B2C ONLINE RIDE-HAILING PRICING AND SERVICE OPTIMIZATION UNDER COMPETITIONS

QINGFENG MENG, WENJING LI AND ZHEN LI
School of Management
Jiangsu University
Zhenjiang, 212013, China

CHANGZHI WU*
School of Management
Guangzhou University
Guangzhou, 510006, China

(Communicated by Shuhua Zhang)

ABSTRACT. B2C online ride-hailing is to provide customers with anytime, anywhere and on-call ride services by professional vehicles and professional drivers. How to maintain good service quality and reasonable pricing under competition is of importance to a platform. In this paper, we will integrate pricing and service together to maximize the profit of a platform through Nash game theory. Specifically, we will establish the models for three scenarios: the demand market competition under decline of ride demand, the supply market competition under surge of ride demand, and the coexistence of demand and supply market competition for stable ride demand. Then, the Nash equilibriums are derived for the three models which are corresponding to minimize ride price, optimize quality of efforts and maximize profit. Our results uncover that the driver’s incentive amount is conducive to the profit of both platform and the drivers for the case of demand market competition. The platforms and drivers achieve the highest profit under supply market competition, and the strategy through minimizing price and maximizing service can effectively adjust the balance between market supply and demand.

1. Introduction. With the advancement of Internet technology and the surge of market demand for high-quality travel services, online ride-hailing platforms have been developed and widely used [36]. A B2C online ride-hailing platform adopts “professional vehicles and professional drivers” to provide customers with “anytime, anywhere” on-call ride service. Customers place orders online. Then, a B2C online ride-hailing platform will provide offline services for customers through assigning professional drivers to fulfill customers’ needs [1]. In an online ride-hailing platform, price and service are the most important factors to affect its competitiveness. A good bidding strategy can effectively adjust the balance of supply and demand in the market, while service experience can subconsciously affect people’s cognition, emotion and behavior [41]. Sustainability is an important concern for stakeholders.
and requires a competitive platform to provide good service while keeping costs low in order to achieve steady growth of drivers and passengers [17]. Therefore, how to balance price and service is of great significance to the survival of a B2C online ride-hailing platform. In reality, we need to consider two perspectives: competition among platforms and competition between demand and supply in a platform. The competition among different platforms will not only compete for the demand market, but also compete for the drivers to supply service [31]. In a platform, if the demand and supply is imbalance, how to match between supply and demand will affect the quality of services for this platform.

There are some literatures related to this issue. However, they are mainly focusing on platform competition and online ride-hailing platform. In terms of platform competition, an approach based on system dynamics is introduced to study the development and competition of platforms [29]. The research outline of platform competition by modeling and simulation is summarized in [28]. In terms of factors affecting platform competition, the influence of online ride-hailing platform competition on new car purchase is studied in [14]. The influence of government regulation on competition based on the case of online ride-hailing market is analysed in [34]. Some literatures have studied the influence of coordination bias [18], user privacy [30], suppliers’ spatial network structure [37], intrinsic attribution [20], network security [13], shopping environment [19], market segmentation [15], platform incentive mechanism and other factors on platform competition. In terms of multilateral platform competition, a framework for analyzing platform competition in bilateral markets is established in [7]. The allocation effect of platform competition transition from single to multiple affiliations is discussed in [2], and market channels of multilateral platform competition is studied in [26]. The horizontal mergers between multisided platforms in Cournot competition is studied in [8]. In the recent years, the enterprise strategy for a platform under competitive environment have attracted research attentions. For example, the pricing problem for a competitive platform in [32], the quality assurance strategy for a B2C platform under competitive environment [16]. Although there are many results available on key issues regarding of platform competition, the results considering demand fluctuations are few.

The second is about online ride-hailing platforms. Under competitive environment, matching between supply and demand is vital to success for an online ride-hailing platform. Regarding matching between supply and demand, subsidy and employment for B2C online ride-hailing under monopoly and duopoly competition environment is studied in [42]. The influence of platform competition on subsidy strategy, profitability and social welfare are analyzed. The variation of supply and demand in the sunset district and financial district of San Francisco through Uber’s data is analysed in [38]. A comprehensive planning model is proposed to discuss the impact of demand response on system decision-making from the perspective of long-term planning in [43]. Queuing theory is also introduced to study the matching of supply and demand in an online ride-hailing system in [4]. In terms of platform pricing for an online ride-hailing platform, a pricing strategy based on maximizing the utility of drivers and passengers through considering the details of customers’ travel and the geographical location of drivers is studied in [33, 35]. The influence of geographical space on pricing is discussed and concluded that the price difference based on passenger position can increase the residual profit of drivers, platforms and consumers [5]. The influence of static pricing and peak pricing on participants to
choose an online ride-hailing platform is studied in [6]. The peak-hour pricing for an online ride-hailing platform under different labor supply behavior assumptions are discussed in [44]. The dynamic pricing strategy of C2C online ride-hailing platform under different competition situations are studied, and obtained the change track of the ride supply rate and ride demand rate [45]. The aforementioned results have analyzed the factors that affect platform competition, the competition of multilateral platforms, and the strategies of platform enterprises under the competitive environment. However, most of them are for C2C platforms, not for B2C platforms. Moreover, they are focusing on pricing without considering pricing and quality of service simultaneously. The impact of the operation mode and characteristics of B2C online ride-hailing platforms on its pricing and quality of service are also not discussed.

In this paper, we will integrate pricing and quality of service together to maximize the profit of B2C online ride-hailing platform and driver through Nash game theory. We will establish the models for demand market competition under decline of ride demand, the supply market completion under surge of ride demand, and the coexistence of demand and supply market competition for stable ride demand. Through numerical simulation, the optimal strategies and profits under different competition situations are compared and analyzed, and management enlightenment is given, in order to provide theoretical basis for B2C online ride-hailing platform to make reasonable decisions on pricing and quality of services.

