Research Article

Product Line Optimization for Car-Sharing Platforms in the Sustainable Transportation

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As the sharing economy develops in sustainable transportation, car-sharing platforms improve the allocation efficiency of idle cars to customers. However, as the travel demand increases, and the vehicle type becomes various, the sharing market faces a new challenge to satisfy the customers’ diverse needs for quality-differentiated cars. Each customer would like to choose the right car type, while the manufacturing firm and the e-commerce platform should set the right car price for profit maximization. How to match the platform’s product line with the customer’s choice behavior becomes a problem for all the stakeholders in the sharing economy. From the perspective of customer heterogeneity, we establish a game-theoretic framework to study product line optimization in business-to-consumer (B2C) and consumer-to-consumer (C2C) sharing. We solve the optimal quality decision and the optimal pricing strategy for the manufacturing firm and the e-commerce platform in the sharing economy. In numerical experiments, we investigate how the sensitivity of the quality and the cost can jointly influence the profits of sustainable transportation. Our findings show that within the product line, the firm’s selling profit in the C2C sharing is negatively influenced by the sharer’s valuation, while the platform’s sharing profit in the B2C sharing is independent of either buyer’s valuation. We give some policy implications for scholars, practitioners, and policymakers in the sharing economy and point out some limitations and recommendations for the product line design.

1. Introduction

The sharing economy has developed rapidly in recent years, especially in developing countries. According to the Chinese National Development and Reform Commission, the market transaction volume in the sharing market was about 4,920.5 billion yuan in 2017, an increase of 47.2% over the previous year (https://www.ndrc.gov.cn/xwdt/ztzl/zgxxjbg/201911/t20191114_1213801.html). The sharing economy is emerging in many industries, such as transportation, durable goods, and personal service, so it provides great opportunities for customers, manufacturing firms, and online platforms. Especially, in the field of low-carbon transportation, car-sharing platforms reduce the number of private vehicles on the road and take responsibility for environmental sustainability, which is conducive to decreasing greenhouse gas emissions and relieving traffic pressure in urban areas. This green transportation mode improves the allocation efficiency of idle vehicles, provides new job opportunities, and creates a resource-saving society.

However, the development of the sharing economy has not been smooth as expected. A lot of debates arise from different stakeholders who have been involved in the sharing market, such as the manufacturer’s heavy capital cost, the platform’s low technical threshold, and the government’s insufficient resource allocation. Especially, the biggest challenge in the sharing market comes from the customer’s heterogeneous valuation for the differentiated products in the product line. For example, if a manufacturing firm produces two products and sells them to two customers, it
should consider that each customer will buy which type of the two products. Similarly, if the e-commerce platform has two products and rents out to two customers, it should consider which type of the two products should be shared with each customer. To solve this problem, the product line design is proposed.

Each consumer in the market has his preference and makes the best choice by evaluating the quality of each product [1–3]. This will further lead the manufacturing firm to launch a variety of products to meet the needs of customers. With the introduction of the e-commerce platform, the sharing market adds a new option for the customers, and flexible online pricing brings extra benefits to the platform transaction [4–6]. As a prime example of C2C platforms, all the cars on Uber are owned by private sharers, not the platform itself. According to the prices of car models, Uber has launched several ride-hailing services for different passengers, like Uber X for office workers, Uber XL for leisure travelers, Uber Black for businessmen, and Uber Wav for disabled people. Unlike C2C car sharing, Hertz purchases and owns various self-supported vehicles on its B2C platform, like Economy 2/4 Door for a family of three, Large SUV for group tourists, Large Luxury Sedan for administrative officers, and Small Commercial Van/Truck for passengers with lots of luggage. Therefore, how to match the platform’s product line with the customer’s choice behavior is the most important issue for the supply and demand side in the sharing market. For the seller’s profit maximization, when two (or more) products are in the same market, the seller should consider how to set the quality attribute and the pricing strategy to induce two (or more) customers to buy. Otherwise, some designed products will cause dull sales and some unsatisfied customers will be empty-handed when leaving the market.

In this study, we set up a game-theoretic model to study the customer’s choice behavior and the platform’s product line pricing. The sequence of events is shown in Figure 1. In Figure 1(a), B2C sharing proceeds as follows. In period 1, when the manufacturing firm sells the products, all customers decide to buy or not (buyer/nonbuyer). In period 2, the buyers decide whether to use it, and if not, they can rent the self-supported products from the sharing platform (user/lessee). The nonbuyers decide to rent or not from the platform (lessee/nonlessee). In Figure 1(b), C2C sharing proceeds as follows. In period 1, when the manufacturing firm sells the products, all customers decide to buy or not (buyer/nonbuyer). In period 2, the buyers decide whether to use it, and if not, they can share the purchased products on the sharing platform (user/sharer). The nonbuyers decide to rent or not from the sharers (lessee/nonlessee). Compared with the benchmark of homogeneous customers and the single product, we introduce two customer segments with the valuation heterogeneity into the product line and solve the equilibrium product quality, selling price, and sharing price in the B2C and C2C sharing. The numerical experiments show the impact of the valuation heterogeneity and the cost structure on the pricing strategy over the two periods.

