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CSR investment for a two-sided platform: Network externality and risk aversion

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ABSTRACT

The business of two-sided platforms, such as those used for online ride-sharing, has expanded rapidly thanks to opportunities to efficiently match supply- and demand-side users. However, the development of these platforms faces the challenge of complying with corporate social responsibility (CSR) regulations, particularly on the supply side of two-sided platforms. How to improve CSR investment, in order to reduce CSR violations while ensuring profitability, is now an important question. In this paper, we develop a game-theoretic model for a two-sided platform and analyze the impacts of network externalities (including customer network externality and provider network externality) and risk aversion on CSR investment decision-making. The analytical results show that, contrary to our intuition, greater network externalities do not necessarily stimulate the platform to invest in CSR. When the strength of customer network externality is high, investment in CSR may have a "dilution effect", i.e., CSR investment may reduce the platform's number of users and profit. Conversely, risk aversion always has an "incentive effect" on CSR investment, thereby increasing the platform's willingness to invest in CSR. Second, both provider and customer network externalities will increase the platform's prices. Interestingly, when the strength of customer network externality is high, the platform attracts more customers, even at high prices. Finally, our analysis indicates that risk aversion may reduce customer surplus when the strength of customer network externality is high. This result contradicts the initial expectation that risk aversion inspires platforms to invest in CSR, thereby improving customer utility and customer surplus.

1. Introduction

The rise of two-sided platforms has transformed the way in which firms serve their customers. Firms no longer need to invest in conventional assets, such as machinery or fleets, to satisfy customers' demands directly; instead, they can offer digital platforms that connect end consumers and service providers from the two sides of the market (Rochet & Tirole, 2006). The platforms allow for independent interactions between "on board" consumers and providers, and they charge fees for their service transactions. This new business model significantly increases the efficiency of matching consumers and providers, who are usually small entities or individuals (Benjaafar & Hu, 2020). Examples of two-sided platforms are Airbnb in the lodging industry, Alibaba in the retailing industry, Just Eat in the food delivery industry, and Uber in the online ride-sharing industry.

A platform plays a solely functional role as an intermediary while the actual service in practice is, provided to consumers by independent providers. An increasing number of concerns have been raised about the insufficient corporate social responsibility (CSR) of platforms (Tang et al., 2021). In 2018, for instance, two female passengers using the ride-sharing platform Didi Chuxing Technology (Didi) were sexually assaulted and killed by their drivers (Zhang & Munroe 2018). The Chinese government immediately required Didi to cease its "Hitch-ride" service, which resulted in an 800 million CNY yearly profit loss (Fortune Magazine, 2018). Similarly, Airbnb receives thousands of sexual assault claims every year, although most of these are not disclosed to the public (Businessinsider, 2021). Another example is the sale of counterfeit products on e-commerce platforms: Amazon, for example, was sued by Mercedes for selling "strikingly similar" counterfeit autoparts (Audrey, 2020). These scandals call for platforms to invest in corporate social responsibility (Tang et al., 2021).

We collaborate with Didi for more insights into the two-sided platform's CSR decisions, which further inspired our research. With an annual revenue of 141.7 billion CNY and daily transactions to-

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Table 1
Didi's pricing tariff in Beijing (Didi, 2021a).

	Fees collected from passengers	Remuneration paid to drivers
Price per kilometer traveled	Off-peak time: CNY 1.45/km 06:00–10:00: CNY 1.80/km 17:00–21:00: CNY 1.50/km 21:00–06:00: CNY 2.15/km	Off-peak time: CNY 1.10/km 06:00–10:00: CNY 1.35/km 17:00–21:00: CNY 1.15/km 21:00–06:00: CNY 1.65/km

taling an average 4.1 million, Didi is regarded as the world's largest mobile transportation platform (Didi, 2021b). After the acquisition of Uber China in 2016, it achieved a national market share of about 90% (Forbes, 2021), and thus enjoys an effective monopoly with pricing power. Didi treats drivers as contractors and maintains centralized price control. Even though competitive dynamics do exist in the market - such as during a rush hour when several consumers are competing for a ride - drivers are not allowed to increase their prices. Instead, Didi centrally determines a single price mechanism for every ride, while the only decision for drivers/riders is whether to join the platform or not. Table 1 presents Didi's current price tariff in Beijing. The structure of the tariff is consistent with findings in the literature (e.g., Sun et al. 2019).

It is worth mentioning that not all two-sided platforms have the same pricing strategy as Didi. Cachon et al. (2021) use *centralized* control to describe such a strategy, which is in contrast to *decentralized* control through which each provider may select its own price based on the degree of competition in the market. The former is typical in the ride-sharing (e.g., Uber, Didi) or food-delivery (e.g., Just Eat) industries, while the latter is generally observed in room-sharing (e.g., Airbnb) or work-for-hire (e.g., LinkedIn) platforms.

Despite its rising revenue, Didi has been heavily criticized for a lack of CSR-related initiatives (Tang et al., 2021) and is facing critical challenges in CSR investment. First, CSR investment is costly. After the aforementioned scandals and consequential governmental intervention, Didi invested 2 billion CNY in 2019 to improve platform security, including strengthening cooperation with the police, improving the warning system, updating safety policies, and tripling the size of its safety team (Didi, 2019), which collectively accounted for 1.4% of its revenue in 2019. Second, rigid CSR-related regulation or censorship may drive some platform users away, which would be undesirable for the platform. As highlighted by giants such as Uber and Airbnb in their annual reports, the number of "on board" users is always a key performance indicator (Wang et al., 2019b) because of a distinct feature of two-sided platforms: namely the *network externality effect*. The utility of users on one side of the platform (e.g., Uber passengers) increases in line with the number of users on the other side of the platform (e.g., Uber drivers) (see, for example, Armstrong 2006). A reduction in service providers, in a vicious circle, may therefore decrease the number of consumers and, ultimately, the platform's profitability. Third, the level of CSR investment should be jointly considered alongside the platform's attitude toward risk. In light of the significantly high losses that would be caused if a scandal were to occur (despite the relatively low probability), platforms often demonstrate marked risk aversion (Wen & Siqin, 2020). The risk attitude in turn naturally affects platforms' profit and CSR investment decisions (Liu & Wang, 2015; Yang & Xiao, 2017).

Motivated by these observations, we aim to study the following primary questions for a two-sided platform:

(1) Considering a platform's network externality and risk aversion, when should the two-sided platform invest in CSR?
(2) How do network externalities and risk aversion affect platform decisions, numbers of users (consumers and providers) and consumer surplus?

To conduct our assessment, we develop a two-sided platform model, whereby the platform connects customers on the demand side and providers on the supply side. As a leader and an intermediary, the platform first sets prices and makes CSR decisions, and, based on these decisions, consumers and providers decide whether to join the platform. We obtain optimal CSR investment and pricing decisions analytically, and further analyze the impacts of network externality and risk aversion. Although our model directly reflects a ride-sharing platform, the implications can be applied to other types of two-sided platforms with network externalities, such as e-commerce, rental, and lending platforms, etc.

We find that, intuitively, when the strength of network externality is higher, the platform may be more motivated to invest in CSR in order to minimize the negative impacts of CSR violations. However, we find that although provider network externality will stimulate the platform's investment in CSR, as the strength of customer network externality increases, CSR investment instead produces a "dilution effect". That is, investing in CSR in this case will reduce the number of users on the platform, thereby damaging profit margins and, as a result, will lead the platform to abandon CSR initiatives. In contrast, platform risk aversion will have an "incentive effect" on the platform's CSR investment, thereby increasing the platform's willingness to finance this initiative.

Interestingly, when the strength of customer network externality is high, the platform can still attract more customers, even if it raises its prices. The impact of risk aversion on price and the number of users depends on the strength of the network externality: when it is low, risk aversion will increase the platform's price and the number of customers, and vice versa. With respect to a platform's attitude toward risk, risk aversion may increase CSR investment, customer utility and customer surplus. However, when the strength of customer network externality is high, the platform's risk aversion will eventually reduce customer surplus. In addition, customer surplus will increase as the strength of provider network externality increases. Finally, as the strength of customer network externality increases, customer surplus first decreases and then increases.

2. Literature review

Three streams of literature are relevant to this study, relating to: (1) two-sided platforms, (2) CSR management and (3) risk aversion.

2.1. Research on two-sided markets

Typically, a two-sided market is a platform acting as an intermediary for two groups of agents - providers and consumers - who match on the platform to conduct transactions (Armstrong, 2006; Casadesus-Masanell & Zhu, 2010; Zhong et al., 2019). Two-sided markets are widespread in industries such as media (Dou et al., 2016; Gao, 2018), online ride-hailing (Kung & Zhong, 2017) and logistics and transportation (Liu et al., 2019b; Liu et al., 2020). A distinct feature of a two-sided market is the so-called "network externality" i.e. the utility of one agent in the market will be affected by the number of agents on the other side (Armstrong & Wright, 2007).

Competition among providers in a two-sided market significantly differs from that in a traditional one-sided market. In a fully competitive traditional market, a price is set to clear the market and providers' profit margin is thin; whereas in a market with entry barriers restricting competition, the price can be raised by providers to customers' willingness to pay and the profit margin is fat. In a two-sided market, however, regardless of the competition among providers, the platform is oftentimes the monopoly (oligopoly) with pricing power. In the pioneering study of a two-sided market model proposed by Rochet & Tirole (2006), a platform determines the price to maximize its own utility without incorporating competition among service providers. In a more generalized model, Weyl (2010) finds that the pricing strategies of a monopolistic platform *internalize* network effects - namely, the optimal price set by the platform already reflects positive or negative network externalities resulting from competition. Much effort has since been focused on the platforms' optimal pricing by incorporating network externalities (Wang et al., 2016; Liu et al., 2019a). Kung & Zhong (2017) study three pricing strategies: namely membership-based pricing, transaction-based pricing and cross-subsidization strategy, and subsequently analyze the optimal strategy of the platform. Sun et al. (2019) find that the optimal price set by the platform consists of a ride length-based fare and a rush hour congestion fee. Feldman et al. (2022) find that the current pricing in a food-delivery platform is suboptimal, and they propose a contract to coordinate the platform and the providers for higher revenues.

Recent studies have started to investigate *providers*' price adjustments according to market competition. This might also be partially driven by governmental regulations urging platforms to treat workers as independent agents (so that they have the freedom to choose their own prices) instead of contractors. Cachon et al. (2021) distinguish between centralized pricing (the platform selects the prices) and decentralized pricing strategies (the service providers determine their prices according to market competitions). They find that decentralized pricing may be necessary in order to distinguish providers. Chen et al. (2019a) find that allowing competition and flexible wage mean that providers can utilize their private information and therefore increase their profits. Filippas et al. (2021) empirically show that centralized pricing harms provider participation due to its inability to fully compensate their costs.

In this paper, following the operational features of Didi, we study a monopoly platform with a centralized pricing strategy. The platform maximizes its own utility by incorporating provider competition: When the number of providers increases, they receive a disutility due to negative network effect. Moreover, the platform also needs to determine its CSR investment given network externalities and risk-averse attitudes. The model setup is motivated by and applicable to practical cases of ride-sharing platforms.

2.2. Research on CSR management

CSR has attracted extensive attention within industry and academia in recent years (Servaes & Tamayo, 2013; Letizia & Hendrikse, 2016; Bian et al., 2021; Su et al., 2021). In this area, many studies focus on managing the CSR related to upstream suppliers (Chen & Lee, 2016; Lee & Li, 2018; Letizia & Hendrikse; 2016; Awasthy & Hazra, 2019; Liu et al. 2022; Raj et al., 2021). For example, Chen & Lee (2016) compare the effects of three different supplier CSR management methods: certification, audits and contingency payment. Letizia & Hendrikse (2016) analyze the incentivizing effects of different supply chain structures on supplier CSR, whilst Ma et al. (2017) investigate supply chain coordination issues in the context of CSR. In another recent study by Liu et al. (2022), CSR management is discussed in the context of a traditional multi-tier supply chain. Our study also considers CSR management concerning upstream providers, but the difference lies in the CSR investment decisions made by the platform, which faces unique operational features concerning network externality of two-sided market. In the CSR literature relating to traditional companies, some researchers also consider externalities in a competition context. For example, Orsdemir et al. (2019) reflect on demand externality when analyzing a company's vertical integration decision to ensure the supplier's CSR level. Demand externality refers to the impact of one company's violation of CSR regulations on the demand of its competitors. It is quite different from network externality of two-sided market, which strongly influences the number of users between the supply and demand sides, rather than competitors' demand. As a result, results of previous studies on two-sided platform may not apply to situations with CSR initiatives, and our study closes this research gap.

2.3. Research on risk aversion

According to the risk acceptance of decision-makers, their risk attitudes can usually be classified into risk appetite, risk-neutrality and risk aversion (Avinadav et al., 2015). Generally, risk-neutral decision-makers aim to maximize expected profits, but risk-averse managers will tolerate a certain level of reduction in profit in order to reduce risk (Agrawal & Seshadri, 2000). We consider the platform's risk aversion caused by the provider's uncertain CSR violation probability. In operations management, risk aversion has been widely discussed. For example, previous studies have analyzed the impact of risk aversion on the introduction of new products (Cui et al., 2016), order allocation (Wang et al., 2019a), and contract design (Chiu et al., 2019).

In research on risk aversion, the mean-variance (MV) model is widely applied (Choi et al., 2008; Choi, 2015; Cui et al., 2016). Similar to previous studies, this paper also adopts the MV model to measure the risk aversion of the platform. Zheng et al. (2020) study the risk aversion of shipping service providers when facing uncertain demands and analyze the impact of risk aversion on CSR and pricing decisions. However, very few studies have focused on CSR management in the context of platforms. The study most relevant to ours is that of Wen & Siqin (2020), who explore the influence of a platform's risk aversion when the shared platform faces uncertainty relating to product/service quality. The authors conclude that risk aversion may reduce product quality, albeit their research involves neither CSR-related concerns nor platform-specific network externalities in decision-making. In the context of a two-sided market, we comprehensively consider the impact of risk aversion and network externalities on platform CSR decision-making and provide guidance for platforms.

2.4. Summary of the literature

The literature review reveals that current studies on CSR focus on traditional supply chains, while research on platforms focuses on pricing and quality decisions without considering CSR-related issues. Table 2 lists the comparisons between this study and the current literature.

3. Model formulation

3.1. Problem description

We consider a platform connecting the demand side (i.e. the customers) and the supply side (i.e. the providers). For example, on a ride-sharing platform, providers are drivers while customers are riders who require travel services. Users of the platform include both customers and providers. We use subscripts c and $d$to represent customers and providers, respectively.