2. Problem description and model assumptions.

2.1. Problem description. In this paper, we suppose that there are two B2C online ride-hailing platforms in a market. Each platform employed ride-hailing drivers to supply service. The B2C online ride-hailing platform is to develop and maintain the platform, and attract customers through marketing efforts, such as Shenzhou special car. The quality of service is mainly determined by the strategy to match between demand and supply and the accuracy of the real time information acquired[46, 21]. The platform needs to determine the price for a customer ride. After receiving the message from the platform, the driver will supply the ride service. The upper limit incentive of quality of service will encourage drivers to deliver high quality service. The quality of service for a ride includes delivery efficiency, route selection, service attitude, etc. To simplify analysis, for a B2C online ride-hailing platform, let $s_1$ denote the quality of service, $s_2 \in (0, 1]$ be the level of efforts that the driver delivered, and $\lambda$ be the upper limit of the driver’s incentive amount. Similar to the model in [25], $\lambda s_2$ is the incentives obtained by drivers to quantify the quality of service that they delivered.

Figure 1 shows the operation process of the ride-hailing platform where $p$ stands for the pricing. At first, customers choose a B2C online ride-hailing platform according to their rides and experience, and send a ride request online. Then, the platform sends the ride-hailing demand information to drivers. Once the platform assigns a driver for this ride, the driver will deliver the riding service. After the completion of the ride, the customers pay the fare through a third-party payment to the platform, and the driver’s wage is paid by the platform.

2.2. Model parameter setting. In this paper, the parameter variables are set in Table 1.
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Platform A

Platform B

Ride demand
pay the fare

Wage

Competition

Figure 1. The operation process of the online ride-hailing platform

Table 1. Variable description

| Variable | Variable description |
|----------|----------------------|
| \( p_j \) | The ride price of online ride-hailing platform in the \( j \)-th model |
| \( s_{1j} \) | The quality of service effort of the online ride-hailing platform in the \( j \)-th model |
| \( s_{2j} \) | The quality of service efforts of the driver in the \( j \)-th model |
| \( j \) | \( j = l, u, b \) represent the demand market competition, the supply market completion, and the coexistence of demand and supply market competition, respectively |
| \( c \) | The unit operating costs of the B2C online ride-hailing platforms |
| \( m \) | The fixed delivery cost for drivers |
| \( D_0 \) | The initial market ride demand |
| \( a \) | The market ride demand fluctuation factor |
| \( q_1 \) | The cost of platform unit quality of service improvement |
| \( q_2 \) | The cost of driver unit quality of service improvement |
| \( M_1 \) | The fixed development and operation costs of B2C online ride-hailing platform |
| \( M_2 \) | The fixed training and management costs for drivers |
| \( \theta \) | The ride price sensitivity coefficient |
| \( \beta \) | The sensitivity coefficient of quality of service efforts of B2C online ride-hailing platforms and drivers |
| \( k_D \) | The ride demand market competition coefficient |
| \( \lambda \) | The incentive upper limit of drivers |
| \( \pi_{1j} \) | The profit of the B2C online ride-hailing platforms respectively in the \( j \)-th model |
| \( \pi_{2j} \) | The profit of the drivers in the \( j \)-th model |

\[ D^* \] is the optimal variable value

\[ p^*_j, \pi^*_1, \pi^*_2 \] is the optimal decision variable value

2.3. The basic assumptions. Based on the operation process of the above B2C online ride-hailing platform, this paper gives the following assumptions:

(1) Assume that there are two B2C online ride-hailing platforms in the market, they have the same service operation mode, but with different unit operating costs. The ride price competition between the two online ride-hailing platforms affects the demand market. At the same time, there is also driver’s wage competition that affects the supply market.

(2) During the B2C online ride-hailing platform service time, assuming that the supply and demand at time \( 0 \) are balanced, customers will not cancel orders and drivers will not stop service.

(3) In this paper, exponential time-varying demand function is used to describe the fluctuation of the demand for online ride-hailing platform [45].

\[
D = D_0e^{-at} + k_D (p_0 - p(t)) - \theta p(t) + \beta (s_1(t) + s_2(t))
\]

is the potential total demand of the market, where \( D_0 > 0 \) is the initial market ride demand, \( \beta > 0 \) is the coefficient to quantify the efforts of a B2C online ride-hailing platform and drivers on improving quality of service, \( \theta \) is the ride price sensitivity coefficient, \( p_0 \) is the ride price of a competitive platform. Clearly, the potential total demand \( D \) increases with the increase of \( \beta \).
(4) The effort cost $C_r$ to improve quality of service for a B2C online ride-hailing platform increases with the improvement of quality of service $s_1$, $C_r = q_1 s_1^2(t)/2$ [27].

(5) The risk cost of driving $C_d$ increases with the increase of delivery service effort $s_2$, $C_d = q_2 s_2^2(t)/2$ [27].

3. Model construction and solution analysis. This paper combines qualitative analysis with quantitative analysis to optimize pricing and quality of service for a B2C online ride-hailing platform. Qualitative analysis refers to relevant theories to analyze the impact of B2C ride-hailing platform decisions on the market at different time scales [11]. There are different methods for quantitative analysis, such as optimization methods [24, 39], neural network related methods [12, 10], decision making based methods [22, 23], fuzzy related methods if uncertainty emerges in the model [9, 40, 3]. Instead of the above mentioned methods, we will adopt Nash equilibrium game theory for quantitative analysis in this paper. Nash equilibrium means that in the course of a game, regardless of the strategy choice of the other players, each player’s strategy is to achieve the maximum of his expected return. During operations of a B2C online ride-hailing platform, there are three parties involved: platform, drivers and customers. All the parties are to maximize their own interests. Therefore, Nash equilibrium game theory is more suitable to solve such a problem comparing with the above mentioned methods.

