International Journal for Housing Science and Its Applications
Publish August 6, 2025. Volume 46, Issue 3 Pages 7507-7520

https://doi.org/10.70517/ijhsa463644

Research on subsidy strategy of online cab platform considering cab behavior in the case of order overflow of online taxi platform based on game theory model

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Abstract The rapid development of online cab platforms has formed a great impact on the traditional cab industry, and there is both competition and cooperation between the two. In the case of overflow of orders from online taxi platforms, cab behavior has a significant impact on the construction of subsidy strategy of online taxi platforms. Based on bilateral market theory and evolutionary game theory, this study establishes a subsidy strategy model of online cab platform considering cab behavior, and explores the influence mechanism of cab behavior on subsidy strategy of online taxi platform in the case of order overflow of online taxi platform. The equilibrium points and stability of the game among the net booking platform, cab companies and passengers are analyzed by constructing replicated dynamic equations and Jacobi matrices. The results of the study show that: under the dynamic pricing strategy of online taxi platform, the price rises gradually with the increase of demand, and it can effectively balance the relationship between supply and demand; the cab price is significantly higher in the case of order overflow than in the case of no overflow, indicating that the overflow orders provide support for the cab price; the profit of online taxi is lower than that of centralized decision-making under the decentralized decision-making, and the profit shows a tendency to increase firstly and then decrease when the quality of the service improves; in the competing environment, the When the competitiveness of NetJourney cars and cabs is similar and the degree of competition is moderate, the two can realize stable coexistence. The study suggests that a reasonable platform subsidy strategy can promote the synergistic development of NetJourney cars and cabs, optimize the market structure, and improve the service experience of passengers, and the platform should dynamically adjust the subsidy according to the market supply and demand, and establish a sound competition mechanism.

Index Terms Internet taxi platform, order overflow, cab cruising behavior, game theory model, bilateral market, subsidy strategy

I. Introduction

In recent years, the sharing economy has widely penetrated into all areas of production and life. Shared travel, as an emerging mode of travel, has the most profound impact on public travel, and at present, NetJourney has gradually become the preferred mode of public travel [1]. The emergence of net dating breaks the traditional urban transportation structure, generates a new pattern of urban transportation structure, reconfigures the social idle resources, and improves the efficiency of resource utilization while meeting public demand [2]-[4]. As a market economy organization, the online taxi platform assumes the social function of urban quasi-public transportation supply and coordination [5]. For the travelers, more available travel options are added [6]. For urban public transport providers, it does not rely on government subsidies and enriches the supply market [7]. For urban transport managers, the platform organizes the fragmented elements in the market by setting rules and reduces the management cost [8]. However, because of its rapid development, the problem of online cab drivers competing with traditional cab drivers for passengers during peak hours occurs from time to time in the case of insufficient effective regulation [9], [10]. The reason for this is that the operation mode of the online taxi platform is unreasonable, especially the pricing problem in the operation mode has not been reasonably solved, which also hinders the balanced development of urban transportation to a certain extent [11]-[13].

It is known from economic theory that the service price is determined by the supply and demand situation, and in order to improve the driver's motivation to go out and take orders at peak times, the major platforms have strengthened the subsidies for the drivers at peak times [14]. The goal of the subsidy strategy implemented by online taxi platforms is to attract and keep users and drivers active through direct or indirect financial incentives, so as to rapidly expand market share and build brand loyalty [15]-[17]. For users, discounts can increase the frequency of use by existing users [18]. For drivers, providing incentives and target rewards incentivizes them to increase service supply and ensure that orders on the platform can be fulfilled in a timely and efficient manner [19], [20]. Exploring such a two-way subsidy mechanism not only quickly regulates the balance between supply and demand of peak order volume, but also promotes long-term user and driver loyalty building, which supports the stable development of the platform and market competitiveness enhancement [21]-[23].

The diversified development of transportation and travel modes is profoundly changing the daily travel patterns of urban residents. In recent years, the rapid development of smartphones and Internet technology has prompted the rapid rise of online taxi platforms, which have become an important choice for urban travel. This new travel mode not only improves the efficiency of passenger travel, but also creates new employment opportunities for society. However, the widespread popularity of online cab has also brought unprecedented challenges to the traditional cab industry, triggering a complex competitive relationship between the two modes of travel. As an important part of the urban public transportation system, traditional cabs have long maintained stable operations through government regulation and price control, while online taxis have rapidly seized market share with their flexible pricing mechanism and convenient booking methods. This change in the market pattern makes it especially necessary to explore the synergistic development mechanism between net cabs and cabs. Current research has mostly focused on the pricing strategy of online cab platforms or the survival of the cab industry, with less attention paid to the interaction between the two in the case of supply-demand imbalance. Especially in the scenario of overflow of orders from online taxi platforms, there is still a lack of systematic analysis on how the behavior of cabs affects the formulation of subsidy strategies of online taxi platforms and how to achieve the optimal allocation of market resources. Meanwhile, passengers, as the demand side of the market, their choice behavior also largely affects the competitive strategies of both parties, and the complexity of this three-way game relationship urgently needs to be explored in depth through theoretical models.

Based on bilateral market theory and evolutionary game theory, this study constructs a subsidy strategy model of online cab platform considering cab behavior. First, we analyze the basic characteristics of the pricing mechanism of the net booking platform and the cab cruising behavior, and establish the benefit matrix of the net booking platform, the cab company and the passengers. Second, the evolution path of the three-party strategy selection is described by replicating the dynamic equation, and the stability of the evolution equilibrium point is judged by using the Jacobi matrix. Further, MATLAB simulation is used to analyze the price change trend and profit change under different scenarios, and explore the competition and synergy evolution law between cabs and net taxis under the order overflow condition.

II. Theoretical and modeling foundations

With the advancement of smartphone technology, smartphone-based e-applications are developing rapidly around the globe, and net rides have emerged. Users in many cities of China's online taxi platform, providing more aspects of fast mobile travel services. The rapid development of online taxi has formed a huge impact on the traditional operating industry, and the external environment of passenger cab fare control has undergone a fundamental transformation. Therefore, on the basis of considering the cab cruising behavior, rationalizing the price formation mechanism of online taxi and establishing the pricing strategy of online taxi platform are conducive to giving full play to the leverage of tariff regulation in the relationship between supply and demand in the online taxi transportation market.

II. A. Pricing Strategies and Taxi Behavior of Online Rental Car Platforms

II. A. 1) Pricing Strategies for Online Rental Cars

The main element of the operation of online car rental platforms is to balance supply and demand. For this purpose, it is necessary for online car rental platforms to analyze the behaviors of passengers and drivers, and then develop appropriate operational strategies for research and so on. The net taxi market is a typical bilateral market, in which the platform makes decisions on price and wages at the same time. The net taxi platform can adjust the demand through the price decision and influence the supply of drivers through the wage decision. With the in-depth research on platform pricing strategies, two branches, dynamic pricing and static pricing, have emerged.

(1) Dynamic Pricing Strategy

In order to better solve the problem of the dynamics of supply and demand, in the operation of online taxi platforms, dynamic pricing is manifested in the automatic adjustment of ride fees according to the real-time number of vehicles supplied and the demand of passengers at different time periods (e.g., during the peak period of commuting, in bad weather, after large-scale activities, etc.), in different geographic locations (e.g., in crowded places such as airports, railway stations, etc.), or in the event of special events. Relevant studies show that the optimal dynamic pricing curve changes dynamically with the market demand rate, and the adoption of this dynamic pricing strategy can effectively reduce order delays during peak periods.