The platform is a monopoly in the two-sided market and thus the price maker. It decides the unit price p paid by customers and pays $(1-\lambda)p$ to the provider after retaining a portion of the price, i.e. λp with $\lambda \in (0,1)$, as commission. Such centralized pricing gives the platform full control over the market (Liu et al., 2019b; Cachon et al.,2021). Moreover, there is a probability that providers will violate CSR regulations, and when this occurs, the platform will incur losses. The platform decides whether to invest in CSR

Table 2
Comparisons between this study and the current literature.

	Platform context	Two-sided market	CSR	Network externality	Risk aversion
Liu et al. (2022)			√		
Zheng et al. (2020)			√		√
Wang et al. (2019b)	√	√		√	
Kung & Zhong (2017)	√	√		√	
Wen & Siqin (2020)	√				√
This study	√	√	√	√	√

at a cost, in order to reduce the probability of CSR violations by providers.

The sequences of events are as follows. *Step 1*: The platform decides whether to invest in CSR. *Step 2*: If investing in CSR, the platform decides the CSR investment level e and price p; if not ($e = 0$), the platform decides only p. *Step 3*: Providers and customers observe the platform's decisions, as well as their own serving costs or valuations of the service. *Step 4*: Based on e and p, customers and providers decide whether to join the platform. *Step 5*: The number of providers and customers is decided, customer demand is satisfied and the probability of CSR violations by providers is determined.

Considering the potential disruptions resulting from CSR violations and the large amount of losses involved, the platform is considered risk-averse. However, both providers and customers are risk-neutral since the money involved in a single transaction with a consumer and a provider is small compared with their overall wealth.

3.2. Customers

Each customer obtains different utilities from rides. For example, a rider catching a flight may place a higher valuation on the ride. We capture this heterogeneity by setting the valuation of a unit product/service v as a random variable. Following Kung & Zhong (2017) and Choi & He (2019), we assume v is uniformly distributed in [0, 1] and use $F(v)$ and $f(v)$ to represent its cumulative distribution function and probability density function, respectively. Uniformly distributed customer utility is consistent with the classic linear price-dependent demand function widely used in operations management (Wen & Siqin, 2020). According to the network externality, customer utility U_c increases in line with the number of providers (Gao, 2018). We use $a_c > 0$ to indicate the marginal utility that each customer obtains from their interaction with a provider (Lin et al., 2020). Therefore, this increased utility is captured by $a_c n_d$, where n_d is the number of providers (Armstrong, 2006; Kung & Zhong, 2017). For simplicity, we call $a_c > 0$ the strength of customer network externality. In addition, if the platform invests in CSR and the investment level is $0 < e < 1$, we assume customer utility will increase βe as the platform's reliability is enhanced, where $\beta > 0$ is the sensitive coefficient of the CSR of customers, which also represents the incremental utility of the unit investment CSR provided to consumers. This assumption also captures the positive impact of CSR investment on the platform, as it helps the platform improve its reputation and attract more customers. Therefore, customer utility with valuation v is

$$U_c = v - p + a_c n_d + \beta e. \tag{1}$$

Subsequently, a customer will join the platform and transact with a provider only if his utility U_c is non-negative. It is worth noting the assumption that each customer with $U_c \geq 0$ will complete an order. The number of customers is equal to the demand in our setting. According to the utility function, we know that only customers with $v \geq v^*$ will join the platform, where $v^* = p - a_c n_d - \beta e$ and the number of customers n_c is

$$n_c = \int_{v^*}^{1} f(v)dv = 1 - (p - a_c n_d - \beta e). \tag{2}$$

All parameters in this paper are normalized to be consistent with the normalized market size; all parameters are less than or equal to one and the decision variable $e < 1$.

3.3. Providers

After the platform collects a commission, the unit income of providers is $(1 - \lambda)p$. The income can be seen as the providers' utility to join the platform due to the risk-neutral behavior. Moreover, providers also obtain extra utility $a_d n_c$ due to network externalities, where $a_d > 0$ represents the marginal utility that each provider obtains from their interaction with an additional customer, which we call the degree of provider network externality. When serving each consumer, providers may also receive additional utility due to the total number of consumers on the platform. For example, on e-commerce platforms, the marginal utility obtained by the provider may be associated with the effects of advertising; on the Didi platform, the marginal utility includes quick accessibility for customers or a reduction in idle run time.

Providers incur their own cost to provide services, which can vary considerably (Chen et al. 2019a). For example, providers have different opportunity costs to dedicate time to the platform, which they may invest elsewhere. We capture this heterogeneity by assuming that the unit service cost c of providers is uniformly distributed within [0, 1] (Kung & Zhong, 2017; Liu et al., 2019b). The cumulative distribution function and probability density function of cost c are $G(c)$ and $g(c)$, respectively. Total service costs incurred by providers in the platform are determined by the unit service cost c and the number of orders.

As discussed in Section 1, CSR investments may increase barriers to entry and providers' costs may increase, thus causing some providers to leave the platform. As a result of CSR initiatives, providers may need to incur additional expense and effort to implement, for example, real-time face authentication, ID checking and additional communications for each consumer (Uber, 2019; Didi, 2019). Following Chen & Lee (2016), we assume that the increased marginal cost is me; therefore, the unit cost for each service becomes $c + me$ after CSR investment. Denote γn_d the disutility that a provider obtains from competition (or the negative network effect), the expected utility of a provider is then:

$$U_d = \frac{n_c}{n_d}[(1 - \lambda)p + a_d n_c - \gamma n_d - c - me]. \tag{3}$$

Provider competition is incorporated into the model from two perspectives. On the one hand, a provider will join the platform only when $U_d \geq 0$. Fierce competition with a larger n_d decreases $(1 - \lambda)p + a_d n_c - \gamma n_d - c - me$ and therefore restrains a provider's decision to join the platform. On the other hand, a provider is expected to make $\frac{n_c}{n_d}$ trips matched by the platform. A larger n_d reduces the number of consumers that a provider can serve and therefore reduces utility U_d.

Similar to the situation with customers, there exists a certain threshold $c^* = (1 - \lambda)p + a_d n_c - \gamma n_d - c - me$. Providers with $c \leq c^*$ will join the platform, and the number of providers n_d on the platform is

$$n_d = \int_{0}^{c^*} g(c)dc = (1 - \lambda)p + a_d n_c - \gamma n_d - c - me. \tag{4}$$

3.4. Platform

The platform connects customers and providers, and makes a profit by charging a commission fee for each ride. In the following, we first introduce the platform profit function when the platform is risk-neutral (Section 3.4.1), and then provide the platform profit function when the platform is risk-averse (Section 3.4.2).

3.4.1. Risk-neutrality

First, we discuss platform profits under risk-neutral conditions. Platform revenue is derived from commissions. Following previous studies (Kung & Zhong, 2017; Wang et al., 2019b), we assume that all customers match with providers on the platform and demand is equal to the number of customers. Therefore, the platform's revenue is $\lambda n_c p$. CSR violations by providers incur loss L for the platform. Violation losses L include all direct or indirect costs, such as compensation and loss of reputation, incurred due to providers' violations. Following previous studies (Chen & Lee, 2016; Chen et al., 2019b; Cho et al., 2019; Liu et al., 2022), we assume that L is an exogenous variable. Changing the values of L reveals different kinds of CSR violations or regulations. For example, loose or minor regulations such as jumping a red traffic signal cause fewer losses, while strict or major regulations violations would result in greater losses. Assume that the provider's uncertain probability of a CSR violation is η with mean μ and variance σ^2 when the platform does not invest in CSR. Therefore, when the platform does not invest in CSR, it determines the price p to maximize its expected profit as follows:

$$\max \mathrm{E}(\Pi) = \mathrm{E}[\lambda n_c p - \eta L]. \tag{5}$$

If the platform invests in a high level of CSR, the average CSR violation probability becomes lower. Without loss of generality, we assume that the mean value of η becomes $(1-e)\mu$ after the CSR investment. The effect of improving CSR investment on violation probability is reflected in a reduction of the mean. Due to the unified screening or training of providers by the platform, the uneven quality of these providers will also improve and consequently, the variance will decrease (Liu et al., 2018). We assume that this decrease in variance is $(1-e)\sigma^2$ [1]. The CSR investment cost of the platform is $\frac{1}{2}ke^2$, where k refers to the cost coefficient of CSR investment. The CSR investment cost is related to an overall improvement in the safety or insurance system of the platform, such as strengthening cooperation with the police, improving warning systems and updating safety policies. Therefore, we adopt a generalized quadratic cost function, which is based on the economic principle of increasing marginal costs (that is, as the CSR level increases, the investment cost required for each increase in the CSR level will gradually increase). This principle is widely used in the operations management literature (Ma et al., 2017; Wen & Siqin, 2020). Moreover, CSR investment has a threshold e_0, because when the platform decides to invest in CSR to improve the security or reliability of the platform, in most cases, the platform has to reach a certain standard in order to make customers aware of the improvement and bring about customer utility enhancement. Typical examples include achieving ISO14001 or SA8000 certification (Grimm et al., 2016). For example, Didi's investment in CSR aims to establish a secure database and establish a face recognition system, which requires a certain threshold of achievement. Therefore, when the platform invests in CSR, it jointly decides p and e to maximize the expected profit:

$$\begin{aligned} &\max \mathrm{E}(\Pi) = \mathrm{E}\left[\lambda n_c p - \eta L - \tfrac{1}{2}ke^2\right] \\ &s.t.\, e \geq e_0 \end{aligned} \tag{6}$$

[1] We also consider the case in which the variance becomes $(1-e)^2\sigma^2$ when the platform invests in CSR. The main results do not change qualitatively. Please see the appendix for detailed proof.

3.4.2. Risk aversion

In the case of risk aversion, the platform will be averse to the uncertain profit loss caused by the providers violating CSR. We use the MV model to study risk aversion. It was first proposed in the 1950s and has since proved to be an important theory for risk management in finance. In recent decades, the MV model has been widely used for conducting risk analysis in supply chain operational models (Chiu & Choi, 2016; Choi et al., 2019). Moreover, previous studies have used it to capture platforms' risk aversion (Choi et al., 2020; Wen & Siqin, 2020). In our study, the risk of provider CSR violations is uncertain, and the platform is risk-averse in this respect, which is well suited to the MV model. According to the MV model, the risk-averse platform maximizes its expected utility $E(U) = E(\prod) - \frac{r}{2}Var(\prod)$ (Chiu & Choi, 2016; Choi et al., 2019; Wen & Siqin, 2020), where $\mathrm{E}(\prod)$ refers to the expected profit and $Var(\prod)$ represents the effect due to the uncertain violation probability of providers. $r \geq 0$ represents the platform's degree of risk aversion. A large r value indicates a high degree of risk aversion. When $r = 0$, the platform becomes risk-neutral.

When the platform does not invest in CSR, $\mathrm{E}(\prod)= \mathrm{E}[\lambda n_c p - \eta L]$ and $Var(\prod)=L^2\sigma^2$. The platform decides price p to maximize its utility:

$$\max \mathrm{E}(U) = \mathrm{E}[\lambda n_c p - \eta L] - \frac{r}{2}L^2\sigma^2. \tag{7}$$

When the platform invests in CSR, $\mathrm{E}(\prod)= \mathrm{E}[\lambda n_c p - \eta L - \frac{1}{2}ke^2]$ and $Var(\prod)=L^2(1-e)\sigma^2$. The platform decides p and e jointly to maximize the expected utility under risk aversion:

$$\begin{aligned} &\max \mathrm{E}(U) = \mathrm{E}\left[\lambda n_c p - \eta L - \tfrac{1}{2}ke^2\right] - \tfrac{r}{2}L^2(1-e)\sigma^2 \\ &s.t.\, e \geq e_0 \end{aligned} \tag{8}$$

To facilitate the calculation, similar to Niu et al. (2015) and Zhang et al. (2021), we assume $m = 1$ in the following analysis because the parameter m only increases the complexity of mathematical expressions in the analysis and does not provide new implications.

4. Model analysis

We use superscripts "I" and "C" to represent the scenarios without and with an investment in CSR, respectively, and "N" and "R" to represent a risk-neutral and a risk-averse platform, respectively.

4.1. Number of users in equilibrium

Once aware of their private cost and valuation of information, the only decision for providers and customers is whether or not to join the platform. The platform can influence this decision by its pricing strategy. Naturally, customers and providers with non-negative utility will enter the market. By jointly solving Eqs. (2) and (4), we calculate, for a given price p and a CSR investment level e, the number of customers and providers on the platform as follows.

Lemma 1. ***(Number of users in equilibrium):*** *Given p and e, the number of customers is $n_c = \frac{1+\gamma-(1+\gamma-a_c(1-\lambda))p+(\beta(1+\gamma)-a_c)e}{1+\gamma-a_c a_d}$ and the number of providers is $n_d = \frac{(1-a_d-\lambda)p+(a_d\beta-1)e+a_d}{1+\gamma-a_c a_d}$.*

Lemma 1 clearly shows that the number of customers decreases with p. However, the platform's higher CSR investment level does not necessarily lead to an increase in the number of customers. When the strength of customer network externality is high (i.e., $a_c > \beta(1+\gamma)$), an increase in e actually leads to a decrease in the number of customers. This happens because CSR investment directly increases customers' utility and may reduce the number of providers. When a_c is relatively large, network externality forces many customers to leave the platform due to the decreasing number of providers. This negative impact exceeds the increase in customers brought by utility enhancement associated with CSR investment. Therefore, the number of customers decreases.

Similarly, we find that a higher price does not necessarily result in a higher number of providers. Although the provider may obtain higher revenue in this case, the higher price may lead to a rapid decline in the number of customers. Under the influence of the network externality, the utility of providers will be reduced. When the strength of the provider's network externality is significant, a high price will, in turn, lead to a decline in the number of providers. This conclusion is also consistent with practice. When Didi raises prices, many customers choose lower-priced platforms. Due to the loss of customers, providers have also begun to move away from Didi and seek other platforms.

4.2. Optimal solutions under the risk-neutral condition

This section analyzes optimal decisions when the platform is risk-neutral. The platform has two choices: not investing in CSR (case IN) and investing in CSR (case CN). Using methods based on the backward induction method, we obtain the platform's optimal price, CSR investment level and profits in these two cases (see Lemma 2). See the Appendix for the solution process.

