Int. J. Production Economics 224 (2020) 107544

Contents lists available at ScienceDirect

International Journal of Production Economics

journal homepage: http://www.elsevier.com/locate/ijpe

How do product quality uncertainties affect the sharing economy platforms with risk considerations? A mean-variance analysis

Xin Wen [*], Tana Siqin [1]

Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

ARTICLE INFO

Keywords:
Sharing economy
Uncertain product quality
Pricing strategy
Consumer utility
Mean-variance theory

ABSTRACT

The sharing economy is of increasing importance for various aspects of our society by providing people with cost-efficient and convenient access to services or products. However, the profitability and healthy development of the sharing economy platforms are greatly restricted by the intensive uncertainties arising from product quality. How to determine the optimal product quality improvement efforts and the optimal prices for the sharing platforms becomes crucial. Moreover, it is reasonable that many sharing economy platforms and consumers are holding a risk-averse attitude during decision making in the highly volatile market. In this paper, we employ the Mean-Variance theory to model the risk-averse attitudes of decision makers, and analytically derive the optimal average quality levels and prices that the platform should provide for the market. We also explore how the critical factors like product quality uncertainty and risk sensitivity affect the platform's equilibrium decisions and consumer surplus. Our analytical results reveal the importance of reducing the difficulty of improving product quality for enhancing the platforms' profitability and consumer surplus. Besides, we identify that it is not always wise for platforms to invest in improving product quality, especially when the related cost becomes increasingly expensive. Moreover, it is shown that the increasing risk aversion or product quality volatility will induce the platform to reduce his quality improvement efforts. Finally, we interestingly find that the platform will always suffer if he becomes risk averse from risk neutral, while consumers may benefit from this attitude change.

1. Introduction

1.1. Background and motivation

In recent years, owing to the fast development of the disruptive technologies such as mobile and online communications, the sharing economy has attracted extensive attention from many aspects of the society, and obtained remarkable achievements (Asian et al., 2019; Cannon and Summers, 2014). The sharing economy refers to the business model which is built upon on-demand access to products or services, facilitated by online platforms which link many small owners with small consumers (Benjaafar and Hu, 2019). Currently, the concepts and ventures of the sharing economy have appeared in various sectors of our life, like food (e.g., OLIO), bicycle (e.g., ofo, Mobike), car (e.g., Uber, Didi, Grab), hospitality (e.g., Airbnb), fashion products (e.g., Reheart), and charger (e.g., Laidian), which have revolutionized the traditional business systems and further changed the world we live in. As predicted by Schroders, the global industry-wide revenue of the key parts of the sharing economy will grow up to $335 billion by 2025 from $15 billion today.[2]

The sharing economy brings extensive benefits for the society. First of all, through renting[3] the shared products from platforms at a low price, consumers are provided with an access to a higher standard of life without the burden of buying the products. Second, people can enjoy high flexibility and freedom, but are free from the financial, emotional, and social obligations embedded in the ownership through using the shared products (Eckhardt and Bardhi, 2015). Third, product owners can earn profits from making productive use of their possessions when they would otherwise be idle by connecting with strangers desiring such a product through the sharing platforms. Fourth, the society and the environment can be benefited from the sharing economy through the reduced resource consumption, pollution, and wastes. Therefore, the importance of the sharing economy for human being has been realized, and tremendous efforts have been devoted to enhancing the

* Corresponding author.
E-mail addresses: windyy.wen@connect.polyu.hk (X. Wen), tana-t.siqin@connect.polyu.hk (T. Siqin).

[1] Tana Siqin's research was fully supported by a grant from the Research Committee of The Hong Kong Polytechnic University under student account code RK2T.

[2] https://www.schroders.com/nl/sysglobalassets/digital/resources/pdfs/2016-08-the-sharing-economy.pdf. Retrieved on 30 Sept 2019.

[3] In this paper, we use the term "rent" to represent the access of consumers to the shared products.

https://doi.org/10.1016/j.ijpe.2019.107544
Received 11 October 2019; Received in revised form 18 October 2019; Accepted 29 October 2019
Available online 2 November 2019

development of this industry.

However, the sharing economy is facing with diverse challenges which significantly restrict its prosperous development (Ganapati and Reddick, 2018). For example, it is difficult to build trust among product owners and consumers, while the security concerns have created a great trouble for the sharing economy practitioners. More importantly, the industry is intensively challenged by the uncertain product quality problem. In practice, the shared products are usually used by consumers without the control of the platform or the owner. For example, charger sharing platforms commonly place the shared charger stations at shopping malls, supermarkets, and restaurants, where consumers can easily approach when their telephones have "low battery". The consumers can bring the shared chargers anywhere they want. After consumption, they only need to return the chargers to any stations from the same platform. During these processes, the chargers are not well-monitored by the platform.[4] Besides, some of the shared products are often placed outside with a large quantity, while inspections are insufficient (e.g., shared bicycles). As a result, the conditions of the shared products are inevitably uncertain, and damages are commonly seen nowadays (see examples in Fig. 1). For example, it is reported that around 40% of the shared bicycles in Shanghai are partially broken, which creates great safety risks for users.[5] However, the platforms offering these shared bicycles lack sufficient financial and labor support for maintenance. As consumers are typically sensitive to the quality of on-demand services and products (Benjaafar and Hu, 2019), the uncertain product quality of the shared products brings huge negative impacts on the consumption experiences of consumers, thus affecting market demand and the development of platforms. As a result, the sharing economy service providers are significantly suffering from the volatile product quality problem. In the research domain, the importance of quality control for the sharing economy systems is also realized. For example, Jiang and Tian (2016) show that it is optimal for service providers to strategically improve product quality to obtain a higher profit in the existence of a sharing market. However, the quality improvement efforts made by the service providers inevitably incur non-trivial costs, which restrict the benefits of the increased demand brought by the higher product quality. Consequently, the sharing economy platforms nowadays are keen to identify the optimal product quality levels they should provide for consumers, in order to maximize their profitability.

To tackle the problem of uncertain product quality and reduce the difficulty of quality improvement, recently, some sharing platforms encourage consumers to report the conditions of the shared products after they finish the usage. For example, Mobike provides non-monetary incentives for users if they correctly report the locations and the specific problems of the shared bicycles in time through App.[6] This measurement makes it easier for the sharing platforms to identify which specific product needs maintenance or proper "repair", and how much efforts are required. Accordingly, the platforms can better allocate resources to improve product quality with lower difficulty. Therefore, the service providers in the sharing economy can benefit from a reduction in the quality improvement costs through useful consumer feedback reports, which deserves more analytical investigations.[7]

Moreover, the pricing problem is also critical for the sharing economy. As pointed out by Eckhardt and Bardhi (2015), consumers in the sharing economy are more interested in accessing the products with lower prices, instead of fostering social relationships with the service provider or other customers. Therefore, companies who understand this philosophy will own competitive advantages. For example, although both Uber and Lyft are famous car-sharing platforms in the world offering similar services, Uber experiences a higher growth rate than Lyft owing to the different strategic positions. To be specific, Uber positions "low pricing" as the main target of its operations, while Lyft aims to provide "friendly" car ride experiences for consumers (Eckhardt and Bardhi, 2015). Moreover, in the literature, Cachon et al. (2017) insist that the pricing mechanism for dynamic demand conditions is crucial for the profits of sharing platforms and the welfare of consumers, while Jiang and Tian (2016) demonstrate the importance of deciding the retail prices and product quality simultaneously in the sharing market.

Besides, considering the extensive uncertainties arising from product quality, it is reasonable that some platforms in the sharing economy hold a risk-averse attitude towards profit volatilities to maintain profitability in the highly uncertain and competitive environment. Besides, consumers can also be risk averse considering that they are typically sensitive to the quality of the shared products. Consequently, improving the strategic decision making, especially with risk considerations, becomes essential for the sharing economy industrialists.