3.1. The demand market competition. To continue, let the fixed operation and development costs of a platform be $M_1$, the training and management costs of the driver be $M_2$, and the drivers wages be $m + \lambda s_2(t)$. The demand market competition refers to the situation that the supply is more than the demand with $a > 0$. Suppose that $k_D > 0$. Then, the demand function of the market is

$$D_t = D_0 e^{-at} + k_D (p_0 - p(t)) - \theta p(t) + \beta (s_1(t) + s_2(t))$$

(1)

The profit function of the B2C online ride-hailing platform is

$$\pi_{1i}(t) = (p_i(t) - c - m - \lambda s_2(t)) \left[ D_0 e^{-at} + \beta (s_1(t) + s_2(t)) - \theta p(t) + k_D (p_0 - p(t)) \right]$$

$$- \frac{q_1 s_{1t}^2(t)}{2} - M_1 - M_2$$

(2)

The profit function of driver is

$$\pi_{2i}(t) = (m + \lambda s_2(t)) \left[ D_0 e^{-at} + \beta (s_1(t) + s_2(t)) - \theta p(t) + k_D (p_0 - p(t)) \right]$$

$$- \frac{q_2 s_{2t}^2(t)}{2}$$

(3)

Theorem 3.1. Under the demand market competition, the optimal price of B2C online ride-hailing platforms, the optimal quality of service efforts of B2C online ride-hailing platforms and drivers are as follows
Therefore, the optimal ride price of B2C online ride-hailing platform is convex and monotonously decrease.

Lemma 3.2. Suppose that the ride demand decreases with time evolving. Then,

\[
\begin{align*}
\frac{dt}{e} & = -
\begin{cases}
-\beta \lambda (m \beta + e^{-at} D_0 \lambda + p_0 k_D) \\
-(-c \beta - m \beta) (2 \beta \lambda - q_2)
\end{cases} \\
& + \begin{cases}
-(-c \beta - m \beta) [\beta - \lambda (-\theta - k_D)] - \beta \lambda 
\begin{cases}
e^{-at} D_0 - c (-\theta - k_D) \\
-m (-\theta - k_D) + p_0 k_D
\end{cases}
\end{cases}
\end{align*}
\]

\[
\begin{align*}
\frac{dt}{e} & = -
\begin{cases}
-\beta^2 \lambda^2 + q_1 (2 \beta \lambda - q_2) \\
-\beta^4 \lambda^2 + 3 \beta^2 \theta^2 \lambda^2 q_1 - \beta^2 \theta^2 \lambda^3 q_1 + 3 \beta^2 \lambda^2 k_D q_1 - 2 \beta \theta \lambda^3 k_D q_1 - \beta \lambda^3 k_D q_2
\end{cases}
\end{align*}
\]

Proof. Based on the equations (2) and (3), the optimal strategy under Nash equilibrium can be obtained through solving partial derivatives of the respective decision variables \( p_t^* \), \( s_{1t}^* \) and \( s_{2t}^* \). This process is straightforward, so we omit here.

Lemma 3.2. Suppose that the ride demand decreases with time evolving. Then, the optimal price of B2C online ride-hailing platforms, the optimal efforts of quality of service for the B2C online ride-hailing platforms and the drivers are all convex and monotonously decrease.

Proof. The first derivative and the second derivative of the optimal ride price in terms of time \( t \) are as follows:

\[
\begin{align*}
\frac{dp_t^*}{dt} & = \left\{ \begin{array}{c}
n e^{-at} D_0 \beta \lambda^2 \{\beta^2 \lambda - \lambda (-\theta - k_D)\} + e^{-at} D_0 \beta \lambda [\beta^2 \lambda^2 + q_1 (2 \beta \lambda - q_2)] \\
+e^{-at} D_0 \beta \lambda [\beta^2 \lambda^2 + q_1 (2 \beta \lambda - q_2)] \\
+\beta^4 \lambda^2 - 3 \beta^2 \theta^2 \lambda^2 q_1 - \beta^2 \theta^2 \lambda^3 q_1 + 3 \beta^2 \lambda^2 k_D q_1 + 2 \beta \theta \lambda^3 k_D q_1 + \beta \lambda^3 k_D q_2
\end{array} \right\}
\end{align*}
\]

Since the supply is more than the demand with \( a > 0, k_D > 0, D_0, \beta, \theta, q_1, q_2, M_1, M_2 > 0, \lambda \in (0, 3) \), and according to the reality, the four parameters \( q_1, q_2, M_1, M_2 \) are far greater than the other parameters, \( \frac{dp_t^*}{dt} < 0, \frac{dp_t^{*2}}{dt^2} > 0 \) can be obtained. Therefore, the optimal ride price of B2C online ride-hailing platform is convex and decreasing with respect to the time \( t \).
The first derivative and the second derivative of the optimal quality of service effort of B2C online ride-hailing platform to time $t$ are respectively:

$$\frac{ds_{11^*}(t)}{dt} = \frac{ae^{-at}D_0\beta}{\beta^2(\beta\lambda - q_2) + (\theta + k_D)q_1(-3\beta\lambda + \theta\lambda^2 + \lambda^2\kappa_D + 2q_2)}$$  \hspace{1cm} (9)

$$\frac{ds_{11^*2}(t)}{dt^2} = \frac{a^2e^{-at}D_0\beta}{\beta^2(\beta\lambda - q_2) + (\theta + k_D)q_1(-3\beta\lambda + \theta\lambda^2 + \lambda^2\kappa_D + 2q_2)}$$  \hspace{1cm} (10)

Similarly, we can prove that $\frac{ds_{21^*}(t)}{dt} < 0$, $\frac{ds_{21^*2}(t)}{dt^2} > 0$. Therefore, the optimal quality of service effort of B2C online ride-hailing platform is and decreasing in terms of the time $t$.

The first derivative and the second derivative of the optimal quality of service effort of driver to time $t$ are respectively:

$$\frac{ds_{21^*}(t)}{dt} = \frac{ae^{-at}D_0\lambda(\theta + k_D)q_1}{\beta^2(\beta\lambda - q_2) + (\theta + k_D)q_1(-3\beta\lambda + \theta\lambda^2 + \lambda^2\kappa_D + 2q_2)}$$  \hspace{1cm} (11)

$$\frac{ds_{21^*2}(t)}{dt^2} = \frac{a^2e^{-at}D_0\lambda(\theta + k_D)q_1}{\beta^2(\beta\lambda - q_2) + (\theta + k_D)q_1(-3\beta\lambda + \theta\lambda^2 + \lambda^2\kappa_D + 2q_2)}$$  \hspace{1cm} (12)

Similarly, we can also prove that $\frac{ds_{21^*}(t)}{dt} < 0$, $\frac{ds_{21^*2}(t)}{dt^2} > 0$. Thus, the optimal quality of service effort of driver is also convex and decreasing in terms of the time $t$. 