Lemma 2. ***(Optimal solutions under risk-neutral conditions):***

(1) Case IN: when the platform is risk-neutral and does not invest in CSR, the optimal price and profit of the platform are as follows:

$$p^{IN} = \frac{1+\gamma}{2(1+\gamma-a_c(1-\lambda))},$$

$$\Pi^{IN} = \frac{\lambda(1+\gamma)^2}{4(1+\gamma-a_ca_d)(1+\gamma-a_c(1-\lambda))} - \mu L$$

(2) Case CN: when the platform is risk-neutral and invests in CSR, the optimal price, CSR investment level and profit of the platform are as follows:

$$p^{CN} = \begin{cases} \frac{(1+\gamma-a_ca_d)(k(1+\gamma)-\mu L(a_c-(1+\gamma)\beta))}{2k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2}, ifk < k_1, \\ \frac{1+\gamma+(\beta(1+\gamma)-a_c)e_0}{2(1+\gamma-a_c(1-\lambda))}, \quad ifk \geq k_1. \end{cases}$$

$$e^{CN} = \begin{cases} \frac{2\mu L(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(1+\gamma)(a_c-(1+\gamma)\beta)}{2k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2}, ifk < k_1, \\ e_0, \quad ifk \geq k_1. \end{cases}$$

$$\prod^{CN} = \begin{cases} \frac{\left\{2\mu L(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)(\mu L-2k)+2\mu L\lambda(a_c-(1+\gamma)\beta)(a_c-(1+\gamma)(\beta+1))+\lambda k(1+\gamma)^2\right\}}{4k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-2\lambda(a_c-(1+\gamma)\beta)^2} \quad if, k < k_1, \\ \frac{\lambda(1+\gamma-(a_c-(1+\gamma)\beta)e_0)^2}{4(1+\gamma-a_c(1-\lambda))(1+\gamma-a_ca_d)} - \mu(1-e_0)L - \frac{1}{2}ke_0^2, ifk \geq k_1. \end{cases}$$

where $k_1 = \frac{\lambda(\beta(1+\gamma)-a_c)(1+\gamma-e_0(a_c-(1+\gamma)\beta))}{2e_0(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)} + \frac{\mu L}{e_0}.$

Lemma 2 shows that when investing in CSR, the optimal price, CSR investment level and profit of the platform are divided into two parts regarding the cost coefficient of CSR investment k. When k is large ($k \geq k_1$), the platform invests in CSR at threshold e_0. When k is small, the platform has a stronger motivation to invest in an endogenous CSR investment level e, which increases as k decreases.

4.3. Optimal solutions under the risk-averse condition

This section analyzes optimal decisions when the platform is risk-averse. Again, the platform has two choices - either to invest in CSR (case CR) or not to do so (case IR). The optimal solutions are summarized in Lemma 3.

Lemma 3. (Optimal solutions under risk-averse conditions):

(1) Case IR: when the platform is risk-averse and does not invest in CSR, the optimal price and expected utility of the platform are as follows:

$$p^{IR} = \frac{1+\gamma}{2(1+\gamma-a_c(1-\lambda))},$$

$$E(U)^{IR} = \frac{\lambda(1+\gamma)^2}{4(1+\gamma-a_ca_d)(1+\gamma-a_c(1-\lambda))} - \mu L - \frac{rL^2\sigma^2}{2}.$$

(2) Case CR: when the platform is risk-averse and invests in CSR, the optimal price, CSR investment level and expected utility of the platform are as follows:

$$p^{CR} = \begin{cases} \frac{(1+\gamma-a_ca_d)(2k(1+\gamma)-(2\mu L+rL^2\sigma^2)(a_c-(1+\gamma)\beta))}{4k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-2\lambda(a_c-(1+\gamma)\beta)^2}, ifk < k_2, \\ \frac{1+\gamma+(\beta(1+\gamma)-a_c)e_0}{2(1+\gamma-a_c(1-\lambda))}, \quad ifk \geq k_2. \end{cases}$$

$$e^{CR} = \begin{cases} \frac{\left\{\begin{array}{c}(2\mu L+rL^2\sigma^2)(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)- \\ \lambda(a_c-(1+\gamma)\beta)(1+\gamma)\end{array}\right\}}{2k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2}, ifk < k_2, \\ e_0 \quad ifk \geq k_2. \end{cases}$$

$$E(U)^{CR} = \begin{cases} \frac{\left\{\begin{array}{l}(2\mu L+rL^2\sigma^2)(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)(2\mu L+rL^2\sigma^2-4k)+ \\ 2\lambda(2\mu L+rL^2\sigma^2)(a_c-(1+\gamma)\beta)(a_c-(1+\gamma)(\beta+1))+2\lambda k(1+\gamma)^2\end{array}\right\}}{8k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-4\lambda(a_c-(1+\gamma)\beta)^2}, ifk < k_2, \\ \frac{\lambda(1+\gamma-(a_c-(1+\gamma)\beta)e_0)^2}{4(1+\gamma-a_c(1-\lambda))(1+\gamma-a_ca_d)} - \mu(1-e_0)L - \frac{r}{2}L^2(1-e_0)\sigma^2 - \frac{1}{2}ke_0^2, ifk \geq k_2. \end{cases}$$

where $k_2 = \frac{\lambda(\beta(1+\gamma)-a_c)(1+\gamma-e_0(a_c-(1+\gamma)\beta))}{2e_0(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)} + \frac{2\mu L++rL^2\sigma^2}{2e_0}.$

Lemma 3 indicates that the optimal price of the platform remains unchanged when there is no CSR investment compared to the case of risk-neutrality. However, because the platform pays more attention to the uncertain risk of CSR violations, the platform's utility will be lower than expected profit under risk-neutrality. When investing in CSR, the optimal decisions and utility of the platform are divided into two components regarding k, as under risk-neutral condition.

4.4. CSR investment decision

Based on Lemmas 2 and 3, we derive the conditions when the platform invests in CSR.

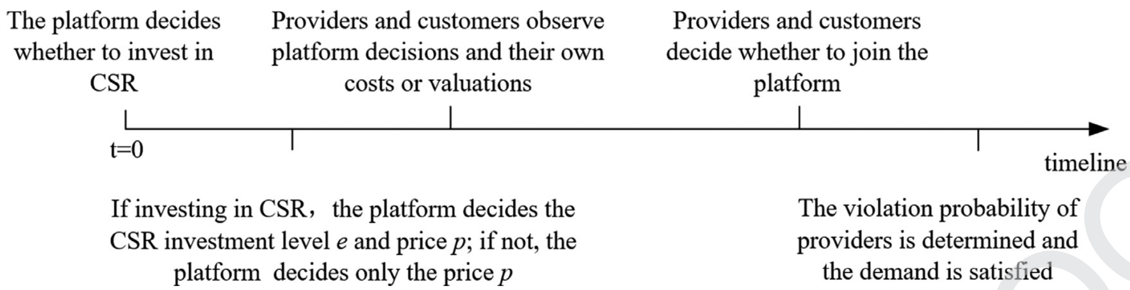


Fig. 1. Sequences of events.

Proposition 1. ***(CSR investment decision):***

(1) When the platform is risk-neutral, if $k < \bar{k}_1$, the platform will choose to invest in CSR at level e^{CN}; if $k \geq \bar{k}_1$, the platform will not invest in CSR;

(2) when the platform is risk-averse, if $k < \bar{k}_2$, the platform will choose to invest in CSR at level e^{CR}; if $k \geq \bar{k}_2$, the platform will not invest in CSR; where

$$\bar{k}_1 = \frac{\lambda(\beta(1+\gamma) - a_c)(2+2\gamma - e_0(a_c - (1+\gamma)\beta))}{2e_0(1+\gamma - a_c a_d)(1+\gamma - (1-\lambda)a_c)} + \frac{2\mu L}{e_0},$$

$$\bar{k}_2 = \frac{\lambda(\beta(1+\gamma) - a_c)(2+2\gamma - e_0(a_c - (1+\gamma)\beta))}{2e_0(1+\gamma - a_c a_d)(1+\gamma - (1-\lambda)a_c)} + \frac{2\mu L + rL^2\sigma^2}{e_0}.$$

Proposition 1 indicates that there is a threshold k in both the risk-neutral ($\bar{k}_1$) and the risk-averse ($\bar{k}_2$) cases. When the platform's cost coefficient of CSR investment is higher than the threshold, it will quit investing in CSR due to profit losses. Therefore, $\bar{k}_1$ and $\bar{k}_2$ measure the platform's investment willingness in cases of risk-neutrality and risk aversion, respectively. An increase in $\bar{k}$ indicates that the platform is more willing to invest in CSR. This conclusion is rather intuitive, but it explains that cost is always the main factor considered in the platform's decision to invest in CSR. In the next section, we compare these two thresholds, analyze the influence of a_c and a_d on them and then determine the impacts of risk aversion and network externalities.

5. Sensitivity analysis

This section focuses on the impacts of risk aversion and network externalities. Specifically, we comprehensively analyze their impacts on CSR investment decisions, pricing and numbers of customers. To gain more insights, we also analyze how the competition among providers affects the platform's CSR investment decision.

5.1. The impact of risk aversion

5.1.1. The impact of risk aversion on CSR investment decisions

CSR investment decisions include the willingness to invest and the investment level. In this section, we compare $\bar{k}_1$ and $\bar{k}_2$ to show the impact of risk aversion on the willingness to invest in CSR and compare e^{CN} and e^{CR} to show the impact of risk aversion on the CSR investment level (Fig. 1).

Proposition 2. ***(The impact of risk aversion on CSR investment decisions):*** *Compared with being risk-neutral, when the platform is risk-averse, the platform is more willing to invest in CSR and the CSR investment level is also higher; that is, $\bar{k}_1 < \bar{k}_2$, and $e^{CN} \leq e^{CR}$.*

Through Proposition 2, we know that risk aversion increases a platform's willingness to invest in CSR and induces it to invest in a greater level of CSR. Specifically, when $k \in [\bar{k}_1, \bar{k}_2]$, the platform would normally not invest in CSR; however, due to risk aversion, it does so. In this way, risk aversion has an ***"incentive effect"*** on CSR investment, reflected in Fig. 2. In addition, the higher the degree of risk aversion, the more obvious the incentive effect. This conclusion is consistent with practice. After the CSR scandals in 2018, the executives of Didi showed strong risk aversion to safety issues. Therefore, in November 2019, when Didi resumed its hitch ride services, Didi invested heavily in CSR management. According to Didi executives, hitch ride services made such substantial investment that they are current operating at a loss (Sina News, 2019). However, Didi's extreme aversion to CSR risks resulted in the company choice to investment to reduce CSR violations.

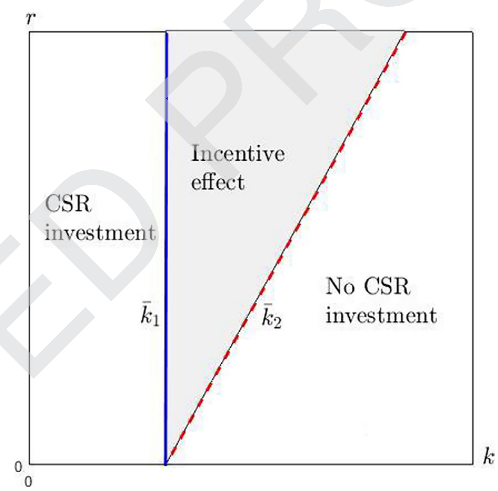


Fig. 2. Impact of risk aversion on CSR investment decisions.

5.1.2. The impact of risk aversion on prices and customer numbers

Based on Lemmas 2 and 3, we compare the optimal price and number of customers under risk-neutrality and risk aversion in this section.

Proposition 3. ***(The impact of risk aversion on the price and number of customers):*** *when $a_c < \beta(1+\gamma)$, risk aversion will increase the price and number of customers; otherwise, it will decrease the price and number of customers.*

Proposition 3 demonstrates an interesting conclusion: When $a_c < \beta(1+\gamma)$, although the platform increases the price, it still attracts more customers. Fig. 3 shows the impact of risk aversion on pricing decisions. The horizontal axis of Fig. 3 is k, and the decision made by the platform is different in the range of different k values. Taking p^N in Fig. 3 (a) as an example, when $0 < k < k_1$, the platform invests in CSR at a level of e^N; when $k_1 \leq k < \bar{k}_1$, the platform changes the CSR investment level to e_0; when $k \geq \bar{k}_1$, the platform stops investing in CSR completely. Additionally, when