(2) Static Pricing Strategy

Static pricing is a pre-set, relatively fixed pricing model, which does not change with the immediate changes in market supply and demand conditions. In reality, under the static pricing strategy, the cost of online car service is usually calculated based on the starting price, mileage fee and hourly fee, and the charge remains stable for a certain period of time, without being affected by the high or low demand for cars or the tightness of the vehicle supply in a specific period of time.

(3) Other pricing strategies

In addition, other pricing strategies are key indispensable tools in the competition and management of the online car rental market, which directly affect the market and the realization of the platform's operational objectives. By implementing a reasonable pricing strategy, the platform can effectively adjust the relationship between supply and demand, thus accomplishing the corresponding management objectives.

II. A. 2) Taxi cruising behavior

The current mode of finding passengers for cabs is usually based on historical experience of cruising, but scholars believe that this type of matching mode is less efficient. While cruising cab drivers are able to subjectively and actively avoid areas with poor traffic conditions, at the same time, instant roadside pickup also reduces the time and distance cost of picking up passengers compared to using a platform. Therefore, the study of the influence factors of cab passenger-seeking is an important way to explore how to improve the efficiency of cab cruising.

Cab passenger-seeking behavior is mainly affected by the driver's personal factors and external factors, and some researchers have used the matrix decomposition method to analyze the cab operation mode in depth, and revealed that each driver has his or her unique inertia operation area. Some researchers also started from the personal characteristics of cab drivers and studied their daily cruising behavior in depth. The results show that cruising drivers combine their personal habits with the frequent time and location of carrying passengers. Some scholars, on the other hand, look at external factors to study cab cruising behavior. Some researchers found that factors such as the probability of a cab cruising empty to carry a passenger, the effectiveness of the passenger source, the cost of the passenger-seeking path, and the state of the road traffic all affect cab passenger-seeking behavior. Some researchers calibrated the influencing factors using the MNL model, and the study showed that the empty time as well as the expected waiting time for passengers in the target area had a significant effect on the driver's passenger-seeking behavior. Some researchers have also shown that the impact of travel time in the process of passenger seeking is greater than the impact of travel distance by analyzing the driver's frequent path type, and the impact of factors such as land use, traffic condition and road class and driving experience on the cruising area of an unladen vehicle has been analyzed by using the zero-inflated negative binomial model, and it is found that external factors have a more significant impact on the choice of cruising position of cabs compared to the internal factors.

II. B. Relevant theoretical modeling foundations

II. B. 1) Bilateral market theory

Bilateral market means that two groups of participants need to trade through an intermediary platform and the return of one party determines the number of participants of the other party. There are three distinctive features of bilateral markets i.e. network externalities, asymmetry in price structure, and complementarities [24].

(1) Cross network externalities. The network externality in a bilateral market is a cross network externality, cross network externality means that the number of users on one side will affect the utility of users on the other side. Cross-network externality is an important condition for judging whether the market is a bilateral market. For example, the shared mobility market as a typical bilateral market, the number of passengers on a particular online taxi platform positively affects the utility of drivers, and the same number of drivers positively affects the utility of passengers.

(2) Asymmetry of prices. The conclusion of a transaction in the shared mobility market involves three parties: the online car, the driver and the passenger. Due to the existence of large cross-network externalities in the shared mobility market, when the network car platform subsidizes the passengers, it can charge a larger proportion of the driver's commission, so that the passengers will lead to an increase in the scale due to an increase in utility, and an increase in the scale of the passengers due to cross-network externalities will also increase the utility of the driver. From the above analysis, it can be seen that the price structure of the online taxi platform needs to be rationally distributed among different users in the bilateral market, so the prices charged to different users on the bilateral platform are asymmetric.

(3) Interdependence and complementarity. The buyer in the bilateral market has a demand for the products and services provided by the seller in the platform, and similarly, the seller has a demand for the products and services

of the buyer in the platform. The products and services of the platform enterprise have value only when the bilateral users have demand for the products and services provided at the same time, otherwise, only one party has demand or both parties have no demand, then the products and services of the platform enterprise will not have value [25].

To sum up, as a typical bilateral market, the net car platform connects the two main bodies of passengers and drivers on the platform, and passengers and drivers conduct transactions through the net car platform, so this paper constructs a model based on the bilateral market theory to study the subsidy problem under the net car platform.

II. B. 2) Game Theory Models

Evolutionary game theory is based on the assumption of complete rationality of participants, which is more in line with the actual decision-making behavior based on the assumption of limited rationality of participants. Evolutionary stable strategy, replication dynamics and evolutionary game equilibrium are the three basic concepts of evolutionary game theory, which are crucial to the construction and solution of the model in this paper, and are briefly introduced in the following.

(1) Evolutionary stabilization strategy

Evolutionary stabilization strategy is a stable strategy achieved by the group through continuous learning and adjustment. This strategy is the best choice made by the group in the external environment, and it is the first choice of many individuals. Evolutionary stabilization strategy is resistant to changes in the external environment, and it will not change with very small fluctuations in the external environment [26].

An evolutionarily stable strategy is specifically defined by assuming that the strategy x is the survival strategy for a given population, however, due to changes in the natural environment and other factors, a mutation strategy y emerges. Let the number of individuals that appear to be mutated as a proportion of the total be ε, $\varepsilon \in (0,1)$, then the proportion of individuals that do not appear to be mutated is $1-\varepsilon$. When these individuals are constantly competing for survival, u represents the gains that can be made when competing with different strategies, assuming that there exists $\bar{\varepsilon}_y, \bar{\varepsilon}_y \in (0,1)$ such that the following inequality:

$$u[x, \varepsilon y + (1-\varepsilon)x] > u[y, \varepsilon y + (1-\varepsilon)x] \tag{1}$$

Eq. (1) holds constant for all $\varepsilon \in (0, \bar{\varepsilon}_y)$, then x is said to be an evolutionarily stable strategy.

(2) Replication dynamics equation

The replication dynamics equation describes the rate of change in the number of individuals in a population adopting a mutation strategy, and it is defined as follows:

$$F(x) = \frac{dx_i}{dt} = [u(s_i, x) - u(x, x)]x_i \tag{2}$$

where t is time, s_i is the set of choice strategies, x_i is the proportion of individuals choosing the set of strategies s_i at a given moment in time, $u(s_i, x)$ is the expected payoff of choosing the pure strategy s_i, and $u(x,x)$ is the average expected payoff of the group.

(3) Evolutionary game equilibrium

The evolutionary game equilibrium is the replicated dynamic equation of the command system equal to 0. Then:

$$\frac{dx_i}{dt} = [u(s_i, x) - u(x, x)]x_i = 0 \tag{3}$$

If there exists a solution x^* to the above equation, then x^* is referred to as the equilibrium point of the system.

For a replicated dynamic equation there may be more than one equilibrium point, but not all equilibrium points are stable state points, therefore, the state stability of each equilibrium point needs to be further tested. When the equilibrium point satisfies the condition $F'(x^*) < 0$, then the equilibrium point x^* is said to be the stable state point of the evolutionary game model [27].