It can be known from lemma 3.2 that, within the service time $[0, T]$, if the ride demand is declining, then the B2C online ride-hailing platforms compete for the ride demand market. This competition will stimulate the ride demand through lowering the ride price. At the same time, the lower the ride price is, the less the drivers will demand market. This competition will stimulate the ride demand through lowering the ride price.

Theorem 3.3. Under the demand market competition, the optimal profits of B2C online ride-hailing platforms and drivers are respectively

$$\pi_{11^*}(t) = e^{-2at}\left\{\begin{array}{l}D_0(2\beta\lambda - q_2) + e^{at}\\2e^{at}m^2(\theta + k_D)q_1q_2\\-e^{2at}m^2\beta^2q_2 - (\theta + k_D)^2q_1^2\\D_0^2\lambda^2(2\beta\lambda - q_2) - 2e^{at}D_0(2\beta\lambda - q_2) - \lambda\left[m\beta + c\theta\lambda + (c - p_0)\lambda\kappa_D\right] - \lambda q_2\\2\beta\lambda[m\beta + c\theta\lambda + (c - p_0)\lambda\kappa_D] - \lambda q_2\\+e^{2at}\left\{\begin{array}{l}2\beta\lambda[m\beta + c\theta\lambda + (c - p_0)\lambda\kappa_D] - \lambda q_2\\\theta\left(2m(5c + 3m)\beta + (c - m)(c + m)\theta\lambda\right) + k_D\\2m(5c + 3m - 5p_0)\beta - 2\theta\lambda\\+4m^2q_2\left[(c + m)\beta + k_D\right]\\2\left\{2\beta^2(\beta\lambda - q_2) + (\theta + k_D)q_1[\lambda(-3\beta\lambda + \theta\lambda + \lambda\kappa_D) + 2q_2]\right\}^2\end{array}\right.\right.\end{array}\right.\right.$$  \hspace{1cm} (13)
The supply market completion.

3.2. The supply market completion. The supply market competition refers to the situation that the demand is more than the supply with \( a < 0 \). In fact, the rides demand increases either due to peak commuting periods, or due to the weather or events. For this case, the balance between supply and demand is broken as the supply is insufficient to match the demand. Suppose that \( k_D = 0 \), then the demand function of the market is

\[
D_u = D_0 e^{-at} + \beta (s_{1u}(t) + s_{2u}(t)) - \theta p_u(t)
\]

The profit function of the B2C online ride-hailing platform becomes

\[
\pi^u_1(t) = (p_u(t) - c - m \lambda s_{2u}(t))[D_0 e^{-at} + \beta (s_{1u}(t) + s_{2u}(t)) - \theta p_u(t)]
- \frac{q_1 s_{1u}^*(t)}{2} - M_1 - M_2
\]

The profit function of driver is

\[
\pi^u_2(t) = (m + \lambda s_{2u}(t))[D_0 e^{-at} + \beta (s_{1u}(t) + s_{2u}(t)) - \theta p_u(t)] - \frac{q_2 s_{2u}^*(t)}{2}
\]

**Theorem 3.4.** Under the supply market competition, the optimal price, the optimal quality of service efforts of the B2C online ride-hailing platforms and drivers are as follows:

\[
p^*_u(t) = \left\{ \begin{array}{ll}
- \frac{-\beta (-c\beta - m\beta) \lambda - (m\beta + e^{-at} \alpha \lambda) q_1}{[\beta^2 \lambda - (\beta + \theta) q_1] + \left[ -\beta (-c\beta - m\beta) - (e^{-at} D_0 + c\theta + m\theta) q_1 \right]} \\
/ (\beta^3 \lambda q_1 - 3\beta \theta \lambda q_1^2 + \theta^2 \lambda^2 q_1^2 - \beta^2 q_1 q_2 + 2\theta q_1 q_2)
\end{array} \right. (18)
\]

\[
s^*_1u(t) = \frac{e^{(-at)} \beta (e^{at} m\beta^2 - D_0 \beta \lambda + c e^{at} \beta \theta \lambda + D_0 q_2 - c e^{at} q_2)}{\beta^3 \lambda - 3\beta \theta \lambda q_1 + \theta^2 \lambda^2 q_1 - \beta^2 q_2 + 2\theta q_1 q_2} (19)
\]

\[
s^*_2u(t) = \frac{e^{-at} (e^{at} m\beta^3 - 2e^{at} m\beta \theta q_1 - D_0 \theta \lambda q_1 + c e^{at} \theta^2 \lambda q_1 + e^{at} m\theta^2 \lambda q_1)}{\beta^3 \lambda - 3\beta \theta \lambda q_1 + \theta^2 \lambda^2 q_1 - \beta^2 q_2 + 2\theta q_1 q_2} (20)
\]

**Proof.** By solving the partial derivatives of the respective decision variables \( p_u(t) \), \( s^*_1u(t) \) and \( s^*_2u(t) \) through the formulas (16) and (17), the optimal strategy under Nash equilibrium can be obtained, theorem 3.3 can be proved. □
Theorem 3.6. Supply will achieve balance through this dynamical adjustment. The ride price, which in return reduces demand in the market. The demand and supply will encourage more drivers to join online ride-hailing platforms through increasing capacity to provide service. In order to enhance their capacity, the platforms will increase.

Lemma 3.5. If the demand is more than the supply in the market, then the optimal ride price, the optimal quality of service effort of the B2C ride-hailing platform and the optimal quality of service effort of the driver are all convex and monotonically increasing.