The contribution of our study is summarized as follows:

1. Our study is the first to introduce the product line design into the sharing economy
2. We establish an analytical model to solve the optimal quality and the optimal price in the B2C and C2C sharing
3. Numerical experiments examine the impact of the quality sensitivity and the cost sensitivity on the manufacturing firm’s selling profit and the e-commerce platform’s sharing profit

The remaining of this study proceeds as follows. We give a literature review in Section 2. Section 3 sets up the equilibrium pricing model in the B2C and C2C sharing markets. In Section 4, we give a sensitivity analysis of the numerical experiments. The last section summarizes some managerial insights and future directions. All proofs of the propositions are supplemented in the appendix.

2. Literature Review

2.1. B2C/C2C Sharing. Recently, the sharing economy has had potential in many industrial fields (e.g., car sharing, home sharing, and crowdfunding), and some related academic studies have been published in leading journals. By using a dynamic game, Yu et al. [7] studied the regulatory policy in C2C sharing. Different from our study, they investigated the role of the government in regulating the on-demand services (Uber/DiDi) and concluded that imposing a strict policy towards ride-hailing services was not effective in the transportation system while lowering the taxi fare was a beneficial way for the total social welfare. Jiang and Tian [8] established an analytical framework for C2C sharing in the distribution channel. They concluded that when the capacity was relatively costly, C2C sharing was more profitable for the downstream retailer than the upstream manufacturer. Although our study sets up a game-theoretic model, we mainly clarify the interplay between sellers and buyers instead of the relationship between manufacturers and retailers. Pei et al. [9] considered a two-period game by extending the B2C and C2C sharing to internal and external sharing. They compared whether an incumbent firm or an entrant firm should join the sharing market. However, they did not consider product differentiation among competitors as in our study. From the view of ownership, Filippas et al. [10] investigated the short-run equilibrium and the long-run equilibrium in the sharing economy. By studying the exchange of ownership between owners and nonowners, they empirically surveyed the bring-to-market costs and showed some economics of owning, using, and renting to the stakeholders in the sharing market.

2.2. Product Leasing. Another relevant stream is product leasing. The first study related to leasing dates from the 1970s [11]. The author drew the classic conclusion that leasing was often a less costly way to obtain durable goods. Desai and Purohit [12] proposed a different viewpoint by considering the depreciation rate. When the durable products had a high depreciation rate, selling the products was a better-off
decision rather than leasing. Later, Desai and Purohit [13] studied a combination of the selling and leasing market. By developing a game-theoretic model, they proved that a higher fraction of leasing was a disadvantage for the firm in the competition. Bhaskaran and Gilbert [14] filled the gap by giving the decision-making power of leasing to the downstream dealers. When the level of competitive intensity was high among dealers, selling durable goods was the dominant strategy. From the view of the lifecycle environmental impact, Agrawal et al. [15] established an analytical framework of green leasing. They proved that disposal fees or remanufacturing could both efficiently improve environmental performance.

Different from B2C or C2C sharing, which is called short rental, product leasing usually requires the customers to rent on a long-term basis, and the platform’s charging method is more flexible. Benjaafar et al. [16] proposed that the leasing product was often supplied to the market without ownership and was charged for a weekly or monthly cost. In contrast, the product on the peer-to-peer sharing platform was charged per use. Similarly, Tian and Jiang [17] concluded that leasing could be regarded as a bundle of sharing, where the consumer’s product usage would last over many periods instead of one single period in the sharing. In the context of car sharing, Bellos et al. [18] pointed out that the customer’s payment was directly linked to vehicle use. Besides, they demonstrated that the vehicle production volume was much larger in car leasing because there was a pooling effect on the sharing platform.

2.3. Product Line Design. From the academic review, how to design a product line optimally was first proposed in the 1970s [19]. Then, Moorthy [20] set up mathematical modeling to address this issue. Moorthy and Png [21] discussed the benefit of the product line design and concluded that the monopolist should always sell high-quality products to high-valuation customers and sell low-quality products to low-valuation customers. Based on the literature, our study applies the classic theory of product line design to the sharing economy. The study most close to ours is the study by Bellos et al. [18]. Based on the mechanism of incentive compatibility, they considered an original equipment manufacturer shared differentiated cars in the B2C sharing. By investigating the impact of the corporate average fuel economy, they found that higher fuel efficiency led to a higher price in the high-end market. However, our study has two obvious differences. First, we set up a game-theoretic model in that the participants can choose to buy from the manufacturing firm and then share or rent on the e-commerce platform. Second, we apply the product line pricing to both B2C sharing and C2C sharing.

2.4. Research Methods in the Sustainable Transportation. There are three main streams of research methods in sustainable transportation. The first stream is mathematical programming. Aydin et al. [22] set up a multi-objective stochastic optimization model to solve the optimal location and demand allocation in car sharing. The findings could minimize the total cost and the average unsatisfied demand in the region with sensitive parameters. Johnsen and Meisel [23] built a mixed-integer program model to solve the dial-a-ride problem in rural areas. They tested how different interrelated trips influenced the service quality and the total transportation cost. Aydin et al. [24] established a mixed-integer linear programming model for the location and routing problem when the postdisaster damage happened. By developing the new version of the ant colony algorithm, the experiment results manifested that the improved algorithm could be time-saving in very small-scale instances.
The second stream is the fuzzy set. Deveci et al. [25] proposed a decision support system based on the q-rung orthopair fuzzy set in the sustainable transportation. With the weighted sum and weighted product models, the system’s effectiveness was examined by numerous influencing factors and input uncertainties. Krishankumar and Ecer [26] adopted a similar approach to select the optimal service provider for the internet-of-things. The sensitivity analysis investigated the impact of availability, total cost, and security on the evaluation of the service provider.