1.2. Research questions and major findings

Motivated by the importance of the sharing economy and the real challenge revealed (i.e., uncertain product quality), in this work, we analytically study the quality improvement decisions and the pricing strategies of sharing economy platforms with risk considerations. To be specific, we consider a platform who offers shared products with uncertain product quality. The consumers are heterogeneous in product valuation. Besides, the platform can make efforts to improve product quality with a cost, which increases market demand. We first analyse the scenarios when the platform is risk-neutral and risk-averse, exploring the optimal average quality levels and the optimal prices for the platform with product quality uncertainties. Then, we extend the analyses to consider risk-averse consumers, and highlight the importance of useful consumer feedback reports for the sharing economy. Specifically, in this paper, we aim at addressing the following research questions:

1. What are the optimal average quality levels and the optimal pricing decisions for risk-neutral and risk-averse sharing platforms when they operate with stochastic product quality? What are the differences between the risk-neutral and risk-averse case? What are the equilibrium outcomes if consumers are also risk-averse?
2. Will consumers benefit from the risk-averse attitude of the platform? How do the crucial factors (e.g., quality improvement cost coefficient and risk sensitivity coefficient of the platform) affect consumer surplus?
3. Is it always wise for the platform to provide a higher average quality level to attract more consumers? Is it always beneficial to reduce the difficulty of quality improvements (e.g., through consumer reports)?

As will be shown later on in this study, by solving the above research questions, a number of important insights are identified. First, by addressing the first research question, we identify that whether optimal decisions (i.e., the optimal average quality levels and the optimal prices) exist depends on the difficulty of improving product quality for the platform, the product quality sensitivity of consumers, the risk attitudes of the platform, and the uncertainty of product quality (note that the last two factors apply to risk-averse platforms). Second, when the risk attitudes of consumers are not considered, the platform would reduce its retail price and provide a lower average quality level if he becomes risk averse from risk neutral. Accordingly, the platform will suffer from a

[4] https://www.sixthtone.com/news/2182/phone-chargers-chinas-latest-sharing-economy-fad. Retrieved on 17 Oct 2019.

[5] https://www.shobserver.com/news/detail?id=87258. Retrieved on 30 Sept 2019.

[6] https://mobike.com/cn/. Retrieved on 9 Oct 2019.

[7] Note that the sharing platforms nowadays also upgrade their control systems to reduce the difficulty of quality improvement with an upgrading cost. However, the consumer report is the most common and cost-efficient quality-improvement difficulty reduction method in the industry. Besides, the impact of consumers on the performances of platforms is critical. Therefore, in this paper, we would like to explore and highlight the crucial impact of consumer reports on the optimal decision making of sharing platforms.

[8] The figures are collected from http://image.baidu.com/. Retrieved on 17 Oct 2019.

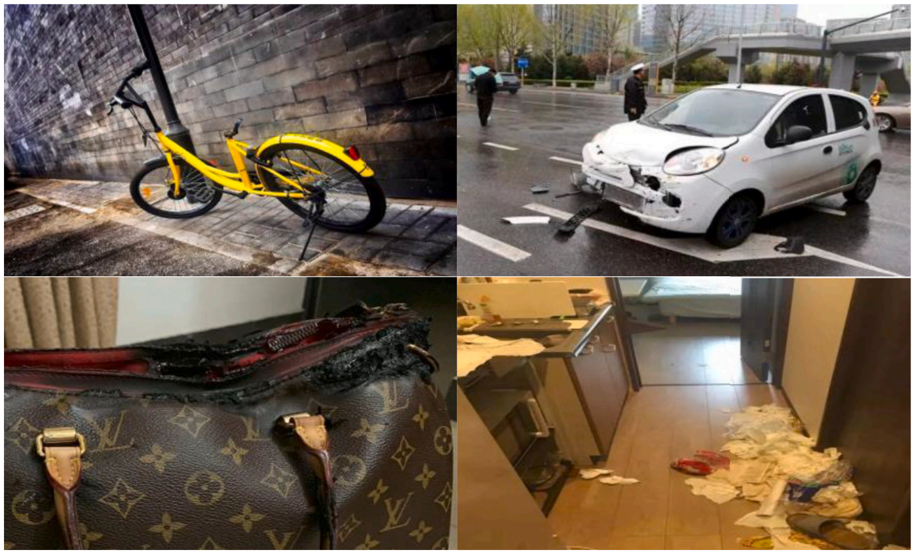

Fig. 1. Damaged shared product examples (bicycle, car, handbag, house).[8]

profit reduction, while consumers may either suffer or even benefit from this attitude change. However, if the platform is risk averse, consumer surplus will always be impaired when consumers become risk averse compared to the risk neutral case (which answers the second research question). Third, regarding the third research question, we find that it is not always optimal for the platform to enhance product quality, especially when quality improvement efforts become much harder, regardless of his risk attitude. Besides, the platform can be more conservative in the investments for quality improvement when he is more risk averse or the product quality becomes increasingly volatile. Fourth, no matter when the platform or consumers are risk neutral or risk averse, reducing the difficulty of quality improvements benefits all the participants. Therefore, it is of great importance to encourage consumers to provide valuable feedback reports regarding the product problems for the sharing economy.

1.3. Contribution statements and organization

To the best of our knowledge, this work is the first analytical study which comprehensively investigates how product quality uncertainty and the risk attitudes of decision makers affect the optimal quality and pricing decisions for sharing economy platforms. The integration of risk considerations into the decision framework derives novel implications regarding the impact of risk attitudes on the operations of sharing platforms. The MV theory is employed to characterize the risk-averse behaviors of both platforms and consumers. More importantly, the uncertain product quality is considered, which is crucial for the profitability and development of the sharing economy, thus providing valuable and useful guidelines for practitioners to deal with the volatility arising from product quality. All findings/results are derived in closed-form and proven mathematically. In conclusion, considering the significance of the optimal quality and price decisions for sharing economy platforms and the increasing interests from both the academia and the industry, our work provides critical managerial insights to help enhance the competitiveness of the sharing economy service providers in the highly uncertain market.

The remaining parts of this work are organized as below. First, Section 2 reviews the related literature. Then, the model setting is introduced in Section 3. Next, Section 4 derives the equilibrium solutions and managerial insights for the sharing economy platforms with and without risk considerations. In Section 5, we extend the analyses to integrate the risk behaviors of consumers into the decision framework. Finally, Section 6 concludes for this study and proposes a number of future research directions.

2. Related literature

First of all, our study belongs to the research stream for the sharing economy. Second, due to the importance of platforms for the sharing economy, we review the recent academic achievements on platform operations. Third, as we consider the risk attitudes of both platforms and consumers, this paper thus relates to the stream of risk-averse decisions.

2.1. Sharing economy

The sharing economy has been widely recognized as a main growth sector of the current world (Li et al., 2019b; Ma et al., 2019; Roma et al., 2019; Wang et al., 2019). It has disrupted many industries through providing consumers with cost-efficient and convenient access to products or services without the burden of ownership (Gong et al., 2019; Yuan and Shen, 2019). Therefore, the issues related to this emerging industry have attracted extensive attention from the academia. Recently, Choi et al. (2019a) explore the value of food leftover sharing platforms by constructing a supply chain consisting of a single supplier and multiple retailers. Choi et al. (2019a) analytically prove that the supplier, the retailers, the consumers, and the environment can benefit from the food leftover sharing scheme. Different from Choi et al. (2019a), Cachon et al. (2017) concentrate on the “self-scheduling” providers (e.g., Uber), and analyse the optimal pricing decisions for the sharing platforms. Interestingly, Cachon et al. (2017) find that the surging pricing strategy can increase the platform’s profits compared to the fixed pricing strategy, although it is criticized by the public. Similarly, Jiang and Tian (2016) also investigate the pricing strategies in the sharing economy. In the model of Jiang and Tian (2016), manufacturers determine prices with the anticipation that some consumers will share their products with others (which is the so-called Collaborative Consumption) through platforms. On the other hand, Bellos et al. (2017) explore the product line design problem for the car-sharing industry, and try to find the optimal type of vehicles that OEMs should provide for the market. However, through analyses, Bellos et al. (2017) demonstrate that the car-sharing scheme is not always beneficial for the environment. Besides, the performance of a hybrid bike-sharing system is investigated in Albiński et al. (2018) through a usage pattern and demand analysis. The authors find that the service levels are usually overestimated, and suggest an adjusted incentive and reposition strategy to improve consumer satisfaction as well as the system’s profitability.

Similar to the above research, we also investigate the operations management problems for the sharing economy. However, different from them, we focus on investigating the optimal quality improvement efforts and the corresponding pricing strategies for the service providers who are challenged by uncertain product quality. Accordingly, we are able to explore the critical impacts of product quality uncertainty on the performances of the sharing economy platforms, thus producing useful managerial implications. Moreover, the risk attitudes of the decision maker are integrated into the decision framework with product quality uncertainty, which is novel in the sharing economy literature.