Proof. The first derivative and the second derivative of the optimal ride price to the time \( t \) are respectively:

\[
\frac{dp^*_t(t)}{dt} = \left\{ \begin{array}{l}
-a e^{-at} D_0 \log[e] q_1 \left[ \beta^2 \lambda - (\beta + \theta \lambda) q_1 \right] \\
+a e^{-at} D_0 \log[e] q_1 \left[ \beta^2 \lambda^2 - q_1 (2 \beta \lambda - q_2) \right] \\
(\beta^3 \lambda q_1 - 3 \beta \theta \lambda q_1^2 + \theta^2 \lambda^2 q_1^2 - \beta^2 q_1 q_2 + 2 \theta q_1^2 q_2)
\end{array} \right. / \tag{21}
\]

\[
\frac{dpc^*_t(t)}{dt} = \left\{ \begin{array}{l}
a^2 e^{-at} \alpha \log[e] q_1^2 \left[ \beta^2 \lambda - (\beta + \theta \lambda) q_1 \right] \\
a^2 e^{-at} \alpha \log[e] q_1^2 \left[ \beta^2 \lambda^2 - q_1 (2 \beta \lambda - q_2) \right] \\
(\beta^3 \lambda q_1 - 3 \beta \theta \lambda q_1^2 + \theta^2 \lambda^2 q_1^2 - \beta^2 q_1 q_2 + 2 \theta q_1^2 q_2)
\end{array} \right. / \tag{22}
\]

Based on the assumption that the demand is more than the supply with \( a < 0 \), \( k_D = 0 \), \( D_0, \beta, \theta, q_1, q_2, M_1, M_2 > 0 \), \( \lambda \in (0, 3) \), the four parameters \( q_1, q_2, M_1, M_2 \) are far greater than the other parameters based on practice experience, \( \frac{dp^*_t(t)}{dt} > 0, \frac{dpc^*_t(t)}{dt} > 0 \) can be obtained. Therefore, the optimal ride price is a convex function of time \( t \), and it increases monotonically over time \( t \).

The first derivative and the second derivative of the optimal quality of service effort of B2C online ride-hailing platform to time \( t \) are respectively:

\[
\frac{ds_{1u}^*(t)}{dt} = \frac{ae^{-at} \beta \log[e] (\beta (-\alpha \lambda + 2 e^{at} (m \beta + c \theta \lambda)) + (D_0 - 2 e^{at} (c + m) \theta) q_2)}{\beta^2 (\beta \lambda - q_2) + \theta q_1 (\lambda (-3 \beta + \theta \lambda) + 2 q_2)} \tag{23}
\]

\[
\frac{ds_{1u}^{*2}(t)}{dt^2} = \frac{a^2 e^{-at} D_0 \beta \log[e] (\beta \lambda - q_2)}{\beta^2 (\beta \lambda - q_2) + \theta q_1 (\lambda (-3 \beta + \theta \lambda) + 2 q_2)} \tag{24}
\]

Similarly, we can prove that \( \frac{ds^*_t(t)}{dt} > 0, \frac{ds_{1u}^{*2}(t)}{dt} > 0 \) and \( \frac{dpc^*_t(t)}{dt} > 0, \frac{dpc_{1u}^{*2}(t)}{dt} > 0 \). Therefore, the optimal service efforts for both platform and drivers are convex and increases monotonically over time \( t \).

\[
\pi_{1u}^*(t) = \left\{ e^{-2at} q_1 (-\beta^2 + 2 \theta q_1) \left\{ D_0 (-\beta \lambda + q_2) + e^{at} \left[ \beta (m \beta + c \theta \lambda) \right] \right\}^2 \right. \\
2 \left[ \beta^2 (\beta \lambda - q_2) + \theta q_1 (\lambda (-3 \beta + \theta \lambda) + 2 q_2) \right]^2 - M_1 - M_2 \tag{25}
\]

It can be known from Lemma 3.5 that, within the service time \([0, T]\), when the ride demand surged in the market, the B2C online ride-hailing platform has not enough capacity to provide service. In order to enhance their capacity, the platforms will attract more drivers through increasing the drivers’ wages. For this case, the market will encourage more drivers to join online ride-hailing platforms through increasing the ride price, which in return reduce the demand in the market. The demand and supply will achieve a balance through this dynamical adjustment.

Theorem 3.6. Under the supply market competition, the optimal profits of the B2C online ride-hailing platform and drivers are respectively:
\[\pi^u(t) = e^{-2at}\]
\[
\begin{cases}
-e^{2at}m^2\beta^2q_2 + 2e^{at}m\beta^2\theta q_2 \beta D_0 \beta + e^{at} \left\{ \beta [m\beta - (2c + m) \theta \lambda] \right\} + \\
\theta^2 q_1^2 \left\{ -2\beta \lambda [\alpha \lambda - e^{at} (m\beta + c\theta \lambda)]^2 + \\
\alpha^2 \lambda^2 - 2e^{at} D_0 \{ \lambda (5m\beta + c\theta \lambda) - 2mq_2 \} \\
+ e^{2at} \theta \left\{ \lambda \left[ 2m (5c + 3m) \beta + (c - m) (c + m) \theta \lambda \right] - 4m (c + m) q_2 \} \right\}
\end{cases}
/2 \left\{ \beta^2 (\beta \lambda - q_2) + \theta q_1 \left[ \lambda (-3\beta + \theta \lambda) + 2q_2 \right] \right\}^2
\] (26)

**Proof.** Substitute the optimal ride price \(p^u(t)\), the optimal quality of service effort of the B2C online ride-hailing platform \(s^1_u(t)\) and the optimal quality of service effect of the driver \(s^2_u(t)\) into Equations (16) and (17), and theorem 3.6 can be proved. \(\square\)

### 3.3. The coexistence of demand and supply market competition.

The coexistence of demand and supply market competition refers to that the ride demand in the market is between peak and off-peak with \(a = 0\). The ride demand during this period is relatively stable. For this case, the demand equals to the supply. The platform 1 and platform 2 compete for both the ride demand market and the supply market at the same time to secure more orders. Suppose that \(k_D > 0\), then the demand function of the market is

\[D_b = D_0 + \beta (s_{1b}(t) + s_{2b}(t)) - \theta p_b(t) + k_D (p_0 - p_b(t))\] (27)