III. Models of competing relationships that take into account the conduct of cabs

As one of the modes of short- and medium-distance travel, cabs are both a substitute for private cars and an effective supplement to public transportation. After the third-party Internet shared travel service platform initially entered the public's field of vision, according to the supply and demand matching mode, the net car net car to attract private car owners to join the platform, creating a new type of employment opportunities, alleviate the “difficult to get a taxi” problem. At the same time, the network car threatened the cab market share and cab drivers and other industry-related subjects of interest, competition conflicts intensified. How to consider the impact of cab behavior on the construction of subsidy strategy of online taxi platforms in the case of overflow of orders from online taxi platforms is the key to further realize the equilibrium between the evolution of cabs and online taxis.

III. A. Pricing Strategy Model for Online Rental Car Platforms

III. A. 1) Problem description and model assumptions

The research in this paper is based on a dual-channel supply chain consisting of a group of service providers, a cab company, and an online taxi platform, where the group of service providers consists of the registered drivers of the online taxi platform and the cab drivers of the cab company. The structure of the dual-channel supply chain is shown in Figure 1. In the supply chain formed in the forward direction, the service provider group picks up and drops off passengers through the platform or the cab company at a certain service and cost; in the supply chain formed in the reverse direction, the passengers pay the online taxi platform or the cab company according to the agreed price, and the platform or the company in turn pays the wages due to the service provider group to ensure a smooth trip for the passengers.

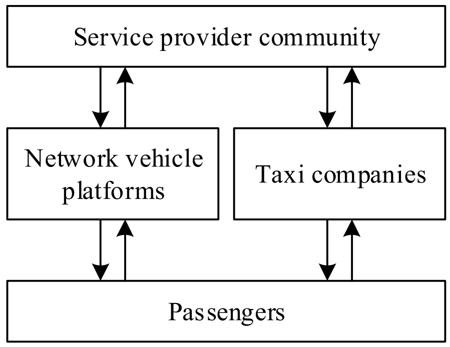


Figure 1: Dual-channel supply chain structure

When the group of service providers chooses to cooperate with the online taxi platform, assuming that only the effect of the service level s is considered, the passengers will have a certain evaluation εs on the quality of their service, and only when there are more favorable comments, the number of orders will be higher. After delivering the passenger to the destination, the passenger will pay the fee p_t according to the platform's pricing, and at the same time, the platform will pay the service provider a corresponding salary βw. When the group of service providers chooses to join the cab company, the company's expenditure on their management training or other expenses are considered as unit cost c_m. Similarly, passengers are required to pay fares at a specified price p_m, and the company is required to pay the service providers their fair share of wages w. But whichever party the service provider group chooses to work with, it needs to pay a unit cost of c_o.

The demand functions of the cab company and the online car platform are respectively:

$$q_m = a - p_m + bp_t \tag{4}$$

$$q_t = a - p_t + bp_m + \varepsilon s \tag{5}$$

And the total service cost that the online taxi platform needs to pay in the end is $s^2/2$, which mainly includes the platform's own operation service, staff training and management, and other various costs. And as shown by the survey, the wages paid to service providers by cab companies are generally higher than those paid to service providers by online taxi platforms, i.e. $0 < \beta \le 1$.

According to the parameter settings, the assumptions of the model are as follows:

(1) Both the online taxi platform and the cab company are risk-neutral and fair-neutral, and are fully rational decision makers.

(2) The platform and the company are engaged in a complete information dynamic game, with the cab company as the leader and the online taxi platform as the follower.

Based on the above parameters and assumptions, the profits of the online taxi platform, the cab company and the service provider group can be obtained, respectively, as follows:

$$\pi_t = (p_t - \beta w)(a - p_t + bp_m + \varepsilon s) - \frac{1}{2}s^2 \tag{6}$$

$$\pi_m = (p_m - w - c_m)(a - p_m + bp_t) \tag{7}$$

$$\pi_o = [(\beta w + w) - c_o](q_m + q_t) \tag{8}$$

III. A. 2) Revenue matrix construction

By integrating the relevant assumptions and parameter meanings in the previous paper, the payoff matrix of the two-party evolutionary game model of online taxi (OCH) and touring cab (TTS) is first established. On this basis, the passenger subject is introduced, and the gain matrix of the three parties when the passenger chooses the monitoring strategy is shown in Table 1.

Table 1: The tripartite group revenue matrix during passenger supervision

-		TTS	
		Cooperation	Competition
OCH	Cooperation	$B_1+l_1-C_1+V_1$, $B_2+l_2-C_2+V_2$, $S-C_3$	$B_1+l_1'-C_1+V_1+\partial_{12}$, $B_2+\varepsilon_{12}+V_2'+\Delta B_2$, $S'-C_3'$
	Competition	$B_1+\Delta B_1+\varepsilon_{21}+V_1'$, $B_2+l_2'-C_2+V_2+\partial_{21}$, $S'-C_3'$	$B_1+\Delta B_1+V_1'$, $B_2+\Delta B_2+V_2'$, $S''-C_3''$

where V_1 and V_2 represent the revenue impacts of passengers adopting the monitoring strategy on net taxis and cruisers respectively when net taxis and cruisers respectively adopt the cooperative strategy, which is mainly determined by the cost of improving the quality of service, and the inflow of new passengers attracted by the improvement of the quality of service, and other factors. Similarly V_1' , V_2' are the revenue impacts of the monitoring strategy on the network car and the cruiser respectively when the competitive strategy. S , S' , and S'' are the combined passenger gains in terms of service quality and travel convenience when the set of net-taxi and cruise strategies are (cooperation, cooperation), (cooperation, competition), or (competition, cooperation), (competition, competition), respectively, and when the net-taxi and the cruise are forced to take actions to improve the quality of the service due to passenger supervision. C_3 , C_3' , and C_3'' are the economic costs of travel for passengers when the set of strategies of net rides and cruisers is (cooperation, cooperation), (cooperation, competition), or (competition, cooperation), (competition, competition), respectively. In real life, in the case where the online taxi group and the cruiser group agree on a cooperative strategy, the two parties also agree in pricing, and in the case where both adopt a competitive strategy, the two parties may take measures to reduce prices to attract passengers in order to capture the market share, so that in general $C_3 > C_3' > C_3''$.

The benefit matrices of the three when passengers adopt unsupervised strategies are shown in Table 2. Where ΔS , $\Delta S'$, and $\Delta S''$ are the combined gains in terms of service quality and convenience of passenger travel when the set of strategies of net and cruiser is (cooperation, cooperation), (cooperation, competition), or (competition, cooperation), (competition, competition), respectively. Generally $\Delta S < S$, $\Delta S' < S'$, $\Delta S'' < S''$, and $\Delta S'' < S''$, and similarly ΔC_3 , $\Delta C_3'$, and $\Delta C_3''$ are the cost of traveling corresponding to the above strategies.

