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RESEARCH ARTICLE

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Pricing and capacity allocation strategies: Implications for manufacturers with product sharing

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Abstract

Emerging sharing modes, like the consumer-to-consumer (C2C) sharing of Uber and the business-to-consumer (B2C) sharing of GoFun, have considerably affected the retailing markets of traditional manufacturers, who are motivated to consider product sharing when making pricing and capacity decisions, particularly electric car manufacturers with limited capacity. In this paper, we examine the equilibrium pricing for a capacity-constrained manufacturer under various sharing modes and further analyze the impact of capacity constraint on the manufacturer's sharing mode selection as well as equilibrium outcomes. We find that manufacturers with low-cost products prefer B2C sharing while those with high-cost products prefer C2C sharing except when the sharing price is moderate. However, limited capacity motivates manufacturers to enter into the B2C sharing under a relatively low sharing price, and raise the total usage level by sharing high-cost products. We also show that the equilibrium capacity allocated to the sharing market with low-cost products first increases and then decreases. Finally, we find that sharing low-cost products with a high limited capacity leads to a lower retail price under B2C sharing, which creates a win-win situation for both the manufacturer and consumers. However, sharing high-cost products with a low limited capacity creates a win-lose situation for them.

KEYWORDS

capacity allocation, pricing, product sharing, sharing mode

1 | INTRODUCTION

Across a wide range of fields, there has been a shift away from exclusive ownership and consumption of resources toward shared use and collaborative consumption. Many successful businesses, for example, Getaround for cars, 3D Hubs for 3D printers, LiquidSpace for office space, Airbnb for short-term house rentals, and Uber and Didi for transportation services, have provided evidence for the viability of the collaborative consumption of products and services and they are shaping the so-called sharing economy. As these examples suggest, the sharing economy has begun to permeate nearly every sector of the economy. According to PricewaterhouseCoopers, the sharing economy was already worth \$15 billion globally in 2013, and was projected to grow to \$335 billion by 2025, equaling the retail sector. China's State Information Center reports that the sharing economy in China will maintain a 40% annual growth rate in the coming years, with transaction volume expected to account for approximately 20% of the country's GPD by 2025.

In general, two types of sharing modes have emerged in practice. One is consumer-to-consumer (C2C) sharing, where consumers seek or provide sharing products and services through a third-party platform, for example, Airbnb and Didi. The other type of sharing mode, business-to-consumer (B2C) sharing, such as Mobike and Youon in China, allows the firm itself to compete with consumer providers by directly supplying sharing products. On the one hand, for both modes, consumers may switch from buying a product to just using a sharing product. Thus, the retail price should be lowered to maintain potential buying consumers. On the other hand, consumers may be willing to pay a higher retail price as they can gain incremental value by buying one product and then sharing the vacant product with others. It is thus not clear how the retail price should be adjusted in the presence of product sharing. Additionally, motivated by the rise of the sharing economy, traditional manufacturers in recent years have begun to play an active role in the sharing market. Particularly, many car manufacturers have combined sharing with retailing via various electric car-sharing programs, for example, GoFun launched by Shouqi Group in over 80 cities of China, ReachNow (2018) backed by BMW i3 EV, and WeShare which uses Volkswagen's e-Golf cars. The latest news and reports on mobility in China also focus on the emerging car-sharing programs. For example, in 2019 Caocao Zhuanche, as the first B2C new energy vehicle (NEV) sharing platform in China, was pushing for collaboration with Geely Auto and placed 33 000 of its Emgrand NEVs in operation in 31 cities. In these car-sharing programs, the manufacturer plays the role of both a product seller and a sharing-product owner. Such entry into the sharing market cannibalizes a manufacturer's retailing market as the sharing product can be viewed as a substitute, but entering the sharing market also creates extra sharing profits. Although the sharing market is the new trend, its profitability remains controversial, which motivates us to investigate whether and when these manufacturers should enter the sharing market.

As more traditional car manufacturers engage in electric car B2C sharing, we are witnessing significant capacity constraints in electric car production in three aspects. The first is the power battery (a key component of electric cars) supply shortage. On April 22, 2019, Green Cars Reports reported that battery shortages caused production delays for Audi e-tron. On August 12, 2019, Clean Technica reported that electric car growth produces battery shortages, and carmakers cannot match supply with demand. Furthermore, according to Herron (2013) and Elahi, Pun, and Ghamat (2019), Tesla cannot produce own-brand vehicles despite strong demand because it has limited battery supply. Based on our investigation of general motors' power battery supply program, we find that the scarcity of key battery metals such as lithium, cobalt, graphite and nickel accounts for the shortage of battery supply to a large extent, and the large price spikes of these metals make battery supply even harder. Second, there is an increase on the demand for the power battery with higher energy density, in response to the government's subsidization policy. Such subsidization policy is highly uncertain every year, for example, the energy density threshold in China has been raised from 105 Wh/kg in 2018 to 125 Wh/kg in 2019. This poses challenges for battery suppliers in reaching technology requirements, and at the same time, causes hesitation among power battery suppliers with respect to investments in battery production capacity. The third reason is the mismatch between the increasing rate of demand for electric cars and limited battery supply. According to the survey by J.D. Power, only 4.1% of global car sales were NEVs, but this number is expected to reach 35.8% by 2027. According to the China Association of Automobile Manufacturers, NEV production and sales in China were 1 270 000 and 1 256 000 in 2018, an increase of 59.9% and 61.7%, respectively. The increasing rate of lithium-ion power battery, however, was only 23.1% (EnergyTrend (2019)). Therefore, capacity constraint is a common and crucial factor affecting the electric car industry. Moreover, the existing literature has shown that capacity constraint affects both the firms' strategy selections, such as the distribution channel (see Yang, Hu, Gurnani, & Guan, 2018), and operational decisions, such as pricing and capacity allocation (see Cachon & Lariviere, 1999a, 1999b; Roels & Tang, 2017). The strategic role of capacity constraint in the product sharing setting, however, has yet to be fully studied. This motivates us to investigate how capacity constraint influences and interacts with a manufacturer's product sharing strategies. Apart from the electric car industry, our work can be applied to other capital-intensive industries for which capacity constraint is also crucial (Durango-Cohen & Yano, 2006), such as computer numerically controlled machines sharing.

The goal of this paper is to propose a stylized model to examine equilibrium pricing for a capacity constrained manufacturer under various sharing modes, including no sharing, C2C sharing, and B2C sharing, and to further address whether and when the manufacturer will be better off with B2C sharing. Additionally, capacity constraint is considered as a key factor in determining the capacity allocation strategies for a manufacturer that enters into the sharing market. We further investigate the strategic role of capacity constraint in terms of the manufacturer's strategic sharing mode selection, operational decisions, and social implications. We highlight a few major findings as follows.

First, in contrast to Jiang, Tian, and Xu (2019), we examine equilibrium pricing for a capacity-constrained manufacturer under both C2C sharing and B2C sharing, and investigate how different exogenous sharing prices and marginal production costs affect the manufacturer's entry into the sharing market. In the benchmark case with no capacity constraint, our results demonstrate that manufacturers with low-cost products under a high sharing price are reluctant to enter the sharing market. Otherwise, manufacturers with high-cost products prefer C2C sharing, as is concluded by Jiang and Tian (2018), while manufacturers with low-cost products prefer to enter the sharing market except when the sharing price is moderate.

Second, we contribute to the literature by modeling the competition between a manufacturer's retailing and sharing market which is not considered by Bellos, Ferguson, and Toktay (2017), and further analyzing the impact of capacity constraint on the manufacturer's entry into the sharing market and the manufacturer's capacity allocation strategies. We find that moderate limited capacity will motivate the manufacturer to enter the sharing market under a relatively low sharing price. The equilibrium capacity allocated to the retailing market is monotone increasing in the manufacturer's total capacity while that allocated to the sharing market is not always monotone. Particularly, for low-cost products, the equilibrium capacity allocated to the sharing market first increases and then decreases as total capacity increases.

Third, we investigate how capacity constraint affects consumers in terms of the retail price and society in terms of total usage level. Our results reveal that sharing low-cost products with a significantly limited capacity leads to a lower consumer price under B2C sharing, which creates a win-win situation for both the manufacturer and the consumer. However, sharing high-cost products with a less limited capacity creates a win-lose situation for them. Furthermore, a moderately capacity-constrained manufacturer's entry into the sharing market with high-cost products could increase the total usage level.

We also verify the robustness of our results and insights to several alternative modeling assumptions. First, we discuss whether our main results are affected if the sharing price is endogenously determined or matching friction is considered. Second, we provide an extension analysis of the hybrid sharing mode where B2C sharing coexists with C2C sharing. This helps us link pure C2C sharing with pure B2C sharing and characterize the impact of consumers' sharing mode preference. Third, we extend our basic two-period model to an n-period products bundling model. We find most of these main results still hold under mild conditions or a low commission fee.

The reminder of the paper is organized as follows. In the next section, we briefly review the related literature. Section 3 describes our proposed model to investigate the manufacturer's product sharing problem. Section 4 presents the equilibrium outcomes in the presence of product sharing and capacity constraint. Then in Section 5, we investigate the strategic role of capacity constraint in terms of the manufacturer's capacity allocation, sharing mode selection and other equilibrium outcomes. We discuss three extensions in Section 6, and finally, we provide concluding remarks in Section 7.

2 | LITERATURE REVIEW

There are four streams of literature related to this study. First, an emerging stream of empirical research examines the implications of the sharing economy, which can be categorized in terms of the consumer's side, the provider's side, and the incumbent firm's side. Narasimhan, Papatla, and Ravula (2016) examine how consumer's price sensitivity changes following the advent of shared services. Nijland, van Meerkerk, and Hoen (2015) study car sharing that involves a third-party service provider and find that car sharing leads to a net decrease in car usage. Ballus-Armet, Shaheen, Clonts, and Weinzimmer (2014) show that approximately 25% of surveyed car owners would be willing to share their vehicles through C2C sharing, with liability and trust concerns being the primary deterrents. Wu, Wang, and Zhu (2016) also focus on the provider's side by investigating how the productivity of providers is affected by demand-allocation mechanisms. Using Airbnb listings in Paris as a relevant application, Cui and Hu (2019) offer empirical evidence that sharing living accommodations can create value for both consumers and providers, which is termed social utility, and further considered in a theoretical pricing model. Another side affected by the sharing economy is the incumbent firm. Zervas, Proserpio, and Byers (2017) present that the market entry of Airbnb in Texas negatively influenced hotel room revenue and a 10% increase in the size of Airbnb supply resulted in an approximate 0.4% reduction in hotel room revenue. Wallsten (2015) examines how conventional taxi firms respond to the rise of Uber and other similar services in New York and Chicago. The author suggests that these taxi firms should respond to new competition by improving their service quality. All of the mentioned studies show that the advent of C2C sharing has considerably affected the participants' valuation, usage, and thus the incumbent manufacturers' retailing market. However, few studies examine equilibrium pricing in the presence of C2C sharing, or B2C sharing. Our work enriches this stream of literature by investigating equilibrium pricing for traditional manufacturers considering the potential interaction between a manufacturer's own retailing and sharing markets, and analytically provide suggestions as to how the manufacturer should respond to product sharing.

A second body of literature analytically addresses the sharing economy pricing. One common perspective is that the platform decides the sharing price and wage (see Benjaafar & Hu, 2020). For example, both Riquelme, Banerjee, and Johari (2015) and Cachon, Daniels, and Lobel (2017) compare the impact of static versus dynamic prices and wages. Gurvich, Lariviere, and Moreno (2019) examine the optimal price and wage decisions by developing a newsvendor-style model. Hu and Zhou (2019) show that it is optimal for the platform to offer a constant payout ratio, depending on the price and wage sensitivity coefficients of the linear demand and supply functions. Furthermore, Taylor (2018) examines the precommitted price and wage based on consumer demand and other operating factors in the context of on-demand services. Complementing Taylor's work, Bai, So, Tang, Chen, and Wang (2019) focus on the impact of the demand rate, sensitivity to waiting time, service rate, and the size of available providers on the optimal price, wage and payout ratio. This perspective is mainly studied in the context of on-demand services based on the two-sided market theory, which differs from our setting of product sharing. Another perspective that is closer to ours is the manufacturer's pricing in the sharing economy. Weber (2016), which uses an overlapping-generations model to study the incumbent firm's optimal pricing in the presence of sharing markets, is later extended in Razeghian and Weber (2016) by allowing for product-durability decisions. Based on product bundling theory, where a product can be viewed as a bundle of the consumer's product usage over all periods when it can be used in multiple periods, Jiang and Tian (2018) present a two-period model in which the demand always matches the supply through a market-clearing mechanism and investigate how the existence of a peer-to-peer rental market affects the incumbent firm's pricing and quality decisions. Our work is also inspired by product bundling theory, but there are two major differences in our work. One difference is that we assume an exogenous sharing price in the basic model and consider endogenously determined prices in extensions as in Benjaafar, Kong, Li, and Courcoubetis (2019). We focus on whether and when the manufacturer has motivation to engage in B2C sharing. The other difference is that we characterize two types of interactions between a manufacturer's retailing and sharing, which are not fully studied in the previous literature. One interaction comes from the manufacturer's own consumers who may indirectly compete with the manufacturer itself by sharing the purchased products with other consumers. The other interaction is caused by the manufacturer's entry into the sharing market, which cannibalizes the retailing market.

The third body of literature considers the manufacturer's business model design. Bellos et al. (2017) study the economic and environmental implications of an auto manufacturer offering a car-sharing service in addition to sales. Agrawal and Bellos (2017) examine the broader implications of business models by analytically investigating when and why servicizing is both more profitable and environmentally superior to a conventional sales model. These two works focus on green product design. However, these studies do not consider the interaction between the sharing market and the retailing market. Abhishek, Guajardo, and Zhang (2019) compare monopoly selling and rental with a corporate-sponsored peer-to-peer market and find that when the usage rates are low, an OEM who manufactures durable goods prefers to offer both purchase and rental options. Additionally, from the perspective of an OEM manufacturing durable goods, Blaettchen, Hasija, and Taneri (2018) emphasize economic factors, such as breakdowns and after-sales services, and investigate whether the OEM should continue the sales model with after-sales services or move toward an access-based consumption model of servicization. Furthermore, Razeghian and Weber (2019) examine a manufacturer's optimal strategy for offering products, be it for sale, rent, or a combination thereof. The authors' main concern is how the selected strategy is affected by the population's sharing propensity. Jiang et al. (2019), the closest study to our work, investigate the specific conditions under which a manufacturer enters into the product sharing market to compete with C2C sharing and the potential impact of such entry on consumers and society. Instead of analyzing the choices among a series of business models, we consider a manufacturer's sharing mode selection, for example, when to engage in B2C sharing as in Jiang et al. (2019). However, what distinguishes our work from the above literature is the impact of the manufacturer's capacity constraint on the sharing mode selection and other equilibrium outcomes.