The profit function of the B2C online ride-hailing platform is

\[\pi^b_1(t) = (p_b(t) - c - m - \lambda s_{2b}(t)) [D_0 + \beta (s_{1b}(t) + s_{2b}(t)) - \theta p_b(t) + k_D (p_0 - p_b(t))] - \frac{q_2 s^2_{2b}(t)}{2} - M_1 - M_2\] (28)

The profit function of driver is

\[\pi^b_2(t) = (m + \lambda s_{2b}(t)) [D_0 + \beta (s_{1b}(t) + s_{2b}(t)) - \theta p_b(t) + k_D (p_0 - p_b(t))] - \frac{q_2 s^2_{2b}(t)}{2}\] (29)

**Theorem 3.7.** Under the coexistence of demand and supply market competition, the optimal pricing of the B2C online ride-hailing platforms, the optimal quality of service effect of the drivers, and the optimal quality of service effort of the B2C online ride-hailing platform is
Under the coexistence of demand and supply market competition, the ride demand remains unchanged, the B2C online ride-hailing platform will compete based on the quality of service and the upper limit of the driver incentive amount, and the platform will maintain the balance between supply and demand.

Theorem 3.7 shows that when the ride demand remains unchanged, the optimal quality of service effort of the B2C online ride-hailing platform and drivers are as follows:

$$p^*_t(t) = \begin{cases} \beta^2 \lambda + \left(\beta - \lambda - (\theta - k_D)\right)q_1 \\ -\beta\lambda(m\beta + D_0\lambda + p_0\lambda k_D) \\ \left(\beta^2 \lambda^2 + q_1(2\beta\lambda - q_2)\right) -\beta\lambda\left[\left(\beta^2 \lambda^2 + q_1(2\beta\lambda - q_2)\right) -\beta\lambda\left(\beta - \lambda + (\theta - k_D)\right)\right] \end{cases}$$

$$s^*_t(t) = \begin{cases} -\beta^4 \lambda^2 + 3\beta^2 \theta \lambda^2 q_1 - \beta^2 \lambda^3 q_1 + 3\beta^2 \lambda^2 q_1\left(2\beta \lambda q_1 - 2\beta \lambda^3 q_1\right) \\ -\beta^4 \lambda^2 q_1 + \beta^3 \lambda q_2 - 2\beta \theta \lambda q_1 q_2 - 2\beta \lambda k_D q_1 q_2 \end{cases}$$

Proof. Substitute the optimal ride price $p^*_t(t)$ the optimal quality of service effort of the B2C online ride-hailing platform $s^*_t(t)$ and the optimal quality of service effect of the driver $s^*_2(t)$ into Equations (28) and (29), and theorem 3.7 can be proved.

\[\Box\]

Lemma 3.8. The ride demand remains unchanged in the market, considering the platform competition ride demand market and ride supply market at the same time, the optimal ride price, the optimal quality of service effort of the B2C online ride-hailing platform and the optimal quality of service effort of the driver do not change with time.

Proof. Theorem 3.7 shows that when the ride demand remains unchanged, the platform will maintain the balance of supply and demand, and the optimal ride price, the optimal quality of service effort of the B2C online ride-hailing platform and the optimal quality of service effort of the driver are all constants related to $\lambda, k_D$ and other parameters, and the first derivative of time $t$ is 0.

It can be known from lemma 3.8 that, within the service time $[0, T]$, when the ride demand remains unchanged, the B2C online ride-hailing platform will compete based on the quality of service and the upper limit of the driver incentive amount, and the platform will maintain the balance between supply and demand.

Theorem 3.9. Under the coexistence of demand and supply market competition, the optimal profits of the B2C online ride-hailing platform and drivers are respectively:
\[ \pi_{1\lambda}(t) = \]
\[ q_1 \left[ -\beta^2 + 2(\theta + k_D) q_1 \right] \left\{ \frac{\beta [m \beta - D_0 \lambda + c \theta \lambda + (c - p_0) \lambda k_D] + \frac{1}{2} \{ \beta^2 (\beta \lambda - q_2) + (\theta + k_D) q_1 [\lambda (-3 \beta + \theta \lambda + \lambda k_D) + 2q_2] \}}{\lambda - M_1 - M_2} \right\} \]

\[ \pi_{2\theta}(t) = \]
\[ 2m \beta^2 (\theta + k_D) q_1 q_2 \left\{ \frac{\beta}{q_1} \left[ \frac{-m \beta - 2D_0 \lambda + 2c \theta \lambda + m \theta \lambda + \lambda k_D (2c + m - 2p_0)}{\theta} \right] \right\} q_2 \]
\[ - \left\{ \frac{2 \beta \lambda [m \beta - D_0 \lambda + c \theta \lambda + (c - p_0) \lambda k_D]^2 - \lambda q_2}{\theta} \right\} \]
\[ + m^2 \beta^6 q_2 \frac{1}{2} \left\{ \beta^2 (\beta \lambda - q_2) + (\theta + k_D) q_1 [\lambda (-3 \beta + \theta \lambda + \lambda k_D) + 2q_2] \right\} \]

\[ \frac{1}{2} \left\{ \beta^2 (\beta \lambda - q_2) + (\theta + k_D) q_1 [\lambda (-3 \beta + \theta \lambda + \lambda k_D) + 2q_2] \right\} \]

**Proof.** Substitute the optimal ride price \( p_\lambda^*(t) \), the optimal quality of service effort of the B2C online ride-hailing platform \( s_\lambda^*(t) \) and the optimal quality of service effect of the driver \( s_\theta^*(t) \) into Equation (28) and (29), and theorem 3.9 can be proved. \( \square \)

4. The example analysis. In this section, numerical experiments are used to illustrate our proposed model. Assume that \( m = 2, q_1 = 20, q_2 = 20, \beta = 1, \theta = 1, c = 2, D_0 = 40, p_0 = 30, M_1 = 15, M_2 = 5 \). We use \( a = (0.09, -0.05, 0) \) to represent the decline, surge and invariability of ride demand, and \( k_D = (0.1, 0.5, 0.9) \) respectively to represent the low, medium and high competitive intensity of ride demand. In addition, \( x \) represents the demand market competition, \( y \) represents the supply market competition, \( z \) represents the coexistence of demand and supply market competition.