Table 2: The tripartite group revenue matrix when passengers are not supervised

-		TTS	
		Cooperation	Cooperation
OCH	Cooperation	$B_1+l_1-C_1$, $B_2+l_2-C_2$, $\Delta S-\Delta C_3$	$B_1+l_1'-C_1$, $B_2+\varepsilon_{12}+\Delta B_2$, $\Delta S'-\Delta C_3'$
	Competition	$B_1+\Delta B_1+\varepsilon_{21}$, $B_2+l_2'-C_2$, $\Delta S'-\Delta C_3'$	$B_1+\Delta B_1$, $B_2+\Delta B_2$, $\Delta S''-\Delta C_3''$

III. B. Pricing strategy model stabilization point solution method

III. B. 1) Replicated Dynamic Equation Construction

Suppose the proportion of ride-hailing vehicles choosing the "cooperation" strategy is $x\left(x\in[0,1]\right)$, and the proportion choosing the "competition" strategy is $1-x$. The proportion of traditional taxis choosing the "cooperation" strategy is $y\left(y\in[0,1]\right)$, and the proportion choosing the "competition" strategy is $1-y$. The proportion of passengers choosing the "supervised" strategy is $z\left(z\in[0,1]\right)$, and the proportion choosing the "unsupervised" strategy is $1-z$.

For network about car, adopt the strategy of "cooperation" expected revenue of $u_1^{(1)}$, adopt the strategy of "competition" expected revenue of $u_1^{(2)}$, average income of $\overline{u}_1$, Then the expected revenue and the average revenue of the group for online car-hailing vehicles adopting the "cooperation" and "competition" strategies are respectively:

$$\begin{aligned} u_1^{(1)} &= [y(I_1+\Delta I_1-C_1-C_z+B)+(1-y)(I_1+\Delta I_1'-C_1-C_z+B)]z \\ &+[(I_1+\Delta I_1-C_1)y+(I_1+\Delta I_1'-C_1)(1-y)](1-z) \end{aligned} \tag{9}$$

$$\begin{aligned} u_1^{(2)} &= [y(I_1+\varepsilon_{21}-C_z)+(1-y)(I_1-C_z)]z \\ &+[y(I_1+\varepsilon_{21})+(1-y)I_1](1-z) \end{aligned} \tag{10}$$

$$\overline{u}_1 = xu_1^{(1)}+(1-x)u_1^{(2)} \tag{11}$$

From the important elements of evolutionary game theory, the dynamic equation for the replicator of Netflix can be obtained as:

$$\frac{dx}{dt}=x(u_1^{(1)}-\bar{u}_1)=x(1-x)[\Delta I_1'-C_1+y(\Delta I_1-\varepsilon_{21}-\Delta\Delta I_1')+Bz] \tag{12}$$

For traditional cabs, the expected return from adopting the "cooperative" strategy is $u_2^{(1)}$, the expected return from adopting the "competitive" strategy is $u_2^{(2)}$, and the average return is $\bar{u}_2$, the expected return and the group average return of traditional cabs adopting "cooperative" and "competitive" strategies are respectively:

$$\begin{aligned}u_2^{(1)}&=[x(I_2+\Delta I_2-C_2+L)+(1-x)(I_2+\Delta I_2'-C_2+L)]z\\&+[x(I_2+\Delta I_2-C_2+L_1)+(1-x)(I_2+\Delta I_2'-C_2+L_1)](1-z)\end{aligned} \tag{13}$$

$$\begin{aligned}u_2^{(2)}&=[x(I_2+\varepsilon_{12})+(1-x)I_2]z\\&+[x(I_2+\varepsilon_{12}+L_1)+(1-x)(I_2+L_1)](1-z)\end{aligned} \tag{14}$$

$$\bar{u}_2=yu_2^{(1)}+(1-y)u_2^{(2)} \tag{15}$$

The dynamic equation for the replicator of a conventional cab can be obtained from the important elements of evolutionary game theory as:

$$\frac{dy}{dt}=y(u_2^{(1)}-\bar{u}_2)=y(1-y)\left[\Delta I_2'-C_2+x(\Delta I_2-\varepsilon_{12}-\Delta I_2')+Lz\right] \tag{16}$$

For passengers, adopt the strategy of "regulation" expected revenue of $u_3^{(1)}$, adopt the strategy of "no regulation" expected revenue of $u_3^{(2)}$, the average income of $\bar{u}_3$, Then the expected benefits and the average group benefits of passengers adopting the "regulated" and "unregulated" strategies are respectively:

$$\begin{aligned}u_3^{(1)}&=[x(F_1-M-B-L)+(1-x)(F_3-M-L)]y\\&+[x(F_2-M-B)+(1-x)(F_4-M-C)](1-y)\end{aligned} \tag{17}$$

$$\begin{aligned}u_3^{(2)}&=[x(F_5-L_1)+(1-x)(F_7-L_1)]y\\&+[x(F_6-L_1)+(1-x)(F_8-C-L_1)](1-y)\end{aligned} \tag{18}$$

$$\bar{u}_3=zu_3^{(1)}+(1-z)u_3^{(2)} \tag{19}$$

The replicator dynamic equation for passengers can be obtained from important elements of evolutionary game theory:

$$\frac{dz}{dt}=z(u_3^{(1)}-\bar{u}_3)=z(1-z)[L_1-M-\alpha C_z-Bx-Ly] \tag{20}$$

The associative replicator dynamics equations yield a three-dimensional dynamical system that depicts the evolutionary dynamics equations for the passenger group, the group of online taxi companies, and the group of traditional cab companies. To wit:

$$\begin{cases}\dfrac{dx}{dt}=x(u_1^{(1)}-\bar{u}_1)=x(1-x)\left[\Delta I_1'-C_1+y(\Delta I_1-\varepsilon_{21}-\Delta I_1')+Bz\right]\\[2mm]\dfrac{dy}{dt}=y(u_2^{(1)}-\bar{u}_2)=y(1-y)\left[\Delta I_2'-C_2+x(\Delta I_2-\varepsilon_{12}-\Delta I_2')+Lz\right]\\[2mm]\dfrac{dz}{dt}=z(u_3^{(1)}-\bar{u}_3)=z(1-z)\left[L_1-M-\alpha C_z-Bx-Ly\right]\end{cases} \tag{21}$$

III. B. 2) Model stabilization point solution

Based on the previously constructed system of replicated dynamic equations, which describes the group dynamics of the players of the game, the speed and direction of strategy changes between the 2 groups of drivers and passengers are shown. When the system of replicated dynamic equations are both equal to 0, the corresponding p and q values are the strategy equilibrium points. There are multiple such strategy equilibrium points, where $(1,1)$ is a pure strategy equilibrium point, (P_m,Q_m) is a mixed strategy equilibrium point, $P_m=\dfrac{v+\Delta v-\Delta d-l-\Delta l}{\Delta v-\Delta l}$, $Q_m=\dfrac{u+\Delta u-\Delta c}{\Delta u}$. The Jacobi matrix J of the game system can be expressed as:

$$J=\begin{bmatrix}a_{11}&a_{12}\\a_{21}&a_{22}\end{bmatrix}=\begin{bmatrix}\dfrac{\partial f(p,q)}{\partial p}&\dfrac{\partial f(p,q)}{\partial q}\\[2mm]\dfrac{\partial g(p,q)}{\partial p}&\dfrac{\partial g(p,q)}{\partial q}\end{bmatrix} \tag{22}$$