The third stream is the simulation experiment. By adopting the data sources of connected autonomous vehicles, Gokasar et al. [27] put forward an algorithm with the modified standard normal deviation and validated its effectiveness in the traffic simulation software. In the simulation of urban mobility platform, Nguyen and Jung [28] applied swarm intelligence to green transportation and demonstrated that the average fuel consumption and the average trip duration could be both reduced by the framework. Gokasar et al. [29] used the shockwave speed to control the connected autonomous vehicles in sustainable transportation. The simulation results showed that the traffic density throughout the network was lower than in other traffic management systems.

Recently, the sharing economy is becoming one popular stream. However, how to match the platform’s product line with the customer’s choice behavior becomes a problem for all the stakeholders in the sharing market. Table 1 compares the customer’s choice behavior becomes a problem for the internet-of-things. The sensitivity analysis investigated the impact of availability, total cost, and security on the evaluation of the service provider.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Comparison of Customer Behavior</th>
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<td>Behavior 1</td>
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<td>Characteristics</td>
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3. Modeling

Considering a product line consisting of two differentiated products, two customer segments choose to buy from the manufacturing firm in period 1 or rent on the e-commerce platform in period 2. The lessee in the sharing period can rent from the platform directly in the B2C sharing or the sharer indirectly in the C2C sharing.

On the demand side, the customer segment j ∈ {H, L}’s choice behavior of the product j = {h, l} is dependent on the valuation and the expectation. In the traditional utility theory, different customers have their preferences for the same product [30]. If one customer likes the product very much, the intensity of the customer preference is strong, so the customer is called the high-valuation customer H. Conversely, if the customer dislikes the product, the intensity of the customer preference is weak, so the customer is called the low-valuation customer L. However, in the product line design, the seller often provides more than one product for the customers, so the products in the sharing market are quality-differentiated [19–21]. If the product quality in the product line is high, the product is called a high-end product h; otherwise, the product is a low-end product l. The valuation vj = θjqlj is linear with the personal preference θj ∈ (0, 1) and the product quality qlj ∈ (0, 1), where θj > θl, qlh > ql. Due to the owner of the product, the customers have n ≥ 1 times the valuations from buying in period 1 than renting in period 2. Assuming the customers are risk neutral, ξ ∈ [0, 1] denotes the probability that the buyer in period 1 expects to use in period 2 and 1 − ξ denotes the probability that the buyer in period 1 expects sharing in period 2. The number of each segment is Nh, so the demand Nh,j (i.e., the customers who buy from the firm) in period 1 and the demand Nh,j (i.e., the customers who rent through the platform) in period 2 are both dependent on Nh.

On the supply side, the firm’s profit πj and the platform’s profit πp, are dependent on the price and the cost. The firm sets the selling price pfj in period 1, and then the owner of the product sets the sharing price ppj in period 2 [16] (in the B2C sharing, the owner of the product is the platform, and in the C2C sharing, the owner of the product is the sharer). Specifically, in the C2C sharing, the platform charges a commission fee γppj from the sharer, where the commission rate is γ ∈ [0, 1]. The production cost is quadratic with the product quality cqlj, where c ∈ [0, 1] is the cost sensitivity. Let t ∈ [0, 1] denote the coefficient of transaction cost for each sharing, and the linear transaction cost is tcj [8]. The discounted rate satisfies δ ∈ [0, 1].

3.1. Product Line in the B2C Sharing

In the traditional product line design, the optimal price and quality are solved by the mechanism of incentive compatibility [20, 21], i.e., H buys h and L buys l. However, the introduction of the e-commerce platform changes the market structure, so the firm should consider the impact of product sharing on the product line design.

In the B2C sharing, the firm sells h, l to H, L in period 1 and the platform shares h, l to H, L in period 2. The profit optimization of the firm in period 1 is as follows:

\[
\max_{pfj, H, L} \pi_j = (pfj - cqlj^2)Nh + (pfj - cqlj^2)Nfj, \quad \text{s.t.} \\
\begin{align*}
(1R_{bf}) & \quad n\theta_Hq_h - pfj \geq 0, \\
(1R_{fl}) & \quad n\theta_lq_l - pfj \geq 0, \\
(1C_{bf}) & \quad n\theta_Hq_h - PfH \geq n\theta_Hq_h - PfH, \\
(1C_{fl}) & \quad n\theta_lq_l - PfL \geq n\theta_lq_l - PfL, \\
(1R_{bfh}) & \quad n\theta_Hq_h - PfH \geq \delta(\theta_Hq_h - PfH), \\
(1R_{bfl}) & \quad n\theta_lq_l - PfL \geq \delta(\theta_lq_l - PfL).
\end{align*}
\]