4.1. The influence of the upper limit of incentive amount on the optimal strategy. In order to analyze the influence of the upper limit of driver incentive amount \( \lambda \) in the optimal strategy, assuming \( t = 6, k_D = 0.5, \lambda \in (0, 3) \).

It can be seen from Figure 2 that under the three competitive situations, the optimal ride price and the optimal quality of service efforts of driver both increase with the increase of the upper limit of the driver’s incentive amount \( \lambda \). In the case of the demand market competition, the optimal quality of service efforts of the B2C online ride-hailing platform will decrease with the increase of the upper limit of the driver’s incentive amount \( \lambda \); in the case of supply market competition and the coexistence of demand and supply market competition, the optimal quality of service effort of the B2C online ride-hailing platform first increases and then decreases as the upper limit of the driver’s incentive amount \( \lambda \) increases. When \( \lambda \in (0, 3) \), under the same upper limit of the driver’s incentive amount \( \lambda \), the optimal ride
price is compared as follows $p^*_l < p^*_b < p^*_u$, and gradually flattening out, the fastest growth under the supply market competition. The optimal quality of service effort of the B2C online ride-hailing platform is compared as follows $s^*_l < s^*_b < s^*_u$. The optimal quality of service effort of driver is compared as follows, at the early stage, there is little difference between the supply market competition and the coexistence of demand and supply market competition, but at the late stage, the difference is obvious, but it always remains $s^*_l < s^*_b < s^*_u$.

It can be seen that when there is the supply market competition between platforms, as the upper limit of the driver’s incentive amount $\lambda$ increases, the quality of service driver’s level will increase, and the platform can appropriately increase quality of service efforts to attract more customers with better services. However, when the upper limit of the driver’s incentive amount $\lambda$ increases to a certain level, the ride price is too high, and the operating cost of the B2C online ride-hailing platform continues to increase, which may lead to a reduction in consumer surplus, which in turn affects the order volume. In order to control operating costs, under the condition of ensuring certain quality of service, the platform can appropriately reduce the quality of service efforts of the B2C online ride-hailing platform’s or control the upper limit of the driver’s incentive amount $\lambda$ to control operating costs, which makes the ride prices for consumers more reasonable.

From Figure 3(a), it can be seen that under the situation of demand market competition, the optimal profit of the platform decreases with the increase of the upper limit of the driver’s incentive amount $\lambda$; in the other two competitive situations, the optimal profit of the platform first increases and then decreases with
the increase of the upper limit of driver incentive amount, when the upper limit of the incentive amount \( \lambda \) is the same, \( \pi_{1l}^* < \pi_{1b}^* < \pi_{1u}^* \). This shows that there is a certain degree of competition in the supply market between platforms that can increase platform profits, but whether it is excessive competition in demand market or excessive competition in supply market, it is not conducive to the platform to obtain optimal profits. In addition, increasing the upper limit of the driver’s incentive amount \( \lambda \) can encourage drivers to provide better services to customers, thereby increasing the platform’s profits. However, the excessively high upper limit of the driver’s incentive amount \( \lambda \) increases the operating cost of the platform and reduces the platform’s profit. Therefore, a moderate upper limit of the driver’s incentive amount \( \lambda \) is more conducive to the platform to obtain greater profits.

It can be seen from Figure 3(b) that in the three competitive situations, the optimal profit of the driver first increases and then decreases as the upper limit of the driver’s incentive amount \( \lambda \) increases. When the upper limit of the incentive amount is the same, \( \pi_{2l}^* < \pi_{2b}^* < \pi_{2u}^* \). This shows that as the upper limit of the driver’s incentive amount \( \lambda \) increases, the driver’s quality of service continues to improve, and the increase of the driver’s incentive amount \( \lambda \) increases the driver’s optimal profit. However, as the quality of service effort of drivers continues to increase, the cost of driver delivery risks also increases rapidly. When the upper limit of driver’s incentive amount \( \lambda \) exceeds a certain value, the optimal profit of drivers is negatively correlated with the upper limit of driver’s incentive amount \( \lambda \). In addition, as far as drivers are concerned, when the upper limit of the driver’s incentive amount is the same, more profits can be obtained under the situation of the supply market competition.

4.2. Dynamic trajectory of optimal strategy. In order to analyze the influence of ride demand market competition on the optimal strategy change trajectory of the B2C online ride-hailing platform and driver, assume \( \lambda=3, t \in (0, 16), k_D = (0.1, 0.5, 0.9) \), and the analysis results are shown in FIG 4 5 6 below:

As shown in Figure 4(a), when platforms compete for the demand market under decline of ride demand, the optimal ride price is a monotonically decreasing convex function over time, and when the ride demand market competition is fiercer, that is, \( k_D \) is larger, the optimal ride price decreases more slowly and the optimal ride price trajectory moves downward. As shown in Figure 4(b), when platforms compete for
Figure 4. The influence of ride demand market competition on the optimal price change trajectory

As shown in Figure 4(c), when platforms compete for the coexistence of demand and supply market for stable ride demand, the optimal ride price does not change over time, and the fiercer the competition in the market for ride demand, the greater the $k_D$, the trajectory of the optimal ride price moves downward.

As shown in Figure 5(a), when platforms compete for the demand market under decline of ride demand, the optimal quality of service effort of the B2C online ride-hailing platform is a convex function that monotonically decreases with time, and when the ride demand market competition is fiercer, that is, $k_D$ is larger, the optimal quality of service effort of the B2C online ride-hailing platform decreases more slowly, and the optimal quality of service effort of the B2C online ride-hailing platform moves downward. As shown in Figure 5(b), when platforms compete for the supply market under surge of ride demand, the optimal ride price is a convex function of time monotonically increasing. As shown in Figure 5(c), when platforms compete for the coexistence of demand and supply market for stable ride demand, the optimal quality of service effort of the B2C online ride-hailing platform does not change over time, and the fiercer the demand market competition is, the greater the $k_D$ is, and the optimal quality of service effort of the B2C online ride-hailing platform moves downward.