Lastly, our research complements the stream of literature on capacity allocation decisions. Capacity allocation is thoroughly investigated in the game-theoretic framework. For example, Roels and Tang (2017); Kostami, Kostamis, Ziya (2017) study how to improve the efficiency of capacity allocation decisions in a bidirectional alliance that involves the sharing of two complementary resources, for example, production and distribution capacity. The authors propose that contractually specifying certain capacity allocation rules in advance may help avoid potential disputes. Furthermore, extensive research has been conducted in the setting of one capacity-constrained manufacturer and multiple distributors. Cachon and Lariviere (1999a, 1999b) evaluate several allocation rules. The authors find that distributors tend to order more than they actually need under proportional and linear allocation rules whereas truth-telling is induced by uniform and lexicographic rules. Karabuk and Wu (2005) study the reference allocation mechanism. Later, Cho and Tang (2014) establish a new rule called "competitive allocation" which can induce truth-telling. These works focus on how a manufacturer's capacity allocation affects downstream distributors' ordering behaviors. However, they do not consider the impact of different consumer behaviors on the manufacturer's optimal capacity allocation strategies. To characterize such an impact, Liu and van Ryzin (2008) examine the optimal capacity-rationing strategy to induce early purchases where consumers strategically choose the purchase time to maximize their expected surplus. Additionally, Su and Zhang (2008) study how a firm's capacity commitment affects supply chain performance and consumer demand. In the retailing setting, Huang and Liu (2015) evaluate the impact of consumers' bounded rationality on capacity management decisions. More recently, Tian and Jiang (2018) analyze how the upstream manufacturer should strategically choose its production capacity and wholesale price, and how the retailer should strategically choose its retail price to respond to anticipated product sharing by the consumer. In contrast, our work contributes to this stream of literature by studying how strategic consumers' purchasing and sharing behaviors affect a capacity-constrained manufacturer's equilibrium capacity allocation.

3 | MODELING

Consider a monopolist manufacturer who produces a product of quality q at a marginal cost c and then sells it at retail price p or shares it with consumers. The monopolist manufacturer in our model has capacity constraint K. We observe from practice that manufacturers often have limited production capacity, which constrains how many units of product they can produce and the allocation between the retailing and sharing markets.

Each consumer buys at most one unit and can derive usage value from the product in n periods. Each consumer's per-period usage value from the product may vary over time. Consumer i's usage values v_{ij} for period $j \in \{1, 2, \ldots, n\}$

depend on the product's quality (q) and the consumers' willingness to pay for quality (θ_{ij}). We assume $v_{ij} = q\theta_{ij}$, where θ_{ij} is uniformly distributed in the consumer population: $\theta_{ij} \sim \mathcal{U}(0, 1)$. 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); Tirole (1988) For expositional clarity, we assume $n = 2$ for the main model, that is, consumers can derive usage value from the product in two usage periods. Two periods are enough to capture the key market characteristic that a consumer's usage value can vary across time and, during a low usage value period, the consumer can earn some income by sharing the product with others through a sharing platform. Once the consumer becomes a product owner, he can make extra profit by placing the product on the sharing platform during the period of low self-use value. In contrast to the typical case of information goods, the product owner only forgoes his own use of the product for sharing period but still owns the product's future continuation value after the transaction. Or, a consumer can use the product from the sharing platform in period j by paying a usage fee p_j, instead of buying a product. For example, BMW's ReachNow allows consumers who cannot afford an expensive car to still use such a car.

The sharing platform benefits partly from the consumer's usage fee in each period j, denoted by αp_j. Thus $(1-\alpha)p_j$ is paid to the sharing-product owners. Note that the sharing platform's commission rate $\alpha \in [0, 1)$ is given. In contrast to previous studies on sharing transactions highlighting the market-clearing mechanism with an endogenous sharing price, we assume an exogenous sharing price that is fixed across periods (Section 7 offers the discussion of an endogenous sharing price model where it is determined by the sharing platform.) for the following three reasons. First, such exogenous sharing price is not uncommon in reality as a result of intensive competition and governmental regulation (Ministry of Transport of the People's Republic of China (2019)). For example, as is provided by Jiang et al. (2019), Mercedes-Benz CLA-Class 2015 White model was priced \$79 on Car2go versus \$80 on Turo in January 2018. In China, according to iResearch (2019), by February 2019, the number of registered car sharing firms in China has surpassed 1600, and leading players such as Gofun backed by Shou Qi Group and Morefun launched by BAIC Group adopt similar sharing pricing. Second, an exogenous sharing price is also assumed in the existing literature, for example, the basic model in Benjaafar et al. (2019). (The authors also discuss an extended model where the sharing price is optimally chosen by the platform, which motivates our first extension on endogenous sharing prices.) Third, from a technical perspective, endogenizing the sharing price reduces the optimization problem's tractability. When the platform is the game leader, the endogenized sharing price will essentially be a certain exogenous value for the manufacturer. Our focus is how capacity constraint affects the manufacturer's strategic and operational decisions, and an endogenous sharing price complicates the exploration of managerial insights.

Note that usually a product owner shares his product in a short term like the hourly charge of many shared products in practice. However, manufacturers do not change their retail prices p with such frequency. Thus, we concentrate on a fairly reasonable case where the manufacturer strategically chooses its price and does not dynamically adjust the price across periods. Specifically, our work analyzes a capacity-constrained manufacturer's pricing and capacity allocation strategy under various sharing modes: no sharing, C2C sharing and B2C sharing, denoted by N, C, and B, respectively. Under the no sharing mode, the monopolist manufacturer only sells its products to consumers. Neither the manufacturer nor the consumers provide sharing products in the current market, but some consumers are satisfied by an outside option. Under the C2C sharing mode, some consumers can buy and then share the products with others through the sharing platform to gain extra income while some may seek sharing product usage instead of buying the product from the manufacturer. Considering the manufacturer's entry into the product sharing market, B2C sharing, as the third mode, allows the manufacturer to simultaneously sell and share its products, which may cannibalize the manufacturer's retailing market but create extra profits from the sharing market. The model structure is illustrated in Figure 1.

3.1 | Strategic consumer behavior

The consumers in our model are forward-looking. They anticipate the probability of sharing or using the product in the sharing market at the time of product purchase. We assume that consumer i learns his own usage for period j at the beginning of that period and he knows the distribution of his usage values: $v_{ij} \sim \mathcal{U}(0, q)$. Considering a consumer's buying decision and the potential sharing decisions in two periods, there exist eight strategic consumer behaviors which are listed below, with corresponding total expected utility denoted as U_i.

- i Buy the product and use it in both periods: $U_i = v_{i1} + v_{i2} - p$.
- ii Buy the product, use it in period 1, and share it on the sharing platform in period 2: $U_i = v_{i1} + (1-\alpha)p_2 - p$.
- iii Buy the product, share it on the sharing platform in period 1, and use it in period 2: $U_i = v_{i2} + (1-\alpha)p_1 - p$.
- iv Buy the product, share it on the sharing platform in both periods: $U_i = (1-\alpha)p_1 + (1-\alpha)p_2 - p$.
- v Do not buy the product but use the sharing product in period 1: $U_i = v_{i1} - p_1$.
- vi Do not buy the product but use the sharing product in period 2: $U_i = v_{i2} - p_2$.

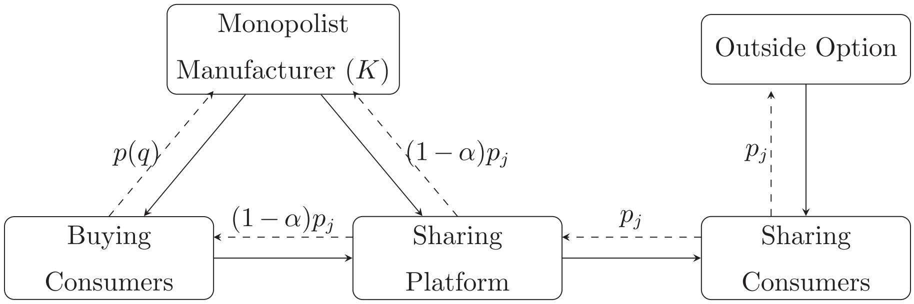


FIGURE 1 Model structure

vii Do not buy the product but use the sharing product in two periods: $U_i = v_{i1} - p_1 + v_{i2} - p_2$.
viii Neither buy nor use the sharing product in both periods: $U_i = 0$.

3.2 | Sequence of events

The sequence of events is as follows. First, the monopolist manufacturer allocates its capacity K between the retailing market and the sharing market (if it enters the product sharing market) and chooses its retail price. Second, consumers strategically decide whether to buy a product from the manufacturer. Third, consumers who have bought the product, including the manufacturer, are called product owners (either C2C or B2C sharing), and decide whether to share the product with others through a sharing platform. Meanwhile, consumers who did not buy the product decide whether to seek use of the product in the sharing market.

3.3 | The manufacturer's optimization problem

Suppose the manufacturer with capacity K has launched the product with quality level $q = 1$ at marginal production cost c. The question is how the monopolist manufacturer facing various sharing modes should use its capacity and optimally price the product in response to the expected retailing and sharing demand. Note that if $c \geq 2q$, the manufacturer will not produce the product because the highest price consumers are willing to pay is $2q$, and the manufacturer cannot profit from selling the product. Our discussion is thus based on the parameter range of $c \in [0, 2q)$. Key notations in this paper are summarized in Table 1.

3.3.1 | No sharing mode

We first consider the benchmark case of the no sharing mode where the manufacturer only acts a seller. Neither the manufacturer nor the consumer can provide sharing products in the current market. Consumers are uniformly distributed on the $q \times q$ square in terms of their product usage value in both periods (Jiang & Tian, 2018; Qi, Chu, & Chen, 2016), and they can choose to use outside option instead of directly buying from the manufacturer. Since quality q does not affect the demand formulation mechanism, we simplify it as 1 in the following analysis. Given the manufacturer's retail price p^N, when it is low enough, for example, $p^N \leq p_1$, consumers above $v_{i1} + v_{i2} = p^N$ prefer to buy the product. When the price increases, for example, $p_1 < p^N \leq 2p_1$, consumers above $v_{i1} + v_{i2} = p^N$ but located in $v_{i1} < p^N - p_2$ or $v_{i2} < p^N - p_1$ prefer to use the outside option because of $v_{i1} + v_{i2} - p^N < v_{i2} - p_2$ or $v_{i1} + v_{i2} - p^N < v_{i1} - p_1$. Others above $v_{i1} + v_{i2} = p^N$ will still buy the product. As shown in Figure 2, consumers in region I or II will use outside option in the second or the first period, and consumers in region III would rather buy the product. When the retail price is high enough, for example, $p^N > 2p_1$, no consumers will buy the product, using the outside option instead. The manufacturer's retailing demand function D_R^N conditional on p^N and p_1 is computed below.

$$D_R^N = \begin{cases} 1 - \frac{1}{2}(p^N)^2 & \text{if } 0 < p^N \leq p_1, \\ (1 - p_1)(1 - 2p^N + 3p_1) + \frac{1}{2}(2p_1 - p^N)^2 & \\ \qquad\qquad \text{if } p_1 < p^N \leq 2p_1, \\ 0 & \text{otherwise.} \end{cases}$$

Note that we only examine the case of $p^N \in (c, 2p_1]$ because $D_R^N = 0$ if $p^N > 2p_1$ or the manufacturer's profit will be negative if $p^N \leq c$, Thus, the manufacturer's optimization problem can be formulated as

$$\max_{\substack{0 < x^N \leq K \\ c < p^N \leq 2p_1}} : \Pi_N(x^N, p^N) = (p^N - c)(D_R^N \wedge x^N), \tag{1}$$

where x^N denotes the capacity allocated to the retailing market under the no sharing mode.