The profit optimization of the platform in period 2 is as follows:

\[
\max_{ppj, H, L} \pi_p = (ppj + \gamma pqj + qtj)Nh + (ppj + \gamma pqj + qtj)Nfj, \quad \text{s.t.} \\
\begin{align*}
(2R_{bf}) & \quad n\theta_Hq_h - ppj \geq 0, \\
(2R_{fl}) & \quad n\theta_lq_l - ppj \geq 0, \\
(2C_{bf}) & \quad n\theta_Hq_h - PfH \geq n\theta_Hq_h - PfH, \\
(2C_{fl}) & \quad n\theta_lq_l - PfL \geq n\theta_lq_l - PfL, \\
(2R_{bfh}) & \quad n\theta_Hq_h - PfH \geq \delta(\theta_Hq_h - PfH), \\
(2R_{bfl}) & \quad n\theta_lq_l - PfL \geq \delta(\theta_lq_l - PfL).
\end{align*}
\]
The platform can rent out the product in period 1, though the product sharing in period 2 is later than the product selling. Differentiated products for heterogeneous customers allow the firm and the platform to supply enough line design in the B2C sharing. Without any capacity constraints, the firm can sell enough products to customers, and the discounted value in the product sharing is counterbalanced by the same product line pricing (as in the product selling). Therefore, the firm’s product line faces new competition from the platform, where its high-quality product is not only cannibalized by the low-quality product in the product selling but also by the high-quality product in the product sharing. The high segment’s surplus in period 1 will be extracted by the platform that offers the same high-quality product in period 2. However, the high-quality product from the platform incurs a lower surplus than the low-quality product from the firm, so it implies that the high-quality product in the product sharing will not cannibalize the product line as long as the low-quality product in the product selling does not. The firm should reduce the price for the high-quality product and optimize the product line by inducing each segment to buy the corresponding product. As a result, the firm’s product line faces new competition from the platform, where its high-quality product is not only cannibalized by the high-quality product in the product sharing. The platform, where its high-quality product is not only cannibalized by the low-quality product in the product selling but also by the high-quality product in the product sharing. The high segment’s surplus in period 1 will be extracted by the platform that offers the same high-quality product in period 2. However, the high-quality product from the platform incurs a lower surplus than the low-quality product from the firm, so it implies that the high-quality product in the product sharing will not cannibalize the product line as long as the low-quality product in the product selling does not. The firm should reduce the price for the high-quality product and optimize the product line by inducing each segment to buy the corresponding product. As a result, the shared product incurs no cannibalization on the product line because both segments buy from the firm in period 1, and the platform in period 2 becomes useless.

Proposition 1. In the B2C sharing, the firm’s optimal product line pricing is \( p_{ph}^* = n \theta_{th} q_h - (n \theta_{th} q_l - n \theta_{fl} q_l) \) and \( p_{pl}^* = \theta_{fl} q_l \) and the platform’s optimal product line pricing is \( p_{pl}^* = \theta_{l} q_l \) and \( p_{fl}^* = \theta_{l} q_l \), where the optimal product quality is \( q_h^* = n(N_{fh} \theta_L - N_{jf} \theta_H + N_{jf} \theta_L)/2N_{fh} c \) and \( q_l^* = n(N_{fh} \theta_L - N_{jf} \theta_H + N_{jf} \theta_L)/2N_{fh} c \).

Proof. See the appendix.

Proposition 1 shows an intuitive result for the product line design in the B2C sharing. Without any capacity constraints, the firm and the platform can supply enough differentiated products for heterogeneous customers. Although the product sharing in period 2 is later than the product selling in period 1, the platform can rent out the same product (as the firm) to customers, and the discounted value in the product sharing is counterbalanced by the same product line pricing (as in the product selling). Therefore, the firm’s product line faces new competition from the platform, where its high-quality product is not only cannibalized by the low-quality product in the product selling but also by the high-quality product in the product sharing. The high segment’s surplus in period 1 will be extracted by the platform that offers the same high-quality product in period 2. However, the high-quality product from the platform incurs a lower surplus than the low-quality product from the firm, so it implies that the high-quality product in the product sharing will not cannibalize the product line as long as the low-quality product in the product selling does not. The firm should reduce the price for the high-quality product and optimize the product line by inducing each segment to buy the corresponding product. As a result, the shared product incurs no cannibalization on the product line design because both segments buy from the firm in period 1, and the platform in period 2 becomes useless.

\[ \text{Table 1: Comparison between the relevant literature and our study.} \]

<table>
<thead>
<tr>
<th>Literature</th>
<th>B2C sharing</th>
<th>C2C sharing</th>
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<th>Intertemporal sales</th>
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<tr>
<td>Tian and Jiang [17]</td>
<td>✓</td>
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<td>Benjaafar et al. [16]</td>
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<td>Yu et al. [7]</td>
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<td>Pei et al. [9]</td>
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<td>Bellos et al. [18]</td>
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<tr>
<td>Our study</td>
<td>✓</td>
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</table>

\[ \max_{p_{ph}, p_{pl}} \pi_p = (p_{ph} - t_{qh}) N_{ph} + (p_{pl} - t_{ql}) N_{pl} \]

\[ \text{s.t.} \]

\[ (IR_{2h}) \delta (\theta_{th} q_h - p_{ph}) \geq 0, \]

\[ (IR_{2l}) \delta (\theta_{l} q_l - p_{pl}) \geq 0, \]

\[ (IC_{2hl}) \delta (\theta_{th} q_h - p_{ph}) \geq \delta (\theta_{th} q_l - p_{pl}), \]

\[ (IC_{2lh}) \delta (\theta_{l} q_l - p_{pl}) \geq \delta (\theta_{l} q_h - p_{ph}). \]