where a_{11} is the partial derivative of the probability p of a cab driver choosing the outbound operation strategy on the cab driver's return function $f(p,q)$, which represents the effect of the cab driver's choice of the outbound operation strategy p on his own return. Specifically:

$$a_{11} = (1-2p)(-\Delta uq + u + \Delta u - \Delta c) \tag{23}$$

a_{12} is the partial derivative of the probability q of an online taxi driver's choice of operating strategy on the cab driver's return function $f(p,q)$, which represents the impact of the cab driver's choice of the outbound operating strategy q on his own return. Specifically:

$$a_{12} = p(1-p)(-\Delta u) \tag{24}$$

a_{21} is the partial derivative of the probability p of a cab driver choosing the outbound operation strategy on the net taxi driver's gain function $g(p,q)$, which denotes the effect of the net taxi driver's choice of the outbound operation strategy p on his own gain. Specifically:

$$a_{21} = q(1-q)(\Delta l - \Delta v) \tag{25}$$

a_{22} is the partial derivative of the probability q of an online driver's choice of operating strategy on the online driver's return function $g(p,q)$, which represents the impact of the online driver's choice of outbound operating strategy q on his own return. Specifically:

$$a_{22} = (1-2q)\left[(\Delta l - \Delta v)p + v + \Delta v - \Delta d - l - \Delta l\right] \tag{26}$$

The stability of the equilibrium point of the replicated dynamic equations can be determined by analyzing the determinant $\det(J)$ and the trace $tr(J)$ of the Jacobi matrix at the equilibrium point.

IV. Simulation of a competing relationship model considering cab behavior

Cabs are passenger vehicles approved by the competent authorities to provide passenger transportation services in accordance with the needs of customers, mostly charging by mileage or time, and they undertake a significant portion of urban passenger transportation. This market is almost monopolized by cabs, however, with the increasing demand for travel, many informal operating vehicles have emerged, disrupting the originally stable cab market. In this case, with the rapid development of the Internet, the network car “came out of nowhere”, which makes the traditional cab industry into a very embarrassing situation. The convenience and speed of online taxi attracts many private car owners to join in, which creates secondary employment opportunities and alleviates the problem of “oversupply”. At the same time, the network car rapidly seized the original market share of cabs, threatening the interests of cab drivers and other related subjects, and further intensifying conflicts and competition.

IV. A. Simulation analysis of price trends

IV. A. 1) Dynamic price trends

In the case of overflow of orders from the online taxi platform, the corresponding dynamic equation system of evolutionary game is constructed with full consideration of the behavior of cruising cabs, and combined with the Jacobi matrix to obtain the optimal dynamic price of the online taxi, which contains the subsidies of the online taxi platform to the online taxi. The system of replicated dynamic equations established in the previous section, set the corresponding simulation parameters, in order to obtain the optimal dynamic price change trend of the network car as shown in Figure 2. From this figure, it can be seen that with the change of time, the optimal dynamic price of the net taxi gradually increases. When the demand for orders on the network car platform increases, raising the price can stimulate more drivers to join the platform to provide capacity for the platform on the one hand, and inhibit more passengers from joining the platform on the other hand. This price adjustment mechanism can promote the balance between supply and demand in the net taxi platform system, help reduce the opportunity loss cost of the platform, and optimize the platform's revenue.

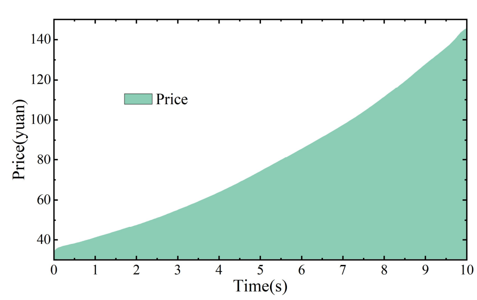
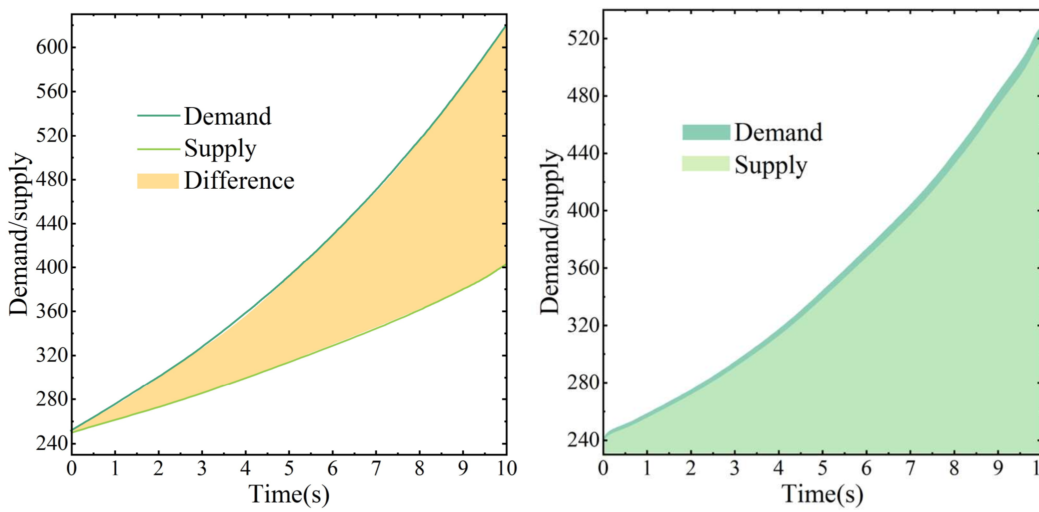


Figure 2: The trend of the price of the net

The changes in the relationship between the passenger demand and the supply of online rides under the dynamic price adjustment strategy are further explored over the course of time. Figure 3 shows the trends of supply and demand under different prices, and Figures 3(a)~(b) show the trends under static and dynamic prices, respectively.

With the change of time, the graph of quantity relationship between demand and supply under dynamic price adjustment shows that the curves of demand and supply gradually overlap and increase with the change of time. It shows that under the optimal dynamic price adjustment, the quantity demanded and the quantity supplied remain in equilibrium, and the matching quantity gradually increases. Assuming that the net taxi platform keeps the price unchanged at moment 0 and does not provide subsidies for net taxi drivers (i.e., static price strategy), it can be seen from the change in the relationship between the quantity demanded and the quantity supplied that the difference between the quantity demanded and the quantity supplied gradually increases, and the number of unmatched passengers gradually increases. The results show that when the market demand increases, the dynamic price effectively adjusts the quantity relationship between passengers and drivers in the NetJourney system. In addition, when the demand for orders on the net taxi platform increases or even overflows, the operational efficiency of the net taxi platform can be significantly improved by adopting the dynamic price strategy, which also increases the subsidy of the net taxi platform to a certain extent and optimizes the revenues of the platform and drivers.