3.3.2 | C2C sharing mode

We now examine the case for which there are product sharing transactions among consumers. Given the manufacturer's retail price p^C, when it is low enough, for example, $p^C \leq p_1$, consumers above $v_{i1} + v_{i2} = p^C$ will buy the product, just as customers do under the no sharing mode. When it is high enough, for example, $p^C > (2 - \alpha)p_1$, only consumers above $v_{i1} + v_{i2} = p^C$ and located in $v_{i1} \geq p^C - p_2$, $v_{i2} \geq p^C - p_1$ prefer to buy the product. Other consumers above $v_{i1} + v_{i2} = p^C$ will use the sharing product from an outside option, which is the same behavior as consumers below $v_{i1} + v_{i2} = p^C$ but located in $v_{i1} > p_1$ or $v_{i2} > p_2$. When the retail price is moderate, for example,

TABLE 1 Notation

Decision variables	
p^k	Retail price under sharing mode $k \in \{N, C, B\}$
x^k	Capacity allocated to the retailing market
y^k	Capacity allocated to the sharing market
Model parameters	
p_j	Exogenous sharing price in period $j \in \{1, 2, \ldots, n\}$
c	Marginal production cost
q	Product quality
K	The manufacturer's total capacity, $K > 0$
$v_{ij} = q\theta_{ij}$	Consumer i's product usage value in period j where $\theta_{ij} \sim \mathcal{U}(0, 1)$
α	Sharing platform's commission rate, $\alpha \in [0, 1)$
Other notations	
U_i	Consumer i's total utility
D_R^k	Retailing demand under sharing mode k
D_S^k	Sharing demand per period under sharing mode k
Π_k	The manufacturer's total profit under sharing mode k

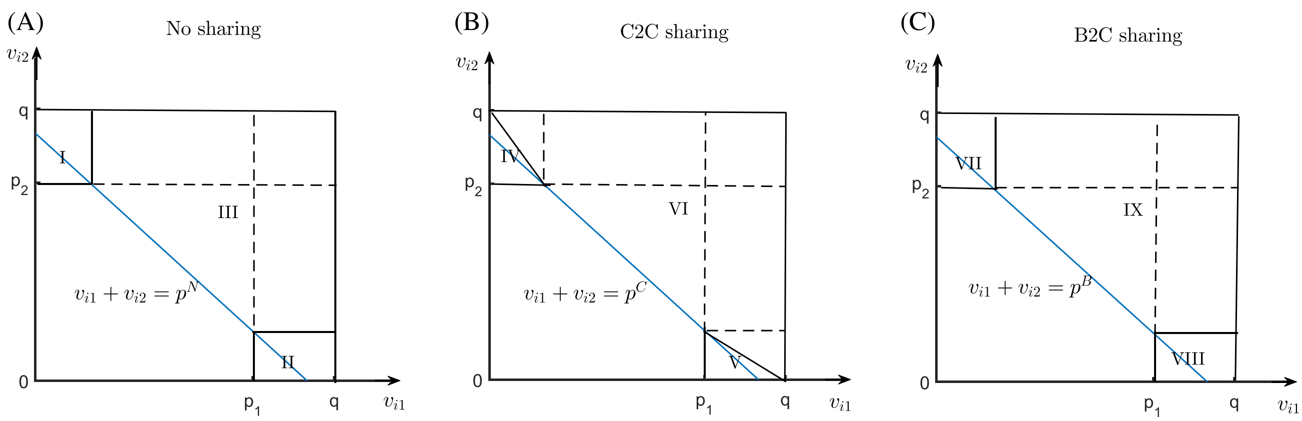


FIGURE 2 Demand formation under three sharing modes [Colour figure can be viewed at wileyonlinelibrary.com]

$p_1 < p^C \leq (2-\alpha)p_1$, consumers above $v_{i1} + v_{i2} = p^C$ and located in $v_{i1} > p^C - p_2$ or $v_{i2} > p^C - p_1$ prefer to buy the product and use it in both periods since $v_{i1} + v_{i2} - p^C > v_{i1} - p_1$ or $v_{i1} + v_{i2} - p^C > v_{i2} - p_2$, which is shown as region VI in Figure 2. Although $v_{i1} + (1-\alpha)p_2 - p^C > v_{i1} + v_{i2} - p^C$ or $(1-\alpha)p_1 + v_{i2} - p^C > v_{i1} + v_{i2} - p^C$ may hold for some consumers, the reluctance of consumers in this region to use the sharing product will discourage these consumers from buying products for speculation purposes. For consumers above $v_{i1} + v_{i2} = p^C$ but located in $v_{i1} \leq p^C - p_2$ or $v_{i2} \leq p^C - p_1$, the behavior will be quite different considering the existence of C2C sharing. Without C2C sharing, these consumers will switch to the outside sharing option, but the existence of C2C sharing keeps them in the current market. Note that we have $v_{i1} + (1-\alpha)p_2 - p^C > v_{i1} - p_1 > v_{i1} + v_{i2} - p^C$, indicating that consumers do not need to switch to the outside option because they know some consumers in the current market are willing to buy the product for speculation purpose. For the same reason, consumers below $v_{i1} + v_{i2} = p^C$ but located in $v_{i1} > p_1$ or $v_{i2} > p_2$ will also stay in the current market. To ensure the success of sharing transactions in the current market, we assume that the number of consumers located in $v_{i1} > p_1, v_{i2} < p^C - p_1$ who will buy the product and share it with others in the second period equals that of consumers located in $v_{i2} > p_2$, $v_{i1} < p^C - p_2$ who will use the sharing product in the second period. Equivalently, as shown in Figure 2, half of consumers from regions IV and V will buy the product for speculation purposes, and the other half of consumers will use the sharing products in the current market. We compute the manufacturer's retailing demand function conditional on p^C and p_1, denoted as D_R^C below.

$$D_R^C = \begin{cases} 1 - \frac{1}{2}(p^C)^2 & \text{if } 0 < p^C \leq p_1, \\ (1-p_1)(1+2p_1-p^C) + \frac{1}{2}(2p_1 - p^C)^2 & \\ & \text{if } p_1 < p^C \leq (2-\alpha)p_1, \\ (1-p_1)(1+3p_1-2p^C) + \frac{1}{2}(2p_1 - p^C)^2 & \\ & \text{if } (2-\alpha)p_1 < p^C \leq 2p_1, \\ 0 & \text{otherwise.} \end{cases}$$

Note that when $(2-\alpha)p_1 < p^C \leq 2p_1$, this is equivalent to the case of no sharing. Considering our focus is to distinguish and compare various sharing modes, we investigate the optimal pricing and capacity allocation strategies under the C2C sharing mode with the assumption $p^C \le (2-\alpha)p_1$. Thus, the manufacturer's optimization problem can be stated as

$$\max_{\substack{0 < x^C \le K \\ c < p^C \le (2-\alpha)p_1}} : \Pi_C(x^C, p^C) = (p^C - c)(D_R^C \wedge x^C), \quad (2)$$

where x^C denotes the capacity allocated to the retailing market under the C2C sharing mode.

3.3.3 | B2C sharing mode

We now examine the last case in which the manufacturer is both a product seller and a sharing product provider. Note that when the marginal production cost is high enough, for example $c > 2(1-\alpha)p_1$, the manufacturer will not profit from product sharing. To ensure the existence of B2C sharing, we assume that the marginal production cost is not very high, that is $c \in [0, 2(1-\alpha)p_1]$. Furthermore, we assume that consumers in our model prefer B2C sharing because the product sharing service provided by the firm is more standardized. (Section 7 offers the discussion of a hybrid sharing model where C2C sharing coexists with B2C sharing.) Given the manufacturer's retail price p^B, when it is low enough, for example, $p^B \le p_1$, consumers above $v_{i1} + v_{i2} = p^B$ will buy the product, as consumers do under the no sharing mode. When the price is high enough, for example, $p^B > 2p_1$, no consumers will buy the product. Only when the retail price is moderate, that is, when $p_1 < p^B \le 2p_1$, consumers above $v_{i1} + v_{i2} = p^B$ and located in $v_{i1} \ge p^B - p_2$, $v_{i2} \ge p^B - p_1$ will buy the product and use it in both periods because $v_{i1} + v_{i2} - p^B > v_{i1} - p_1$ and $v_{i1} + v_{i2} - p^B > v_{i2} - p_2$. Consumers below $v_{i1} + v_{i2} = p^B$ but located in $v_{i1} > p_1$ or $v_{i2} > p_2$, however, prefer to use the sharing product provided by the manufacturer. The manufacturer's retailing and sharing demand functions conditional on p^B and p_1, denoted as D_R^B and D_S^C, are computed below.

$$D_R^B = \begin{cases} 1 - \frac{1}{2}(p^B)^2 & \text{if } 0 < p^B \le p_1, \\ (1-p_1)(1+3p_1-2p^B) + \frac{1}{2}(2p_1 - p^B)^2 & \\ & \text{if } p_1 < p^B \le 2p_1, \\ 0 & \text{otherwise,} \end{cases}$$

and

$$D_S^B = \begin{cases} 0 & \text{if } 0 < p^B \le p_1, \\ (1-p_1)(p^B - p_1) & \text{if } p_1 < p^B \le 2p_1, \\ 0 & \text{otherwise.} \end{cases}$$

The manufacturer's optimization problem can be formulated as

$$\max_{\substack{x^B, y^B \ge 0 \\ x^B + y^B \le K \\ c < p^B \le 2p_1}} : \Pi_B(x^B, y^B, p^B) = (p^B - c)(D_R^B \wedge x^B)$$
$$+ (2(1-\alpha)p_1 - c)(D_S^B \wedge (K - x^B) \wedge y^B), \quad (3)$$

where x^B and y^B denote the capacity allocated to the retailing and sharing markets, respectively, under the B2C sharing mode.

4 | EQUILIBRIUM OUTCOMES IN THE PRESENCE OF PRODUCT SHARING

In this section, we demonstrate equilibrium outcomes in the presence of product sharing. Since our focus is to explore whether and when the manufacturer should engage in B2C sharing, we summarize equilibrium outcomes in the absence of product sharing (which are used for comparison) in Appendix S1 for succinctness. To distinguish equilibrium pricing under various sharing modes, let p^{N*}, p^{C*} and p^{B*} be the equilibrium retail price under the no sharing, C2C sharing and B2C sharing modes, respectively. The same remarks hold for other equilibrium outcomes (eg, manufacturer's profit and capacity) in the following sections.

4.1 | Benchmark model without capacity constraint

We begin with a benchmark model without capacity constraint by setting an infinite K in the above manufacturer's optimization problem. Below is a theorem that presents the equilibrium pricing conditional on C2C and B2C sharing modes.

Theorem 1 *The equilibrium pricing under C2C and B2C sharing modes depend on c and p_1.*

i *Given C2C sharing mode, if* $0 \le c \le \frac{1}{2}p_1^2 + p_1 - 1$, *then* $p^{C*} = p_1$. *If* $\frac{1}{2}p_1^2 + p_1 - 1 < c \le \frac{-(3\alpha^2 - 8\alpha + 4)p_1^2 - (4\alpha - 6)p_1 - 2}{2 - (2 - 2\alpha)p_1}$, *then* $p^{C*} = \frac{2(1+p_1)+c-\sqrt{(2(1+p_1)+c)^2 - 6(c+1)(p_1+1)}}{3}$. *Otherwise,* $p^{C*} = (2-\alpha)p_1$.

ii *Given B2C sharing mode, if* $0 \le c \le \frac{(3-4\alpha)p_1^2 + 4\alpha p_1 - 2}{2}$, *then* $p^{B*} = p_1$. *If* $\frac{(3-4\alpha)p_1^2 + 4\alpha p_1 - 2}{2} < c \le [(3 + 2\alpha)p_1 - 1] \wedge 2(1-\alpha)p_1$, *then* $p^{B*} = \frac{c + 4 - \sqrt{6(3-2\alpha)p_1^2 - 6(4 - 2\alpha + c)p_1 + c^2 + 2c + 10}}{3}$. *Otherwise,* $p^{B*} = 2p_1$.

Theorem 1 shows the equilibrium pricing in the presence of product sharing. Intuitively, the equilibrium retail price increases with the marginal production cost for both sharing modes, while B2C sharing mode presents less sensitivity to the marginal production cost. To trade off the extra sharing revenue and retailing loss by the cannibalization effect, we compare the manufacturer's equilibrium profit denoted as Π^{i*} under sharing mode $i \in \{N,$

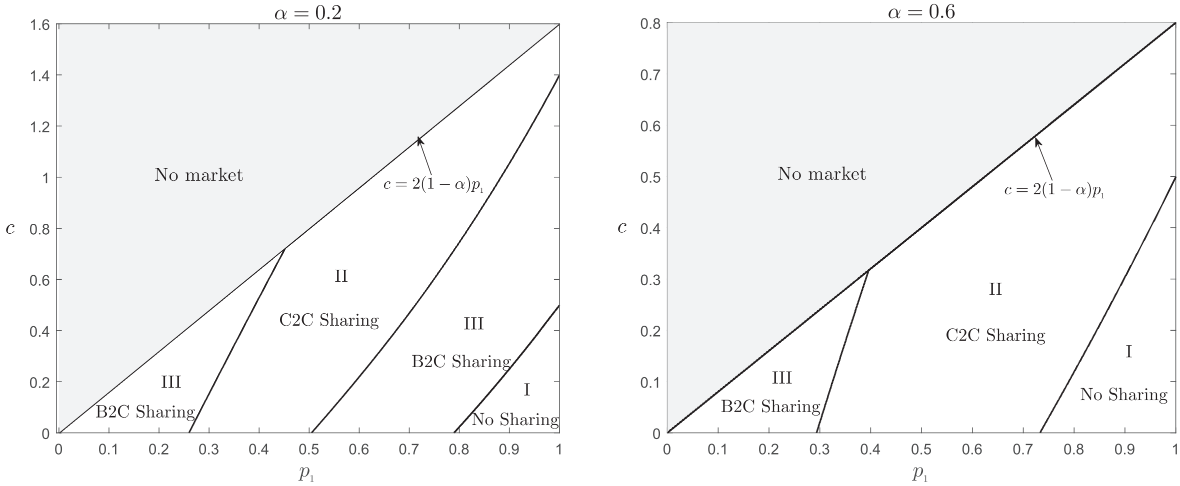


FIGURE 3 The manufacturer's optimal sharing strategies with $\alpha = 0.2$ (left), $\alpha = 0.6$ (right), and $K = 1$

C, $B\}$, and investigate specific conditions under which the manufacturer has motivation to engage in the B2C sharing. (We first examine the manufacturer's sharing mode selection without capacity constraint since it allows us to analytically compare different sharing modes, which is less studied in prior literature.) Below is a proposition that states the manufacturer's equilibrium profit comparison results under condition $c \in [0, 2(1-\alpha)p_1]$ which ensures the feasibility of C2C sharing and B2C sharing. Define a threshold $\hat{c}$ such that $\frac{\hat{c}+4-\sqrt{(\hat{c}+4)^2+6(3-2\alpha)p_1^2-6(4-2\alpha+\hat{c})p_1-6\hat{c}-6}}{3} = \frac{2(1+p_1)+\hat{c}-\sqrt{(2p_1+2+\hat{c})^2-6(\hat{c}+1)(p_1+1)}}{3}$.