Proposition 1 shows an intuitive result for the product line design in the B2C sharing. Without any capacity constraints, the firm and the platform can supply enough differentiated products for heterogeneous customers. Although the product sharing in period 2 is later than the product selling in period 1, the platform can rent out the same product (as the firm) to customers, and the discounted value in the product sharing is counterbalanced by the same product line pricing (as in the product selling). Therefore, the firm’s product line faces new competition from the platform, where its high-quality product is not only cannibalized by the low-quality product in the product selling but also by the high-quality product in the product sharing. The high segment’s surplus in period 1 will be extracted by the platform that offers the same high-quality product in period 2. However, the high-quality product from the platform incurs a lower surplus than the low-quality product from the firm, so it implies that the high-quality product in the product sharing will not cannibalize the product line as long as the low-quality product in the product selling does not. The firm should reduce the price for the high-quality product and optimize the product line by inducing each segment to buy the corresponding product. As a result, the shared product incurs no cannibalization on the product line design because both segments buy from the firm in period 1, and the platform in period 2 becomes useless.

3.2. Product Line in the C2C Sharing. In the C2C sharing, the firm sells \( h, l \) to \( H, L \) in period 1, and the sharer \( H, L \) (who buys the product) shares \( h, l \) to the lessee \( H, L \) (who does not buy the product) in period 2. The profit optimization of the firm in period 1 is as follows:

\[ \max_{p_{fh}, p_{fl}, q_h, q_l} \pi_f = (p_{fh} - c q_h^2) N_{fh} + (p_{fl} - c q_l^2) N_{fl} \]

\[ \text{s.t.} \]

\[ (IR_{1h}) n \theta_{th} q_h - p_{fh} \geq 0 \]

\[ (IR_{1l}) n \theta_{l} q_l - p_{fl} \geq 0 \]

\[ (IC_{1hl}) n \theta_{th} q_h - p_{fh} \geq n \theta_{th} q_l - p_{fl} \]

\[ (IC_{1lh}) n \theta_{l} q_l - p_{fl} \geq n \theta_{l} q_h - p_{fh} \]

\[ (IR_{2hl}) \xi (n \theta_{th} q_h - p_{fh}) + (1 - \xi) \left[ (1 - \gamma) p_{ph} - p_{fl} \right] \geq \delta (\theta_{th} q_h - p_{pl}) \]

\[ (IR_{2lh}) \xi (n \theta_{l} q_l - p_{fl}) + (1 - \xi) \left[ (1 - \gamma) p_{pl} - p_{fl} \right] \geq \delta (\theta_{l} q_h - p_{ph}) \]
The profit optimization of the platform in period 2 is as follows:

$$\max_{p_{ph}, p_{pl}} \pi_p = (\gamma p_{ph} - tq_h)N_{ph} + (\gamma p_{pl} - tq_l)N_{pl},$$

s.t.

$$\max \left\{ \delta (\theta_{th}q_h - p_{ph}), \delta (\theta_{qh}q_h - p_{ph}) \right\} \geq 0,$$

$$\max \left\{ (1 - \xi)\left[ (1 - \gamma)p_{ph} - f_{qh} - H_{qh} \right], (1 - \xi)\left[ (1 - \gamma)p_{pl} - f_{ql} - H_{ql} \right] - \xi (n_{th}q_h - p_{ph}) \right\} \geq 0.$$  (4)

**Proposition 2**

(a) When \( p_{ph}^* = \theta_{th}q_h, p_{pl}^* = \xi n_{th}q_h/(1 - \xi) (1 - \gamma) \),

(1) If \( \theta_{th}/\theta_{qh} \geq [(1 - \xi)n_{th}q_h + \delta q_h] / [(1 - \xi) (1 - \gamma)q_h + \delta q_h] / (1 - \gamma) \), \( p_{ph}^* = n_{th}q_h - (n_{th}q_h - n_{th}q_l) \), \( p_{pl}^* = \xi n_{th}q_h \).

(b) If \( \theta_{th}/\theta_{qh} < (1 - \xi) (1 - \gamma)q_h + \delta q_h \), \( p_{ph}^* = n_{th}q_h - (n_{th}q_h - n_{th}q_l) \), \( p_{pl}^* = n_{th}q_h \).

where \( \theta_{th} = \xi n_{th}q_h + (1 - \xi) (1 - \gamma)\theta_{qh} - \delta (\theta_{qh} - n_{th}q_h)(1 - \gamma) \).

(b) When \( p_{ph}^* = (\xi n_{th}q_h - p_{th}^*) / (1 - \xi) \),

(1) If \( \theta_{th}/\theta_{qh} \leq [(1 - \xi) (1 - \gamma)q_h + \delta q_h] / [(1 - \xi)n_{th}q_h + \delta q_h] \), \( p_{ph}^* = n_{th}q_h - (n_{th}q_h - n_{th}q_l) \), \( p_{pl}^* = n_{th}q_h \).

(2) If \( \theta_{th}/\theta_{qh} > (1 - \xi) (1 - \gamma)q_h + \delta q_h \), \( p_{ph}^* = n_{th}q_h - (n_{th}q_h - n_{th}q_l) \), \( p_{pl}^* = n_{th}q_h \).

where \( \theta_{th} = \xi n_{th}q_h + (1 - \xi) (1 - \gamma)\theta_{qh} - \delta (\theta_{qh} - n_{th}q_h)(1 - \gamma) \).