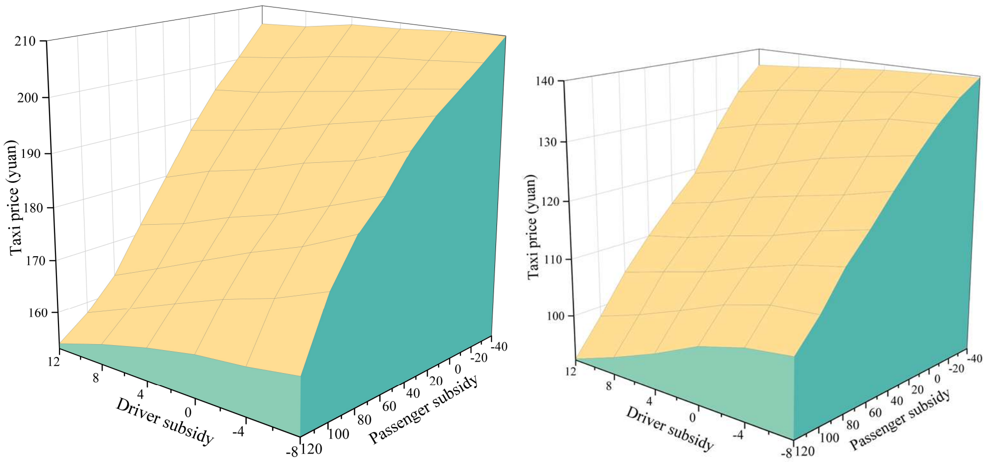
(a) Static price (b) Dynamic price

Figure 3: Trend of Supply and demand changes

IV. A. 2) Changes in taxi prices

With the support of the constructed system of replicated dynamic equations, the relevant parameters of the game model are set up in the simulation software to solve the price changes of cruising cabs under different numbers of passengers taking online taxis before traveling, respectively, in order to analyze the changes of the respective prices and profits of both sides of the game, as well as the changes of the number of passengers taking online taxis along with the platform's subsidies given to the prices of the passengers and drivers of online taxis. In the case of overflow of orders from the online taxi platform, the trend of cab price changes with the subsidy given by the platform to the driver and the subsidy given to the passenger is shown in Figure 4. Where Fig. 4(a)~(b) shows the trend of cab price changes in the case of no overflow and overflow of net taxi platform orders, respectively.

From the figure, it can be seen that firstly, the more passengers preferring to take online cabs before traveling the lower the cab pricing. This is due to the fact that the survival space of cab companies is drastically compressed when there are more passengers preferring to take online taxis before traveling, and cab companies have to take drastic measures to reduce prices to win over consumers. Second, regardless of the number of passengers who prefer to take online taxis before traveling, cab pricing achieves the minimum value when both the subsidy given by the platform to passengers and the subsidy given by the platform to online taxi drivers are larger. Cab pricing achieves its maximum value when both the platform subsidy to passengers and the platform subsidy to online taxi drivers are small. Therefore, in the case of overflow of orders from the online taxi platform, as online taxis are unable to meet passenger demand in a timely and effective manner, they can provide some support for cab price increases. In contrast, under the unsaturated market, the price of cruising cabs will be squeezed by the net taxi market, which in turn will result in the compression of cab prices and the market.



(a) Nonoverflow condition (b) Overflow condition

Figure 4: The price change of taxis

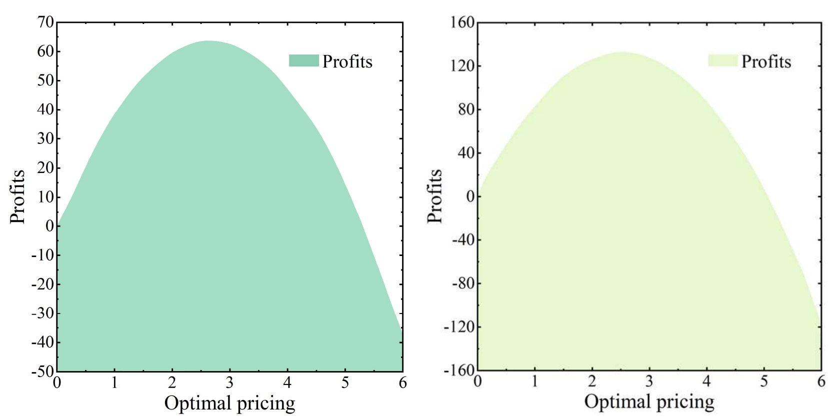
IV. B. Competitive Synergy Evolution Simulation Analysis

IV. B. 1) Changes in Profits from Different Strategies

On the basis of clarifying the price changes of online car and cab, this section will use MATLAB software to conduct a number analysis, as a way to explore the changes in cab behavior to participate in the subsidy strategy of online car platform. The relevant parameters in the model are set up, and then different types of profit changes are obtained as shown in Fig. 5, where Fig. 5(a)~(b) shows the trend of profit changes of online car and cab, respectively.

As can be seen from the figure, the profits of both online cab and cruising cab show a trend of increasing first and then decreasing with the increase in the price of their respective services, and there exists an optimal pricing to maximize their profits, and in the case of the two modes of travel services competing with each other, the increase in the price of the service on the one hand, can increase the revenue. But on the other hand, the increase of its own price will increase the passengers' willingness to choose each other's service, which will reduce its own demand, when the price's impact on the reduction of demand exceeds the impact on the growth of revenue, the profit is a declining trend. Therefore the competing parties should set appropriate service prices to achieve game equilibrium.

Before the emergence of online taxi, cruising cab has occupied a major position in the travel service market, is the leader of the competitive market, online taxi is a new way to enter the market in recent years, is the follower of the competitive market, the two form Starkelberg game. Net taxi platform as a follower its pricing strategy will change according to the pricing of the cruising cab, as the price of the cruising cab service increases, the net taxi platform will also increase the pricing appropriately, on this basis to give the platform subsidies to the net taxi drivers, thus enhancing the competitiveness of the net taxi.

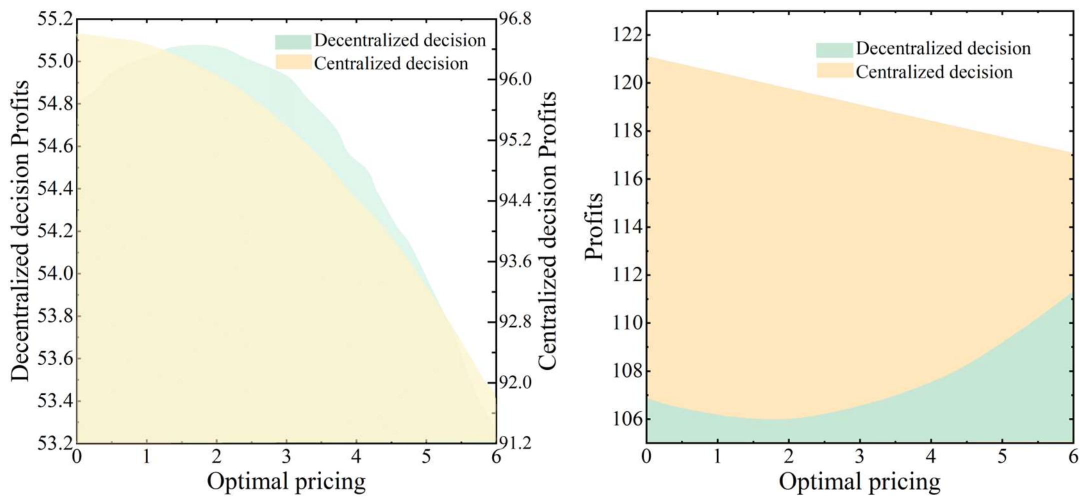


(a) Network profit (b) Taxi profit

Figure 5: The changes in different types of profits

On this basis, this paper further analyzes the change of profits of online taxis and cruising cabs with optimal pricing strategies under two kinds of decisions (decentralized and centralized). Figure 6 shows the results of profit comparison under different decisions, in which Figures 6(a)~(b) show the results of profit comparison between online taxi and cruising cab, respectively.