Proposition 1 *Given α, the relationship of Π^{N*}, Π^{C*}, and Π^{B*} depends on c and p_1.*

a *Suppose* $0 \le \alpha \le \frac{1}{2}$. *When* $0 < c \le \left(\frac{(3-4\alpha)p_1^2+4\alpha p_1-2}{2} \vee 0\right)$, *then* $\Pi^{B*} = \Pi^{C*} = \Pi^{N*}$, *when* $\left(\frac{(3-4\alpha)p_1^2+4\alpha p_1-2}{2} \vee 0\right) < c \le \hat{c}$, *then* $\Pi^{B*} \ge \Pi^{C*} > \Pi^{N*}$, *when* $\hat{c} < c \le \left(\frac{-(\alpha^2+4\alpha-8)p_1^2-(2\alpha-10)p_1-2}{2+(\alpha-2)p_1} \wedge 2(1-\alpha)p_1\right)$, *then* $\Pi^{C*} \ge \Pi^{B*} > \Pi^{N*}$, *and otherwise*, $\Pi^{B*} > \Pi^{C*} \ge \Pi^{N*}$.

b *Suppose* $\frac{1}{2} < \alpha < 1$. *When* $0 < c \le \left(\left(\frac{1}{2}p_1^2 + p_1 - 1\right) \vee 0\right)$, *then* $\Pi^{B*} = \Pi^{C*} = \Pi^{N*}$, *when* $\left(\frac{1}{2}p_1^2 + p_1 - 1\right) \vee 0 < c \le \left(\frac{-(\alpha^2+4\alpha-4)p_1^2-(2\alpha-10)p_1-2}{2+(\alpha-2)p_1} \wedge 2(1-\alpha)p_1\right)$, *then* $\Pi^{C*} \ge \Pi^{B*} \ge \Pi^{N*}$, *and otherwise*, $\Pi^{B*} > \Pi^{C*} > \Pi^{N*}$.

Proposition 1 reveals that the manufacturer prefers product sharing except when low-cost products are shared at a high sharing price. Given a high sharing price, the manufacturer producing high-cost products is better off with C2C sharing rather than B2C sharing. In the presence of C2C sharing, some low-end consumers (with low valuation) who are unwilling to buy in the case of no sharing will now buy to realize potential sharing earnings, which leads to a larger retailing market and benefits the manufacturer with C2C sharing. If the context is B2C sharing, although the total market is greater (including retailing and sharing), the profitability of sharing products is lower. This finding suggests that instead of directly benefiting from the sharing market, manufacturers producing high-cost products have an incentive to encourage consumer product sharing and indirectly benefit from strategic pricing to extract some of the value created by the sharing market. For manufacturers producing low-cost products, however, entry into the sharing market may be the right choice, which corresponds with the increasing amounts of venture capital for many shared mobile power businesses such as Zudian, Laidian, Emie, whose parent companies specialize in manufacturing batteries or chargers (for both retailing and sharing purposes).

The above finding is affected by both the sharing price and commission rate which is presented in Figure 3. Interestingly, when the sharing price is moderate, the manufacturer producing low-cost products is also better off with C2C sharing. In contrast, a much higher or lower sharing price, makes matching the sharing demand with supply among consumers difficult, and thus negatively impacts the manufacturer with C2C sharing. For example, in the left part of Figure 4, the manufacturer producing low-cost products (eg, $c = 0.5$,) prefers C2C sharing if $0.42 \le p_1 \le 0.75$. Otherwise, the manufacturer is better off with B2C sharing. When the platform's commission rate is substantially high, low-cost products shared at a high sharing price will no longer be suitable for B2C sharing because the marginal sharing profit is minimal.

To summarize, the above findings give at least three implications for the manufacturer's product sharing mode selection. First, when very low-cost products are shared at a high price, both C2C sharing and B2C sharing fail to improve

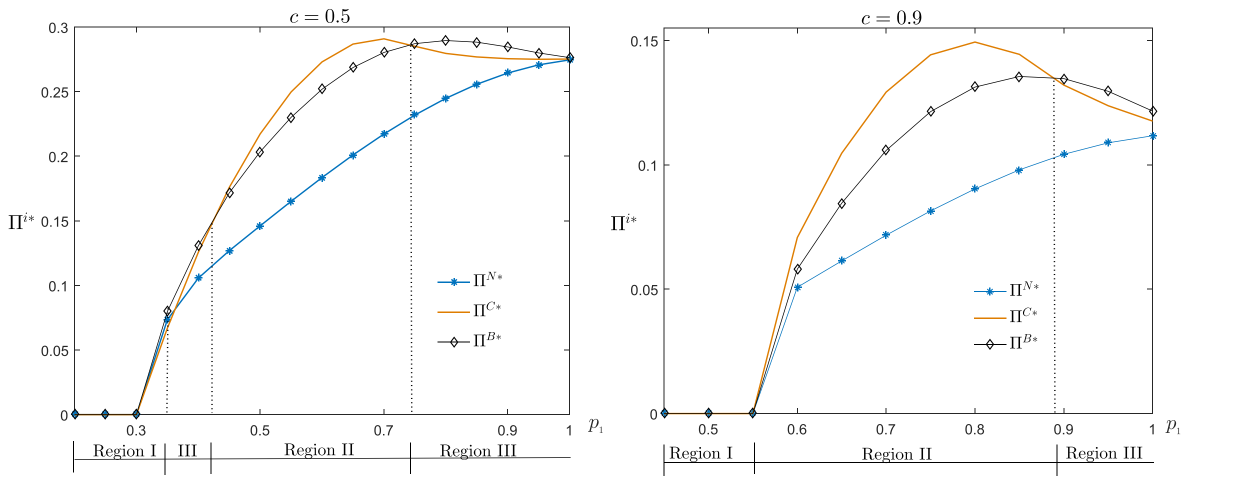


FIGURE 4 Impact of various sharing prices and marginal production costs on the manufacturer's equilibrium profit with $K = 1$, $\alpha = 0.2$, $c = 0.5$ (left) and $c = 0.9$ (right) [Colour figure can be viewed at wileyonlinelibrary.com]

the manufacturer's profit. Second, the manufacturer is better off if it encourages high-cost products sharing among consumers. Third, manufacturers producing low-cost products should enter into the sharing market except when the sharing price is moderate. Motivated by these findings, it would be interesting to further investigate the strategic role of capacity constraint, for example, in terms of the manufacturer's capacity allocation, which will be discussed in details in Section 5.1.

4.2 | Main model with capacity constraint

In this subsection, we show how equilibrium pricing in the presence of product sharing is affected by the manufacturer's capacity constraint. Below is a theorem that states the equilibrium pricing under the C2C sharing mode. For convenience, we define $K_C = (1-p_1)\left(1+2p_1 - \frac{2(1+p_1)+c-\sqrt{(2(1+p_1)+c)^2-6(1+p_1)(1+c)}}{3}\right) + \frac{1}{2}\left(2p_1 - \frac{2(1+p_1)+c-\sqrt{(2(1+p_1)+c)^2-6(1+p_1)(1+c)}}{3}\right)^2$.

Theorem 2 *The equilibrium pricing under capacitated C2C sharing mode depends on c, p_1, and K.*

a *If $0 \le c \le \frac{1}{2}p_1^2 + p_1 - 1$, when $0 < K \le (1-p_1)(1+\alpha p_1) + \frac{1}{2}\alpha^2 p_1^2$, then $p^{C*} = (2-\alpha)p_1$, when $(1-p_1)(1+\alpha p_1) + \frac{1}{2}\alpha^2 p_1^2 < K \le 1 - \frac{1}{2}p_1^2$, then $p^{C*} = 1 + p_1 - \sqrt{p_1^2 + 2K - 1}$, and otherwise, $p^{C*} = p_1$.*

b *If $\frac{1}{2}p_1^2 + p_1 - 1 < c \le \frac{-(3\alpha^2-8\alpha+4)p_1^2-(4\alpha-6)p_1-2}{2-(2-2\alpha)p_1}$, when $0 < K \le (1-p_1)(1+\alpha p_1) + \frac{1}{2}\alpha^2 p_1^2$, then $p^{C*} = (2-\alpha)p_1$, when $(1-p_1)(1+\alpha p_1) + \frac{1}{2}\alpha^2 p_1^2 < K \le K_C$, then $p^{C*} = 1 + p_1 - \sqrt{p_1^2 + 2K - 1}$, and otherwise, $p^{C*} = \frac{2(1+p_1)+c-\sqrt{(2(1+p_1)+c)^2-6(c+1)(p_1+1)}}{3}$.*

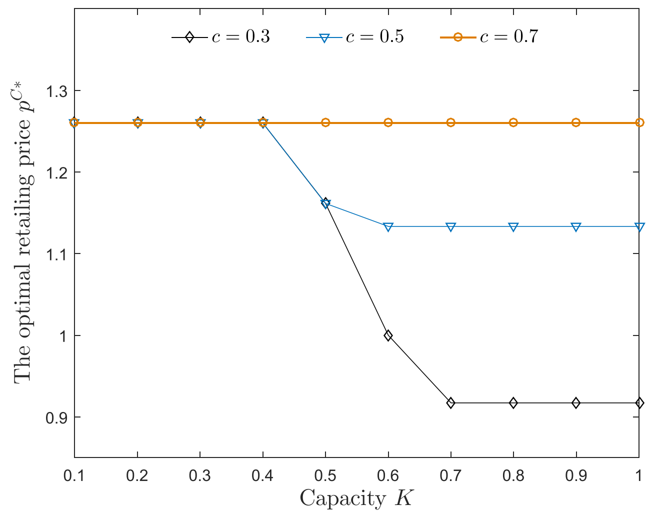


FIGURE 5 Impact of capacity constraint on the equilibrium pricing under C2C sharing mode with $\alpha = 0.2$, $p_1 = 0.7$ [Colour figure can be viewed at wileyonlinelibrary.com]

c *If $\frac{-(3\alpha^2-8\alpha+4)p_1^2-(4\alpha-6)p_1-2}{2-(2-2\alpha)p_1} < c \le (2-\alpha)p_1$, then $p^{C*} = (2-\alpha)p_1$ always holds.*

Theorem 2 shows equilibrium pricing for a capacity-constrained manufacturer under the C2C sharing mode. Similarly, when the total capacity is so tight that the supply falls short of demand, products of different costs will be priced the same. When the total capacity increases to a certain level where the supply can perfectly match demand through pricing, the equilibrium retail price is monotone decreasing. When the total capacity is sufficiently high so that the manufacturer is no longer capacity-constrained, the equilibrium retail price stays constant. Additionally, we find that the equilibrium pricing for low-cost products is more easily affected by the capacity constraint. Figure 5 shows how capacity constraint influences equilibrium pricing for products at various cost levels under the C2C sharing mode.

Below is a theorem that states equilibrium pricing under the B2C sharing mode. For convenience, we define $K_{B1} = (1-p_1)(1+3p_1-2p_{B1}) + \frac{1}{2}(2p_1-p_{B1})^2$ where $p_{B1} = \frac{4+2(1-\alpha)p_1-\sqrt{(4+2(1-\alpha)p_1)^2-6(1+2p_1-p_1^2+4(1-\alpha)p_1)}}{3}$ and $K_{B2} = (1-p_1)(1+2p_1-p_{B2}) + \frac{1}{2}(2p_1-p_{B2})^2$ where $p_{B2} = \frac{c+4-\sqrt{(c+4)^2+6(3-2\alpha)p_1^2-6(4-2\alpha+c)p_1-6c-6}}{3}$.

Theorem 3 *The equilibrium pricing under capacitated B2C sharing mode depends on* c, p_1, *and* K.

i *Given a low sharing price* $p_1 \in \left[0, \frac{1}{4\alpha+1}\right]$.
(*a*) *If* $0 \le c \le \frac{(3-4\alpha)p_1^2+4\alpha p_1-2}{2}$, *when* $0<K\le 1-p_1$, $p^{B*}=2p_1$, *when* $1-p_1 < K \le 1-\frac{1}{2}p_1^2$, $p^{B*} = p_1+1-\sqrt{p_1^2-1+2K}$, *and otherwise*, $p^{B*}=p_1$. (*b*) *If* $\frac{(3-4\alpha)p_1^2+4\alpha p_1-2}{2} < c \le (3+2\alpha)p_1-1$, *when* $0<K\le 1-p_1$, $p^{B*}=2p_1$, *when* $1-p_1<K\le K_{B2}$, $p^{B*}=p_1+1-\sqrt{p_1^2-1+2K}$, *and otherwise*, $p^{B*}=p_{B2}$. (*c*) *If* $(3+2\alpha)p_1-1<c\le 2(1-\alpha)p_1$, *then* $p^{B*}=2p_1$ *always holds*.

ii *Given a high sharing price* $p_1 \in \left(\frac{1}{4\alpha+1}, 1\right]$.
(*d*) *If* $0 \le c \le \frac{(3-4\alpha)p_1^2+4\alpha p_1-2}{2}$, *when* $0<K\le(1-p_1)^2$, $p^{B*}=2p_1$, *when* $(1-p_1)^2<K\le K_{B1}$, $p^{B*}=2-\sqrt{2p_1^2-4p_1+2+2K}$, *when* $K_{B1}<K\le\frac{1-p_1^2+(p_1+1-p_{B1})^2}{2}$, $p^{B*}=p_{B1}$, *when* $\frac{1-p_1^2+(p_1+1-p_{B1})^2}{2}<K\le 1-\frac{1}{2}p_1^2$, $p^{B*}=p_1+1-\sqrt{p_1^2-1+2K}$, *and otherwise*, $p^{B*}=p_1$. (*e*) *If* $\frac{(3-4\alpha)p_1^2+4\alpha p_1-2}{2} < c \le 2(1-\alpha)p_1$, *when* $0<K\le(1-p_1)^2$, $p^{B*}=2p_1$, *when* $(1-p_1)^2<K\le K_{B1}$, $p^{B*}=2-\sqrt{2p_1^2-4p_1+2+2K}$, *when* $K_{B1}<K\le\frac{1-p_1^2+(p_1+1-p_{B1})^2}{2}$, $p^{B*}=p_{B1}$, *when* $\frac{1-p_1^2+(p_1+1-p_{B1})^2}{2}<K\le K_{B2}$, $p^{B*}=p_1+1-\sqrt{p_1^2-1+2K}$, *and otherwise*, $p^{B*}=p_{B2}$.