2.2. Platform operations

In recent years, platform operations have become one of the most critical topics in operations management (Choi et al., 2018a). For example, Du et al. (2019) examine the platform's investment strategies for green product advertisement. Through exploring diverse budget allocation rules, Du et al. (2019) analytically find that the advertisement for green products can enhance the platform's profitability. Besides, many studies focus on examining the problems related to online platforms. For instance, Wang et al. (2016) analyse the advertising strategies for a mobile platform (e.g., Apple's iOS) by developing a game-theoretical model, while Liu et al. (2019) investigate the pricing strategies for "online-to-offline" (O2O) platforms with the considerations from both the demand side and the supply side. From the perspective of e-commerce, Zhang et al. (2018) explore the reason why brands are using the flash sale (FS) strategy to sell a limited number of new products at a discounted price before the normal selling season. Besides, Barenji et al. (2019) deal with the scheduling and synchronization problems for the logistics parks in the e-commerce environment by developing a hybrid agent-based approach.

Moreover, the platform operations in the sharing economy have attracted growing attention due to the fast development of the sharing economy industry and the importance of platforms for it. For example, Choi and He (2019) examine the benefits of peer-to-peer collaborative consumption facilitated by fashion products sharing platforms for fashion brands, as well as the crucial impacts of fashion brands' advertisement on the market performances. Besides, Kung and Zhong (2017) explore the important pricing decisions for platforms who provide delivery services from independent retailers to consumers in the era of sharing economy. A two-sided profit maximization problem is formulated to examine three pricing strategies (i.e., transaction-based pricing, membership-based pricing, and cross subsidization) with the consideration of network externality in Kung and Zhong (2017). Their results indicate that the three pricing strategies are equivalent if there exists no time discounting while the consumers' order frequency is insensitive to price. From the above discussion, it is obvious that the platform operations for the sharing economy are of great importance to study. In this paper, we also explore the issues related to the sharing platform operations. However, our work is totally different from the existing literature as it focuses on the uncertain product quality problem which is commonly seen in the sharing economy industry nowadays, but has not been analytically investigated in the platform operations literature, especially with risk considerations.

2.3. Risk-averse decisions

Decisions with risk considerations are important for the current world with diverse sources of uncertainties (Buzacott et al., 2011; Sun et al., 2018; Choi et al., 2019b; Wen et al., 2019a, 2019b). For example, Chiu et al. (2019) adopt a multi-methodological approach to explore the supply chain contracting problem with supplier's risk considerations. They find that manufacturer's minimum risk level can coordinate the supply chain. On the other hand, Gan et al. (2005) and Choi et al. (2018b) explore the impacts of retailers' risk attitudes on the supply chain performances. Specifically, Gan et al. (2005) demonstrate that the risk-sharing contract, instead of the revenue sharing or buy-back contracts, can coordinate a supply chain composed of a risk-neutral supplier and a risk-averse retailer. Besides, in the quick response supply chain of Choi et al. (2018b), retailers could be either risk-averse or risk-seeking. Interestingly, Choi et al. (2018b) find that a stochastic risk attitude of the retailer is beneficial to the supply chain. Moreover, Chen et al. (2007) incorporate risk aversion into the multiperiod inventory management problem which aims to coordinate the pricing and inventory decisions. They show that with exponential utility functions, the structure of the optimal strategies of a risk-averse company is almost the same as that of a risk-neutral one.

Regarding the risk analysis approaches, the Mean-Variance (MV) theory is commonly employed in both the academia and the industry (Gan et al., 2004). The MV theory was initially constructed for the portfolio optimization problems, which is then widely applied in the supply chain management problems. Readers are referred to Chiu and Choi (2016) and Choi et al. (2019c) for comprehensive reviews of the applications of the MV theory in supply chains. For instance, Chiu et al. (2018) investigate the optimal advertising budget allocation decisions in an MV framework. The authors uncover that the MV efficient frontier is characterized differently under various consumer purchasing scenarios. Besides, in the work of Wen et al. (2019c), the risk aversion against profit volatilities of competing air cargo carriers who are challenged by uncertain market demand is captured by the MV theory. The authors demonstrate the critical impacts of the risk attitudes of decision makers on the optimal strategies, and explore how the important factors like competition level and demand uncertainty affect the equilibrium outcomes. Similar to the above studies, we also apply the MV theory to characterize the risk-averse attitudes of both the platform and consumers in this study.

In summary, it is clear that relatively limited research has explored the product quality and pricing decisions in the uncertain environment for the sharing economy platforms. Moreover, none of the current studies have examined the integrated impact of product quality uncertainty and risk preferences of decision makers on the optimal strategies for the sharing economy industry. Therefore, this paper aims to bridge these critical literature gaps through constructing an MV framework to explore the optimal average product quality levels and the optimal prices for risk-averse sharing economy platforms who are challenged by uncertain product quality.

3. The model

In this work, we consider a sharing economy platform[9] who provides shared products (e.g., bicycles, chargers) for consumers with a unit price of p ($p < 1$) at the unit cost of c ($c < p$). The notations of parameters used in this work are summarized in Table 1. Following the existing literature (Choi and He, 2019; Vorasayan and Ryan, 2006), we consider heterogeneous consumers whose product valuations (v) are uniformly distributed in [0,1]. That is, $v \sim U[0,1]$. Note that the results generated from the uniformly distributed consumer utility can derive abundant useful and important insights. It is also consistent with the classic linear additive price dependent demand function. Therefore, it is widely applied in the operations management and marketing research (Ozinci et al., 2017; Wu, 2015). Besides, we use $f(v)$ and $F(v)$ to represent the probability density function and cumulative distribution function for consumer valuation, respectively. Moreover, as discussed, the shared products are usually in bad conditions that bring negative impacts for

[9] In the following analyses, for simplicity, we use the terms "platform", "service provider", and "company" to represent the sharing economy platform that we considered.

Table 1
Notation of parameters used in this work.

Parameter	Definition
p	The unit price of the shared product, $p < 1$
c	The unit cost of the shared product, $c < p$
v	The heterogeneous consumer valuation, $v \sim U[0,1]$
$F(v)$	The probability density function of v
$F(v)$	The cumulative distribution function of v
$\tilde{q}$	The uncertain product quality, $\tilde{q} \tilde{} G(\overline{q},\ \sigma^2)$
σ	The variance of product quality, $\sigma > 0$
$\overline{q}$	The average product quality, $\overline{q} > 0$
u	The consumer utility, $u > 0$
θ	The product quality sensitivity coefficient of consumers, $\theta > 0$
$d(\tilde{q})$	The market demand for the product with uncertain quality
k	The quality improvement cost coefficient, $k > 0$
$E(\tilde{\pi})$	The expected profit for the service provider
$V(\tilde{\pi})$	The variance of profit for the service provider
cs^*	The equilibrium consumer surplus
$\Delta p^*, \Delta\overline{q}^*, \Delta E(\tilde{\pi})^*, \Delta cs^*$	The modifications in each equilibrium outcome due to the platform's attitude change
$\Delta^{\vdots}p^*, \Delta\overline{q}^*, \Delta^{\vdots}E(\tilde{\pi})^*, \Delta^{\vdots}cs^*$	The modifications in each equilibrium outcome due to the consumer's attitude change

consumers. Therefore, facing uncertain product[10] quality ($\tilde{q} \tilde{} G(\overline{q},\ \sigma^2)$, $\sigma > 0$), the strategic consumers will pay to access the products only when their utilities obtained are positive (i.e., $u > 0$). Specifically, consumer utility (u) equals consumer valuation (v) plus *product quality surplus* ($\theta\tilde{q}$, θ is the product quality sensitivity coefficient of consumers, $\theta > 0$) minus price (p). That is, $u = v + \theta\tilde{q} - p$. Consequently, a consumer will rent the shared products if $v > p - \theta\tilde{q}$. Moreover, the market size is normalized to 1. Accordingly, the market demand for the product with uncertain quality ($d(\tilde{q})$) can be formulated as in Eq. (3-1).

$$d(\tilde{q}) = \int_{p-\theta\tilde{q}}^{1} f(v)dv = 1 + \theta\tilde{q} - p. \tag{3-1}$$

Besides, to provide the products with an average quality level of $\overline{q}$, the service provider should spend a cost of $\frac{k\overline{q}^2}{2}$. Note that k is the quality improvement cost coefficient ($k > 0$), which represents the difficulty of the platform to improve the quality of the shared products in the market. As discussed, k can be reduced by useful consumer feedback reports. The improvement in product quality can bring a higher demand level, while the operating costs for the service provider is increased. Therefore, in this study, we are interested in exploring how much efforts should the platform spend to improve product quality in the uncertain environment. Besides, the unit price of the shared products is also an important decision to make. Therefore, the expected profit for the service provider ($E(\tilde{\pi})$) is formulated as shown in Eq. (3-2). Specifically, $(p - c)$ is the unit profit margin, while $(p - c)(1 + \theta\overline{q} - p)$ is the total expected revenue derived from the shared products. Therefore, the expected profit equals the total expected revenue minus the quality improvement cost.