(c) When \( p_{ph}^* = \theta_{th}q_h, p_{pl}^* = \theta_{qh}q_h \)

(1) If \( \theta_{th}/\theta_{qh} \leq (1 - \gamma)/n \),

When \( \theta_{th}/\theta_{qh} \geq (1 - \gamma)/n \), \( p_{ph}^* = p_{th}^*, p_{pl}^* = p_{pl}^* \).

When \( \theta_{th}/\theta_{qh} \leq (1 - \gamma)/n \), \( p_{ph}^* = n_{th}q_h - (n_{th}q_h - n_{th}q_l) \), \( p_{pl}^* = n_{th}q_h \).

where \( \theta_{th} = \xi n_{th}q_h + (1 - \xi) (1 - \gamma)\theta_{qh} - \delta (\theta_{qh} - n_{th}q_h)(1 - \gamma) \).

Proposition 3

(a) When \( p_{ph}^* = \theta_{th}q_h, p_{pl}^* = (\xi n_{th}q_l - p_{pl}^*) / (1 - \xi) (1 - \gamma) \),

where \( \theta_{th} = \xi n_{th}q_h + (1 - \xi) (1 - \gamma)\theta_{qh} - \delta (\theta_{qh} - n_{th}q_h)(1 - \gamma) \).

\( \theta_{th}/\theta_{qh} \leq (1 - \gamma)/n \),

When \( \theta_{th}/\theta_{qh} > (1 - \gamma)/n \),

When \( \theta_{th}/\theta_{qh} \leq (1 - \gamma)/n \), \( p_{ph}^* = p_{th}^*, p_{pl}^* = p_{pl}^* \).

When \( \theta_{th}/\theta_{qh} > (1 - \gamma)/n \), \( p_{ph}^* = (\xi n_{th}q_h - n_{th}q_l) \), \( p_{pl}^* = n_{th}q_h \).

Proof. See the appendix.
(a1) If \( \theta_H/\theta_h \geq \frac{[1 - (1 - \xi)nq_h \pm \delta q_h]}{[(1 - \xi)(1 - \gamma)q_h + \delta q_h/(1 - \gamma)]} \), \( q_h^* = nq_h / 2c \), \( q_h^* = (N_f h \theta_h - N_f h \theta_h / \theta_h)/(2N_f h / c) \).

(a2) If \( \theta_H/\theta_h \leq \frac{[1 - (1 - \xi)nq_h \pm \delta q_h]}{[(1 - \xi)(1 - \gamma)q_h + \delta q_h/(1 - \gamma)]} \), When \( n\theta_H q_h - n\theta_H q_h \geq p_3 - n\theta_H q_h \geq n\theta_H q_h - n\theta_H q_h, q_h^* = (N_f / \theta_h - \delta q_h/\theta_h)/(1 - \gamma)) / 2N_f h / c \).

(b) If \( \theta_H/\theta_h \geq \frac{[1 - (1 - \xi)(1 - \gamma)q_h + \delta q_h/(1 - \gamma)]}{[(1 - \xi)nq_h \pm \delta q_h]/(1 - \gamma)}, q_h^* = n\theta_H / 2c, q_h^* = (N_f h \theta_h - N_f h \theta_h / \theta_h)/(2N_f h / c) \).

(b1) If \( \theta_H/\theta_h \leq \frac{[1 - (1 - \xi)(1 - \gamma)q_h + \delta q_h/(1 - \gamma)]}{[(1 - \xi)nq_h \pm \delta q_h]/(1 - \gamma)}, q_h^* = n\theta_H / 2c, q_h^* = (N_f / \theta_h - \delta q_h/\theta_h)/(1 - \gamma)) / 2N_f h / c \).

(c) When \( p_{2h}^* = \theta_H q_h, p_{2h}^* = \theta_H q_h \).

(c1) If \( \theta_H \leq \frac{1}{(1 - \gamma)} \), When \( n\theta_H q_h - n\theta_H q_h \geq p_3 - n\theta_H q_h \geq n\theta_H q_h - n\theta_H q_h, q_h^* = (\xi \theta_H - \delta q_h/\theta_h)/(1 - \gamma)) / 2N_f h / c \).

(c2) If \( \theta_H \geq \frac{1}{(1 - \gamma)} \), When \( n\theta_H q_h - n\theta_H q_h \geq p_3 - p_4 \geq n\theta_H q_h - n\theta_H q_h, q_h^* = (\xi \theta_H - \delta q_h/\theta_h)/(1 - \gamma)) / 2N_f h / c \).

Proof. See the appendix.

In Proposition 3, the optimal product quality in the product line changes with the economic parameters in the sharing economy, and we make the comparison between the B2C sharing and C2C sharing in Table 2. In two types of sharing platforms, the product quality decreases with the cost sensitivity. The higher cost sensitivity leads to a higher variable cost of production in period 1, so reducing the product quality is an efficient way for the firm to maintain the profit in the product line. However, the high segment has the intention to buy low-quality products. The firm should set the product line pricing by considering the cannibalization from the low-quality product, and the positive influence of the cost sensitivity depends on the number ratio of the two segments.