The equilibrium pricing for a capacity-constrained manufacturer under the B2C sharing mode is summarized in Theorem 3. We find that conditional on a low sharing price, for example, $p_1 \le \frac{1}{4\alpha+1}$, the impact of capacity constraint on the equilibrium pricing is similar to that under the C2C sharing mode. Conditional on a high exogenous sharing price, for example, $p_1 > \frac{1}{4\alpha+1}$. However, such an impact will be different and more complex. As is shown in case (d) of Theorem 3, when the total capacity is very tight, products of different costs are be priced at the upper bound ($2p_1 \ge c$), in response to the supply shortage. The first decrease occurs when total capacity just right satisfies the retailing demand through pricing. Then, the equilibrium retail price again stays constant because the sharing demand still exceeds the sharing supply. Only when total capacity increases to a certain level can both sharing and retailing demand be fully met, and the equilibrium retailing price will decrease in it. When total capacity is sufficiently high, the manufacturer will not be capacity-constrained, and thus the equilibrium retail price will stay constant in total capacity whose value will vary according to the marginal production cost. Still, low-cost products are more easily affected by capacity constraint. Figure 6 shows how capacity constraint affects the equilibrium pricing for products at various cost levels under the B2C sharing mode.

5 | THE STRATEGIC ROLE OF CAPACITY CONSTRAINT

This section is motivated by the fact that the manufacturer is better off with B2C sharing under certain conditions (see Section 4.1). It would be interesting to further investigate the strategic role of the manufacturer capacity constraint considering the reality that the electric car industry is often capacity constrained.

5.1 | The manufacturer's capacity allocation strategies

We begin with the capacity-constrained manufacturer's capacity allocation strategies. Note that under the no sharing or C2C sharing modes, the manufacturer just decides whether to fully utilize its capacity. (The detailed analysis of capacity utilization under the no sharing or C2C sharing is in Appendix S1). Under the B2C sharing mode, the manufacturer needs to allocate its capacity to the retailing and sharing markets. To be consistent, let x^{i*}, $(i = N, C, B)$ be the equilibrium capacity allocated to the retailing market under the no sharing, C2C sharing and B2C sharing modes, respectively, and y^{B*} be the equilibrium capacity allocated to the sharing market under the B2C sharing mode. Below is a theorem that demonstrates how the manufacturer should allocate the limited capacity given a relative high sharing price. (To keep equilibrium outcomes simple as possible, we do not show the capacity allocation strategies with low sharing price here, which is essentially a special case of high sharing price.) Define thresholds $x_1 = (1-p_1)(1+3p_1-2p_{B1}) + \frac{1}{2}(2p_1-p_{B1})^2$, $x_2 = (1-p_1)(1+3p_1-2p_{B2}) + \frac{1}{2}(2p_1-p_{B2})^2$, and $x(K) = (1-p_1)(p_1-1+2\sqrt{p_1^2-1+2K}) + \frac{1}{2}(p_1-1+\sqrt{p_1^2-1+2K})^2$ for succinctness.

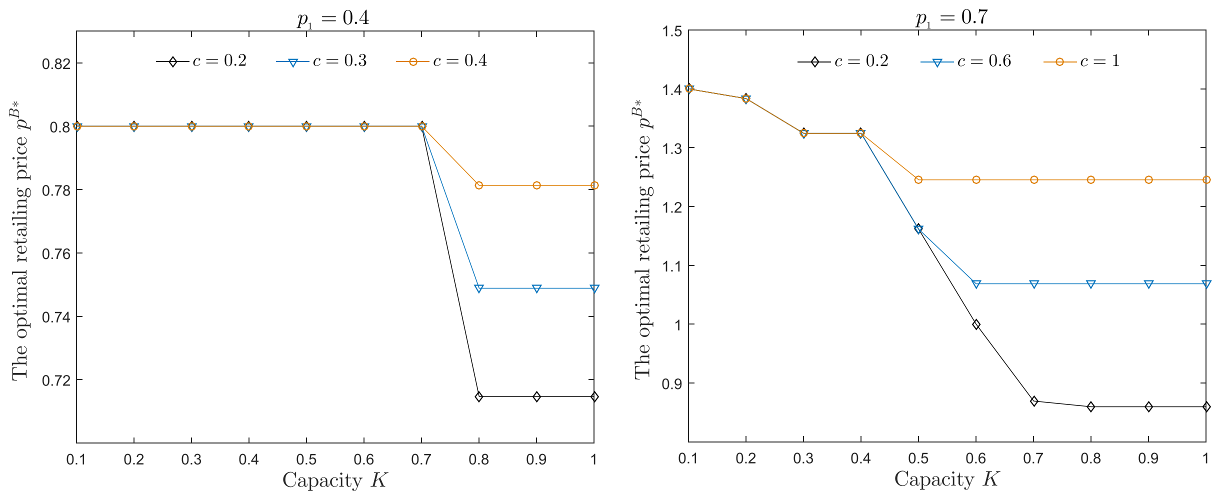


FIGURE 6 Impact of capacity constraint on the optimal pricing strategies under the B2C sharing mode with $\alpha = 0.2$, $p_1 = 0.4$ (left), and $p_1 = 0.7$ (right) [Colour figure can be viewed at wileyonlinelibrary.com]

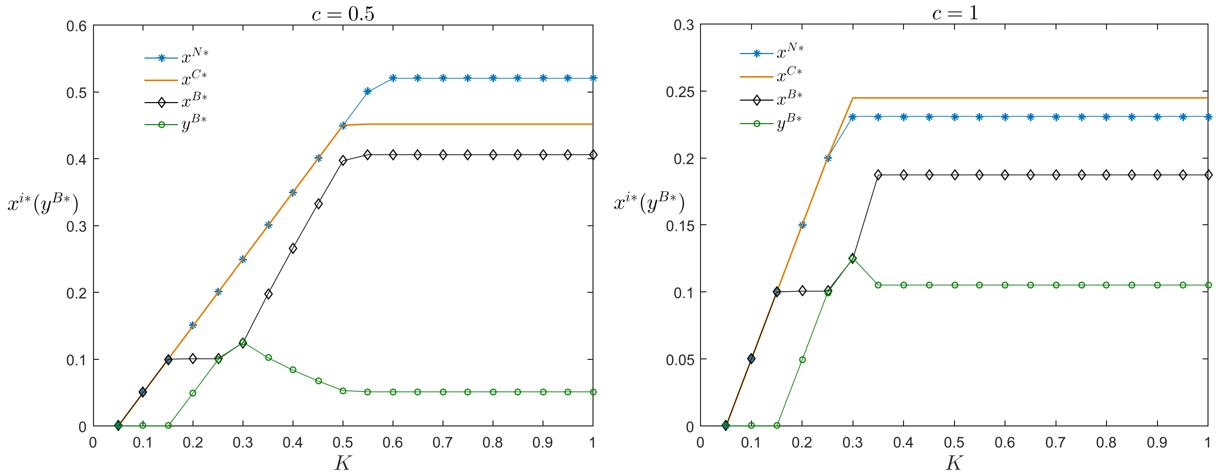


FIGURE 7 The equilibrium capacity allocation strategies with $\alpha = 0.2$, $p_1 = 0.8$, $c = 0.5$ (left), and $c = 1$ (right) [Colour figure can be viewed at wileyonlinelibrary.com]

Theorem 4 *The equilibrium allocated capacity x^{B*} and y^{B*} depend on c, p_1, and K.*

a *If* $0 \le c \le \frac{(3-4\alpha)p_1^2+4\alpha p_1-2}{2}$, *when* $0 < K \le K_{B1}$, *then* $x^{B*} = K$ *with* $y^{B*} = 0$, *when* $K_{B1} < K \le \frac{1-p_1^2+(p_1+1-p_{B1})^2}{2}$, *then* $x^{B*} = x_1$ *with* $y^{B*} = K - x^{B*}$, *when* $\frac{1-p_1^2+(p_1+1-p_{B1})^2}{2} < K \le 1 - \frac{1}{2}p_1^2$, *then* $x^{B*} = x(K)$ *with* $y^{B*} = K - x^{B*}$, *and otherwise*, $x^{B*} = 1 - \frac{1}{2}p_1^2$ *with* $y^{B*} = 0$.

b *If* $\frac{(3-4\alpha)p_1^2+4\alpha p_1-2}{2} < c \le (3+2\alpha)p_1 - 1$, *when* $0 < K \le K_{B1}$, *then* $x^{B*} = K$ *with* $y^{B*} = 0$, *when* $K_{B1} < K \le \frac{1-p_1^2+(p_1+1-p_{B1})^2}{2}$, *then* $x^{B*} = x_1$ *with* $y^{B*} = K - x^{B*}$, *when* $\frac{1-p_1^2+(p_1+1-p_{B1})^2}{2} < K \le K_{B2}$, *then* $x^{B*} = x(K)$ *with* $y^{B*} = K - x^{B*}$, *and otherwise*, $x^{B*} = x_2$ *with* $y^{B*} = (1-p_1)(p_{B2} - p_1)$.

c *If* $(3+2\alpha)p_1 - 1 < c \le 2(1-\alpha)p_1$, *when* $0 < K \le (1-p_1)^2$, *then* $x^{B*} = K$ *with* $y^{B*} = 0$, *when* $(1-p_1)^2 < K \le 1 - p_1$, *then* $x^{B*} = (1-p_1)^2$ *with* $y^{B*} = K - x^{B*}$, *and otherwise*, $x^{B*} = (1-p_1)^2$ *with* $y^{B*} = p_1(1-p_1)$.

Theorem 4 demonstrates the manufacturer's capacity allocation strategies under the B2C sharing mode. Note that in our model the manufacturer gives priority to the retailing market. Thus all capacity is allocated to the retailing market when total capacity is very tight. For relatively low-cost products, as the capacity increases, the equilibrium capacity allocated to sharing begins to increase from zero while that allocated to retailing stays constant. When total capacity can right satisfy all the retailing and sharing demand, the equilibrium capacity allocated to retailing will increase in the total capacity while that allocated to sharing will decrease, as is shown in Figure 7. This can be explained by the equilibrium pricing behind, which is negatively related with total capacity. When total capacity is sufficiently high, both markets are fully satisfied. For very high-cost products, such nonmonotonicity will no longer hold. Instead, the equilibrium capacity allocated to the sharing market is monotone increasing in total capacity.

Another interesting finding is that for very low-cost products, for example, $c \le [(3-4\alpha)p_1^2 + 4\alpha p_1 - 2]/2$, even when the capacity is sufficient, the equilibrium capacity allocated to the sharing market is zero, which implies that the manufacturer would rather not enter into the sharing market because the low pricing behind makes consumers more willing to buy a product for their own use.

5.2 | The impact of limited capacity on sharing mode selection

In the previous discussions, we focused on the strategic role of capacity constraint in terms of the firm's operational issues, for example, pricing and capacity allocation. In this subsection, from the strategic perspective, we investigate how limited capacity affects the manufacturer's sharing mode selection.

> **Proposition 2** *Under a tight capacity constraint, the manufacturer is reluctant to engage in the sharing market.*

Proposition 2 can be easily verified by Theorems 2 and 4. According to Theorem 2, under a tight capacity constraint, the equilibrium retail price $p^{C*} = (2-\alpha)p_1$ always holds. Based on the analysis of the sharing demand under the C2C sharing mode shown in Figure 2, the sharing demand in this case equals zero. Similarly, according to Theorem 4, the equilibrium B2C sharing market under a tight capacity constraint is also zero. Therefore, under a tight capacity constraint, the manufacturer is not better off with product sharing, which implies that the no sharing mode is optimal.

> **Observation 1** Moderate capacity constraint motivates the manufacturer to switch from C2C sharing to B2C sharing under a relatively low sharing price. Decreasing limited capacity motivates the manufacturer to switch from B2C sharing to C2C sharing or no sharing under a relatively high sharing price.

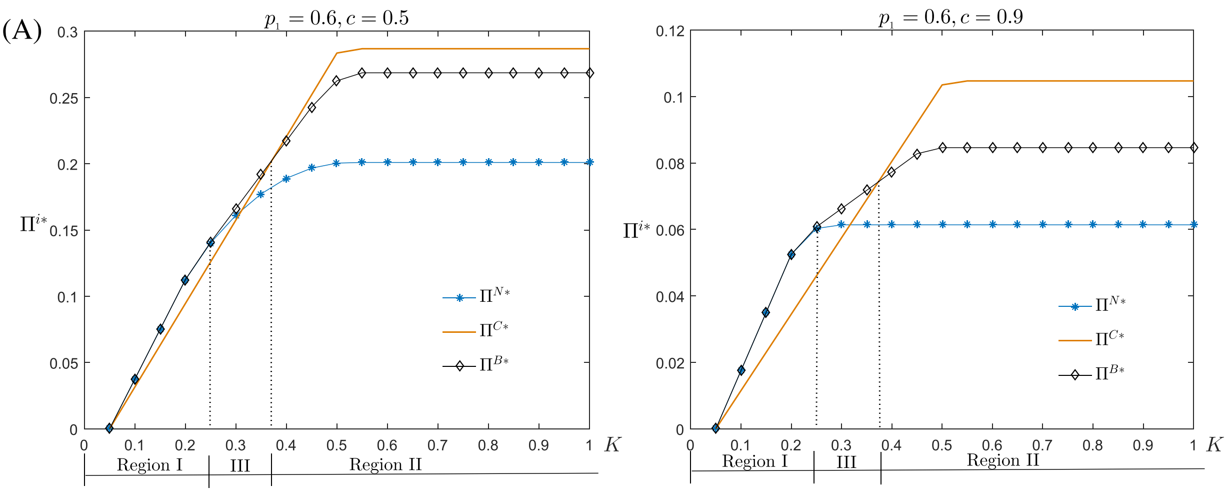
Observation 1 shows that under a relative low sharing price, for example, $p_1 = 0.6$ shown in Figure 8, capacity constraint motivates the manufacturer to switch the sharing mode from C2C sharing to B2C sharing. This can be explained as follows. With moderate capacity constraint, the manufacturer's equilibrium profits under both C2C sharing and B2C sharing decrease, but they differ in their sensitivity to limited capacity, as is shown in Figure 9. Particularly, the manufacturer's equilibrium profit under C2C sharing is more sensitive to limited capacity. Such difference is mainly caused by the nonmonotonicity of the equilibrium sharing profit. As limited capacity decreases, the equilibrium retailing profits under both C2C and B2C sharing decrease while the equilibrium sharing profit of B2C sharing first increases, which mitigates the negative impact of limited capacity on the manufacturer's equilibrium profit. This is because capacity constraint significantly reduces the value enhancement effect from C2C sharing. However, the manufacturer with B2C sharing could alleviate the effect of capacity constraint on decreasing profit using earnings from the sharing market. These results may explain the reason why many electric car manufacturers (often capacity-constrained) engage in car sharing even when the sharing price is relatively low. GoFun launched by Shouqi Group, and Changan Travel by Changan Auto, are typical examples in China. In other countries, Volkswagen recently developed a WeShare program in Germany, where all the shared cars are electric, for example, e-Golf, e-up and ID.3, in response to the increasingly popular ShareNow program composed of BMW and Mercedes-Benz.