$$E(\tilde{\pi}) = (p - c)(1 + \theta\overline{q} - p) - \frac{k\overline{q}^2}{2}. \tag{3-2}$$

Besides, from $\tilde{\pi} = (p - c)(1 + \theta\tilde{q} - p) - \frac{k\overline{q}^2}{2}$, we could obtain the variance of profit for the service provider ($V(\tilde{\pi})$) as shown in Eq. (3-3).

$$V(\tilde{\pi}) = (p - c)^2\theta^2\sigma^2. \tag{3-3}$$

As the product quality is uncertain, the service provider is challenged by profit volatilities. In this study, we first analyse the optimal decisions for the platform without risk considerations (Model 1) in Section 4.1. Then, in Section 4.2, we integrate the risk-averse behaviors of the platform into the decision framework (Model 2), and explore the impact of risk attitudes on the equilibrium[11] solutions. Afterwards, we consider a case when consumers are also risk-averse in the extended analyses (Model 3, Section 5). Accordingly, we use the subscripts "1", "2", and "3" to represent the notations for each model. Note that all the mathematical proofs are relegated to Online Appendix.

4. An equilibrium analysis

4.1. The optimal solutions without risk considerations (Model 1)

In Model 1, when the risk preferences of the decision maker are not considered, the sharing platform aims to maximize his expected profit, which is formulated in Eq. (4-1).

Model 1

$$\text{Max} \quad E(\tilde{\pi})_1 = (p_1 - c)(1 + \theta\overline{q}_1 - p_1) - \frac{k\overline{q}_1^2}{2}. \tag{4-1}$$

Checking the determinant of the Hessian Matrix $det[H(p_1, \overline{q}_1)]$, it is found that if $2k > \theta^2$, $E(\tilde{\pi})_1$ is concave in $(p_1, \overline{q}_1)$. Accordingly, we could obtain the optimal average product quality level ($\overline{q}_1^*$) and the optimal price (p_1^*) for the service provider without risk considerations, which are summarized in Proposition 4-1.

Proposition 4-1. *. In Model 1 where the risk attitude of the decision maker is not considered, the profit-maximization objective function for the platform is strictly concave in $(p_1, \overline{q}_1)$ if $2k > \theta^2$. The optimal average product quality level ($\overline{q}_1{}^*$) and the optimal price ($p_1{}^*$) are given as follows:*

$$\overline{q}_1^* = \frac{\theta(1 - c)}{2k - \theta^2},$$

$$p_1^* = \frac{k(1 - c)}{2k - \theta^2} + c.$$

From Proposition 4-1, it is seen that when the quality improvement cost coefficient for the platform (k) is sufficiently larger than the product quality sensitivity coefficient of consumers (θ), optimal solutions exist for the sharing platform in Model 1. With $\overline{q}_1^*$ and p_1^*, the equilibrium expected profit for the service provider in Model 1 ($E(\tilde{\pi})_1^*$) is then equal to $\frac{k(1-c)^2}{4k-2\theta^2}$. Besides, the sensitivity analyses for $\overline{q}_1^*$, p_1^*, and $E(\tilde{\pi})_1^*$ without risk considerations are summarized in Table 2.

As could be seen from Table 2, in Model 1, when it becomes increasingly expensive for the service provider to improve the product quality, the platform is inclined to make less improvement efforts, in order to avoid extensive operating expenditures. Accordingly, the retail price should be declined to compensate the demand loss due to the reduction in product quality. However, the platform will still suffer from a decrease in the equilibrium expected profit due to the negative impact of the inferior product quality along with the increase in k. Therefore, the importance of reducing the difficulty of shared products quality improvement is highlighted, which can be achieved by encouraging consumers to report the conditions of the shared products after usage to the platform. With lower difficulty in improving product quality, the platform is able to provide consumers with higher average product quality levels at a higher price, which contributes to a growth in the expected profits. As a result, it is suggested that the companies in the current sharing economy industry challenged by product quality uncertainties can be greatly benefited if their consumers are willing to faithfully report the product conditions. On the other hand, it is reasonable that the platform should raise the average quality level of his

[10] The shared products in the sharing economy could be either tangible products or intangible services. In our analyses, we use the term "product" to represent both categories.

[11] In this study, we use the terms "optimal" decision and "equilibrium" decision interchangeably.

Table 2
Sensitivity analysis for the optimal solutions in Model 1 ($2k > \theta^2$).

The optimal decisions/profits	k	θ	c
p_1^*	↓	↑	↓ if $k < \theta^2$, ↑ if $k > \theta^2$
$\overline{q}_1^*$	↓	↑	↓
$E(\tilde{\pi})_1^*$	↓	↑	↓

products if the consumers increasingly care about quality (i.e., θ is larger). Herein, the service provider can charge a higher price due to the increased quality levels, and obtain a higher equilibrium expected profit. Moreover, we also observe the need to cut down the quality improvement related expenditures to compensate an increase in the unit cost c. In addition, the impact of the unit cost on the optimal pricing decisions depends on the relationship between k and θ. Specifically, if improving product quality is relative hard (i.e., $k > \theta^2$), it is optimal for the platform to raise the retail price along with the rise in the unit cost to maintain profitability. In contrast, if the improvement is relatively easy (i.e., $k < \theta^2$), then the service provider can attract more consumers by reducing the retail price even if he is challenged by an increasing unit cost.

4.2. *The optimal solutions with risk considerations (Model 2)*

After evaluating the optimal strategies of the sharing platform without risk considerations in Section 4.1, we now explore the impact of platform's risk attitudes on the equilibrium solutions in Model 2. In this study, we apply the Mean-variance theory to model the risk-averse behaviors of the decision maker. Although there are various types of methods characterizing risk attitudes, such as the Black-Scholes Formula and von Neumann–Morgen-stern utility measure, their real-world utilization is limited due to the complicated solution process and complex results. However, the mean-variance theory is able to provide an implementable and practical solution. Besides, as the mean-variance theory is standard in investigating risk-hedging problems, applying it can make the solutions and insights more understandable by practitioners in the sharing economy industry. Therefore, due to these reasons, we employ the MV theory in this work.

The objective function for the MV theory (O) is shown in Eq. (4-2), which is equal to the expected profit ($E(\tilde{\pi})$) minus the variance of profit ($V(\tilde{\pi})$) multiplying the risk sensitivity coefficient ($r \geq 0$).

$$O = E(\tilde{\pi}) - rV(\tilde{\pi}). \tag{4-2}$$

To be specific, the risk sensitivity coefficient r is a risk aversion indicator for the platform. A rise in r means that the decision maker is becoming increasingly risk-averse against profit volatilities. When $r = 0$, the service provider is risk-neutral (which is equivalent to Model 1). With Eq. (3-2) and Eq. (3-3), the MV objective function for the risk-averse service provider can be formulated as shown in Eq. (4-3)

Model 2

$$\text{Max } O_2 = (p_2 - c)(1 + \theta\overline{q}_2 - p_2) - \frac{k\overline{q}_2^2}{2} - r(p_2 - c)^2\theta^2\sigma^2. \tag{4-3}$$

In order to concentrate on investigating the impact of the risk-averse behaviors of the platform on the optimal decision making, in the following analyses, we restrict our attention to the situations when the service provider is risk averse (i.e., $r > 0$). Then, the optimal average product quality level ($\overline{q}_2^*$) and the optimal price (p_2^*) for Model 2 could be obtained by solving Eq. (4-3), which are summarized in Proposition 4-2.

