((1-\alpha)/(2-\alpha) + (1/(2-\alpha)) \cdot (t/q))((p-\varepsilon)/q) + (1/(2-\alpha))(t/q)$. $\square$

Proof of Proposition 1. For the firm's pricing strategy, taking the derivative gives us

$$\begin{aligned}
&\frac{\partial p^S}{\partial t} \\
&= \frac{1}{q}\frac{\partial p^S}{\partial \tilde{t}} \\
&= \frac{2}{3\alpha}\left(\frac{[2(1-\alpha+\tilde{t}) - \alpha\tilde{c}] + (3/2)\alpha(1+\tilde{c})}{\sqrt{[2(1-\alpha+\tilde{t}) - \alpha\tilde{c}]^2 + 6\alpha[(2-\alpha+\tilde{t}) + (1-\alpha+\tilde{t})\tilde{c}]}} - 1\right) \\
&< 0.
\end{aligned}$$

For other nonmonotonic results, we just need to prove them in the $\alpha = 0$ case, where $\pi^S = ([(2+\tilde{t}) - (1+\tilde{t})\tilde{c}]^2/(8(1+\tilde{t})))q$, $cs^S = [1 - 3(2+\tilde{t})^2/(16(1+\tilde{t})) + \tilde{t}^2/4 - \tilde{t}^3/12 - \tilde{c}(2+\tilde{t})/8 + \tilde{c}^2(1+\tilde{t})/16]q$, and $sw^S = [1 - (2+\tilde{t})^2/(16(1+\tilde{t})) + \tilde{t}^2/4 - \tilde{t}^3/12 - (3\tilde{c}(2+\tilde{t}))/8 + (3\tilde{c}^2(1+\tilde{t}))/16]q$. Note that $\partial\pi^S/\partial t = (1/q)(\partial\pi^S/\partial\tilde{t}) = (((2+\tilde{t}) - (1+\tilde{t})\tilde{c})/(8(1+\tilde{t})^2))[(1-\tilde{c})\tilde{t} - \tilde{c}]$. Note also that $\partial\pi^S/\partial t < 0$ when $t < (\tilde{c}/(1-\tilde{c}))q$ (i.e., $\tilde{t} < \tilde{c}/(1-\tilde{c})$), and $\partial\pi^S/\partial t > 0$ when $t > (\tilde{c}/(1-\tilde{c}))q$ (i.e., $\tilde{t} > \tilde{c}/(1-\tilde{c})$). One can show that $(\tilde{c}/(1-\tilde{c}))q < t^*$ given $0 \le \tilde{c} < \frac{1}{2}$. Furthermore, $\partial cs^S/\partial t = (1/q)(\partial cs^S/\partial\tilde{t}) = (8\tilde{t} - 4\tilde{t}^2 + 3/(1+\tilde{t})^2 - 3 - 2\tilde{c} + \tilde{c}^2)/16$ and $\partial sw^S/\partial t = (1/q)(\partial sw^S/\partial\tilde{t}) = (8\tilde{t} - 4\tilde{t}^2 + 1/(1+\tilde{t})^2 - 1 - 6\tilde{c} + 3\tilde{c}^2)/16$. It is straightforward to show that $\partial cs^S/\partial t \le 0$ and $\partial sw^S/\partial t \le 0$ at $t = 0$ and $\partial cs^S/\partial t > 0$ and $\partial sw^S/\partial t > 0$ at $t = t^*$ given $0 \le \tilde{c} < \frac{1}{2}$. $\square$

Note that because of continuity of functions, we can complete the proof by simply proving the result in the $\alpha = 0$ case for Propositions 2–4.

Proof of Proposition 2. We first compare the firm's profit. Consider the case where $0 \le \tilde{c} < \frac{1}{2}$. Defining $\Delta_1 \equiv \pi^S|_{t=0} - \pi^N = ((2-\tilde{c})^2/8)q - ((\tilde{c}^3 + (\tilde{c}^2 + 6)\sqrt{\tilde{c}^2+6} - 18\tilde{c})/27)q$, we have $\partial\Delta_1/\partial\tilde{c} = (1/6 + \tilde{c}/4 - (\tilde{c}^2 + \tilde{c}\sqrt{\tilde{c}^2+6})/9)q > 0$. If $\tilde{c} = 0$, $\Delta_1 = (1/2 - 2\sqrt{6}/9)q < 0$; if $\tilde{c} = \frac{1}{2}$, $\Delta_1 = (9/32 - 1/4)q > 0$. Thus, there exists some $\tilde{c}_1 \in (0, \frac{1}{2})$ such that $\pi^S|_{t=0} < \pi^N$ if $0 \le \tilde{c} < \tilde{c}_1$ and $\pi^S|_{t=0} > \pi^N$ if $\tilde{c}_1 < \tilde{c} < q/2$. Note that $\partial\pi^S/\partial t < 0$ when $t < (\tilde{c}/(1-\tilde{c}))q$ and $\partial\pi^S/\partial t > 0$ when $t > (\tilde{c}/(1-\tilde{c}))q$ (see the proof of Proposition 1). Given $0 \le \tilde{c} < \tilde{c}_1$, we have shown that $\pi^S < \pi^N$ at $t = 0$. One can also easily show that $\pi^S < \pi^N$ at $t = t^*$. Thus, $\pi^S < \pi^N$ if $0 \le \tilde{c} < \tilde{c}_1$.