When it comes to a relatively high sharing price, for example, $p_2 = 0.8$ shown in Figure 8, decreasing limited capacity motivates the manufacturer to switch from the B2C sharing mode to C2C or no sharing mode. This can be explained in the following way. For low-cost products, the manufacturer is better off with B2C sharing by differentiating retailing products and sharing products. However, when the capacity becomes limited, for example, $0.25 < K < 0.4$ in Figure 9, the initial equilibrium retail price will increase, and there is less differentiation in retailing and sharing pricing. This causes the equilibrium profit under B2C sharing to be more sensitive to limited capacity. However, as the capacity continues to decrease, the retail price will be higher, and there is great differentiation competition. In this case, the nonmonotonicity of the equilibrium sharing profit will again help mitigate the negative impact on profit from limited capacity. For high-cost products, the equilibrium profit under C2C sharing is dominated by that under B2C sharing only with a tight capacity, for example, $K < 0.1$ in Figure 9. However in this case, the equilibrium sharing profit is zero, which implies the no sharing mode is optimal under extreme limited capacity, which is shown in Proposition 2.

5.3 | The impact of limited capacity on consumers

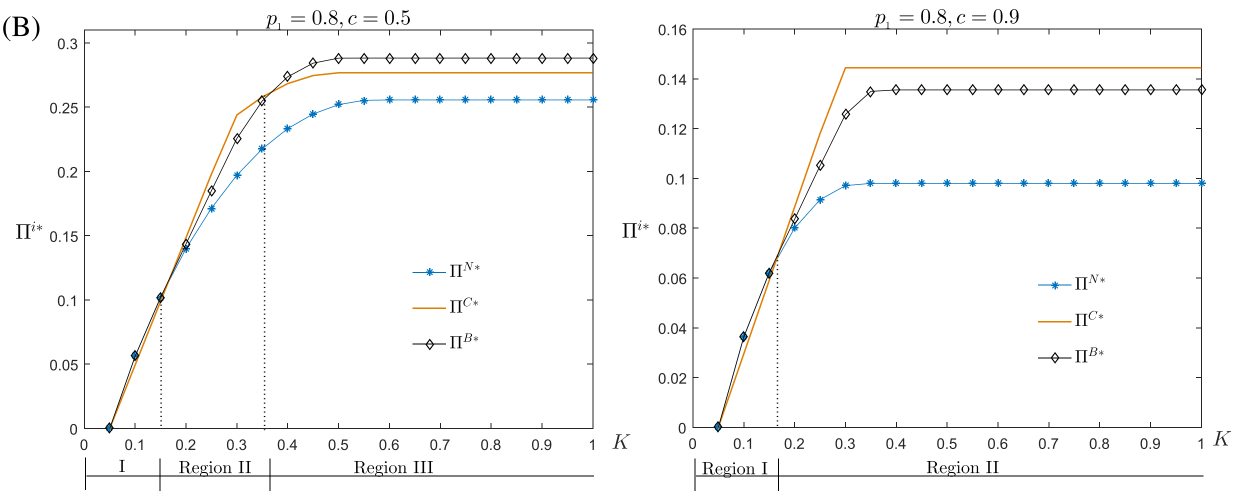
In the following two subsections, we focus on the effect of limited capacity on the consumer and society by measuring the retail price and total usage level. As we mentioned in the introduction, the equilibrium retail price with B2C sharing is always higher for the smaller retailing market (resulting from the cannibalization effect of product sharing). What is less clear is that whether the equilibrium retail price with C2C sharing is similarly higher as we are not sure whether the cannibalization effect dominates the value increment effect under the C2C setting. Additionally, we concerned as to when B2C sharing could lead to a lower retail price compared with C2C sharing and how the conclusion derived is affected

(A)



Impact of K and c on the manufacturer's equilibrium profit with a low sharing price

(B)



Impact of K and c on the manufacturer's equilibrium profit with a high sharing price

FIGURE 8 Interaction of K, p_1, and c on the manufacturer's sharing mode selection with $\alpha = 0.2$ [Colour figure can be viewed at wileyonlinelibrary.com]

by capacity constraint. It would be interesting to combine the findings with those of the manufacturer's sharing mode selection in the last subsection, as we can show when B2C sharing brings a win-win or win-lose situation for both the manufacturer and the consumer.

Next, we provide comparisons of the equilibrium retail prices under three sharing modes. Note that when the marginal production cost is sufficiently high, for example, when $c > 2(1-\alpha)p_1$, B2C sharing and C2C sharing will not be feasible and they can be equivalently viewed as no sharing. Thus, we compare the optimal retail prices only when $c \le 2(1-\alpha)p_1$. For convenience, we define a capacity threshold $K_p = \frac{1}{2}(\alpha^2 - 4\alpha + 2)p_1^2 + (2\alpha - 2)p_1 + 1$.

Proposition 3 *The relationship of p^{N*}, p^{C*}, and p^{B*} depends on c and K.*

a *If* $0 \le c \le \hat{c} \vee 0$, *when* $0 < K \le K_p$, *then* $p^{B*} \ge p^{N*} \ge p^{C*}$, *and otherwise,* $p^{B*} \ge p^{C*} \ge p^{N*}$.

b *If* $\hat{c} \vee 0 < c \le \frac{-(3\alpha^2-8\alpha+6)p_1^2-(4\alpha-8)p_1-2}{2+(2\alpha-2)p_1}$, *when* $0 < K \le K_p$, *then* $p^{B*} \ge p^{N*} \ge p^{C*}$, *when* $K_p < K \le K_N$, *then* $p^{B*} \ge p^{C*} > p^{N*}$, *and otherwise,* $p^{C*} \ge p^{B*} > p^{N*}$.

c *If* $\frac{-(3\alpha^2-8\alpha+6)p_1^2-(4\alpha-8)p_1-2}{2+(2\alpha-2)p_1} < c \le \frac{-(3\alpha^2-12\alpha+10)p_1^2-(8\alpha-12)p_1-2}{4-2(2-\alpha)p_1}$, *when* $0 < K \le K_p$, *then* $p^{B*} \ge p^{N*} \ge p^{C*}$, *and otherwise,* $p^{B*} > p^{C*} \ge p^{N*}$.

d *If* $c > \frac{-(3\alpha^2-12\alpha+10)p_1^2-(8\alpha-12)p_1-2}{4-2(2-\alpha)p_1}$, *for any* $K > 0$, $p^{B*} \ge p^{N*} \ge p^{C*}$.

Proposition 3 presents the joint impact of marginal production cost and capacity level on equilibrium retail prices. Without capacity constraint, we find that the equilibrium retail price for low-cost products increases in the presence of product sharing (either C2C or B2C), thus harming the consumer. Only for high-cost products, the equilibrium retail price under C2C sharing (marked by a solid line in Figure 10)

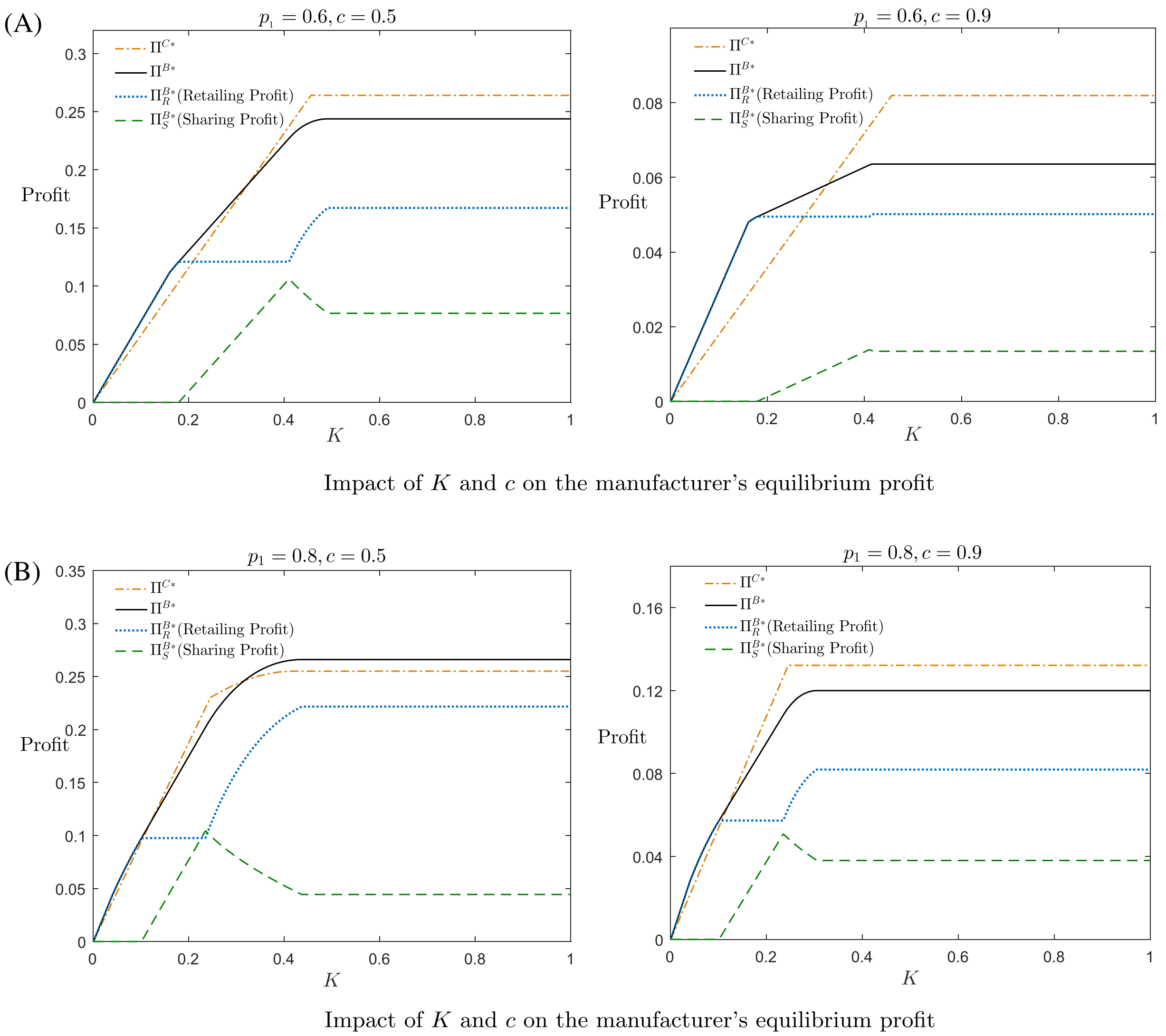


FIGURE 9 Interaction of K, p_1, and c on the manufacturer's equilibrium profit with $\alpha = 0.2$ [Colour figure can be viewed at wileyonlinelibrary.com]

may be lower than that under no sharing (marked with a blue star in Figure 10). Considering capacity constraint, however, the above finding will be adjusted. Particularly, C2C sharing is more likely to lead to a lower equilibrium retail price for low-cost products when total capacity is tight. The above results address the first question as to whether C2C sharing will lead to a higher price as in the case of B2C sharing.

Our other concern is to compare the equilibrium prices under C2C and B2C sharing and examine the impact of limited capacity. An important implication from Proposition 3 is that, B2C sharing is likely to lead to a lower price for consumers when the capacity is sufficient, but only for low-cost products. Recall from Section 4.1, the manufacturer in such cases can also be better off with B2C sharing. Thus low-cost products with a high limited capacity will create a win-win situation for both the manufacturer and the consumer. For high-cost products, although a capacity-constrained manufacturer prefers to engage in B2C sharing, the equilibrium retail price will be higher than that under either no sharing or C2C sharing. This result indicates that sharing high-cost products with a low limited capacity creates a win-lose situation for both the manufacturer and consumer.

5.4 | The impact of limited capacity on total usage levels

In this subsection, we provide a comparison between systems with and without the manufacturer's entry into the sharing market and address the social implications behind B2C sharing, eg, whether electric car sharing programs reduce total product usage. For comparison convenience, we first remark the maximum utilized capacity (equilibrium market demand without capacity constraint) under each sharing mode as K^{i*} where $i \in \{N, C, B\}$. Two thresholds of marginal production cost are defined as $\underline{c}$ such that $K_{B2}(\underline{c}) = K_N(\underline{c})$ and $\overline{c}$ where $K_{B2}(\overline{c}) = (1 - p_1)(1 + \alpha p_1) + \frac{1}{2}\alpha^2 p_1^2$. Below is a lemma that states the equilibrium market demand result under various sharing modes.