Proposition 4-2. . *In Model 2 where the sharing platform is risk-averse, the MV objective function for the platform is strictly concave if* $2k(1 + r\theta^2\sigma^2) > \theta^2$. *The optimal average product quality level* ($\overline{q}_2^*$) *and the optimal price* (p_2^*) *are given as follows*:

$$\overline{q}_2^* = \frac{\theta(1-c)}{2k(1 + r\theta^2\sigma^2) - \theta^2},$$

$$p_2^* = \frac{k(1-c)}{2k(1 + r\theta^2\sigma^2) - \theta^2} + c.$$

From Proposition 4-2, we can see that whether optimal solutions exist for Model 2 depends not only on the relationship between k and θ, but also on the risk sensitivity coefficient r and the variance of product quality σ^2. Therefore, it is demonstrated that the risk preferences of the decision maker and the source of uncertainty play an important role in the strategic decision making under volatile environment, which should be carefully evaluated by the companies in the sharing economy characterized by uncertain product quality. With $\overline{q}_2^*$ and p_2^*, the equilibrium profit for the platform in Model 2 ($E(\tilde{\pi})_2^*$) can be derived as $\frac{k(1-c)^2(2k(1+2r\theta^2\sigma^2)-\theta^2)}{2(2k(1+r\theta^2\sigma^2)-\theta^2)^2}$. It is obvious that the structures of the optimal solutions of Model 2 are much more complicated than those of Model 1. Therefore, we show that the integration of risk considerations increases the difficulty of decision making. Besides, the sensitivity analyses for $\overline{q}_2^*$, p_2^*, and $E(\tilde{\pi})_2^*$ are summarized in Table 3.

Reasonably, we can see that the impacts of some parameters on the optimal solutions in Model 2 are more complex than those in Model 1. First of all, recall that in Model 1 where the service provider is risk-neutral, when consumers are increasingly sensitive about product quality, the service provider should provide a higher average quality level with an increased price. However, in Model 2 where the platform is risk-averse, the impact of consumers' product quality sensitivity (θ) on the optimal solutions further depends on the quality improvement difficulty (k), the quality uncertainty (σ), and platform's risk averse attitude (r). For example, if $r\theta^2\sigma^2 > 1$, only when it is sufficiently easy for the platform to enhance quality $\left(\text{i.e., } k \prec \frac{1}{2r\sigma^2}\right)$, will the platform provide higher-quality products and increase his retail price along with a growth in consumers' sensitivity regarding quality. However, if the risk-averse service provider finds it expensive for quality improvement (i.e., $k > \frac{\theta^2}{2(r\theta^2\sigma^2-1)}$, $r\theta^2\sigma^2 > 1$) it is unwise for him to increase the quality improvement efforts to grasp the increasingly-sensitive consumers due to the related high costs. Instead, it is optimal for the platform to provide a lower quality level for cost control and alleviate profit risks by reducing the unit price along with the rise in θ. Besides, different from Model 1, two parameters (σ and r) associated with risk preferences and uncertainties now affect the optimal decision making in Model 2. Interestingly p_2^*, $\overline{q}_2^*$, and $E(\tilde{\pi})_2^*$ are all negatively related to σ and r.As the decision maker is risk-averse to profit uncertainties, when the product quality becomes increasingly volatile, the service provider would like to

Table 3
Sensitivity analysis for the optimal solutions in Model 2 ($2k(1 + r\theta^2\sigma^2) > \theta^2$).

The optimal decisions/ profits	k	θ	c	σ	r
p_2^*	↓	↓ if $k > \frac{1}{2r\sigma^2}$, ↑ if $k < \frac{1}{2r\sigma^2}$	↓ if $k < \frac{\theta^2}{1 + 2r\theta^2\sigma^2}$, ↑ if $k > \frac{\theta^2}{1 + 2r\theta^2\sigma^2}$	↓	↓
$\overline{q}_2^*$	↓	↓ if $k > \frac{\theta^2}{2(r\theta^2\sigma^2 - 1)}$, ↑ if $k < \frac{\theta^2}{2(r\theta^2\sigma^2 - 1)}$ when ($r\theta^2\sigma^2 > 1$)	↓	↓	↓
$E(\tilde{\pi})_2^*$	↓	↓ if $k < \frac{\theta^2(1 + 8k^2r^2\sigma^4)}{2(3r\theta^2\sigma^2 + 1)}$, ↑ if $k > \frac{\theta^2(1 + 8k^2r^2\sigma^4)}{2(3r\theta^2\sigma^2 + 1)}$	↓	↓	↓

decline his retail price to hedge against the growing profit uncertainty. However, the reduction in price leads to a decrease in profit margin. Therefore, in order to keep profitability, the platform has to provide a lower average product quality level to reduce the associated quality improvement costs. With the integrated impacts of price reduction and quality decline, the platform thus suffers from a profit loss along with an increase in quality variance. Therefore, it is essential for the sharing platform to keep a low level of quality uncertainty for his shared products in the market. Besides, the risk-aversion indicator r imposes similar influences on the optimal solutions as σ.

On the other hand, the quality improvement difficulty coefficient (k) affects the equilibrium outcomes in the two models similarly. That is, no matter when the risk attitude of the platform is considered or not, the optimal unit price, the optimal average product quality level, and the corresponding optimal profits for the sharing platform increase when it becomes simpler to improve the shared product quality. This is because that the service provider has more incentives to attract consumers through improving product quality when the related costs become less significant. Moreover, the improvement of product quality leaves room for the platform to charge a higher price. Accordingly, the sharing platform is able to enjoy a higher profit margin, which enhances the profitability of the company. Therefore, the importance of alleviating the difficulty of quality improvement is highlighted again with risk considerations. Moreover, we also notice that the impacts of unit cost c on the equilibrium outcomes are similar in the two models, except that the threshold for the quality improvement cost coefficient in Model 2 is more complicated than that in Model 1.

4.3. Consumer surplus

In addition to exploring the optimal decisions from the perspective of the sharing platform, we are also interested in investigating the impacts of the uncertain product quality on consumers. Therefore, following Choi and He (2019), we derive the equilibrium consumer surplus ($cs(\overline{q}^*, p^*)$) at the optimal average product quality level ($\overline{q}^*$) and the optimal price (p^*) in Eq. (4-4) as follows.

$$cs^* = \int_{p^*-\theta\overline{q}^*}^{1} (v+\theta\overline{q}^* - p^*)f(v)dv = \frac{(1+\theta\overline{q}^* - p^*)^2}{2}. \tag{4-4}$$

Accordingly, the equilibrium consumer surplus of Model 1 (cs_1^*) can be obtained as $\frac{k^2(1-c)^2}{2(2k-\theta^2)^2}$, while that of Model 2 (cs_2^*) as $\frac{k^2(1-c)^2(1+2r\theta^2\sigma^2)^2}{2(2k(1+r\theta^2\sigma^2)-\theta^2)^2}$. Besides, to ensure the existence of the optimal solutions for both Model 1 and Model 2, the condition of $2k > \theta^2$ should be satisfied. Table 4 summarizes the relationship between the equilibrium consumer surplus with the major parameters.

As we can see from Table 4, the impacts of k, θ, and c on the equilibrium consumer surplus with and without risk considerations (i.e., cs_1^* and cs_2^*) are identical. For example, consumers will suffer from a decline in consumer surplus along with an increase in the product quality improvement cost coefficient k, no matter when the sharing platform is risk-neutral or risk-averse. In contrast, a lower level of quality improvement difficulty (i.e., a smaller k) is welcomed by consumers due to the corresponding higher consumer surplus. Recall that a decrease in k can also bring a higher expected profit for the sharing platform (for both risk-neutral and risk-averse ones). Therefore, the importance of simplifying quality improvement is further highlighted as it contributes to a win-win situation for both the sharing platform and the consumers, which can be achieved through valuable consumer feedback reports. We use Corollary 4-1 to emphasize this important finding.

Corollary 4-1. *When consumers provide valuable feedback reports on the conditions of the shared products so that improving product quality becomes easier, both the sharing economy platform and the consumers can be benefited, leading to a win-win situation, regardless of the risk attitudes of the platform.*

Table 4
Sensitivity analysis for the equilibrium consumer surplus in Model 1 & 2 ($2k > \theta^2$).

Equilibrium consumer surplus	k	θ	c	σ	r
cs_1^*	↓	↑	↓	NA	NA
cs_2^*	↓	↑	↓	↓ if $k < \theta^2$, ↑ if $k > \theta^2$	↓ if $k < \theta^2$, ↑ if $k > \theta^2$

In addition, it is interesting to find that when the consumers are increasingly aware of the importance of product quality (i.e., θ is higher), they will enjoy a higher level of consumer surplus, regardless of the risk attitudes of the service provider. The reason behind can be explained as follows. When consumers lay more emphasis on product quality, the platform has more incentives to improve the quality level of his products, in order to compete against his competitors and attract more consumers. Accordingly, the requirement of consumers for superior product quality can be better satisfied, leading to a growth in consumer surplus. Furthermore, it is straightforward that consumers are always impaired with an increase in the unit cost of the platform, as this cost growth can be transferred to consumers.