From Fig. 6(a), it can be seen that the profit of online taxi when the optimal pricing strategy under decentralized decision-making is used increases firstly and then decreases with the improvement of the platform's service quality, and improving the service quality of online taxi can increase the differentiation between the online taxi service and the cruising cabs, so that the passengers' willingness to choose the online taxi increases, which increases the demand for the online taxi platform. But on the other hand, improve the service quality at the same time the service price of online taxi also increased, the increase in demand and price increase at the same time affect the platform profit, online taxi profit with the increase in service price first increased and then decreased, the two factors affect each other so that online taxi profit with the improvement of service quality first increased and then decreased trend. Under centralized decision-making net car profit decreases with the improvement of service quality. This is because the optimal pricing of net booking under centralized decision-making is not affected by the service quality, but improving the service quality needs to invest a certain cost, which makes the profit decrease. Comparing the two curves, it can be seen that the expected profit of net booking under decentralized decision-making is smaller than the expected profit under centralized decision-making. From Figure 6(b), it can be seen that under decentralized decision-making, the profit of cruising cabs decreases first and then increases with the improvement of the service quality of net taxis, while under centralized decision-making, it decreases monotonically with the service quality of net taxis, and the change of profit is consistent with the change of service price, which can be seen that the expected profit of cruising cabs under decentralized decision-making is smaller than the expected profit under centralized decision-making.

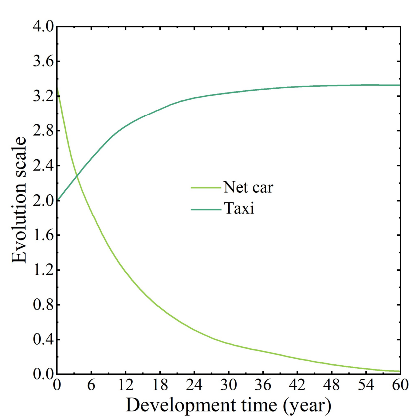


(a) Network profit (b) Taxi profit

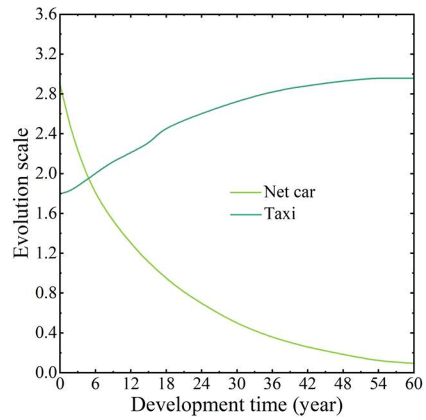
Figure 6: Profit comparison under different decisions

IV. B. 2) Competitive Synergy Evolutionary Patterns

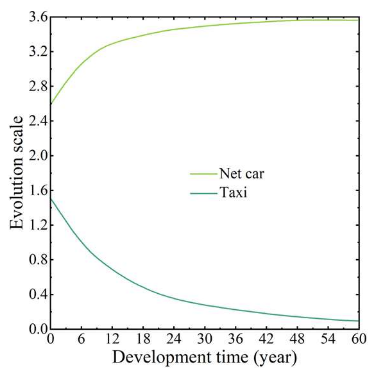
In the competitive environment, fully considering the coefficients of competitive and cooperative influence effects on cabs and online taxis in the previous section, the evolution law under different model parameters is simulated and analyzed using MATLAB software, and the simulation results are shown in Fig. 7. In Fig. 7(a)~(d), when one party is more competitive, it is enough to rule the whole market and eliminate the other party, although this evolution law is also satisfied in the competitive environment, but because of the existence of a certain degree of cooperation with each other, the demise of the inferior party will be greatly delayed. In Fig. 7(e)~(f), compared with the competition simulation results, when the competition between net cabs and cabs is more moderate, together with the cooperation between them, they have more room for development, but they will not exceed the size thresholds of urban net taxis and cabs, and the time for both of them to reach a stable state will be delayed. Compared to the results of the cooperative simulation, the size of net rides and cabs is somewhat constrained. Overall, there is an obvious competition and cooperation synergy effect between net cabs and cabs, which shows the trend of both sides, which requires the net taxi platform to subsidize the strategy for net taxi drivers to a certain extent, so as to better meet the profit demand of net taxi drivers. And cab behavior can significantly affect the development of subsidy strategy for the net taxi platform, but also for the passenger travel to produce a certain degree of influence.



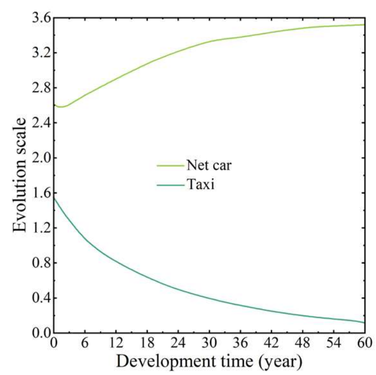
(a) $a_{11}=1.2, a_{12}=0.6$
$a_{21}=0.5, a_{22}=0.5$



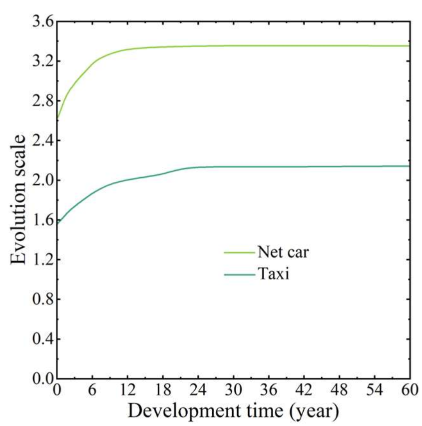
(b) $a_{11}=1.0, a_{12}=0.8$
$a_{21}=0.2, a_{22}=0.2$



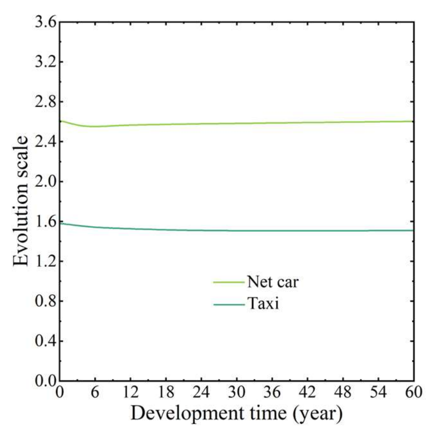
(c) $a_{11}=0.6, a_{12}=1.2$
$a_{21}=0.5, a_{22}=0.5$