As shown in Figure 6(a), when platforms compete for the demand market under decline of ride demand, the optimal quality of service effort of driver is a convex function that decreases monotonically with time, and when the ride demand market
competition is fiercer, that is, $k_D$ is greater, and the optimal quality of service effort of driver decreases more slowly. As shown in Figure 6(b), when platforms compete for the supply market under surge of ride demand, the optimal quality of service effort of driver is a convex function that monotonically increases with time. As shown in Figure 6(c), when platforms compete for the coexistence of demand and supply market for stable ride demand, the optimal quality of service effort of driver does not change over time. And when the ride demand market competition is fiercer, that is, $k_D$ is larger, and the optimal quality of service effort trajectory of driver moves downward.

It can be seen from Figure 4 5 6 that, when platforms compete for the demand market under decline of ride demand, the ride demand competition intensity $k_D$ increases, both the optimal ride price and the optimal quality of service efforts of the B2C online ride-hailing platform are reduced, while the optimal quality of service effort of driver is improved. When platforms compete for the supply market under surge of ride demand, the ride demand competition intensity $k_D$ increases, and the optimal ride price, when platforms compete for the supply market under surge of ride demand, and the optimal quality of service effort of drivers all increase. When platforms compete for the coexistence of demand and supply market for stable ride demand, the ride demand market competition is fiercer, the greater $k_D$ is, and the optimal ride price, the optimal quality of service efforts of the B2C online ride-hailing platform, and the optimal quality of service efforts of the driver are all reduced.
Figure 6. The influence of ride demand market competition on the optimal drives service change trajectory

Figure 7. The influence of market competition of ride demand on the optimal profit change trajectory

As shown in Figure 7, when platforms compete for the demand market under decline of ride demand, the optimal profit of the B2C online ride-hailing platform is a convex function that monotonically decreases with the demand market competition intensity $k_D$, the optimal profit of driver is a convex function that monotonically increases with the demand market competition intensity $k_D$ of the demand market; when platforms compete for the supply market under surge of ride demand, the optimal profit of the B2C online ride-hailing platforms and the drivers will not change with the demand market competition intensity $k_D$; when platforms compete for the
coexistence of demand and supply market for stable ride demand, the optimal profit of both the B2C online ride-hailing platform and the driver are convex function that monotonically decreases with the demand market competition intensity $k_D$.

Therefore, for the B2C online ride-hailing platform, $\pi_{1l}^* < \pi_{1b}^* < \pi_{1u}^*$, the profit is the highest under the situation of the supply market competition. For the other two situations, increasing competition for ride demand will reduce the profits of the B2C online ride-hailing platform. For the driver, $\pi_{2l}^* < \pi_{2b}^* < \pi_{2u}^*$, the profit is the highest under the situation of the supply market competition. Under the situation of the demand market competition, the optimal profit of driver increases with the increase of the demand market competition intensity $k_D$. For the case of the coexistence of demand and supply market competition, the optimal profit of driver decreases with the increase of the demand market competition intensity $k_D$.

5. Conclusions. In this paper, we have integrated pricing and service together to maximize the profit of the B2C online ride-hailing platform and driver through Nash game theory. We have established the models for demand market competition under decline of ride demand, the supply market completion under surge of ride demand, and the coexistence of demand and supply market competition for stable ride demand. Finally, the effectiveness of the model is verified by numerical simulation analysis, and the influences of the upper limit of the driver’s incentive amount $\lambda$ and the demand market competition intensity $k_D$ on the optimal strategy and profit of supply chain members are further discussed. Through theoretical analysis and numerical simulation, the ride price is optimized, the service level of the B2C online ride-hailing platform and drivers is improved, and then the matching rate of the B2C online ride-hailing market is improved. The specific research conclusions are as follows

(1) When the B2C online ride-hailing platforms compete for the demand market under decline of ride demand, they can stimulate ride demand by reducing ride prices, avoiding too many drivers to join the platform, and reducing the platform’s excess supply capacity.

(2) When the B2C online ride-hailing platforms compete for the supply market under surge of ride demand, they can encourage more drivers to join the platform by increasing ride prices, improving the platform’s supply capacity and promoting the balance of market supply and demand.

(3) When the B2C online ride-hailing platforms compete for the demand and supply market at the same time for stable ride demand, they compete based on the quality of service and the upper limit of driver’s incentive amount, and the market will maintain a balance between supply and demand. Based on these results, we can get some enlightenment to guide the operation of B2C Online Ride-hailing platform, and provide some suggestions for drivers.

Finally, the limitations of this paper are discussed. This paper takes B2C online ride-hailing platform as the main research object. However, in the actual operation process, not only the internal competition of B2C Ride-hailing platforms, but also the common competition of taxi and C2C Ride-hailing platforms in the ride-hailing market. Therefore, the next study can comprehensively consider the pricing and service decisions of the three parties when they compete in the market at the same time. In addition, further empirical data can be used to test the model results, which will have a stronger guiding significance for the actual operation of ride-hailing platform.
Acknowledgments. This work was supported by the National Natural Science Foundation of China (Nos. 72071096, 71971100, 71671078); Social Science Fund of Jiangsu Province (19GLB005, 19GLB018); The Key Project of Philosophy and Social Science Research in Colleges and Universities in Jiangsu Province (2018SJZDI052); sponsored by Qing Lan Project of Jiangsu Province; Key Research Base of Universities in Jiangsu Province for Philosophy and Social Science “Research Center for Green Development and Environmental Governance”.

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Received February 2021; 1st revision May 2021; 2nd revision June 2021.

E-mail address: mqf@ujs.edu.cn
E-mail address: 2221910029@stmail.ujs.edu.cn
E-mail address: janeli@ujs.edu.cn
E-mail address: changzhivu@gzhu.edu.cn