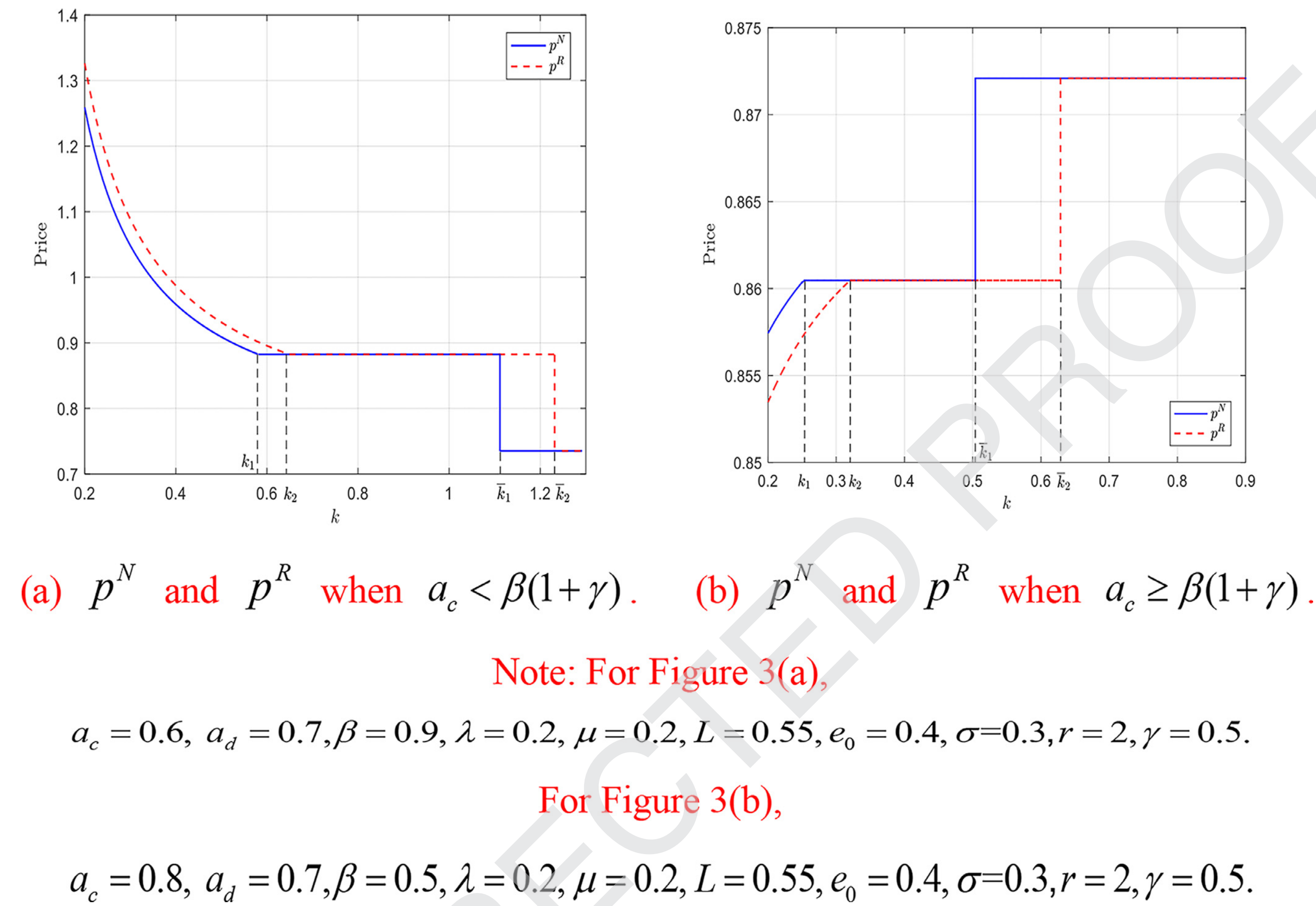


Fig. 3. Impact of risk aversion on pricing decisions.
Note: For Fig. 3(a), $a_c = 0.6$, $a_d = 0.7$, $\beta = 0.9$, $\lambda = 0.2$, $\mu = 0.2$, $L = 0.55$, $e_0 = 0.4$, σ=0.3, $r = 2$, $\gamma = 0.5$.
For Fig. 3(b), $a_c = 0.8$, $a_d = 0.7$, $\beta = 0.5$, $\lambda = 0.2$, $\mu = 0.2$, $L = 0.55$, $e_0 = 0.4$, σ=0.3, $r = 2$, $\gamma = 0.5$.

$a_c < \beta(1+\gamma)$, whether the platform invests in CSR or not, p^R is always above p^N, and therefore, it can be claimed that risk aversion will increase the price, which verifies Proposition 3. The rationale behind this claim is as follows. Proposition 2 implies that risk aversion will motivate the platform to invest in higher-level CSR, which will further affect customer utility. With a lower strength of customer network externality (i.e., $a_c < \beta(1+\gamma)$), customer utility is less negatively affected by a decrease in the number of providers due to CSR investment. By comparison, the positive impact of CSR investment on customer utility dominates, and the overall utility of customers increases. Thus, a platform can increase its prices to attract more customers and make greater profits through CSR investment. In contrast, when $a_c \geq \beta(1+\gamma)$, risk aversion associated with CSR investment leads to a decline in customer utility; therefore, platforms must lower prices to avoid losing customers.

5.2. The impact of network externalities

This section analyzes the impact of network externalities. We also illustrate their impact on CSR investment decisions and pricing decisions.

5.2.1. The impact of network externalities on CSR investment decisions

Proposition 4. ***(The impact of network externality on CSR investment decisions):***

(1) When the degree of provider network externality is higher, the platform is more willing to invest in CSR; that is, the investment thresholds $\bar{k}_1$ and $\bar{k}_2$ both increase with a_d;

(2) If $e_0 > \frac{2(\beta-\lambda\beta+a_d\beta-1)}{\beta(2-\beta+\lambda\beta-a_d\beta)}$, the investment thresholds $\bar{k}_1$ and $\bar{k}_2$ both decrease with a_c; if $e_0 \leq \frac{2(\beta-\lambda\beta+a_d\beta-1)}{\beta(2-\beta+\lambda\beta-a_d\beta)}$, the investment thresholds $\bar{k}_1$ and $\bar{k}_2$ first increase and then decrease with a_c.

Proposition 4 (1) illustrates that a high degree of provider network externality will motivate the platform to invest in CSR. A higher a_d means that an increase in the number of customers will greatly enhance the utility of providers. CSR investment can provide customers with more protection and attract more of them to the platform; therefore, more providers will also flood onto the platform. Incremental users can create more profits for the platform, thereby inspiring the latter to invest in CSR.

However, as Proposition 4 (2) suggests, in most cases, the platform is less willing to invest in CSR if a_c increases, except for a situation in which both e_0 and a_c are relatively small. In Fig. 4, we show the trend of $\bar{k}_1$ and $\bar{k}_2$ changing along with a_c when $e_0 \leq \frac{2(\beta-\lambda\beta+a_d\beta-1)}{\beta(2-\beta+\lambda\beta-a_d\beta)}$. In Proposition 1, $\bar{k}_1$ and $\bar{k}_2$ represent the willingness of the platform to invest in CSR under conditions of risk-neutrality and risk aversion, respectively. Fig. 4 indicates that when e_0 is small, the platform's willingness to invest in CSR increases first and then decreases as a_c enlarges. The phenomenon in which a platform's willingness to invest in CSR decreases with a_c is known as the ***"dilution effect"***. Possible explanations for the con-

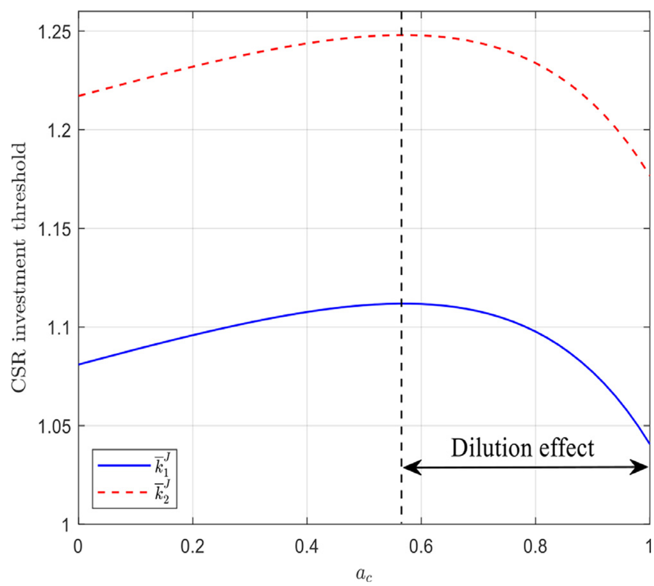


Fig. 4. Impact of a_c on CSR investment decisions with a low e_0.
Note: $a_d = 0.7, \beta = 0.9, \lambda = 0.2, \mu = 0.2, L = 0.55, e_0 = 0.4, \sigma$=0.3, $r = 2, \gamma = 0.5$.

clusions in Proposition 4(b) include the following. Although CSR investment may entice more customers to the platform and thus attract certain providers, it ultimately causes a substantial reduction in the number of providers due to the stricter selection criteria. A higher a_c means that customers are very sensitive to the number of providers on the platform. The decrease in the number of providers, in turn, reduces customer utility, thereby simultaneously reducing the number of two-sided users and platform profits, and thus reflecting the ***"dilution effect"*** of the platform's CSR investment due to customer network externalities. This phenomenon can also be observed in practice. For example, after the outbreak of the CSR scandals, Didi temporarily closed its hitch services in order to address safety concerns. This in turn led to a sharp reduction in the number of providers, leading to very long wait times for customers. As a result, more customers chose alternative modes of travel.

Proposition 4 has important implications. To alleviate the adverse impact of the dilution effect of CSR investment on platform profits, regulators can lower the threshold. Fig. 4 shows the impact of customer network externality on CSR investment when the threshold is low. We can see that when both e_0 and a_c are small, the platform is more willing to invest in CSR (i.e., $\bar{k}_1$ and $\bar{k}_2$ become larger) as a_c increases. The emergence of the dilution effect is mainly due to high levels of CSR investment, which results in a sharp drop in the number of providers on the platform. A lower CSR investment threshold gives providers some buffer. Although CSR investment may cause some providers to leave the platform, it may also attract more customers and, in turn, new providers. With a low barrier to entry (i.e., low e_0), these new providers may outnumber those who left, and so two-sided users on the platform will increase, thus creating sustainable profits for the platform. However, when the degree of customer network externalities is very high, even lowering the CSR investment threshold will not alleviate the dilution effect. The reduction in the number of providers caused by CSR investment will cause the platform to suffer a significant setback. However, this extreme scenario generally occurs in low-quality markets. For example, in some e-commerce platforms, customers are more concerned with finding products quickly rather than checking whether the products are genuine.

5.2.2. The impact of network externalities on pricing decisions and number of customers

Proposition 5. ***(The impact of network externality on pricing decisions):*** *The optimal price increases as the degrees of customer network externality a_c and provider network externality a_d increase.*

Proposition 5 confirms that an increase in network externalities will encourage platforms to set higher prices for customers and providers. Take customer network externality as an example. When a_c is high, increasing the number of platform providers can significantly increase the utility of customers. Therefore, the platform has an incentive to raise the price and increase the provider's revenue, thereby attracting more providers. As a result, the platform does not need to use price concessions to attract customers, and it retains customers by attracting more providers. For example, in the early stages of Didi and Uber, there were only a small number of (price-sensitive) users, and the network externalities were still weak. The platforms thus utilized massive price subsidies to attract users. However, now that platforms have matured, their network externalities have increased, and they have raised prices to attract more providers, in order to ensure prompt customer service, thereby increasing platform profits.

We then discuss the impacts of a_c and a_d on the number of customers n_c, the result for which is shown in Fig. 5. Interestingly, with the increase in a_c, the number of customers on the platform first declines and then increases, mainly as a result of two factors. On the one hand, with an increase in a_c, the price of the platform is constantly increasing, which negatively affects the number of customers. On the other hand, the number of platform providers has increased, which will attract more customers. The negative impact of the price initially dominates the positive impact of the number of providers, so the number of customers declines. When the degree of customer network externality reaches a certain level, the positive impact exceeds the negative impact, so more customers will join the platform.

5.3. The impact of competition

In this section, we analyze the impact of the competition coefficient γ. The result in Fig. 6 shows that fierce competition among providers (larger γ) stimulates the platform to invest in CSR. The reason for this is the intensified competition among providers, which decrease the utility of providers, and subsequently cause a decline in the number of providers. Moreover, due to the influence of network externalities, the utility and number of customers will also decrease. In order to prevent the loss of customers, platforms should invest in CSR to attract more customers.

Note:$a_c = 0.5, a_d = 0.6, \beta = 0.55, \lambda = 0.25, \mu = 0.2, L = 0.55, e_0 = 0.4, r = 2.$

6. Analysis of customer surplus

6.1. The impact of risk aversion on customer surplus

According to Kök et al. (2018), customer surplus refers to $CS = \int_{p^*}^{p^{\max}} n_c(p)\mathrm{d}p$, where p^* is the optimal price, $p^{\max}$ is the maximum price at which demand equals 0 and $n_c(p)$ is the number of customers at price p.

Proposition 6. ***(The impact of risk aversion on customer surplus):*** *If $a_c < \beta(1+\gamma)$, risk aversion will increase customer surplus; otherwise, it will decrease customer surplus.*

When the platform is risk-averse, it will increase its CSR investment level, customer utility will be improved, and more customers will be willing to join the platform. Thus, intuitively, the

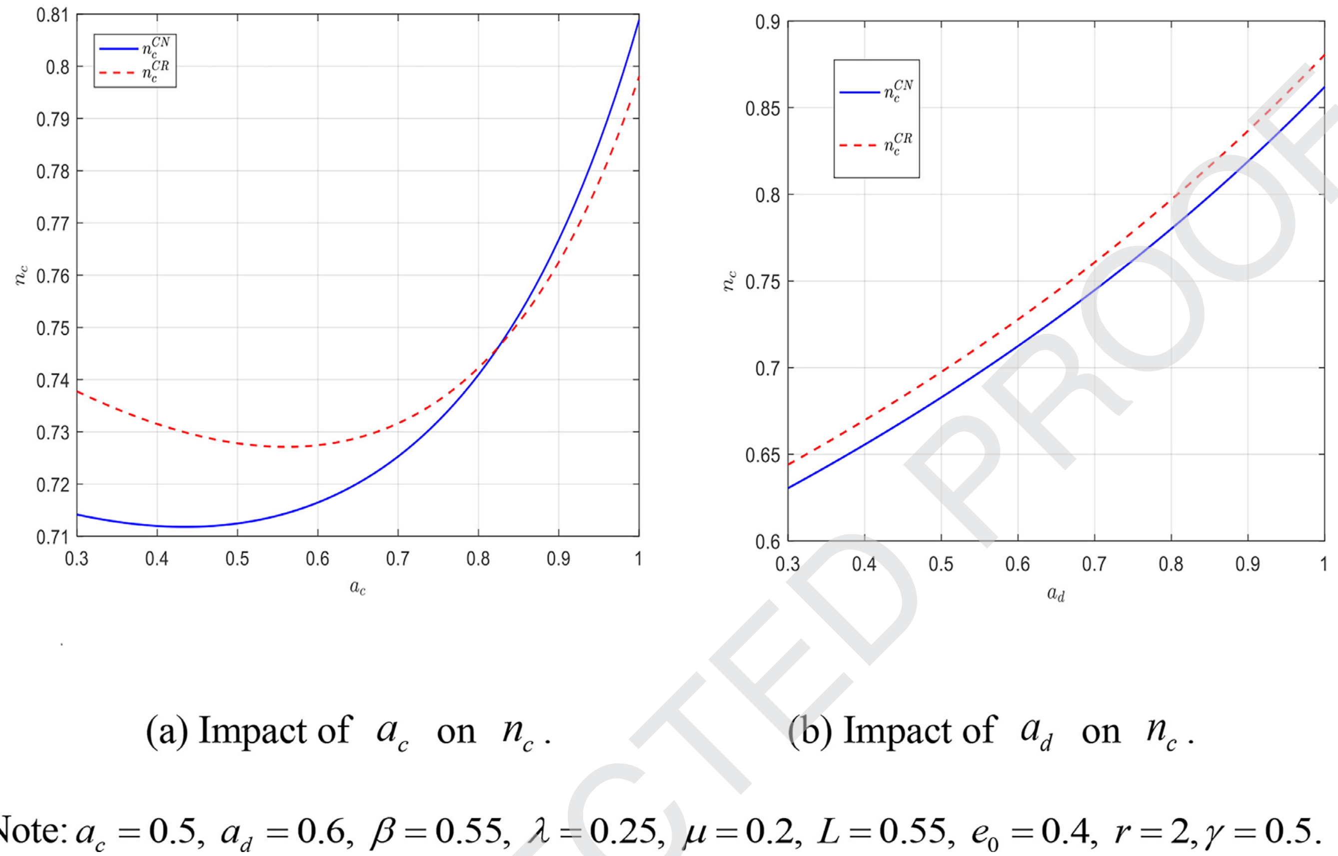


Fig. 5. Impacts of a_c and a_d on n_c.
Note:$a_c = 0.5$, $a_d = 0.6$, $\beta = 0.55$, $\lambda = 0.25$, $\mu = 0.2$, $L = 0.55$, $e_0 = 0.4$, $r = 2$, $\gamma = 0.5$.