In the C2C sharing, the low segment would like to buy the product and then share it, so the sharing probability only influences the low-quality product in the product line. Differently from the B2C sharing, the higher commission rate is profitable for the platform and has no impact on the firm directly. The firm should decrease the quality of the shared product or increase the quality of the used product, to reduce the cannibalization effect from the platform in period 2.

4. Numerical Experiment

In this section, we compare the impact of some parameters on different sharing markets and show the managerial implications for the platform, product, and customers in the product line. We take Proposition 2(b) as an example in which Proposition 2(b1) is the equivalence of the B2C sharing and the second scenario in Proposition 2(b2) is the simplification of the C2C sharing. The parameter setting is \( \xi = 0.5, \gamma = 0.5, \delta = 0.95, \) and \( n = 1, \) which guarantees that \( \theta_H \leq 2\theta_L, \) so that all variables are nonnegative in the experiments.

4.1. Firm's Profit. In B2C sharing and C2C sharing, the firm's profit is mainly influenced by the cost sensitivity from the seller side and the quality sensitivity from the buyer side. Given the cost sensitivity, we examine how the quality sensitivity influences the firm's profit.

In Figures 2 and 3, when the cost is more sensitive to the product quality, the firm's profit decreases because of the higher variable cost in production. In Figure 2, the firm's profit increases with the quality sensitivity. In the B2C sharing, both segments buy from the firm in period 1 and no segments rent from the platform in period 2.

However, in Figure 3(b), the firm's profit decreases with the quality sensitivity. In the C2C sharing, both segments buy from the firm in period 1 and only the low segment shares in period 2. The firm faces cannibalization from the platform in period 2 and should reduce the price for the low-quality product, to induce the low segment to buy in period 1.
Table 2: Sensitivity analysis of the product quality in the product line.

(a) $\theta_H, \theta_L, c$ in B2C sharing

<table>
<thead>
<tr>
<th>$q_h$</th>
<th>$\theta_H$</th>
<th>$\theta_L$</th>
<th>$c$</th>
</tr>
</thead>
<tbody>
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<td>×</td>
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$N_f/N_f^H < (\theta_H - \theta_L)/\theta_L$  \quad  $N_f/N_f^H > (\theta_H - \theta_L)/\theta_L$

(b) $\theta_H, \theta_L, \xi$ in C2C sharing (the second scenario in Proposition 3(b2))

<table>
<thead>
<tr>
<th>$q_h$</th>
<th>$\theta_H$</th>
<th>$\theta_L$</th>
<th>$\xi$</th>
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$N_f/N_f^H < [n - (1 - \xi)(1 - \gamma)]/([1 - \xi](1 - \gamma)]$  \quad  $N_f/N_f^H > [n - (1 - \xi)(1 - \gamma)]/([1 - \xi](1 - \gamma)]$

$\theta_L/\theta_H < (1 - \gamma)/n  \quad  \theta_L/\theta_H > (1 - \gamma)/n$

(c) $c, \xi, \delta$ in C2C sharing (the second scenario in Proposition 3(b2))

<table>
<thead>
<tr>
<th>$q_h$</th>
<th>$\theta_H$</th>
<th>$\theta_L$</th>
<th>$\xi$</th>
<th>$\delta$</th>
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<tr>
<td>↑</td>
<td>$c$</td>
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$N_f/N_f^H < [n\theta_H - \delta \theta_L - (1 - \xi)(1 - \gamma)\theta_H]/[\xi\theta_L + (1 - \xi)(1 - \gamma)\theta_H]$  \quad  $N_f/N_f^H > [n\theta_H - \delta \theta_L - (1 - \xi)(1 - \gamma)\theta_H]/[\xi\theta_L + (1 - \xi)(1 - \gamma)\theta_H]$

$\xi\theta_L + (1 - \xi)(1 - \gamma)\theta_H$  \quad  $\delta\theta_L + (1 - \xi)(1 - \gamma)\theta_H$
Figure 2: Firm's profit in the B2C sharing (a) when $\theta_H$ changes and (b) when $\theta_L$ changes.
Figure 3: Firm's profit in the C2C sharing (a) when $\theta_H$ changes and (b) when $\theta_L$ changes.
In Figures 2 and 3, the quality sensitivity satisfies $\theta_L \leq \theta_H \leq 2\theta_L$ or $\theta_H/2 \leq \theta_L \leq \theta_H$ (to keep the firm's profit nonnegative). There is always a valuation difference between two segments, so we define the customer heterogeneity as $\Delta = \theta_H - \theta_L$ where $0 \leq \Delta \leq \theta_L$ when $\theta_H$ changes and $0 \leq \Delta \leq \theta_H/2$ when $\theta_L$ changes. The impact of the customer
Figure 5: Platform’s profit in the C2C sharing (a) when $\theta_H$ changes and (b) when $\theta_L$ changes.
heterogeneity is contingent on the intervals with the solid line, while the dashed line implies that the firm’s profit varies nonmonotonically in other intervals.

If the customer heterogeneity is higher, i.e., lower $\theta_L$ in Figure 3(a) and higher $\theta_H$ in Figure 3(b), the firm obtains more profit from the C2C sharing. Because there is a sharing price for the same quality product in period 2, the firm always faces price competition with the platform. To make up for the loss, the firm keeps or lowers the price for both products in the product line, but the price difference should be the same for the two heterogeneous segments. The participants in C2C sharing are the customers instead of the platform, so customer heterogeneity in C2C sharing plays a more important role than in B2C sharing.