Second, we compare the consumer surplus. Also consider the case where $0 \le \tilde{c} < \frac{1}{2}$, $\partial cs^S/\partial t \le 0$ at $t = 0$, and $\partial cs^S/\partial t > 0$ at $t = t^*$ (see the proof of Proposition 1). Note that $\partial^2 cs^S/\partial t^2 = (1/q)(\partial^2 cs^S/\partial t\partial \tilde{t}) = (4 - 4\tilde{t} - 3/(1+\tilde{t})^3)/(8q)$. Plugging in $\partial cs^S/\partial t = 0$, we have $\partial^2 cs^S/\partial t^2 = (8 - 4\tilde{t}^2 + 3/(1+\tilde{t})^2 - 6/(1+\tilde{t})^3 - 3 - 2\tilde{c} + \tilde{c}^2)/(16q) > (8 - 4\tilde{t}^2 + 3/(1+\tilde{t})^2 - 6/(1+\tilde{t})^3 - 4)/(16q) = (4(1+\tilde{t})(1-\tilde{t}) - 3(1-\tilde{t})/(1+\tilde{t})^3)/(16q) > 0$. It indicates that cs^S first decreases and then increases in t. One can easily show that $cs^S < cs^N$ at $t = 0$, $cs^S > cs^N$ at $t = t^*$. Thus, $\exists\, t_1 \in (0, t^*]$ such that $cs^S < cs^N$ if $t \in [0, t_1)$, $cs^S > cs^N$ if $t \in (t_1, t^*)$.

Note that $\tilde{c} = (c - \varepsilon)/q$. Summarizing the above results, we can conclude that $\exists\, c_1 \in (\varepsilon, q/2 + \varepsilon)$ and $t_1 \in (0, t^*]$ such that $\pi^S < \pi^N$ and $cs^S < cs^N$ if $c < c_1$ and $t < t_1$. □

Proof of Proposition 3. First, we compare the firm's profit. Consider the case where $\frac{1}{2} \le \tilde{c} < 2$. Note that $\partial \pi^S/\partial t = (1/q)(\partial \pi^S/\partial \tilde{t}) = (((2+\tilde{t}) - (1+\tilde{t})\tilde{c})/(8(1+\tilde{t})^2))[(1-\tilde{c})\tilde{t} - \tilde{c}]$. Because $(1-\tilde{c})\tilde{t} - \tilde{c} < 0$, we have $\partial \pi^S/\partial t < 0$. Since $\pi^S = \pi^N$ when $t = t^*$, we have $\pi^S > \pi^N$.

Second, we compare the consumer surplus. Also consider the case where $\frac{1}{2} \le \tilde{c} < 2$. Define

$$\begin{aligned}\Delta_2 &\equiv cs^S - cs^N \\ &= \left[1 - \frac{3(2+\tilde{t})^2}{16(1+\tilde{t})} + \frac{\tilde{t}^2}{4} - \frac{\tilde{t}^3}{12} - \frac{\tilde{c}(2+\tilde{t})}{8} + \frac{\tilde{c}^2(1+\tilde{t})}{16}\right]q \\ &\quad - \left[\frac{4}{3} + \frac{8(1+\tilde{c})^3}{81} - \frac{4(1+\tilde{c})^2}{9} - \frac{2\tilde{c}(2-\tilde{c})^2}{9} - \frac{2(2-\tilde{c})^3}{27}\right]q.\end{aligned}$$