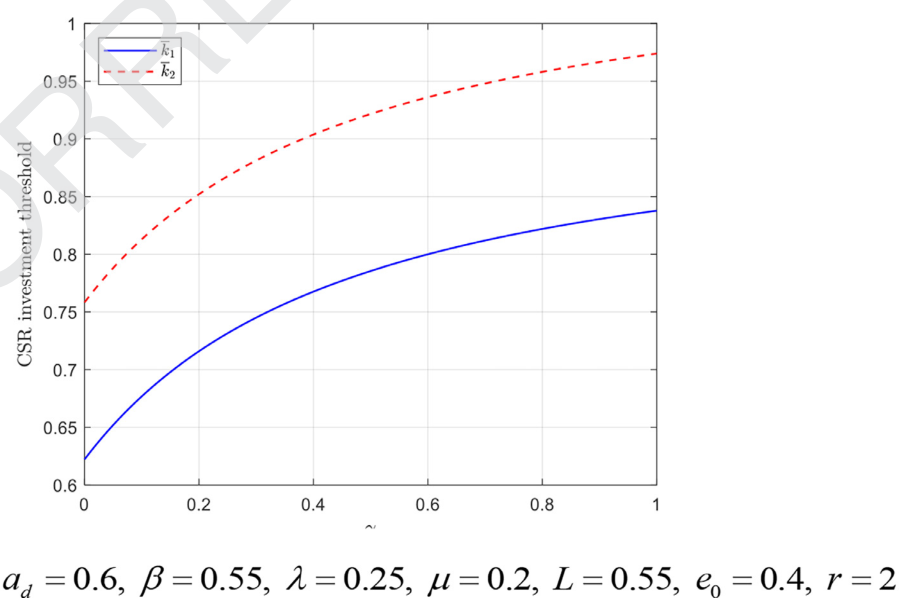


Fig. 6. Impact of γ on CSR investment decisions.
Note:$a_c = 0.5$, $a_d = 0.6$, $\beta = 0.55$, $\lambda = 0.25$, $\mu = 0.2$, $L = 0.55$, $e_0 = 0.4$, $r = 2$.

platform's risk aversion will increase customer surplus. However, when the degree of customer network externality is high (i.e., $a_c \geq \beta(1+\gamma)$), risk aversion reduces customer surplus. Specifically, we have learnt from previous conclusions that risk aversion will directly increase customers' utility, but it may also reduce the number of providers, thereby indirectly reducing customers' utility. When $a_c \geq \beta(1+\gamma)$, customers are more concerned about whether providers can quickly meet their requirements; therefore, the decrease in customer surplus is driven by the decline in the number of providers due to risk aversion.

6.2. The impact of network externality on customer surplus

Due to the complexity of calculation, we use in this section numerical analysis as a supplement to visually demonstrate the im-

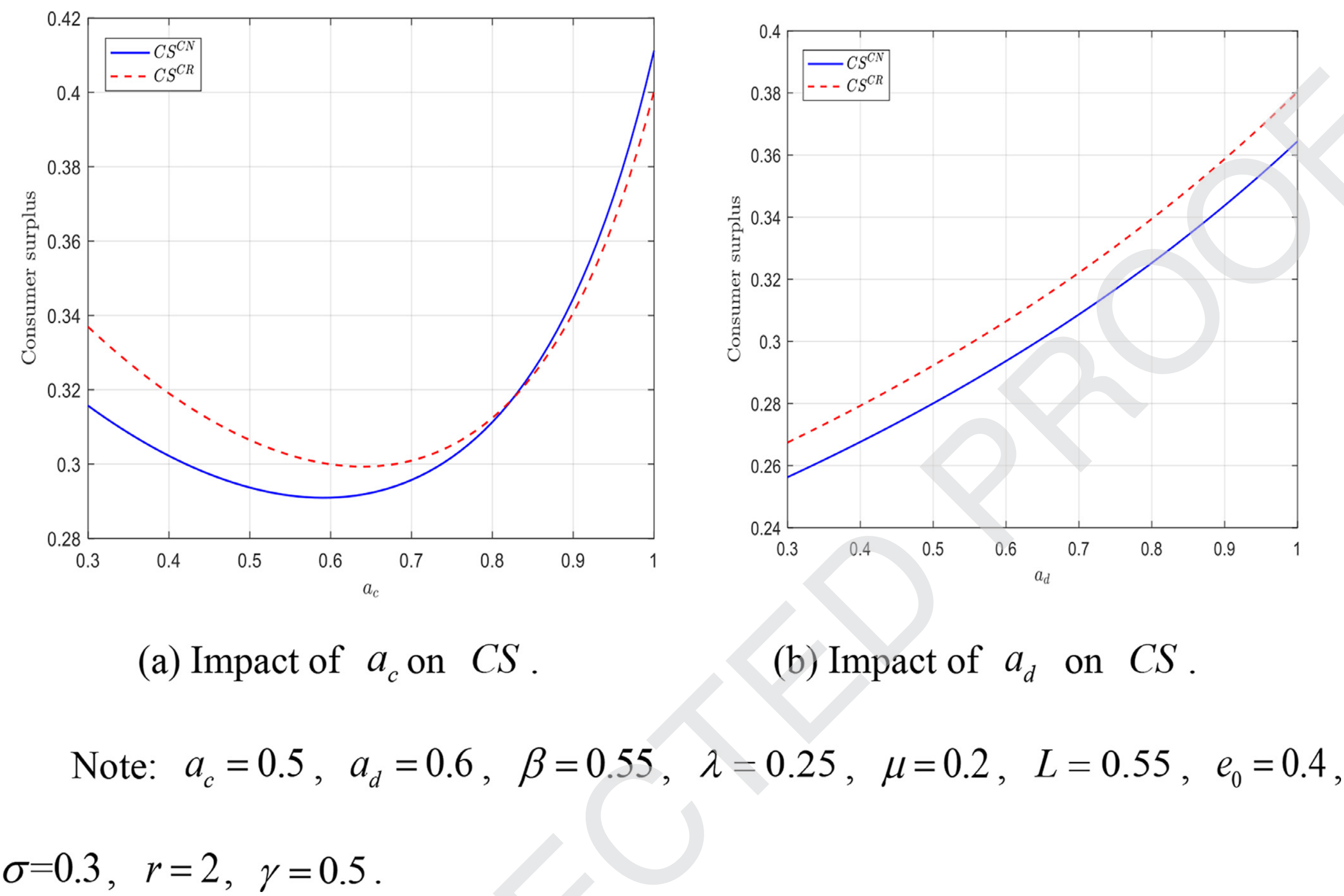


Fig. 7. Impacts of a_c and a_d on customer surplus.
Note: $a_c = 0.5$, $a_d = 0.6$, $\beta = 0.55$, $\lambda = 0.25$, $\mu = 0.2$, $L = 0.55$, $e_0 = 0.4$, σ=0.3, $r = 2$, $\gamma = 0.5$.

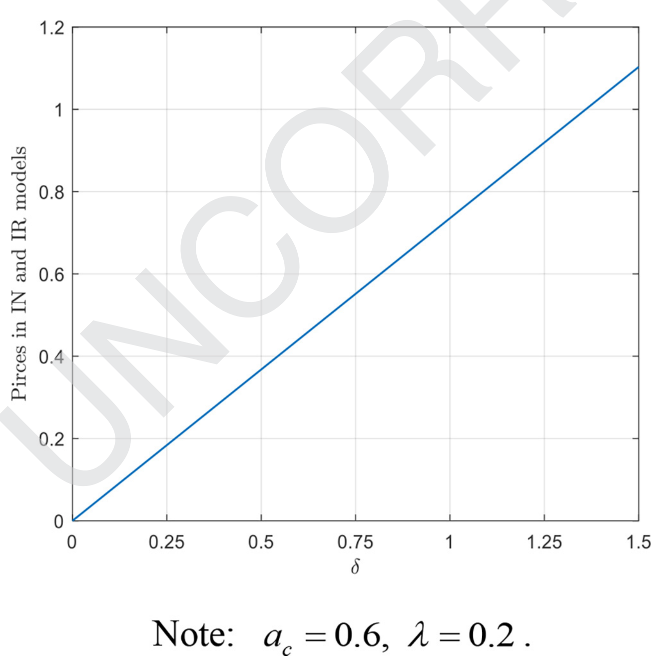


Fig. 8. Price trends with δ.
Note: $a_c = 0.6, \lambda = 0.2$.

pact of network externalities on customer surplus. The results are shown in Fig. 7.

Fig. 7(a) shows that customer surplus first decreases and then increases as a_c increases. For a similar reason, this trend also applies to ustomers for a similar reason (see Fig. 5(a)). Fig. 7 (b) shows that an increase in a_d will increase customer surplus. Recall that in Fig. 5(b), the number of customers increases with a_d. In addition, more providers enhance customer utility due to network externalities, and an increase in both customer utility and the number of customers increases customer surplus.

7. Model extension

In this section, we test the robustness of our conclusions under different scenarios, specifically, with respect to market size fluctuations on the demand side, market size fluctuations on the supply side and risk-averse customers.

7.1. Market size fluctuation on demand side

In Section 3, we consider that the consumer's valuation of service v satisfies a uniform distribution of $[0, 1]$; thus, the consumer market size is standardized to 1. However, as shown in Table 1 in the introduction, the platform will in practice adjust prices based on different time periods because the market size of consumers changes significantly over time. During peak times, the surge in the market size makes it difficult for consumers to obtain ride-sharing services, so the value of these services will increase accordingly. Similarly, when market size shrinks during off-peak times, the value of services for customers declines. To incorporate the impact of market size fluctuations, we introduce a customer market size coefficient $\delta > 0$, and consumers' valuation of services is adjusted

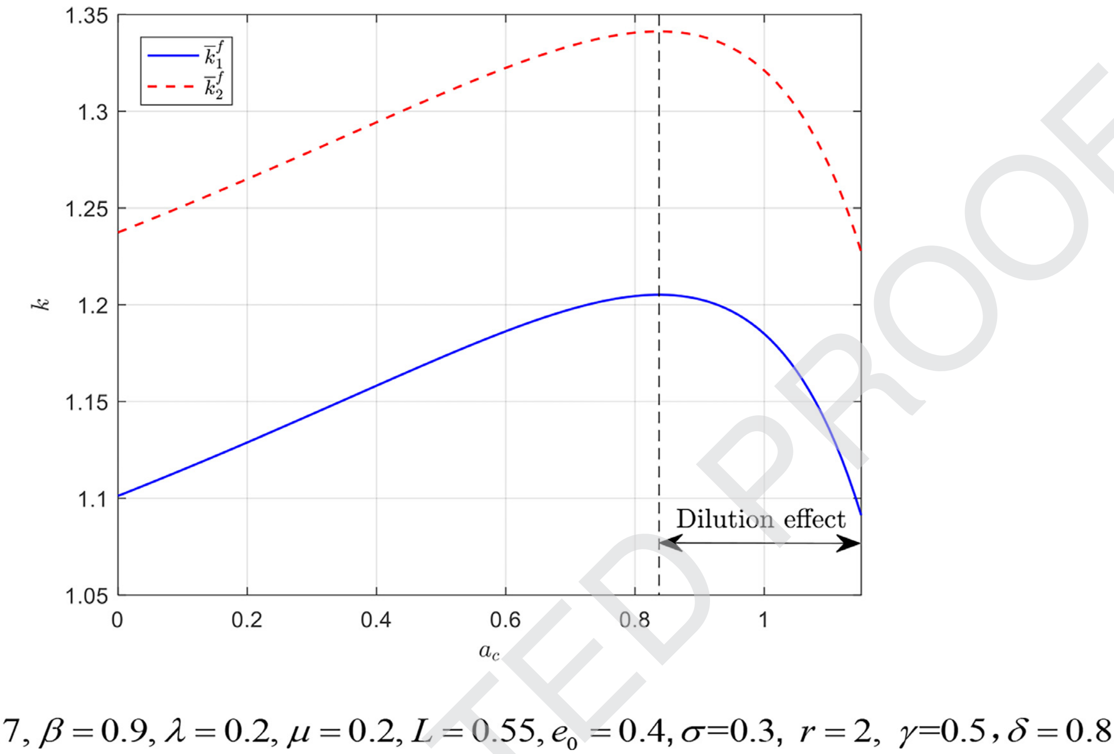


Fig. 9. Low market size.
Note: $a_d = 0.7$, $\beta = 0.9$, $\lambda = 0.2$, $\mu = 0.2$, $L = 0.55$, $e_0 = 0.4$, σ=0.3, $r = 2$, $\gamma = 0.5$, $\delta = 0.8$.