(d) $a_{11}=0.8, a_{12}=1.0$
$a_{21}=0.2, a_{22}=0.2$



(e) $a_{11}=0.3, a_{12}=0.6$
$a_{21}=0.5, a_{22}=0.5$



(f) $a_{11}=0.5, a_{12}=0.8$
$a_{21}=0.5, a_{22}=0.5$

Figure 7: Co-evolution curve of co-opetition

V. Conclusion

In the case of overflow of orders from the online cab platform, the study on the subsidy strategy of the online taxi platform considering cab behavior draws several important conclusions. First, under the dynamic price adjustment strategy, the net taxi price gradually increases over time, which can effectively balance the supply and demand relationship, so that the demand and supply curves gradually overlap, the matching volume rises steadily, and the platform operational efficiency is significantly improved. Secondly, cab prices are significantly higher under the order overflow condition than the no-overflow case, and cab pricing reaches the highest level when both the platform's subsidy to passengers and the subsidy to online taxi drivers are small, and vice versa at the lowest level. In addition, the profits of both online taxis and cabs under decentralized decision-making are lower than those under centralized decision-making, and the profits show a tendency of increasing and then decreasing with the increase of their respective service prices. Finally, there are obvious synergistic effects between the two parties in the competitive environment. When the competition intensity is moderate, NetJets and cabs can coexist stably, but when one party's competitiveness is significantly larger than the other, the inferior party will be eliminated by the market gradually, and the cooperative relationship can only slow down this process. Therefore, online taxi platforms should dynamically adjust their subsidy strategies according to market demand, promote reasonable competition and effective cooperation with the cab industry, and achieve optimal allocation of resources and improvement of service quality.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research was supported by the National Social Science Foundation of China (23BGL008).

References

[1] Jiang, H., & Zhang, X. (2019). An experimental model of regulating the sharing economy in China: The case of online car hailing. Computer Law & Security Review, 35(2), 145-156.
[2] Jin, R., & Chen, K. (2020). Impact of value cocreation on customer satisfaction and loyalty of online car-hailing services. Journal of theoretical and applied electronic commerce research, 16(3), 432-444.
[3] Taylor, T. A. (2024). Shared-ride efficiency of ride-hailing platforms. Manufacturing & Service Operations Management, 26(5), 1945-1961.
[4] Carballa Smichowski, B. (2018). Is ride-hailing doomed to monopoly? Theory and evidence from the main US markets. Revue d'économie industrielle, (162), 43-72.
[5] Heeks, R., Gomez-Morantes, J. E., Graham, M., Howson, K., Mungai, P., Nicholson, B., & Van Belle, J. P. (2021). Digital platforms and institutional voids in developing countries: The case of ride-hailing markets. World Development, 145, 105528.
[6] Bi, H., Ye, Z., Wang, C., Chen, E., Li, Y., & Shao, X. (2020). How built environment impacts online car-hailing ridership. Transportation research record, 2674(8), 745-760.
[7] Fielbaum, A., & Tirachini, A. (2021). The sharing economy and the job market: the case of ride-hailing drivers in Chile. Transportation, 48(5), 2235-2261.
[8] Bi, S., Wang, L., Liu, S., Zhang, L., & Yuan, C. (2023). Identification of Urban Jobs–Housing Sites Based on Online Car-Hailing Data. Sustainability, 15(2), 1712.
[9] Gu, T., Xu, W., Shi, P., Wang, R., & Kim, I. (2024). Taxi in competition with online car-hailing drivers: policy implication to operating strategies. Multimodal Transportation, 3(2), 100129.
[10] Lyu, T., Wang, P. S., Gao, Y., & Wang, Y. (2021). Research on the big data of traditional taxi and online car-hailing: A systematic review. Journal of Traffic and Transportation Engineering (English Edition), 8(1), 1-34.
[11] Wang, Z., & Li, S. (2024). Competition between autonomous and traditional ride-hailing platforms: Market equilibrium and technology transfer. Transportation Research Part C: Emerging Technologies, 165, 104728.
[12] Zhang, K., & Nie, Y. M. (2021). Inter-platform competition in a regulated ride-hail market with pooling. Transportation Research Part E: Logistics and Transportation Review, 151, 102327.
[13] Yan, C., Zhu, H., Korolko, N., & Woodard, D. (2020). Dynamic pricing and matching in ride-hailing platforms. Naval Research Logistics (NRL), 67(8), 705-724.
[14] Zhang, Q., Liu, Y., & Fan, Z. P. (2023). Short-term subsidy strategy for new users of ride-hailing platform with user base. Computers & Industrial Engineering, 179, 109177.
[15] You, J., Jiang, H., Chen, Z., Ming, X., & Sun, P. Z. (2023). Order allocation strategy for online car-hailing platform in the context of multi-party interests. Advanced Engineering Informatics, 57, 102110.
[16] Tang, W., Xie, N., Mo, D., Cai, Z., Lee, D. H., & Chen, X. M. (2023). Optimizing subsidy strategies of the ride-sourcing platform under government regulation. Transportation Research Part E: Logistics and Transportation Review, 173, 103112.
[17] Zhou, C., Li, X., & Chen, L. (2024). Impact of negotiation on subsidy scheme to incentivise the integrated use of metro and ride-hailing services. International Journal of Logistics Research and Applications, 27(10), 1870-1890.
[18] Feng, H., Feng, N., Zhang, L., Jiang, Z., & Li, M. (2025). A Study of Ride-Hailing Platforms' Business Models in the Presence of Surge Demand. Information Systems Research.

[19] Xu, Y., Ling, L., Wu, J., & Xu, S. (2024). On-demand ride-hailing platforms under green mobility: Pricing strategies and government regulation. Transportation Research Part E: Logistics and Transportation Review, 189, 103650.

[20] Xia, Y., Qian, W., Ji, C., & Fan, J. (2025). Subsidy Strategies of Ride-Hailing Platforms Considering Taxi Street-Hailing during Order Overflow. J. COMBIN. MATH. COMBIN. COMPUT, 127, 7331-7349.

[21] Xu, M., & Bansal, P. (2023). Surge pricing and consumer surplus in the ride-hailing market: Evidence from China. Travel Behaviour and Society, 33, 100638.

[22] Battifarano, M., & Qian, Z. S. (2019). Predicting real-time surge pricing of ride-sourcing companies. Transportation Research Part C: Emerging Technologies, 107, 444-462.

[23] Castillo, J. C., Knoepfle, D., & Weyl, E. G. (2024). Matching and pricing in ride hailing: Wild goose chases and how to solve them. Management Science.

[24] Lin Junjie,Zhang Qun & Wei Yuanzhu. (2022). Pricing Strategy and Simulation of Forest Rights Exchange Centers Based on the Two-Sided Market Theory. Mathematical Problems in Engineering,2022.

[25] Kim Gyuseung,Wang Wei & Ha Hun-Koo. (2021). Pricing strategy for own shipping service of E-commerce platform using Two-sided market theory. Electronic Commerce Research and Applications,49.

[26] Wenxuan Song,Ehsan Elahi,Guisheng Hou & Pengmin Wang. (2025). Collaborative governance for urban waste management: A case study using evolutionary game theory. Sustainable Cities and Society,126,106380-106380.

[27] Xiqiang Xia,Zhaohan Huang,Jiahui Jia,Wei Wang,Zhongze Wang,Yanpei Cheng & Jiangwen Li. (2025). The PPP projects for rural residential environment: An evolutionary game model from the synergy perspective of rural enterprises. Expert Systems With Applications,281,127433-127433.