Recall that cs^S first decreases and then increases in t (see the proof of Proposition 2). Plugging in $\partial cs^S/\partial t = 0$ (i.e., $8\tilde{t} - 4\tilde{t}^2 + 3/(1+\tilde{t})^2 - 3 - 2\tilde{c} + \tilde{c}^2 = 0$), we have

$$\begin{aligned}\Delta_2 &= cs^S - cs^N \\ &= \left[1 - \frac{\tilde{c}}{8} + \frac{3(2+\tilde{t})^2 + 3(1+\tilde{t})^2 - 3}{16(1+\tilde{t})} - \frac{\tilde{t}}{2} + \frac{\tilde{t}^3}{6}\right]q \\ &\quad - \left[\frac{4}{3} + \frac{8(1+\tilde{c})^3}{81} - \frac{4(1+\tilde{c})^2}{9} - \frac{2\tilde{c}(2-\tilde{c})^2}{9} - \frac{2(2-\tilde{c})^3}{27}\right]q.\end{aligned}$$

One can easily show that there exists some $\tilde{c}_2 \in (\frac{1}{2}, 2)$ such that $\Delta_2 > 0$ if $\tilde{c} > \tilde{c}_2$, regardless of the value of $\tilde{t}$ (e.g., $\tilde{c} = 2$). Thus, $cs^S > cs^N$ if $\tilde{c} > \tilde{c}_2$.

Note that $\tilde{c} = (c - \varepsilon)/q$. Summarizing the above results, we can conclude that $\exists\, c_2 \in (q/2 + \varepsilon, 2q + \varepsilon)$ such that $\pi^S > \pi^N$ and $cs^S > cs^N$ if $c > c_2$. □

Proof of Proposition 4. (i) Note that

$$\begin{aligned}q_q^S - q_q^N &= \frac{-3 + 3\alpha - 3\tau + \sqrt{9\tau^2 + (18 - 2\alpha)\tau - 7\alpha^2 + 14\alpha + 9}}{8k\alpha} \\ &\quad - \frac{1}{2k} = \frac{1}{8k\alpha} H_1,\end{aligned}$$

where $H_1 \equiv \sqrt{9\tau^2 + (18 - 2\alpha)\tau - 7\alpha^2 + 14\alpha + 9} - (3 + 3\tau + \alpha)$. It can be easily shown that $H_1 > 0$ when $\alpha < 1 - \tau$. Thus, $q_q^S > q_q^N$.

(ii) Because of continuity of functions, we can complete the proof by simply proving the result in the $\alpha = 0$ case. Noting that $\partial \pi_q^S/\partial \tau = ((2+\tau)^2/(54(1+\tau)^3 k))(\tau - 1) < 0$ and $\pi_q^S = \pi_q^N$ at $\tau = 1$, we conclude $\pi_q^S > \pi_q^N$ for any $\tau \in (0, 1)$. Also, $\partial cs_q^S/\partial \tau = (-\tau^5/4 - 5\tau^4/12 + 13\tau^3/36 + 13\tau^2/12 - 1/9)/(3(1+\tau)^3 k) = H_2/(3(1+\tau)^3 k)$, where $H_2 \equiv -\tau^5/4 - 5\tau^4/12 + 13\tau^3/36 + 13\tau^2/12 - 1/9$. Note that $\partial H_2/\partial \tau = -5\tau^4/4 - 5\tau^3/3 + 13\tau^2/12 + 13\tau/6 \ge$. One can show that $H_2 < 0$ at $\tau = 0$ and $H_2 > 0$ at $\tau = 1$. Thus, cs_q^S first decreases and then increases in τ. Since $cs_q^S < cs_q^N$ at $\tau = 0$ and $cs_q^S = cs_q^N$ at $\tau = 1$, we can conclude that $cs_q^S < cs_q^N$ for any $\tau \in (0, 1)$.

(iii) Taking the derivative gives $\partial sw_q^S/\partial \tau = (-\tau^5/4 - 5\tau^4/12 + 5\tau^3/12 + 5\tau^2/4 - 1/3)/(3(1+\tau)^3 k) = H_3/(3(1+\tau)^3 k)$, where $H_3 \equiv -\tau^5/4 - 5\tau^4/12 + 13\tau^3/36 + 13\tau^2/12 - 1/9$. Note that $\partial H_3/\partial \tau = -5\tau^4/4 - 5\tau^3/3 + 5\tau^2/4 + 5\tau/2 \ge 0$. One can show that $H_3 < 0$ at $\tau = 0$ and $H_3 > 0$ at $\tau = 1$. So sw_q^S first decreases and then increases in τ. Since $sw_q^S > sw_q^N$ at $\tau = 0$, and $sw_q^S = sw_q^N$ at $\tau = 1$, we can conclude that $\exists\, \tau_1 \in (0, 1)$ such that $sw_q^S > sw_q^N$ if $\tau \in [0, \tau_1)$, and $sw_q^S < sw_q^N$ if $\tau \in (\tau_1, 1)$. □

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