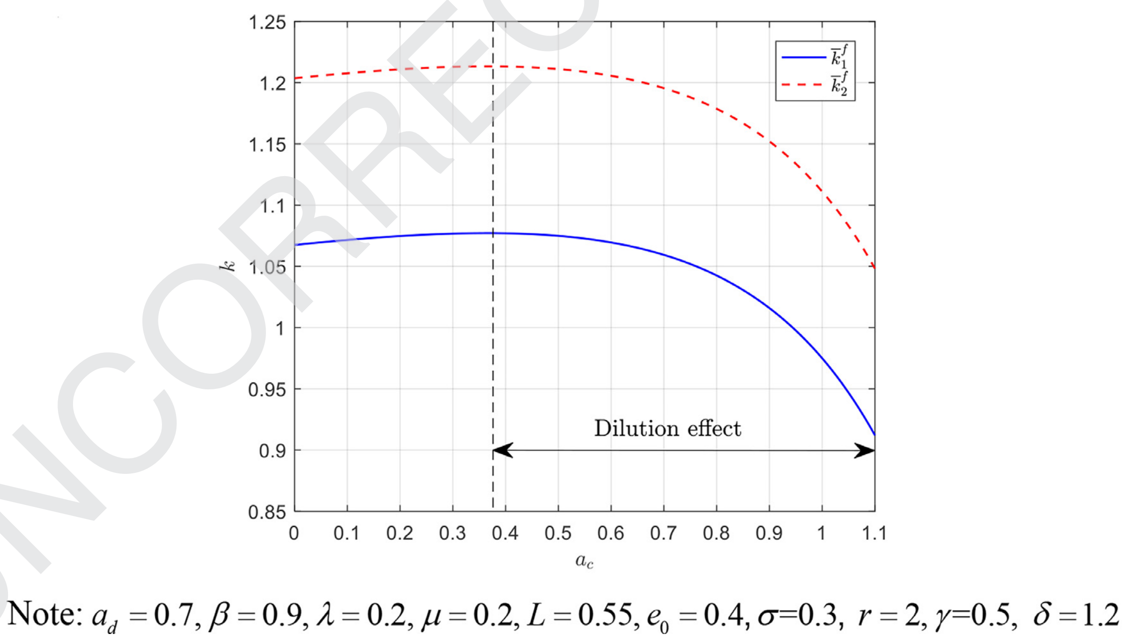


Fig. 10. High market size.
Note:$a_d = 0.7$, $\beta = 0.9$, $\lambda = 0.2$, $\mu = 0.2$, $L = 0.55$, $e_0 = 0.4$, σ=0.3, $r = 2$, γ=0.5, $\delta = 1.2$.

to δv. $\delta > 1$ means that consumers increase the valuation of services and their market size of consumers increases. By contrast, $0 < \delta < 1$ means that consumers reduce their valuation of services, thus decreasing the market scale. Consequently, customer utility is revised to:

$$U_c = \delta v - p + a_c n_d + \beta e$$

Proposition 7. ***(The impact of customer market fluctuations on pricing decisions):*** *In the IN and IR models, the price of the platform increases in line with the customer market size coefficient.*

We demonstrate Proposition 7 in Fig. 8, showing that as δ increases, the platform increases service prices, thereby illustrating that platforms are motivated to charge more during peak times. Consequently, prices during these periods, ranging from 06:00 to 10:00 and 17:00 to 21:00, as highlighted in Table 1, are sig-

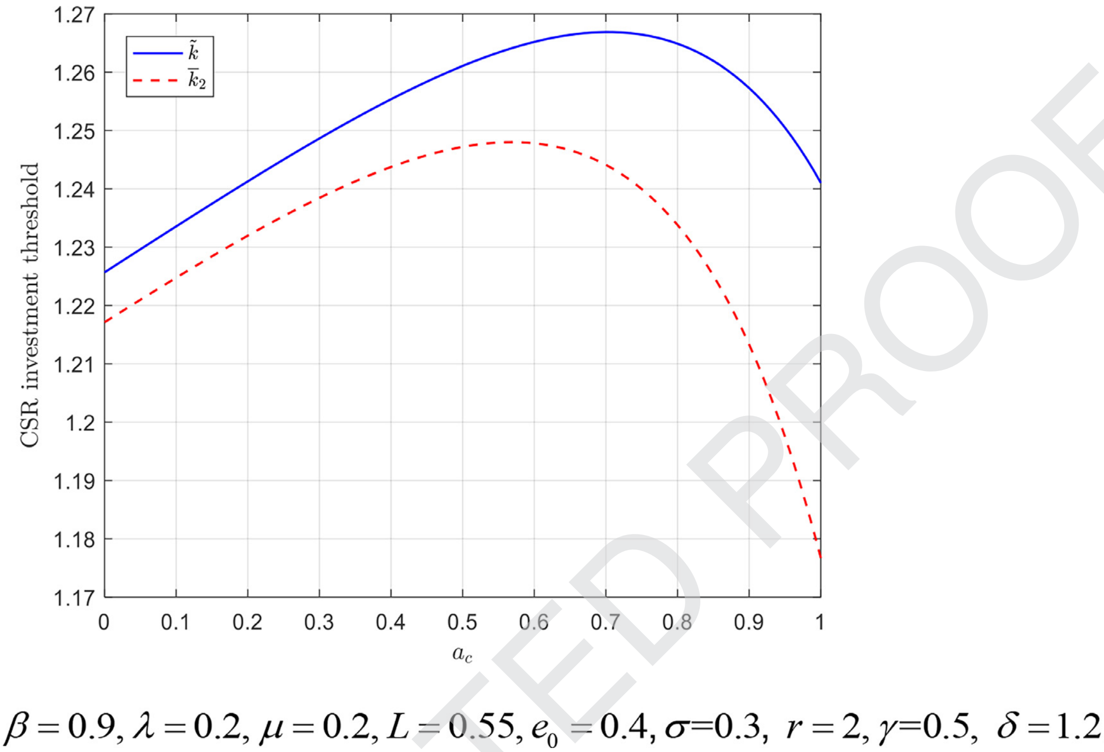


Fig. 11. Impact of customer risk aversion on CSR decisions.
Note: $a_d = 0.7, \beta = 0.9, \lambda = 0.2, \mu = 0.2, L = 0.55, e_0 = 0.4, \sigma = 0.3, r = 2, \gamma = 0.5, \delta = 1.2.$

nificantly higher than during off-peak hours. In addition, Table 1 shows that prices from 21:00 to 06:00 are the highest. During this period, demand may decrease, but there is also a sharp decrease in the market size of providers, which increases prices. We will demonstrate the impact of provider costs on price in Section 7.2.

Next, we analyze whether the influence of network externality on CSR decision-making is valid when considering market size fluctuations, and thus obtain Proposition 8.

Proposition 8. ***(The impact of network externality on CSR investment decisions):***

(1) When the degree of provider network externality is higher, the platform is more willing to invest in CSR; that is, the investment thresholds $\bar{k}_1^f$ and $\bar{k}_2^f$ both increase with a_d;

(2) If $e_0^f > \frac{\delta((-1+(1-\lambda)\beta)\delta+a_d\beta)}{\beta((2-(1-\lambda)\beta)\delta-a_d\beta)}$*, the investment thresholds* $\bar{k}_1^f$ *and* $\bar{k}_2^f$ *both decrease with* a_c*; if* $e_0^f \leq \frac{\delta((-1+(1-\lambda)\beta)\delta+a_d\beta)}{\beta((2-(1-\lambda)\beta)\delta-a_d\beta)}$*, the investment thresholds* $\bar{k}_1^f$ *and* $\bar{k}_2^f$ *first increase and then decrease with* a_c*.*

Under Proposition 8, when market size fluctuations are considered, the influence of network externalities on CSR decision-making is the same as under Proposition 4. Recall that $\bar{k}_1^f$ and $\bar{k}_2^f$ are the thresholds for determining whether a platform invests in CSR. In the case of risk-neutrality (risk aversion), the platform only invests in CSR when $k < \bar{k}_1^f$ ($k < \bar{k}_2^f$). Therefore, an increase in $\bar{k}_1^f$ and $\bar{k}_2^f$ indicates that the platform is more willing to invest in CSR. Moreover, Proposition 8(1) reveals that an increase in provider network externality will increase the platform's willingness to invest in CSR. And Proposition 8 (2) shows that consumer network externality will still cause the dilution effect. We take low market size ($\delta = 0.8$) and high market size ($\delta = 1.2$) as examples to show the dilution effect, as depicted in Figs. 9 and 10.

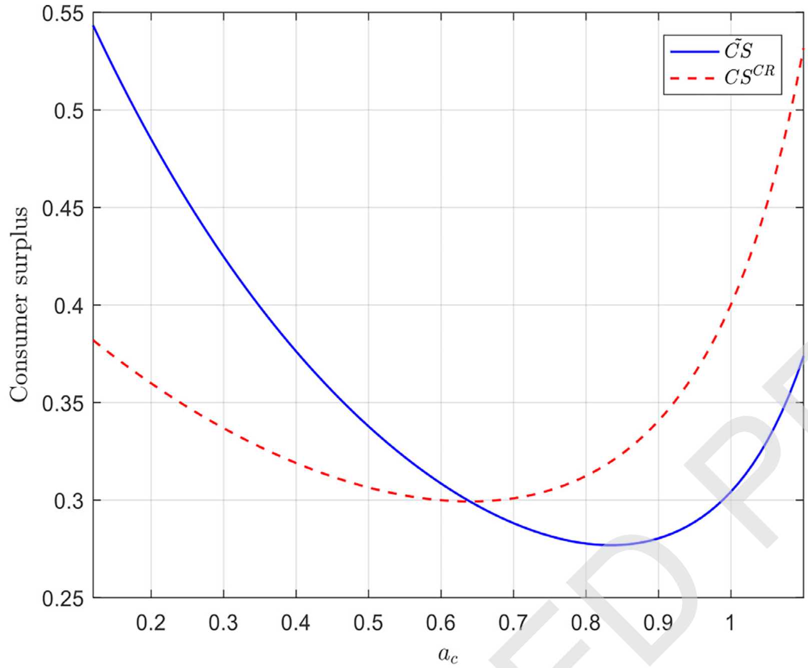
We find that the dilution effect still exists regardless of market size fluctuation. Specifically, as the consumer network externality increases, the platform's willingness to invest in CSR decreases ($\bar{k}_1^f$ and $\bar{k}_2^f$ decrease). The rationale behind this is similar to Proposition 4. Meanwhile, compared with the low market size scenario (Fig. 9), the range of the dilution effect is greater in the high market size scenario (Fig. 10). As the market size is large, the platform can profit more from consumers. In contrast, investing in CSR leads to a sharp decline in the number of providers, which in turn harms platform profits. Therefore, when the market size is large, the platform's profit suffers more and the dilution effect will be significant compared to when the market size is small.

7.2. Market size fluctuations on the supply side

In this section, we demonstrate the impact of market size changes on the supply side. Obviously, there are fewer drivers available at night than during the day. In the base model, we assume that the unit service cost of provider c satisfies a uniform distribution of $[0, 1]$; thus, the consumer market size is standardized to 1. In this section, we introduce a coefficient $w > 0$ to capture the changes in providers' market size, and we let c satisfy a uniform distribution of $[0, w]$. The increase in w refers to the increase in providers' market size. We then propose the price changes with providers' market size.

Proposition 9. ***(The impact of provider market fluctuations on pricing decisions):*** *In the IN and IR models, the platform price decreases with the provider market size coefficient.*

Proposition 9 shows that if the market size of providers decreases, the platform will increase its price to attract more providers. For providers, a higher price means a higher marginal revenue. During the night time, the number of providers shrinks severely, so the platform increases the price to inspire more providers to serve. These changes in provider market size encourage the highest prices during the period from 21:00 to 06:00 in Table 1.



Note: $k = 0.25$, $a_d = 0.6$, $\beta = 0.55$, $\lambda = 0.25$, $\mu = 0.2$, $L = 0.55$, σ=0.3, $r = 2$, γ=0.5, $\delta = 0.8$.

Fig. 12. Impact of customer risk aversion on CS.
Note:$k = 0.25$,$a_d = 0.6$, $\beta = 0.55$, $\lambda = 0.25$, $\mu = 0.2$, $L = 0.55$, σ=0.3, $r = 2$, γ=0.5, $\delta = 0.8$.

7.3. Customer risk aversion

We consider the platform to be risk-averse toward uncertain provider violations. In this model extension, we examine the situation in which customers are also risk-averse, which is denoted by the superscript "∼". Following Wen & Siqin (2020), when customers are risk-averse, the utility function of a customer becomes $\tilde{U}_c = v - p + a_c n_d + \beta e - (1-e)\sigma^2$. Similar to the analysis of the base model, we find a threshold $\tilde{k}$. If $k < \tilde{k}$, the platform will invest in CSR. We use numerical analysis to compare the CSR decision and customer surplus when customers are risk-averse or risk-neutral, where

$$\tilde{k} = \frac{\lambda((\beta+\sigma^2)(1+\gamma) - a_c)(2(1+\gamma)(1-\sigma^2) - e_0(a_c - (1+\gamma)(\beta+\sigma^2)))}{2e_0(1+\gamma - a_c a_d)(1+\gamma-(1-\lambda)a_c)} + \frac{2\mu L + rL^2\sigma^2}{e_0}.$$

From Fig. 11, we know that $\bar{k}_2 < \tilde{k}$, which illustrates that customer risk aversion also motivates the platform to invest in CSR. When customers are risk-averse, CSR is more important to them, so the platform will need to increase CSR investment to attract this cohort. Fig. 12 shows that with a large value of a_c, customer surplus is smaller when customers are risk-averse than that when they are risk-neutral. This conclusion is consistent with Proposition 6. Through model extensions, we illustrate that the main conclusions are robust.

8. Managerial insights and concluding remarks

In this study, we have developed models of a two-sided platform, which connects customers on the demand side with providers on the supply side. We specifically explore the optimal CSR investment levels and prices, and further analyze the impact of network externality and risk aversion. Our study uses a ride-sharing platform as an example to support our assumption and analysis, but our implications can be applied to other types of two-sided platforms with network externalities—such as e-commerce, rental, and lending platforms.

Our primary conclusions are as follows: (1) Unlike previous studies focusing on the impact of network externalities on pricing or service decisions, we creatively illustrate the relationship between network externalities and platform CSR investment. We find that provider network externality will inspire the platform to invest in CSR, while customer network externality has the opposite effect. This is because CSR investment produces a dilution effect when there are higher degrees of customer network externality, which reduces the number of platform users and profits. (2) Platform risk aversion has an incentivizing effect on CSR investment, which leads to increased CSR investment. In contrast to previous studies suggesting that platform risk aversion is always beneficial to customers (Wen & Siqin, 2020), while higher levels of risk aversion may correspond to increased CSR, we find that this is not necessarily beneficial to customers. When customer network externality is high, risk aversion will reduce customer surplus. (3) We also show the impact of network externalities and risk aversion on the platform pricing mechanisms. When the degree of customer network externality is small, risk aversion will increase the optimal price of the platform; otherwise, risk aversion will reduce the price. When a platform invests in CSR, prices may decrease as the degree of customer network externality increases. Table 3 summarizes the impact of network externalities and platform risk aversion.