Besides, for the case when the service provider is risk averse, how the risk sensitivity coefficient (r) and the standard deviation of the uncertain product quality (σ) affect the equilibrium consumer surplus depends on the relationship between k and θ, which is similar to the impact of c on p_1^* in Model 1. For example, when the level of consumer awareness on product quality is sufficiently high compared to the level of quality improvement difficulty (i.e., $k < \theta^2$), reducing the product quality uncertainty is beneficial for consumers. This is because that the service provider is inclined to invest more in quality improvements as the related cost is relatively low, which helps satisfy the consumers' desire for better consumption experiences in the less uncertain environment. In addition, the relationship between k and θ also determines whether the consumers will be benefited or impaired when the service provider becomes more risk-averse against profit volatilities. As discussed, the optimal product quality level and unit price are negatively related to the risk-averse attitude of the platform (Section 4.2). When θ is sufficiently small (i.e., $k > \theta^2$), it is reasonable that the decrease in price surpasses the decline in product quality surplus ($\theta\overline{q}$) along with the growing risk aversion of the platform, thus leading to an increase in consumer surplus.

4.4. Comparison of model 1 and model 2

In this section, we compare the optimal decisions, the equilibrium profits for the sharing platform, and the equilibrium consumer surplus obtained from Model 1 and Model 2, to highlight the impact of the risk attitudes of decision makers on the equilibrium outcomes. To ensure that optimal solutions exist for both Model 1 and Model 2, we assume $2k > \theta^2$ in the following analyses. By comparing the optimal solutions of the two models, Proposition 4-3 can be derived.

Proposition 4-3. *When the sharing economy platform becomes risk-averse against profit volatilities from the risk-neutral case, in equilibrium ($2k > \theta^2$), he will reduce the unit price and provide a lower average quality level for the shared products, which leads to a lower expected profit. Besides, whether the consumers will suffer or benefit from the change in the risk attitude of the platform depends on the relationship between k and θ. The specific modifications in each equilibrium outcome due to the platform's attitude change are listed as follows:*

$$\Delta p^* = p_2^* - p_1^* = \frac{2(c-1)k^2 r\theta^2\sigma^2}{(2k-\theta^2)(2k(1+r\theta^2\sigma^2)-\theta^2)} < 0,$$

$$\Delta\overline{q}^* = \overline{q}_2^* - \overline{q}_1^* = \frac{2(c-1)kr\theta^3\sigma^2}{(2k-\theta^2)(2k(1+r\theta^2\sigma^2)-\theta^2)} < 0,$$

$$\Delta E(\tilde{\pi})^* = E(\tilde{\pi})_2^* - E(\tilde{\pi})_1^* = -\frac{2(c-1)^2k^3r^2\theta^4\sigma^4}{(2k-\theta^2)(2k(1+r\theta^2\sigma^2)-\theta^2)^2} < 0,$$

$$\Delta cs^* = cs_2^* - cs_1^* = \frac{1}{2}\left(c-1\right)^2 k^2\left(\frac{4r\theta^2\sigma^2(k-\theta^2)[(2k-\theta^2)+r\theta^2\sigma^2(3k-\theta^2)]}{(2k(1+r\theta^2\sigma^2)-\theta^2)^2\left(2k-\theta^2\right)^2}\right), \Delta cs^* > 0 \text{ if } k > \theta^2, \text{and } \Delta cs^* < 0 \text{ if } k < \theta^2.$$

From Proposition 4-3, we can summarize the following major findings. First, as the risks of profit volatilities are considered in Model 2, the platform is motivated to reduce the retail price to maintain his market size, which helps alleviate profit uncertainties. Second, it is interesting to identify that the platform will also provide a lower average product quality level when he becomes risk averse. The reason behind can be explained as follows. The price reduction leads to a lower profit margin (as the unit cost of the shared products remains unchanged, the profit margin of Model 2 (i.e., $\frac{k(1-c)}{2k(1+r\theta^2\sigma^2)-\theta^2}$) is thus smaller than that of Model 1 (i.e., $\frac{k(1-c)}{2k-\theta^2}$). Therefore, it is optimal for the platform to reduce the product quality improvement costs (thus reducing the average product quality level) to maintain profitability. Third, it is found that the expected profit for the service provider decreases when his risk attitudes is integrated into the decision framework. Herein, the platform considers not only the expected profit, but also the variance of profit. Therefore, the platform is inclined to reduce profit risks at the cost of a decrease in the expected profit. Fourth, we find that consumers can be benefited from the risk aversion of the service provider when they care little about product quality (i.e., $k > \theta^2$), which is consistent with the analyses regarding the impact of risk aversion coefficient r on consumer surplus in the previous section.

In summary, it is demonstrated that the risk behaviours of the service provider impose significant impacts during decision making. Moreover, from the analyses in Section 4, we could see that the relationship between the quality improvement cost coefficient for the platform (k) and the product quality sensitivity coefficient of consumers (θ) is very important for the decision framework, which should be carefully investigated. In other words, to determine the optimal operating characteristics, the sharing economy service provider who is challenged by uncertain product quality should consider not only his difficulty in improving product quality, but also the consumers' preferences for product quality. More importantly, we have shown that the efforts in reducing the difficulty of quality improvement and encouraging consumers to provide useful feedback reports are beneficial for both platforms and consumers.

5. An extended analysis with risk-averse consumers (Model 3)

In the analyses of previous sections (i.e., Model 1 and Model 2), consumers are assumed to be risk neutral. However, considering the prevalent uncertain product quality problem in the sharing economy industry, it is reasonable that consumers also hold a risk-averse attitude regarding their consumption utility. Therefore, in Model 3, we study the impact of the risk aversion of consumers on the optimal decision making. Following Choi et al. (2019d), the consumer utility for risk-averse consumers can be formulated as: $u_3 = v + \theta\tilde{q} - p - \sigma$. Accordingly, a consumer will rent the shared products if $v > p + \sigma - \theta\tilde{q}$. Thus, the modified market demand can be modeled as shown in Eq. (5-1).

$$d(\tilde{q})_3 = \int_{p+\sigma-\theta\tilde{q}}^{1} f(v)dv = 1 + \theta\tilde{q} - p - \sigma\,. \tag{5-1}$$

Besides, the expected profit for the service provider ($E(\tilde{\pi})_3$) and the variance of profit ($V(\tilde{\pi})_3$) are updated in Eq. (5-2) and Eq. (5-3), respectively.

$$E(\tilde{\pi})_3 = (p_3 - c)(1 + \theta\overline{q}_3 - p_3 - \sigma) - \frac{k\overline{q}_3^2}{2}\,, \tag{5-2}$$

$$V(\tilde{\pi})_3 = (p_3 - c)^2\theta^2\sigma^2 \tag{5-3}$$

Moreover, the equilibrium consumer surplus is modified as shown in Eq. (5-4).

$$cs_3^* = \int_{p^*+\sigma-\theta\overline{q}^*}^{1} (v + \theta\overline{q}^* - p^* - \sigma)f(v)dv = \frac{(1+\theta\overline{q}^* - p^* - \sigma)^2}{2} \tag{5-4}$$

Therefore, by maximizing the MV objective ($E(\tilde{\pi})_3 - rV(\tilde{\pi})_3$), the optimal decisions for Model 3 could be obtained, which are summarized in Proposition 5-1.

Proposition 5-1. *. In Model 3 where both the sharing platform and consumers are risk-averse, the MV objective function for the platform is strictly concave if $2k(1 + r\theta^2\sigma^2) > \theta^2$. Accordingly, the optimal average product quality level ($\overline{q}_3^*$), the optimal price (p_3^*), the equilibrium expected profit for the platform ($E(\tilde{\pi})_3^*$), and the equilibrium consumer surplus (cs_3^*) are given as follows ($c + \sigma < 1$):*

$$\overline{q}_3^* = \frac{\theta(1-c-\sigma)}{2k(1+r\theta^2\sigma^2)-\theta^2},$$

$$p_3^* = \frac{k(1-c-\sigma)}{2k(1+r\theta^2\sigma^2)-\theta^2} + c,$$

$$E(\tilde{\pi})_3^* = \frac{k(1-c-\sigma)^2(2k(1+2r\theta^2\sigma^2)-\theta^2)}{2(2k(1+r\theta^2\sigma^2)-\theta^2)^2},$$

$$cs_3^* = \frac{k^2(1-c-\sigma)^2(1+2r\theta^2\sigma^2)^2}{2(2k(1+r\theta^2\sigma^2)-\theta^2)^2}.$$

It is identified that the condition under which optimal solutions exist for Model 3 is identical as that for Model 2. Besides, $\overline{q}_3^*$, p_3^*, $E(\tilde{\pi})_3^*$, and cs_3^* have similar structures as $\overline{q}_2^*$, p_2^*, $E(\tilde{\pi})_2^*$, and cs_2^*, except that the product quality uncertainty (σ) reduces the values of these equilibrium outcomes when consumers are also risk averse. The sensitivity analyses for $\overline{q}_3^*$, p_3^*, $E(\tilde{\pi})_3^*$, cs_3^* are summarized in Table 5, while Proposition 5-2 illustrates the specific reduction in each equilibrium outcome.