4.2. Platform’s Profit. Compared with the firm’s profit, Figures 4 and 5 show how the platform’s profit varies with the cost sensitivity from the seller side and the quality sensitivity from the buyer side.

As shown in Figure 4, the platform’s profit is independent of cost sensitivity and quality sensitivity. In the B2C sharing, both segments buy from the firm in period 1 and give up renting from the platform in period 2, so the platform’s profit in the B2C sharing is zero.

In contrast to the firm, the platform’s profit in Figure 5(a) decreases with the quality sensitivity but increases with the quality sensitivity in Figure 5(b). The competition between the firm and the platform implies that the selling profit is positively related to the high segment, while the sharing profit is positively related to the low segment. Furthermore, because of the production cost in period 1 and the transaction cost in period 2, the firm’s profit is quadratic with the quality sensitivity and the platform’s profit is linear with the quality sensitivity, which results that the platform’s profit being more sensitive than the firm’s profit.

4.3. Customer Demand. In the sharing market, the customer can be a buyer, sharer, lessee, or user (who fails to share/rent in period 2), which depends on the choice behavior in each period and determines the demand for the firm or the platform.

In Figure 6(a), the customers who buy in period 1 cannot be the sharers in period 2, due to the product owned by the platform. They also cannot be the lessees in period 2 because the firm adopts the product line pricing to induce each segment to buy the corresponding product. In other words, the customers would not like to rent the same product from the platform and use the product that is bought in period 1.

In Figure 6(b), the customers who buy in period 1 can be the sharers or lessees in period 2. There are only three possible cases that make the demand match the supply in the C2C sharing: (i) the high segment shares only, (ii) the low segment shares only, and (iii) two segments share. Only if the on-demand deal is achieved, the lessees can rent the differentiated product from the sharers in period 2; otherwise, they seek the product on the platform.

5. Conclusion

5.1. Policy Implications. As the sharing economy develops in many industries, the sellers face the new challenge to satisfy the customers’ diverse needs for the various products on the sharing platform. How to use the product line design in the sharing market is potential for all stakeholders. Compared with the prior research in the sharing economy, our study further shows the pricing guidelines for the e-commerce platform to meet the diverse needs of customers. This study gives some policy implications in the product line design under the sharing economy, which will be insightful for scholars, practitioners, and policymakers in the sharing market.

First, our study has concluded that within the product line, the platform’s sharing profit in the C2C sharing may be positively influenced by the sharer’s valuation. Unlike B2C sharing, the sharer replaces the role of the e-commerce platform to rent out the products, so the sharer’s willingness to participate will significantly influence the revenue of the C2C platform. In 2016, Uber announces it to stop the ride-hailing service in China and completely leave the local
market. The poor experience on the driver’s side is the main factor that results in Uber’s failure. For the drivers who offer the ride-hailing service (i.e., the sharers), Uber sends the order completed by the background algorithms and prohibits the drivers to choose the order according to their wishes. As a result, a lot of drivers reject the long-distance order and make complaints to the department of transportation.

Second, the C2C sharing platforms should implement a policy that improves product quality. Offering the high-end product can further counterbalance the price competition in the sharing market, thus contributing to the profit maximization of the C2C platform. In the early stage of entering the Chinese market, Uber distributes a large number of coupons in the mobile app, so that ordinary passengers can take Uber X (economic car) with a price close to the taxi fare.

Finally, it is an appropriate strategy for the C2C platform to induce low-value users with a higher price. Customers who have a low-value are more likely to be induced by price discounts, which will be the primary target for the C2C platform to make profits. The subsidy policy helps Uber to capture the low-end traffic market in urban cities and cannibalizes the huge market share of taxis in China. On the demand side, the separation of the owning right and possessing right incurs a variety of passenger types, so the passenger’s behavior will become more flexible (e.g., variety-seeking or boundedly rational) on Uber’s ride-hailing platform.

5.2. Limitations and Recommendations. Although our findings facilitate the optimization of the product line design in B2C sharing and C2C sharing, three limitations should be further addressed. First, competition between two manufacturing firms or e-commerce platforms is very important for customers. Either the quality decision or the pricing strategy in the context of competition will change the customer’s decision in the sharing market. Second, the quantitative modeling of fixed costs will have a potential impact on the manufacturing firm’s profits, and thus influences product sharing on the e-commerce platform. Finally, there are some network externalities or showrooming effects on the e-commerce platform, which will make a difference to the manufacturing firm’s production and supply in advance.

This study will give some recommendations to scholars who focus on the sharing economy for future studies. On the one hand, future directions should consider how to use marketing strategies to coordinate the relationship between manufacturing firms and e-commerce platforms, such as group buying, coupons, and membership. Price promotion can be an effective tool to reduce the loss of market shares in the competition. On the other hand, the role of the government in the sharing market should be evaluated because the financial subsidy or regulatory policy is an important incentive for most e-commerce platforms. As a mediator, government involvement will affect the resource allocation to the manufacturing firm in different sharing markets.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Acknowledgments

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Supplementary Materials

In the supplemental file, we have given detailed mathematical derivations for all propositions in our study. Based on the game theory, we set up the individual rationality constraint and the incentive compatibility constraint to solve the classic problem of the product line design under the sharing economy. Please check the proofs in the appendix for your reference. (Supplementary Materials)

References