The conclusions have important implications for platforms and regulators. From the perspective of platforms, the first of these is that CSR investment decisions should focus on customer network externality. When it is very high, the number of users is the

Table 3
Summary of conclusions.

	Customer network externalitya_c	Provider network externalitya_d	Risk aversion of platform
Platform willingness to invest in CSR	↘ with a_c if e_0 is large, otherwise ↗↘ witha_c	↗ witha_d	↗
Price ($k < k_1$)	↗ witha_c	↗ witha_d	↗ if a_c is small, otherwise ↘
Number of customers	↘↗ witha_c	↗ witha_d	↗ if a_c is small, otherwise ↘
Customer surplus	↘↗ witha_c	↗ witha_d	↗ if a_c is small, otherwise ↘

Note: ↗ represents increasing, ↘ decreasing, ↗↘ first increasing and then decreasing, and ↘↗ first decreasing and then increasing.

most important factor. In this case, investing in CSR will reduce the number of users on the platform, thereby damaging its profits. This conclusion is a good explanation for the current CSR management loopholes in many small-sized platforms. Second, the platform's pricing decisions should also pay attention to the impact of risk aversion. When customers are less sensitive to the number of providers on the platform, risk-averse platforms can appropriately raise prices to compensate for the CSR investment costs; otherwise, they should set a low price to attract more users.

From the perspective of regulators, due to the dilution effect of customer network externality, the first conclusion is that strong measures and high CSR management thresholds may compel the platform to quit investing in CSR. To ensure CSR investment, regulators may therefore wish to reduce the minimum CSR investment threshold to a certain extent. Second, policy design needs to consider different goals. To reduce the likelihood of CSR violations, regulators can reinforce punishment methods for violations, in order to strengthen the risk aversion of the platform, thereby prompting it to increase its investment in CSR. Conversely, the degree of customer network externality must be considered when maximizing customer surplus. When the degree of customer network externality is high, regulation may be relaxed appropriately.

Future research may wish to expand upon this study in the following directions. Our analysis of CSR investment decisions assumes a monopoly platform. Future research should therefore focus on CSR decision-making in a competitive context. In addition, we assume that the platform enhances provider CSR through investment; future research should therefore compare different CSR management methods, such as certification and supervision, to study the effectiveness of these measures in platform operations.

Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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Appendix

A. Proof of Lemma 1

The utility of a customer with a willingness to pay v is $U_c = v - p + a_c n_d + \beta e$. Only if $U_c \geq 0$ will the customer join the platform; that is, customers with $v > v^* = p - a_c n_d - \beta e$ will join the platform. According to the distribution function $f(v)$, we obtain the number of customers $n_c = 1 - v*$. Similarly, the number of providers is $n_d = c*$, where $c^* = (1-\lambda)p + a_d n_c - \gamma n_d - c - me$. By jointly solving the equations $n_c = 1 - v*$ and $n_d = c*$, we obtain the equilibrium number of customers and providers, as shown in Lemma 1.

Table A1

B. Proof of Lemma 2 and Lemma 3

Lemmas 2 and 3 show the equilibrium solutions in four cases: IN, CN, IR and CR.

(1) Case IN:

Knowing the number of customers in Lemma 1, we have the expected platform profit $\mathrm{E}(\Pi) = \lambda p \frac{1+\gamma-(1+\gamma-a_c(1-\lambda))p}{1+\gamma-a_c a_d} - \mu L$. Solving the first order derivative and the second order derivative of the profit with respect to p, we obtain $\frac{\partial\Pi}{\partial p} = \frac{\lambda(1+\gamma-2p(a_c(1-\lambda)+1+\gamma))}{1+\gamma-a_c a_d}$ and $\frac{\partial^2\Pi}{\partial p^2} = \frac{2\lambda(a_c(1-\lambda)-1-\gamma)}{1+\gamma-a_c a_d} < 0$. Therefore, the profit function is concave with p. By letting $\frac{\partial\Pi}{\partial p} = 0$, we obtain the optimal price in case IN $p^{IN} = \frac{1+\gamma}{2(1+\gamma-a_c(1-\lambda))}$. Substituting it into the expected profit function, we obtain the optimal profit of the platform:

$$\Pi^{IN} = \frac{\lambda(1+\gamma)^2}{4(1+\gamma-a_c a_d)(1+\gamma-a_c(1-\lambda))} - \mu L. \tag{A1}$$

(2) Case CN:

Substituting the number of customers into the expected profit function, we have$\mathrm{E}(\Pi) = \lambda p \frac{1+\gamma-(1+\gamma-a_c(1-\lambda))p+(\beta(1+\gamma)-a_c)e}{1+\gamma-a_c a_d} - \mu(1-e)L - \frac{1}{2}ke^2$. Deriving the Hessian matrix, we have:

$$\begin{bmatrix} \frac{\partial^2\Pi}{\partial p^2} & \frac{\partial^2\Pi}{\partial p\partial e} \\ \frac{\partial^2\Pi}{\partial e\partial p} & \frac{\partial^2\Pi}{\partial e^2} \end{bmatrix} = \begin{bmatrix} \frac{2\lambda(a_c(1-\lambda)-1-\gamma)}{1+\gamma-a_c a_d} & \frac{(\beta(1+\gamma)-a_c)\lambda}{1+\gamma-a_c a_d} \\ \frac{(\beta(1+\gamma)-a_c)\lambda}{1+\gamma-a_c a_d} & -k \end{bmatrix}.$$

It is obvious that $\frac{2\lambda(a_c(1-\lambda)-1)}{1-a_c a_d} < 0$. Therefore, when $2k(1+\gamma-a_c(1-\lambda))(1+\gamma-a_c a_d) - \lambda(\beta(1+\gamma)-a_c)^2 \geq 0$, that is, $\lambda \leq \frac{2k(1+\gamma-a_c a_d)(1+\gamma-a_c)}{(a_c-\beta(1+\gamma))^2-2ka_c(1+\gamma-a_c a_d)}$, the expected profit function is jointly concave with p and e. In practice, the commission fee also needs to be lower than a threshold to attract providers. Therefore, we conduct our analysis in this region, which is consistent with practices.

Without considering the threshold e_0, the objective function is jointly concave with p and e. By jointly solving the first-order derivative conditions $\frac{\partial\Pi}{\partial p} = 0$ and $\frac{\partial\Pi}{\partial e} = 0$, we obtain the optimal solutions $p^{CN} = \frac{(1+\gamma-a_c a_d)(k(1+\gamma)-\mu L(a_c-(1+\gamma)\beta))}{2k(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2}$ and $e^{CN} = \frac{2\mu L(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)-\lambda(1+\gamma)(a_c-(1+\gamma)\beta)}{2k(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2}$. Through the equation e^{CN}, we know that e^{CN} decreases in line with k. Therefore, we have $e^{CN} \leq e_0$ if $k \leq k_1 = \frac{\lambda(\beta(1+\gamma)-a_c)(1+\gamma-e_0(a_c-(1+\gamma)\beta))}{2e_0(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)} + \frac{\mu L}{e_0}$. When $k > k_1$, the platform will invest at the threshold level $e = e_0$.

Therefore, when $k \leq k_1$, substituting p^{CN} and e^{CN} into the objective function, we obtain the optimal platform profit in case CN:

$$\prod^{CN} = \frac{\begin{array}{c}\{2\mu L(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)(\mu L-2k)+ \\ 2\mu L\lambda(a_c-(1+\gamma)\beta)(a_c-(1+\gamma)(\beta+1))+\lambda k(1+\gamma)^2\}\end{array}}{4k(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)-2\lambda(a_c-(1+\gamma)\beta)^2}. \tag{A2}$$

When $k > k_1$, the platform invests in CSR at threshold level $e = e_0$. Solving the first order derivative condition $\frac{\partial\Pi}{\partial p} = 0$, we obtain the optimal price $p^{CN} = \frac{1+\gamma+(\beta(1+\gamma)-a_c)e_0}{2(1+\gamma-a_c(1-\lambda))}$ and the optimal platform profit:

$$\prod^{CN} = \frac{\lambda(1+\gamma-(a_c-(1+\gamma)\beta)e_0)^2}{4(1+\gamma-a_c(1-\lambda))(1+\gamma-a_c a_d)} - \mu(1-e_0)L - \frac{1}{2}ke_0^2. \tag{A3}$$

Table A1
Equilibrium solutions considering market size fluctuations.

		p^f	e^f
Case IN:		$\frac{\delta(1+\gamma)}{2(1-a_c(1-\lambda))}$	——
Case CN	if $k < k_1^f$	$\frac{((1+\gamma)\delta-a_c a_d)(k(1+\gamma)\delta-\mu L(a_c-(1+\gamma)\beta))}{2k((1+\gamma)\delta-a_c a_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2}$	$\frac{2\mu L((1+\gamma)\delta-a_c a_d)(1+\gamma-(1-\lambda)a_c)-\lambda(1+\gamma)\delta(a_c-(1+\gamma)\beta)}{2k((1+\gamma)\delta-a_c a_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2}$
	if $k \geq k_1^f$	$\frac{(1+\gamma)\delta+(\beta(1+\gamma)-a_c)e_0}{2(1+\gamma-a_c(1-\lambda))}$	e_0
Case IR		$\frac{\delta(1+\gamma)}{2(1-a_c(1-\lambda))}$	——
Case CR	if $k < k_2^f$	$\frac{((1+\gamma)\delta-a_c a_d)(2k(1+\gamma)\delta-(2\mu L+rL^2\sigma^2)(a_c-(1+\gamma)\beta))}{4k((1+\gamma)\delta-a_c a_d)(1+\gamma-(1-\lambda)a_c)-2\lambda(a_c-(1+\gamma)\beta)^2}$	$\frac{\{(2\mu L+rL^2\sigma^2)((1+\gamma)\delta-a_c a_d)(1+\gamma-(1-\lambda)a_c) -\lambda(1+\gamma)\delta(a_c-(1+\gamma)\beta)\}}{2k((1+\gamma)\delta-a_c a_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2}$
	if $k \geq k_2^f$	$\frac{(1+\gamma)\delta+(\beta(1+\gamma)-a_c)e_0}{2(1+\gamma-a_c(1-\lambda))}$	e_0

(3) Case IR:

Substituting the number of customers in Lemma 1 into the utility function of the platform, we have $E(U) = \lambda p\frac{1+\gamma-(1+\gamma-a_c(1-\lambda))p}{1+\gamma-a_c a_d} - \mu L - \frac{rL^2\delta^2}{2}$. Solving the first order derivative and the second order derivative of utility with respect to p, we have $\frac{\partial \Pi}{\partial p} = \frac{\lambda(1+\gamma-2p(a_c(1-\lambda)+1+\gamma))}{1+\gamma-a_c a_d}$ and $\frac{\partial^2 U}{\partial p^2} = \frac{2\lambda(a_c(1-\lambda)-1-\gamma)}{1+\gamma-a_c a_d} < 0$. Therefore, the utility is concave with p. Subsequently, we obtain the optimal price in case IR $p^{IR} = p^{IN} = \frac{1+\gamma}{2(1+\gamma-a_c(1-\lambda))}$. Substituting it into the utility function of the platform, we obtain the optimal utility of the platform under risk neutrality:

$$E(U)^{IR} = \frac{\lambda(1+\gamma)^2}{4(1+\gamma-a_c a_d)(1+\gamma-a_c(1-\lambda))} - \mu L - \frac{rL^2\sigma^2}{2}. \tag{A4}$$

(4) Case CR:

Substituting the number of customers into the utility function of the platform, we have $E(U) = \lambda p\frac{1+\gamma-(1+\gamma-a_c(1-\lambda))p+(\beta(1+\gamma)-a_c)e}{1+\gamma-a_c a_d} - \mu(1-e)L - \frac{1}{2}ke^2 - \frac{r(1-e)L^2\delta^2}{2}$. The Hessian matrix shows $\begin{bmatrix} \frac{\partial^2 \prod}{\partial p^2} & \frac{\partial^2 \prod}{\partial p \partial e} \\ \frac{\partial^2 \prod}{\partial e \partial p} & \frac{\partial^2 \prod}{\partial e^2} \end{bmatrix} = \begin{bmatrix} \frac{2\lambda(a_c(1-\lambda)-1-\gamma)}{1+\gamma-a_c a_d} & \frac{(\beta(1+\gamma)-a_c)\lambda}{1+\gamma-a_c a_d} \\ \frac{(\beta(1+\gamma)-a_c)\lambda}{1+\gamma-a_c a_d} & -k \end{bmatrix}$, which is the same as in Case CN. According to a similar solution method in Case CN, the optimal decision and utility can be obtained.

C. Proof of Proposition 1

We first discuss the cases when the platform is risk-neutral. When $k < k_1$, the platform invests in an endogenous CSR level. Thus, we compare the Eqs. (A1) and (A2) and find $\Pi^{CN} - \Pi^{IN}$

$$= \frac{(2(1+\gamma-a_c a_d)(1-(1-\lambda)a_c)\mu L - \lambda(1+\gamma)(a_c-(1+\gamma)\beta))^2}{4(1+\gamma-a_c a_d)(1-(1-\lambda)a_c)(2k(1+\gamma-a_c(1-\lambda))(1+\gamma-a_c a_d)-\lambda(\beta(1+\gamma)-a_c)^2)}.$$

As $2k(1+\gamma-a_c(1-\lambda))(1+\gamma-a_c a_d) - \lambda(\beta(1+\gamma)-a_c)^2 \geq 0$ and $\Pi^{CN} - \Pi^{IN} > 0$ always hold, therefore if $k < k_1$, the platform will invest in CSR.

When $k \geq k_1$, we compare Eqs. (A1) and (A3) because the platform invests in CSR at the threshold level. We find that if $k < \bar{k}_1 = \frac{\lambda(\beta(1+\gamma)-a_c)(2+2\gamma-e_0(a_c-(1+\gamma)\beta))}{2e_0(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)} + \frac{2\mu L}{e_0}$, we have $\Pi^{IN} - \Pi^{CN} < 0$; otherwise, $\Pi^{NN} - \Pi^{CN} \geq 0$. At the same time, it follows that $\bar{k}_1 > k_1$. In summary, we have $\Pi^{IN} < \Pi^{CN}$ if $k < \bar{k}_1$. Therefore, when the platform is risk-neutral, it will invest in CSR only if $k < \bar{k}_1$.

The proof when the platform is risk-averse is similar to when the platform is risk-neutral.