Proposition 5-2. *. When both the sharing economy platform and consumers are risk-averse ($2k(1 + r\theta^2\sigma^2) > \theta^2$, $c + \sigma < 1$), compared to the case when only the platform is risk averse, the decline in each equilibrium outcome due to the consumers' attitude change is listed as follows:*

$$\Delta p^* = p_3^* - p_2^* = -\frac{k\sigma}{2k(1+r\theta^2\sigma^2)-\theta^2} < 0,$$

$$\Delta\overline{q}^* = \overline{q}_3^* - \overline{q}_2^* = -\frac{\theta\sigma}{2k(1+r\theta^2\sigma^2)-\theta^2} < 0,$$

Table 5
Sensitivity analysis for the optimal solutions in Model 3 ($2k(1+r\theta^2\sigma^2) > \theta^2,\ c+\sigma < 1$).

The optimal decisions/profits	k	θ	c	σ	r
p_3^*	↓	↓ if $k > \frac{1}{2r\sigma^2}$, ↑ if $k < \frac{1}{2r\sigma^2}$	↓ if $k < \frac{\theta^2}{1+2r\theta^2\sigma^2}$, ↑ if $k > \frac{\theta^2}{1+2r\theta^2\sigma^2}$	↓	↓
$\overline{q}_3^*$	↓	↓ if $k > \frac{\theta^2}{2(r\theta^2\sigma^2-1)}$, ↑ if $k < \frac{\theta^2}{2(r\theta^2\sigma^2-1)}$ when $(r\theta^2\sigma^2 > 1)$	↓	↓	↓
$E(\tilde{\pi})_3^*$	↓	↓ if $k < \frac{\theta^2(1+8k^2r^2\sigma^4)}{2(3r\theta^2\sigma^2+1)}$, ↑ if $k > \frac{\theta^2(1+8k^2r^2\sigma^4)}{2(3r\theta^2\sigma^2+1)}$	↓	↓ if $k > \frac{\theta^2}{2}$	↓
cs_3^*	↓	↑	↓	↓ if $k > \frac{\theta^2+2r\theta^4\sigma(-2+2c+3\sigma)}{2(1+r\theta^2\sigma(-2+2c+5\sigma+2r\theta^2\sigma^3)}$ when $1+r\theta^2\sigma(-2+2c+5\sigma+2r\theta^2\sigma^3) > 0$	↓ if $k < \theta^2$, ↑ if $k > \theta^2$

$$\Delta E(\tilde{\pi})^* = E(\tilde{\pi})_3^* - E(\tilde{\pi})_2^* = \frac{k\sigma(-2+2c+\sigma)\left(k\left(2+4r\theta^2\sigma^2\right)-\theta^2\right)}{2\left(2k\left(1+r\theta^2\sigma^2\right)-\theta^2\right)^2} < 0,$$

$$\Delta cs^* = cs_3^* - cs_2^* = \frac{\sigma(-2+2c+\sigma)\left(k+2kr\theta^2\sigma^2\right)^2}{2\left(2k\left(1+r\theta^2\sigma^2\right)-\theta^2\right)^2} < 0.$$

Proposition 5-2 demonstrates that the integration of consumers' risk attitudes makes the system more conservative, as the service provider will reduce the unit price and provide a lower average quality level for the shared products. Accordingly, the system is impaired due to a profit decline for the platform and a surplus reduction for consumers. Therefore, it is suggested that the service providers in the sharing economy industry should pay more attention to the consumers' risk preferences during decision making, in order to alleviate the related negative impacts on their profitability and the healthy development of the industry.

6. Conclusion

6.1. Concluding remarks, insights and implications

In recent years, the sharing economy is becoming increasingly important for various aspects of our life, which has reshaped the traditional business model and provides people with cost-efficient and convenient access to services or products. However, despite the various benefits for the society, the industry is challenged by intensive highly volatile product quality, which has greatly affected consumption experiences and limited the development and profitability of the industry. Therefore, in order to enhance their profitability in the highly volatile and competitive market, many sharing economy service providers become risk-averse in decision making. Besides, the sharing economy platforms are also facing with the important pricing problems. However, although the importance of the quality and pricing decisions for the sharing economy with risk considerations has been realized, the optimal prices and quality levels for risk-averse sharing platforms in the presence of product quality volatilities are still under-explored. This study thus aims to explore the impacts of product quality uncertainties and risk attitudes of decision makers on the optimal quality and pricing decisions for the sharing economy platforms by employing the MV theory.

With analytical analyses for a risk-neutral/risk-averse sharing economy platform and risk-neutral/risk-averse consumers, we have examined the equilibrium quality improvement efforts and prices for the platform, and investigated the impacts of diverse critical parameters (e.g., the quality improvement cost coefficient and the risk attitudes of the platform) on the optimal decision making. Our analytical results have derived the following major findings. First, we have identified that when the product quality is uncertain while consumers are sensitive to product quality, whether optimal solutions exist for the platform depends on the relationship between quality improvement difficulty and consumer sensitivity to quality. When the platform is risk-averse, the existence of optimal solutions further relies on the quality uncertainty and the risk aversion of the platform. Second, the increase in risk aversion against profit volatilities will induce the platform to charge a lower price while provide an inferior average level of product quality for the consumers. This is mainly because that the platform is inclined to alleviate profit uncertainties at the cost of profit losses. On the other hand, it is interesting to identify that consumers may be benefited from the platform's attitude change (from risk-neutral to risk-averse), if consumers care little about product quality. However, consumers will always suffer from a reduction in consumer surplus if they become risk averse following the platform. Third, we find that it is not always wise for the platform to invest in quality improvements, especially when it becomes more difficult to enhance quality. Interestingly, this result holds for both risk-neutral and risk-averse platforms. Besides, the growing risk aversion or product quality uncertainty will make the platform reduce his quality improvement efforts. Fourth, we have analytically demonstrated the advantages and necessity to encourage consumers to provide valuable feedback reports regarding the problems of shared products, in order to simplify the quality improvement missions for platforms, which can bring intensive benefits for both the platform and consumers.

In conclusion, this paper contributes to the existing literature of the sharing economy and platform operations by integrating product quality volatilities and risk considerations into the optimal quality and pricing decisions for sharing economy platforms. We have analytically investigated the equilibrium outcomes and explored how the critical factors affect the optimal prices and quality levels that the platform should provide for the market. Through comprehensive analyses, we have highlighted the importance to enhance the optimal quality and pricing decisions for sharing platforms by considering the impacts of the crucial factors. Furthermore, it is believed that the practitioners in the sharing economy industry could benefit a lot by applying the insights and suggestions proposed in this research. For example, as consumers may be benefited from the risk attitude change of the platform (i.e., when consumers care little about product quality) with an increase in consumer surplus, the platform can strategically adjust its risk behaviour to cultivate consumer loyalty, which is beneficial for the long-term development of the platform.

6.2. Future studies

This study generates insightful guidelines regarding the optimal pricing decisions and the optimal average product quality levels for service providers who provide shared products and are risk-averse to profit uncertainties caused by stochastic product quality. For future research, it will be interesting to explore the case when the government offers subsidies for the service providers to improve the product quality levels. Besides, more risk measurement approaches such as the mean-downside risk method can be employed to capture the risk attitudes of the platforms in the sharing economy industry. Moreover, the competition between platforms who provide similar shared products or services is also worthwhile to investigate. Last but not least, empirical data can be collected to conduct further analyses around the topic. Methods like data analytics (Luo et al., 2019) and statistical based multi-method approach (Li et al., 2019a) can be adopted.

Acknowledgments

Tana Siqin's research was fully supported by a grant from the Research Committee of The Hong Kong Polytechnic University under account code RK2T.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijpe.2019.107544.