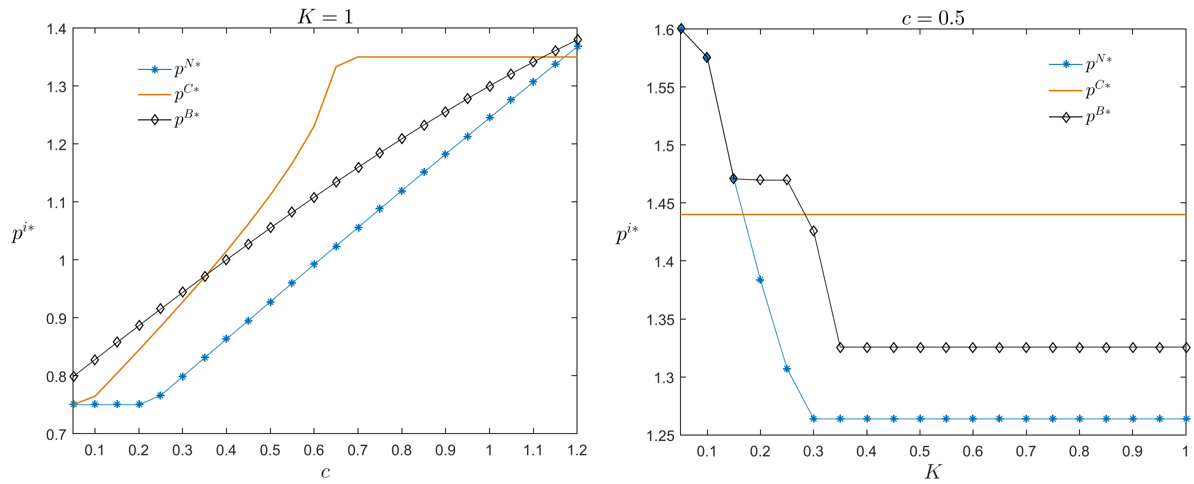


FIGURE 10 Impact of c and K on the equilibrium consumer prices with $\alpha = 0.2$ and $p_1 = 0.8$ [Colour figure can be viewed at wileyonlinelibrary.com]

Lemma 1 *There exist $\underline{c}$ and $\bar{c}$ such that if $c \le \underline{c}$, K^{N*} is the maximum, if $\underline{c} < c \le \bar{c}$, K^{B*} is the maximum, and otherwise, K^{C*} is the maximum.*

Lemma 1 shows that for substantially low-cost products, the equilibrium market demand under no sharing is at its maximum. Otherwise, the presence of product sharing will lead to more market demand. Particularly, for high-cost products, the equilibrium market demand under C2C sharing will be at the maximum. This finding may be surprising to those who advocate collaborative sharing for environmental benefits. In the auto industry, for example, product sharing among consumers actually induces the manufacturer to produce more and, thus, may contribute environmental pollution. For medium-cost products, with B2C sharing, the expansion of the manufacturer's sharing market causes the retailing market to shrink and, in this case, the retail price is lower than the price under C2C setting, which accounts for greater equilibrium market demand. These results reflect that if the manufacturer engages in B2C sharing with medium-cost products, a potential larger market share can be attained, but there is a greater risk of capacity constraint as the capacity threshold is relatively high.

Based on the equilibrium market demand comparison, we compare total usage level with and without B2C sharing under various capacity levels in the following proposition. For succinctness, we define two thresholds of capacity level as follows:

$$K_1(c) = \begin{cases} 1 - \frac{1}{2}p_1^2 & \text{if } 0 < c \le \frac{(3-4\alpha)p_1^2+4\alpha p_1-2}{2}, \\ K_{B2} & \text{if } \frac{(3-4\alpha)p_1^2+4\alpha p_1-2}{2} < c \le \underline{c}, \end{cases}$$

and

$$K_2(c) = \begin{cases} K_N & \text{if } \underline{c} < c \le \frac{5}{2}p_1 - \frac{1}{2}, \\ (1-p_1)^2 & \text{if } \frac{5}{2}p_1 - \frac{1}{2} < c \le 2(1-\alpha)p_1. \end{cases}$$

Proposition 4 *If $c \le \underline{c}$, then $x^{B*} + y^{B*} = x^{N*}$ if $K \le K_1(c)$ and $x^{B*} + y^{B*} < x^{N*}$ if $K > K_1(c)$. If $c > \underline{c}$, then $x^{B*} + y^{B*} = x^{N*}$ if $K \le K_2(c)$ and $x^{B*} + y^{B*} > x^{N*}$ if $K > K_2(c)$.*

Proposition 4 shows the joint impact of c and K on the total usage level. For low-cost products, when total capacity is tight, the total usage level with or without B2C sharing is bounded. As total capacity increases, the manufacturer's entry into the sharing market leads to a lower total usage level. For high-cost products, when total capacity is tight, the total usage level with or without B2C sharing is similarly bounded. As total capacity increases, the total usage level increases with B2C sharing. This is because the sharing of high-cost products, such as electric cars that are less likely to be affordable, is more attractive to those consumers whose willingness to buy is not high and who will easily switch to sharing products. In contrast, in the absence of B2C sharing, when the cost is high, there are mostly nonowners. Hence, B2C sharing is less likely to lead to lower usage when the cost is high and the capacity level is not substantially tight. These results could have implications for public policy. For instance, in regions where electric car sharing is popular, unless the manufacturer's total capacity is seriously constrained, B2C sharing would cause greater usage. This could be an undesirable outcome (eg, negative externalities) from a social perspective as traffic volume increases and consumers use public transport less. Additionally, here we see the positive role of limited capacity as it helps mitigate the increase in product usage.

6 | EXTENSIONS

In this section, we analyze and discuss the robustness of our insights to several alternative modeling assumptions. First, we discuss whether our main results hold if the sharing price is endogenously determined, and we also address the potential mismatch between sharing demand and supply under the exogenous sharing price assumption. Second, we characterize consumer preference for B2C sharing via a hybrid sharing mode and analyze the impact of such a preference. Third, we extend the current two-period model to an n-period model.

6.1 | Endogenous sharing price

In this subsection, we first consider two endogenous sharing price cases and then address the potential mismatch problem with the exogenous sharing price assumption. In one case, the sharing price is endogenously determined by the sharing platform (eg, sharing platform's problems further discussed in Benjaafar et al., 2019). In the other case, a market-clearing price is applied (Since the market-clearing price is formed under a certain capacity level, we select a price without capacity constraint that balances the number of car owners willing to share the car and the number of car users seeking a car.) (eg, Jiang & Tian, 2018; Jiang et al., 2019). Note that the first endogenous sharing price in our setting can be derived by solving the following platform's optimization problem (To keep extension part possibly concise, here we only provide an example of the platform's problem in the B2C sharing and all the computing details are in Appendix S1.):

$$\max_{0\le p_1\le 1} : \Pi_P(p_1) = \alpha p_1 D_S^{B*}(p^{B*}, p_1), \tag{4}$$

where

$$D_S^{B*}(p^{B*}, p_1) = \begin{cases} 0 & \text{if } 0 < p^{B*} \le p_1, \\ (1-p_1)(p^{B*}-p_1) & \text{if } p_1 < p^{B*} \le 2p_1, \\ 0 & \text{otherwise.} \end{cases}$$

We exclude the computing details here. When the platform's commission rate is low enough, we find that our main results preserve when the sharing price is endogenized (either platform-determined or a market-clearing mechanism). As shown in Figure 11, the left blue line is the platform-determined sharing price with B2C sharing, and the right orange line is the platform-determined sharing price with C2C sharing. We observe that the manufacturer has more chance to be better off with B2C sharing. As the commission rate threshold is approximately 20% in the latter setting, but 6% in the former setting. For the market-clearing price (which balances the sharing demand and supply) shown in Figure 12, the commission rate threshold below which the manufacturer's sharing mode selection conclusion still holds is approximately 25%, which is even higher than the fee threshold under platform-determined pricing. This result is expected because in the platform-determined pricing, the platform acts as a leader with the manufacturer as a follower. However, the platform is not a decision maker under the market-clearing mechanism and the sharing price is correlated with the manufacturer's retail price. The above observations show that the endogenous sharing price affects the manufacturer's sharing mode selection to some extent, and the manufacturer is still motivated to engage in B2C sharing when the commission rate is relatively low.

An important finding is that the nonmonotonicity of the equilibrium capacity allocated to the sharing market with respect to total capacity still holds for low-cost products. For example, Figure 13 demonstrates how the capacity allocation conclusion is affected by the platform-determined sharing prices. When the marginal production cost is lower than a certain threshold (eg, $c < 1.2$ in Figure 13), the equilibrium capacity allocated to the sharing market first increases and then decreases in total capacity.

No matter whether the sharing price is exogenous or endogenously determined by the platform, there will be a mismatch between sharing demand and supply. One way to address this problem is to assume the sharing price is determined by a market-clearing mechanism, but this may make the model intractable. Thus in our above discussion, we select a certain market-clearing price based on certain reasonable criteria and check the robustness of our main results via numerical study. An alternative way is to adjust the consumer's utility functions by matching probabilities as follows, and justifying the potential inconsistency (exogenous sharing price without matching friction) does not significantly affect our main results.

If consumer i buys one product, uses it in period one and shares it with others in period two, then the consumer's total utility over two periods is

$$U_i = v_{i1} + \beta(1-\alpha)p_2 - p,$$

If consumer i uses the sharing product in period one, the total utility is

$$U_i = \gamma(v_{i1} - p_1),$$

where $\beta \in (0, 1]$ denotes the probability of a car owner successfully sharing out a car, and $\gamma \in (0, 1]$ denotes the probability of a consumer successfully finding a sharing car. Considering the above matching probabilities, the manufacturer's retailing demand under the C2C sharing mode is adjusted as

$$D_R^C(p^C) = \begin{cases} 1 - \frac{1}{2}(p^C)^2 & \text{if } 0 < p^C \le p_1, \\ (1-p_1)\left(\frac{3-\gamma}{2} + \frac{3+\gamma}{2}p_1 - p^C\right) + \frac{1}{2}(2p_1 - p^C)^2 & \\ \quad \text{if } p_1 < p^C \le [(1+(1-\alpha)\beta]p_1, & \\ (1-p_1)(2-\gamma+(2+\gamma)p_1 - 2p^C) + \frac{1}{2}(2p_1 - p^C)^2 & \\ \quad \text{if } [(1+(1-\alpha)\beta]p_1 < p^C \le 2p_1, & \\ 0 & \text{otherwise.} \end{cases}$$

Similarly, the manufacturer's retailing and sharing demand under the B2C sharing mode are adjusted as

$$D_R^B(p^B) = \begin{cases} 1 - \frac{1}{2}(p^B)^2 & \text{if } 0 < p^B \le p_1, \\ (1-p_1)(2-\gamma+(2+\gamma)p_1 - 2p^B) + \frac{1}{2}(2p_1 - p^B)^2 & \\ \quad \text{if } p_1 < p^B \le 2p_1, & \\ 0 & \text{otherwise,} \end{cases}$$

and

$$D_S^B(p^B) = \begin{cases} 0 & \text{if } 0 < p^B \le p_1, \\ \frac{1}{2}(1-p_1)[2p^B - 1 + \gamma - (1+\gamma)p_1] & \\ \quad \text{if } p_1 < p^B \le 2p_1, & \\ 0 & \text{otherwise.} \end{cases}$$

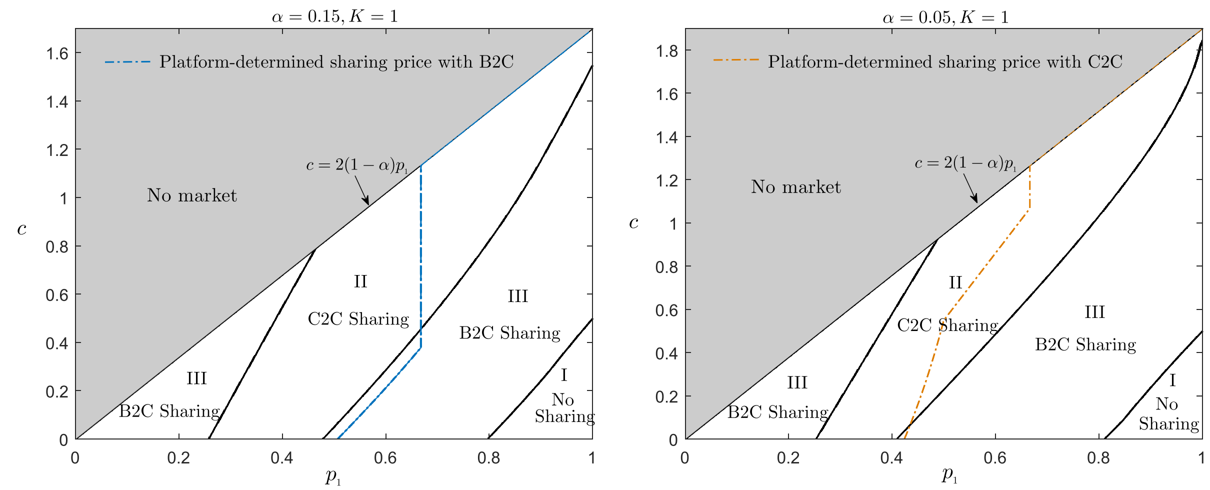


FIGURE 11 The manufacturer's sharing mode selection with platform-determined sharing price when $K = 1$, $\alpha = 0.05$ (left), and $\alpha = 0.15$ (right) [Colour figure can be viewed at wileyonlinelibrary.com]

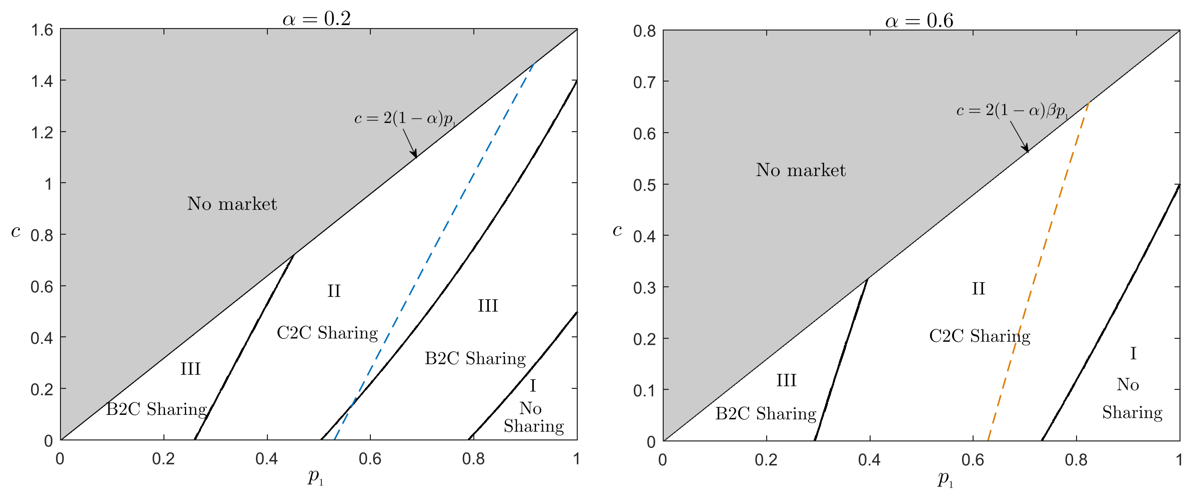


FIGURE 12 The manufacturer's sharing mode selection with market-clearing price when $K = 1$, $\alpha = 0.2$ (left blue dashed line), and $\alpha = 0.6$ (right orange dashed line) [Colour figure can be viewed at wileyonlinelibrary.com]