D. Proof of Proposition 2

First, we compare $\bar{k}_1$ and $\bar{k}_2$, and find that $\bar{k}_2 - \bar{k}_1 = \frac{rL^2\sigma^2}{e_0} > 0$. Then, we compare e^N and e^R. When the platform invests at an endogenous CSR level, we have $e^R - e^N = \frac{rL^2\sigma^2(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)(1+\gamma)}{2k(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2} > 0$. When the platform invests CSR at the threshold level, we have $e^R = e^N = e_0$. Furthermore, because $k_2 - k_1 > 0$ and $\bar{k}_2 - \bar{k}_1 > 0$, $e^R - e^N \geq 0$ always holds.

E. Proof of Proposition 3

(a) Proof of the impacts on price

From Lemma 2 and Lemma 3, we know that when $k_2 \leq k < \bar{k}_1$ or, —that is, the platform does not invest in CSR or invests in CSR at the threshold e_0 with risk-neutral and risk-averse cases, and furthermore the optimal prices are the same in both cases.

When $k < k_1$, the platform invests at an endogenous CSR level in risk-neutral and risk-averse cases. The price difference between risk-averse and risk-neutral case is $p^R - p^N = \frac{rL^2\sigma^2((1+\gamma)\beta-a_c)(1+\gamma-a_c a_d)}{4k(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)-2\lambda(a_c-(1+\gamma)\beta)^2}$. Therefore, if $a_c < \beta(1+\gamma)$, then we have $p^R - p^N > 0$; otherwise, $p^R - p^N \leq 0$.

When $k_1 \leq k \leq k_2$, the platform invests at the threshold CSR level when it is risk-neutral, whereas at an endogenous level when risk-averse. Due to $p^{CR} = \frac{(1+\gamma-a_c a_d)(2k(1+\gamma)-(2\mu L+rL^2\sigma^2)(a_c-(1+\gamma)\beta))}{4k(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)-2\lambda(a_c-(1+\gamma)\beta)^2} = \frac{1+\gamma+(\beta(1+\gamma)-a_c)e^{CR}}{2(1+\gamma-a_c(1-\lambda))}$, the price difference is $p^R - p^N = \frac{1+\gamma+(\beta(1+\gamma)-a_c)(e^{CR}-e_0)}{2(1+\gamma-a_c(1-\lambda))}$. When $k \leq k_2$, we have $e^{CR} - e_0 > 0$ from Proposition 1. Therefore, if $a_c < \beta(1+\gamma)$, we have $p^R - p^N > 0$; otherwise, $p^{CR} - p^{CN} \leq 0$.

When $\bar{k}_1 \leq k \leq \bar{k}_2$, the platform does not invest in CSR when it is risk-neutral but invests at the threshold CSR level when it is risk-averse. Then $p^R - p^N = \frac{(\beta(1+\gamma)-a_c)e_0}{2(1+\gamma-a_c(1-\lambda))}$. Therefore, if $a_c < \beta(1+\gamma)$, we have $p^R - p^N > 0$; otherwise, $p^R - p^N \leq 0$.

In summary, if $a_c < \beta(1+\gamma)$, risk aversion may increase the optimal price; otherwise, it may decrease the optimal price.

(b) Proof of the impacts on the number of customers

When $k_2 \leq k < \bar{k}_1$ or $k > \bar{k}_2$, that is, the platform does not invest in CSR or invests in CSR at the threshold e_0 in both risk-neutral and risk-averse cases, and moreover the pricing and CSR level decisions are the same. Therefore, $n_c^R = n_c^N$. When $k < k_1$, we have $n_c^R - n_c^N = \frac{rL^2\sigma^2((1+\gamma)\beta-a_c)(1+\gamma-(1-\lambda)a_c)}{4k(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)-2\lambda(a_c-(1+\gamma)\beta)^2}$; when $k_1 \leq k \leq k_2$, $n_c^R - n_c^N = \frac{(\beta(1+\gamma)-a_c)(e^{CR}-e_0)}{2(1+\gamma-a_c(1-\lambda))}$, and when $\bar{k}_1 \leq k \leq \bar{k}_2$, $n_c^R - n_c^N = \frac{(\beta(1+\gamma)-a_c)e_0}{2(1+\gamma-a_c(1-\lambda))}$. Therefore, regardless of the value of k, if $a_c < \beta(1+\gamma)$, we have $n_c^R - n_c^N > 0$; otherwise, $n_c^R - n_c^N \leq 0$.

F. The proof of **Proposition 4**

Recall that $\bar{k}_1 = \frac{\lambda(\beta(1+\gamma)-a_c)(2+2\gamma-e_0(a_c-(1+\gamma)\beta))}{2e_0(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)} + \frac{2\mu L}{e_0}$. As a_d increases, it is obvious that $\bar{k}_1$ will increase. Then we differentiate $\bar{k}_1$ with respect to a_c, and obtain:

$$\frac{\partial \bar{k}_1}{\partial a_c} = \frac{\lambda((\beta(1+\gamma)-a_c)e_0+1+\gamma)}{e_0(1+\gamma-a_c a_d)(1+\gamma-(1-\lambda)a_c)} + \frac{\lambda(\beta(1+\gamma)-a_c)(2+2\gamma+e_0((1+\gamma)\beta-a_c))(a_d(1+\gamma-2(1-\lambda)a_c)+(1+\gamma)(1-\lambda))}{2e_0(1+\gamma-a_c a_d)^2(1+\gamma-(1-\lambda)a_c)^2}.$$

Assuming that $\bar{k}_1$ is concave with respect to a_c, therefore in our parameter region, $\bar{k}_1$ may be monotonic or have a peak with respect to a_c. When a_c is relatively large, for instance, $a_c = \beta$, we have $\frac{\partial \bar{k}_1}{\partial a_c} = -\frac{\lambda}{e_0(1-a_d\beta)(1+\gamma)(1-(1-\lambda)\beta)} < 0$. Therefore, $\bar{k}_1$ monotonically decreases with a_c when a_c is large. When a_c is relatively small, for instance,$a_c = 0$, we have $\frac{\partial \bar{k}_1}{\partial a_c} = \frac{\lambda(2\beta(1-\lambda+a_d-e_0)+e_0\beta^2(1-\lambda+a_d)-2)}{2e_0(1+\gamma)}$. In this instance, if $e_0 \le \frac{2(\beta-\lambda\beta+a_d\beta-1)}{\beta(2-\beta+\lambda\beta-a_d\beta)}$, we have $\frac{\partial \bar{k}_1}{\partial a_c}$>0 when $a_c = 0$. Therefore, $\bar{k}_1$ first increases then decreases with a_c. If $e_0 > \frac{2(\beta-\lambda\beta+a_d\beta-1)}{\beta(2-\beta+\lambda\beta-a_d\beta)}$, we have $\frac{\partial \bar{k}_1}{\partial a_c} < 0$ when $a_c = 0$. Therefore, $\bar{k}_1$ monotonically decreases with a_c.

The impact of a_d and a_c on $\bar{k}_2$ is the same.

G. Proof of Proposition 5

We first consider the risk-neutral condition. Lemma 2 shows that when the platform does not invest in CSR, $p^{IN} = \frac{1+\gamma}{2(1+\gamma-a_c(1-\lambda))}$ obviously increases with a_c; when the platform invests in CSR and $k \ge k_1$, $\frac{\partial p^{CN}}{\partial a_c} = \frac{((1-\lambda)+e_0(\beta(1-\lambda)-1))(1+\gamma)}{2(1+\gamma-(1-\lambda)a_c)^2}$. So $\frac{\partial p^{CN}}{\partial a_c} > 0$ if $e_0 < \frac{1+\lambda}{1-\beta(1-\lambda)}$. Moreover, due to $0 \le e_0 < 1$ and $\frac{1+\lambda}{1-\beta(1-\lambda)} > 1$, so $\frac{\partial p^{CN}}{\partial a_c} > 0$ always holds when $k \ge k_1$. Lastly, when the platform invests in CSR and $k < k_1$, we differentiate the p^{CN} when $k < k_1$ with respect to a_c, and obtain $\frac{\partial p^{CN}}{\partial a_c} = \frac{[2(1-\lambda)(1+\gamma-a_ca_d)^2k^2+\mu L(2k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2)+ \mu La_d\beta\lambda(a_c-(1+\gamma)\beta)^2+(2-a_d(a_c+\beta))(k-\mu L(a_c-(1+\gamma)\beta))]}{(2k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2)^2} > 0$. In summary, the optimal price increases with a_c. Besides, when $k \ge k_1$, p^{IN} and p^{CN} are irrelevant to a_d. We differentiate p^{CN} when $k < k_1$ with respect to a_d and obtain $\frac{\partial p}{\partial a_d} = \frac{a_c(a_c-(1+\gamma)\beta)^2(k(1+\gamma)-\mu L(\beta(1+\gamma)-a_c))}{(2k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2)^2} > 0$. Therefore, the optimal price also increases with a_d.

Proof in the risk-averse case is similar to that in the risk-neutral case, because prices are the same when the platform does not invest in CSR or when it does invest in CSR at the threshold e_0. When the platform invests in the endogenous CSR level, the risk-averse parameters do not affect the change trend of p with respect to a_c and a_d.

H. Proof of Proposition 6

According to the definition $CS = \int_{p^*}^{p^{\max}} n_c(p)\mathrm{d}p$, we calculate the customer surpluses in risk-neutral and risk-averse conditions as: $CS^N = \frac{k(1+\gamma-(1-\lambda)a_c)^2(1+\gamma-a_ca_d)^2(k(1+\gamma)-\mu L(\beta(1+\gamma)-a_c))^2}{\{2(2k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2)^2 * (k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2)\}}$, $CS^R = \frac{k(1+\gamma-(1-\lambda)a_c)^2(1+\gamma-a_ca_d)^2(2k(1+\gamma)-(2\mu L+L^2\sigma^2)(\beta(1+\gamma)-a_c))^2}{\{8(2k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2)^2 * (k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2)\}}$. We then obtain

$$CS^R - CS^N = \frac{\{k(1+\gamma-(1-\lambda)a_c)^2(1+\gamma-a_ca_d)^2 * (4k(1+\gamma)+(4\mu L+rL^2\sigma^2)(\beta(1+\gamma)-a_c))(\beta(1+\gamma)-a_c)rL^2\sigma^2\}}{\{8(2k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2)^2 * (k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2)\}}$$

. Therefore, if $a_c < \beta(1+\gamma)$, we have $CS^R - CS^N > 0$; otherwise $CS^R - CS^N \le 0$.

I. Proof of variance change

We show the results when the variance becomes $(1-e)^2\sigma^2$ after the platform invests in CSR. In the risk-neutral case, the equilibriums are the same as those in Lemma 2. We further calculate the solutions when the platform is risk-averse and invests in CSR. The utility function of platform becomes:

$$\begin{aligned} &\max \mathrm{E}(U) = \mathrm{E}\left[\lambda n_c p - \eta L - \tfrac{1}{2}ke^2\right] - \tfrac{r}{2}L^2(1-e)^2\sigma^2 \\ &s.t. e \ge e_0 \end{aligned} \tag{A5}$$

We then have the equilibriums as:

$$e = \begin{cases} \dfrac{\left\{\begin{matrix} 2(\mu L + rL^2\sigma^2)(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)- \\ \lambda(a_c-(1+\gamma)\beta)(1+\gamma) \end{matrix}\right\}}{2(k+rL^2\sigma^2)(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2}, if \quad k < k_3 \\ e_0, if \quad k < k_3 \end{cases}$$

$$p = \begin{cases} \frac{(1+\gamma-a_ca_d)(k(1+\gamma)-(\mu L+rL^2\sigma^2)(a_c-(1+\gamma)\beta)+rL^2\sigma^2(1+\gamma))}{2k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-\lambda(a_c-(1+\gamma)\beta)^2}, & if \quad k < k_3 \\ \frac{1+\gamma+(\beta(1+\gamma)-a_c)e_0}{2(1+\gamma-a_c(1-\lambda))} & if \quad k \ge k_3 \end{cases}$$

$$E(U) = \{ \begin{matrix} \frac{2\lambda\mu L(a_c-(1+\gamma)\beta)(a_c-(1+\gamma)(\beta+1))+\lambda rL^2\sigma^2(a_c-(1+\gamma)(\beta+1))^2+\lambda k(1+\gamma)^2-2L(Lkr\sigma^2-L\sigma^2+2k\mu)(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)}{4k(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)-2\lambda(a_c-(1+\gamma)\beta)^2}, ifk < k_3 \\ \frac{\lambda(1+\gamma-(a_c-(1+\gamma)\beta)e_0)^2}{4(1+\gamma-a_c(1-\lambda))(1+\gamma-a_ca_d)-\mu(1-e_0)L-\frac{r}{2}L^2(1-e_0)^2\sigma^2-\frac{1}{2}ke_0^2}, ifk \ge k_3 \end{matrix}$$

where $k_3 = \frac{\lambda(\beta-a_c)(1-e_0(a_c-\beta))}{2e_0(1-a_ca_d)(1-(1-\lambda)a_c)} + \frac{L(\mu+rL\sigma^2(1-e_0))}{e_0}$.

By comparing the utility with $E(U)^{IR} = \frac{\lambda(1+\gamma)^2}{4(1+\gamma-a_ca_d)(1+\gamma-a_c(1-\lambda))} - \mu L - \frac{rL^2\sigma^2}{2}$, we have: When $k < \bar{k}_3$, the platform will invest in CSR; otherwise, the platform will not, where $\bar{k}_3 = \frac{\lambda(\beta(1+\gamma)-a_c)(2+2\gamma-e_0(a_c-(1+\gamma)\beta))}{2e_0(1+\gamma-a_ca_d)(1+\gamma-(1-\lambda)a_c)} + \frac{2\mu L+rL^2\sigma^2(2-e_0)}{e_0}$. A comparison of above results with Proposition 1 indicates that our conclusions are robust.

J. Equilibrium solutions for Section 7.1

Where $k_1^f = \frac{\lambda(\beta(1+\gamma)-a_c)((1+\gamma)\delta-e_0(a_c-(1+\gamma)\beta))}{2e_0((1+\gamma)\delta-a_ca_d)(1+\gamma-(1-\lambda)a_c)} + \frac{\mu L}{e_0}$, $k_2^f = \frac{\lambda(\beta(1+\gamma)-a_c)((1+\gamma)\delta-e_0(a_c-(1+\gamma)\beta))}{2e_0((1+\gamma)\delta-a_ca_d)(1+\gamma-(1-\lambda)a_c)} + \frac{2\mu L++rL^2\sigma^2}{2e_0}$.

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