References

Albiński, S., Fontaine, P., Minner, S., 2018. Performance analysis of a hybrid bike sharing system: a service-level-based approach under censored demand observations. Transp. Res. E Logist. Transp. Rev. 116, 59–69.
Asian, S., Hafezalkotob, A., John, J.J., 2019. Sharing economy in organic food supply chains: a pathway to sustainable development. Int. J. Prod. Econ. 218, 322–338.
Barenji, A.V., Wang, W., Li, Z., Guerra-Zubiaga, D.A., 2019. Intelligent E-commerce logistics platform using hybrid agent based approach. Transp. Res. E Logist. Transp. Rev. 126, 15–31.
Bellos, I., Ferguson, M., Toktay, L.B., 2017. The car sharing economy: interaction of business model choice and product line design. Manuf. Serv. Oper. Manag. 19 (2), 185–201.
Benjaafar, S., Hu, M., 2019. Operations management in the age of the sharing economy: what is old and what is new? Manuf. Serv. Oper. Manag. (in press).
Buzacott, J., Yan, H., Zhang, H., 2011. Risk analysis of commitment–option contracts with forecast updates. IIE Trans. 43 (6), 415–431.
Cachon, G.P., Daniels, K.M., Lobel, R., 2017. The role of surge pricing on a service platform with self-scheduling capacity. Manuf. Serv. Oper. Manag. 19 (3), 368–384.
Cannon, S., Summers, L.H., 2014. How Uber and the sharing economy can win over regulators. Harv. Bus. Rev. 13 (10), 24–28.
Chen, X., Sim, M., Simchi-Levi, D., Sun, P., 2007. Risk aversion in inventory management. Oper. Res. 55 (5), 828–842.
Chiu, C.-H., Chan, H.-L., Choi, T.-M., 2019. Risk minimizing price-rebate-return contracts in supply chains with ordering and pricing decisions: a multimethodological analysis. IEEE Trans. Eng. Manag. (in press).
Chiu, C.-H., Choi, T.-M., 2016. Supply chain risk analysis with mean-variance models: a technical review. Ann. Oper. Res. 240 (2), 489–507.
Chiu, C.H., Choi, T.M., Dai, X., Shen, B., Zheng, J.H., 2018. Optimal advertising budget allocation in luxury fashion markets with social influences: a mean-variance analysis. Prod. Oper. Manag. 27 (8), 1611–1629.
Choi, T.-M., Guo, S., Liu, N., Shi, X., 2019a. Values of food leftover sharing platforms in the sharing economy. Int. J. Prod. Econ. 213, 23–31.
Choi, T.-M., He, Y., 2019. Peer-to-peer collaborative consumption for fashion products in the sharing economy: platform operations. Transp. Res. E Logist. Transp. Rev. 126, 49–65.
Choi, T.-M., Ma, C., Shen, B., Sun, Q., 2019b. Optimal pricing in mass customization supply chains with risk-averse agents and retail competition. Omega 88, 150–161.
Choi, T.-M., Wen, X., Sun, X., Chung, S.-H., 2019c. The mean-variance approach for global supply chain risk analysis with air logistics in the blockchain technology era. Transp. Res. E Logist. Transp. Rev. 127, 178–191.
Choi, T.-M., Zhang, J., Cai, Y.-J., 2019d. Consumer-to-consumer digital-product-exchange in the sharing economy system with risk considerations: will digital-product-developers suffer? IEEE Trans. Syst. Man Cybern.: Systems (in press).
Choi, T.M., Wallace, S.W., Wang, Y., 2018a. Big data analytics in operations management. Prod. Oper. Manag. 27 (10), 1868–1883.
Choi, T.M., Zhang, J., Cheng, T.E., 2018b. Quick response in supply chains with stochastically risk sensitive retailers. Decis. Sci. J. 49 (5), 932–957.
Du, S., Wang, L., Hu, L., Zhu, Y., 2019. Platform-led green advertising: promote the best or promote by performance. Transp. Res. E Logist. Transp. Rev. 128, 115–131.
Eckhardt, G.M., Bardhi, F., 2015. The sharing economy isn't about sharing at all. Harv. Bus. Rev. 28 (1), 2015.
Gan, X., Sethi, S.P., Yan, H., 2004. Coordination of supply chains with risk-averse agents. Prod. Oper. Manag. 13 (2), 135–149.
Gan, X., Sethi, S.P., Yan, H., 2005. Channel coordination with a risk-neutral supplier and a downside-risk-averse retailer. Prod. Oper. Manag. 14 (1), 80–89.
Ganapati, S., Reddick, C.G., 2018. Prospects and challenges of sharing economy for the public sector. Gov. Inf. Q. 35 (1), 77–87.
Gong, D., Liu, S., Liu, J., Ren, L., 2019. Who benefits from online financing? A sharing economy E-tailing platform perspective. Int. J. Prod. Econ. (in press).
Jiang, B., Tian, L., 2016. Collaborative consumption: strategic and economic implications of product sharing. Manag. Sci. 64 (3), 1171–1188.
Kung, L.-C., Zhong, G.-Y., 2017. The optimal pricing strategy for two-sided platform delivery in the sharing economy. Transp. Res. E Logist. Transp. Rev. 101, 1–12.
Li, G., Li, L., Choi, T.M., Sethi, S.P., 2019a. Green supply chain management in Chinese firms: innovative measures and the moderating role of quick response technology. J. Oper. Manag. (in press).
Li, Y., Bai, X., Xue, K., 2019b. Business modes in the sharing economy: how does the OEM cooperate with third-party sharing platforms? Int. J. Prod. Econ. (in press).
Liu, W., Yan, X., Wei, W., Xie, D., 2019. Pricing decisions for service platform with provider's threshold participating quantity, value-added service and matching ability. Transp. Res. E Logist. Transp. Rev. 122, 410–432.
Luo, S., Lin, X., Zheng, Z., 2019. A novel CNN-DDPG based AI-trader: performance and roles in business operations. Transp. Res. E Logist. Transp. Rev. 131, 68–79.
Ma, H.-L., Wong, C.W.-H., Leung, L.C., Chung, S.-H., 2019. Facility sharing in business-to-business model: a real case study for container terminal operators in Hong Kong port. Int. J. Prod. Econ. (in press).
Ozinci, Y., Perlman, Y., Westrich, S., 2017. Competition between organic and conventional products with different utilities and shelf lives. Int. J. Prod. Econ. 191, 74–84.
Roma, P., Panniello, U., Lo Nigro, G., 2019. Sharing economy and incumbents' pricing strategy: the impact of Airbnb on the hospitality industry. Int. J. Prod. Econ. 214, 17–29.
Sun, X., Chung, S.H., Chan, F.T.S., Wang, Z., 2018. The impact of liner shipping unreliability on the production–distribution scheduling of a decentralized manufacturing system. Transp. Res. E Logist. Transp. Rev. 114, 242–269.
Vorasayan, J., Ryan, S.M., 2006. Optimal price and quantity of refurbished products. Prod. Oper. Manag. 15 (3), 369–383.
Wang, R., Gou, Q., Choi, T.-M., Liang, L., 2016. Advertising strategies for mobile platforms with "Apps". IEEE Trans. Syst. Man Cybern.: Systems 48 (5), 767–778.
Wang, X., Tao, Z., Liang, L., Gou, Q., 2019. An analysis of salary mechanisms in the sharing economy: the interaction between streamers and unions. Int. J. Prod. Econ. 214, 106–124.
Wen, X., Choi, T.-M., Chung, S.-H., 2019a. Fashion retail supply chain management: a review of operational models. Int. J. Prod. Econ. 207, 34–55.
Wen, X., Ma, H.-L., Choi, T.-M., Sheu, J.-B., 2019b. Impacts of the belt and road initiative on the China-europe trading route selections. Transp. Res. E Logist. Transp. Rev. 122, 581–604.
Wen, X., Xu, X., Choi, T., Chung, S., 2019c. Optimal pricing decisions of competing air-cargo-carrier systems - impacts of risk aversion, demand, and cost uncertainties. IEEE Trans. Syst. Man Cybern.: Systems 1–15 (in press).
Wu, C.-H., 2015. Strategic and operational decisions under sales competition and collection competition for end-of-use products in remanufacturing. Int. J. Prod. Econ. 169, 11–20.
Yuan, Q., Shen, B., 2019. Renting fashion with strategic customers in the sharing economy. Int. J. Prod. Econ. 218, 185–195.
Zhang, M., Zhang, J., Cheng, T., Hua, G., 2018. Why and how do branders sell new products on flash sale platforms? Eur. J. Oper. Res. 270 (1), 337–351.