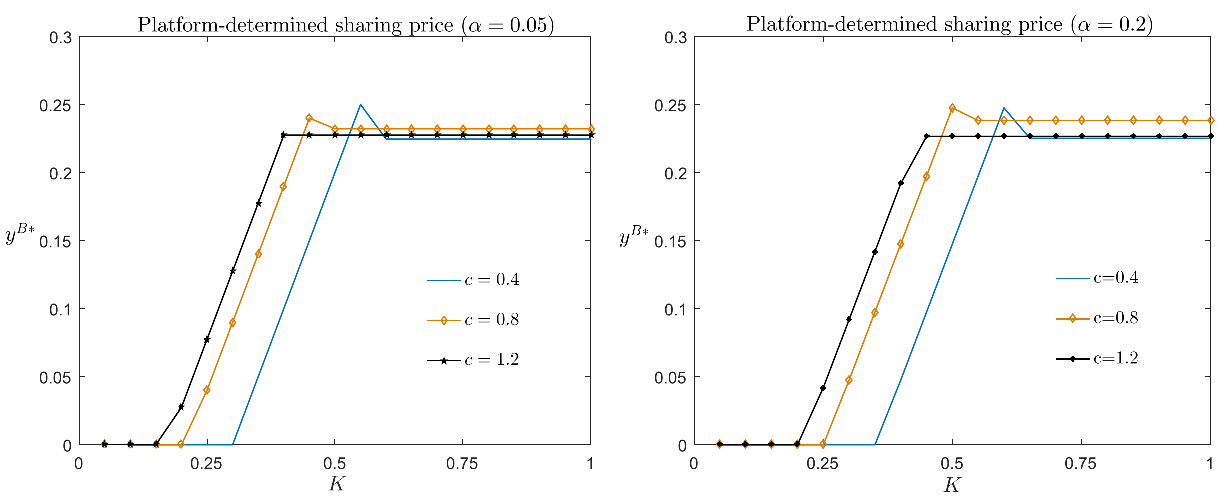


FIGURE 13 The equilibrium capacity allocated to the sharing market with platform-determined sharing price for products of various cost levels $\alpha = 0.05$ (B2C left) and $\alpha = 0.2$ (C2C right) [Colour figure can be viewed at wileyonlinelibrary.com]

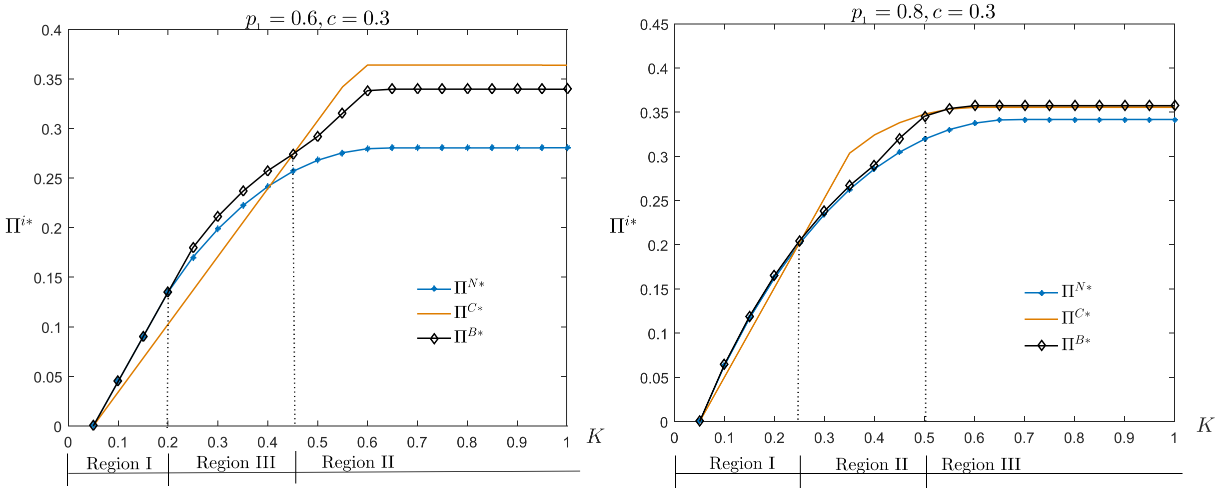


FIGURE 14 The impact of K on the manufacturer's sharing mode selection with market friction $\alpha = 0.2$, $\gamma = 0.9$, $\beta = 0.72$, $c = 0.3$, $p_1 = 0.6$ (left) and $p_1 = 0.8$ (right) [Colour figure can be viewed at wileyonlinelibrary.com]

Based on the demand functions considering the matching friction, Figure 14 presents the impact of limited capacity on the manufacturer's sharing mode selection considering the matching friction. We find a similar effect for limited capacity, which is explored in Section 5.2. When there exists matching friction, the moderate capacity constrained manufacturer still has motivation to engage in B2C sharing under a relative low sharing price.

6.2 | Hybrid sharing mode

In this extension, we consider a more general case where B2C sharing coexists with C2C sharing to link pure B2C sharing with pure C2C sharing. In practice, some consumers may prefer to use the sharing products supplied by the manufacturer as the products typically are more standard and reliable. However, some consumers may be reluctant to use the B2C sharing products as they would rather others did not know that they are using sharing products, particularly in the case of luxuries items such as a BMW car with sharing logos. Hence, we consider it of interest to explore the effect of hybrid sharing on the aforementioned main results.

We characterize such preferences by the proportion of consumers who choose to use C2C sharing products among potential sharing market participants who are C2C sharing product users, C2C sharing product providers, and B2C sharing product users. Assume μ proportion of consumers is the C2C sharing product users, since the sharing demand and supply are balanced, the proportion of C2C sharing product providers will be μ as well. Therefore, the remaining $1-2\mu$ proportion of consumers prefers to use the B2C sharing products. Note that μ ranges from 0 to $\frac{1}{2}$. When $\mu = 0$, it corresponds with the case where only B2C sharing exists. When $\mu = \frac{1}{2}$, it corresponds with the case where only C2C sharing exists. Only when $0 < \mu < \frac{1}{2}$, both C2C sharing and B2C sharing coexist, and this case is denoted as H (hybrid sharing). The manufacturer's retailing and sharing demand functions conditional on p^H and p_1, denoted as D_R^H and D_S^H, are recomputed below.

$$D_R^H = \begin{cases} 1 - \frac{1}{2}(p^H)^2 & \text{if } 0 < p^H \le p_1, \\ 2\mu(1-p_1)(p^H - p_1) + (1-p_1)(1+3p_1-2p^H) & \\ \quad +\frac{1}{2}(2p_1 - p^H)^2 & \text{if } p_1 < p^H \le (2-\alpha)p_1, \\ (1-p_1)(1+3p_1-2p^H) + \frac{1}{2}(2p_1-p^H)^2 & \\ & \text{if } (2-\alpha)p_1 < p^H \le 2p_1, \\ 0 & \text{otherwise,} \end{cases}$$

and

$$D_S^H = \begin{cases} 0 & \text{if } 0 < p^H \le p_1, \\ (1-2\mu)(1-p_1)(p^H - p_1) & \text{if } p_1 < p^H \le (2-\alpha)p_1, \\ (1-p_1)(p^H - p_1) & \text{if } (2-\alpha)p_1 < p^H \le 2p_1, \\ 0 & \text{otherwise.} \end{cases}$$

Plugging the adjusted demand functions into the manufacturer's optimization problems stated in Section 3 yields new equilibrium pricing and capacity allocation strategies (whose technical details are summarized in Appendix S1). Under the hybrid sharing mode, we draw new insights in the manufacturer's sharing mode selection and justify the preservation of capacity-related conclusions. Specifically, we find that hybrid sharing still dominates C2C sharing for low-cost products shared at a relative high price. When low-cost products are shared at a relative low price, however, hybrid sharing is dominated by no sharing or C2C sharing. As shown in Figure 15, the left figure ($\mu = 0$) represents the *pure* B2C sharing case and the right figure ($\mu = 0.2$) represents the *hybrid* sharing case. Hybrid sharing changes the conclusion of sharing mode selection for low-cost products shared at a low price. This is because in such cases, product sharing is less profitable than retailing and the manufacturer tends to choose a high price that consumers are not willing to pay. In the pure B2C sharing case, the possible high price is $2p_1$ while that in the hybrid sharing case can only be $(2-\alpha)p_1$

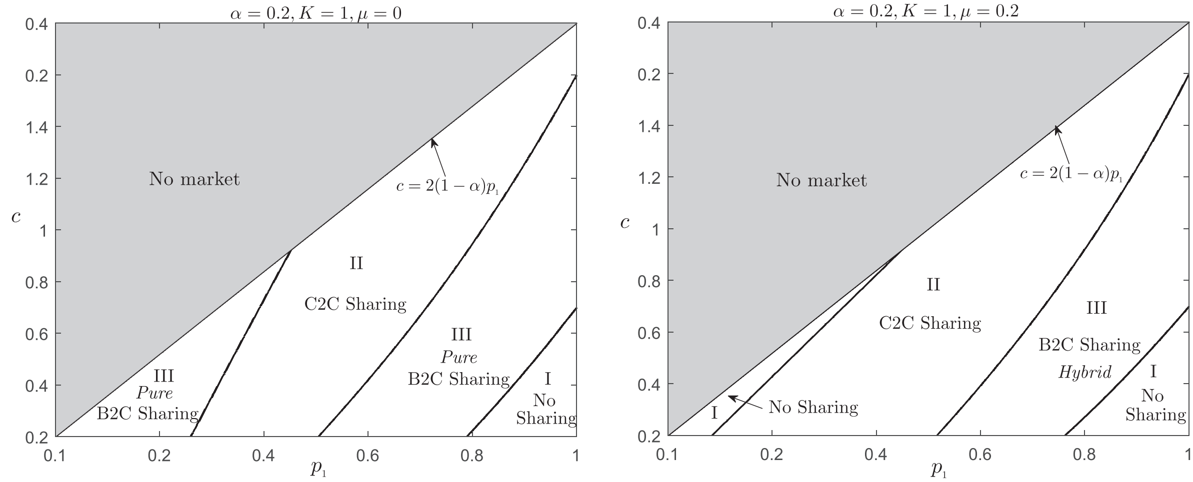


FIGURE 15 The manufacturer's sharing mode selection under hybrid sharing mode with $\alpha = 0.2$, $K = 1$, $\mu = 0$ (left), and $\mu = 0.2$ (right)

to retain sharing product owners. When it comes to high-cost products, the manufacturer prefers the C2C sharing mode as before. Considering the capacity allocation strategy, hybrid sharing does not change the equilibrium capacity allocation structure. Particularly, the equilibrium capacity allocated to the sharing market with low-cost products first increases and then decreases in total capacity. Furthermore, the adverse effect of capacity constraint on the sharing mode selection which is jointly determined by the sharing price and marginal production cost can is still observed in the hybrid sharing setting.

6.3 | *n*-Period model

Lastly, we extend our two-period product sharing model to an n-period model. Consumers learn their usage value in each period at the beginning of that period. That is, when deciding whether to buy a product from the manufacturer in the first period, consumers know their first-period usage value (v_{i1}). For later periods ($j = 2, \ldots, n$), consumers only know the distribution of the usage value, for example, $v_{ij} \sim \mathcal{U}(0, q)$. We find that our main results remain qualitatively the same. The manufacturer's optimal pricing and capacity allocation strategies are in a threshold policy structure. For low-cost products, as total capacity increases, the optimal capacity allocated to the retailing market increases while that allocated to the sharing market first increases and then decreases. The detailed analysis of the n-period model is summarized in Appendix S1.

7 | CONCLUSION

In this paper, considering a capacity-constrained manufacturer in the presence of product sharing, we propose a stylized model to investigate equilibrium pricing under the C2C and B2C sharing modes, respectively. We address whether and when the manufacturer should enter into the sharing market. Furthermore, we analyze the impact of capacity constraint on the manufacturer's sharing mode selection and other equilibrium outcomes. Our three major findings are outlined below.

First, we find that when low-cost products are shared at a high price, no sharing is optimal, and otherwise, the manufacturer is better off with either B2C or C2C sharing. Particularly, manufacturers with low-cost products prefer B2C sharing except when the sharing price is moderate. Additionally, a lower platform commission rate motivates the manufacturer more likely to engage in B2C sharing. Under an endogenously determined sharing price or mismatching friction, the manufacturer's motivation to enter into B2C sharing of low-cost products still holds under a low commission rate.

Second, for a capacity-constrained manufacturer who enters into the sharing market, the equilibrium capacity allocated to the retailing market monotonically increases with the manufacturer's total capacity while the equilibrium capacity allocated to the sharing market with low-cost products first increases and then decreases as total capacity increases, and this structure still holds under an endogenously determined sharing price. Additionally, we find that moderate limited capacity motivates the manufacturer to engage in the sharing market with a relatively low sharing price. While the manufacturer cannot be better off from product sharing when the limited capacity is substantially tight. This impact of limited capacity still holds when matching friction is considered.

Lastly, we show that sharing low-cost products with a high limited capacity leads to a lower retail price under B2C sharing and thus creates a win-win situation for both the manufacturer engaging in B2C sharing and consumers. High-cost products with a low limited capacity will instead create a win-lose situation for manufacturers and consumers. Additionally, a moderate capacity-constrained manufacturer's entry into B2C sharing of high-cost products increases the total usage level.

With realization of works in this paper, our research can be extended in the following ways: (1) further optimize the product quality level; (2) consider settings where there is competition among multiple manufacturers; and (3) endogenize the mismatch probabilities between supply and demand.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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