Research Article
Does Policy Matter in Carsharing Traveling? Evolution Game Model-Based Carsharing and Private Car Study

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As an alternative trip mode to the private car, carsharing mode first emerged in Europe in the 1940s. Although it possesses many merits such as convenience, affordability, and comfort, its development is far slower than the private car in recent years. Identifying the factors affecting the users' choice between carsharing and private car is becoming very important. This paper proposes an evolution game model to explore the competitive choice process between carsharing and private car under different government policies. First, an evolution game model with incomplete information is developed to analyze the travel choice of carsharing over private car. Then, the evolutionary stable strategy solution of the model is derived from replicator dynamics, and a discussion about the stable condition is presented. Finally, a case study is conducted to validate the proposed model. This study provides a rationale for agencies to improve the current carsharing choice rate between carsharing and private car.

1. Introduction

With the accelerated urbanization process in China in the past few decades, the number of private cars surges, reaching 207 million by 2019 (Figure 1(a)) [1]. Emerging issues such as traffic congestion and parking difficulty are recognized as threats to the development of the cities [2–7]. Carsharing is a mobility option similar to personal vehicle ownership and first emerged in Europe in the 1940s in the form of a local business. Carsharing vehicles are mostly electricity driven and generally distributed throughout urban neighborhoods and city centers. As an alternative trip mode to the private car, carsharing is on the rise in different countries and cities, thanks to the merits such convenience and cheap price [8–10]. According to a statistic from Beijing Municipal Commission of Transport, the number of carsharing bookings (carsharing quantity of orders) has increased to 12,116 in 2016 from 95,188 in 2017, growing by more than 686%, as shown in Figure 1(b) [11]. Carsharing could bring the vehicle to achieve maximal service efficiency and share parking resources [12]. Moreover, as most carsharing vehicles are electrical, it can save energy and reduce emission [13–15]. Despite the social benefit, convenience, and flexibility of carsharing, some travelers prefer private car to carsharing [16], which limits the contribution of carsharing such as providing greater mobility at substantial savings and promoting energy and emission benefits [17, 18]. Therefore, precise and definite influence choosing factors and the mechanism of choice between carsharing and private car are of high importance. As a practical reference to macro-level policy-making, when and what policy measures shall be taken is also worth studying. These findings could promote the development of carsharing policies and increase the environmental and social gains.
The objective of this paper is to develop a model that addresses the competitive choice process between car-sharing and private car under different government policies. This paper is organized as follows: the first section introduces background; Section 2 provides a literature review of the existing early studies for car-sharing travel behavior; Section 3 describes research assumptions, model construction, solution, and analysis of the key influencing factors of the model; Section 4 presents a typical case of Beijing to illustrate the application of the proposed model; and finally, Section 5 concludes this study and suggests future research recommendations.

2. Literature Review

Analyzing carsharing travel behavior has been a challenge to researchers and practitioners. Many studies on carsharing travel behavior have been conducted since the 1940s. According to the data source, existing research on carsharing travel behavior can be categorized into two classes, namely, one class based on questionnaire data and another class based on carsharing service system data.

In the beginning, researchers qualitatively analyzed the social characteristics, the travel characteristics, and the intention characteristics of carsharing travelers through conducting questionnaires. Through analyzing survey data...
from 45 members and 76 nonmembers of the carsharing cooperative, Seik found the profile of members that revealed a mean household size of 4.1, 73% of married status, 49% from middle-income households, and 62% have never owned a car before [19]. Shaheen and Cohen comparatively analyzed carsharing travel worldwide, including similarities and differences, and provided a summary of growth trends and anticipated developments [20]. Zhou analyzed carsharing travel behaviors and personal characteristics of commuters at university in Los Angeles, California, and found that carsharing is more popular among bus commuters, university students, and female employees [21]. Through analyzing the questionnaire data of 443 older adults living in a gated community in California, Shaheen et al. examined an electric vehicle carsharing service as an alternative to private car ownership [22]. Kramer et al. analyzed user-friendliness, everyday usability, and modal integration of carsharing by using online surveys. The study revealed unique user groups whose travel patterns are multimodal and dominated by public transport [23]. Through an online survey, Firnkorn and Müller found the electrification scenario of carsharing influenced the respondents' car reduction willingness [9]. Kim et al. explored factors affecting the electric vehicle-sharing program participants' attitudes about car ownership and program participation in Seoul [16]. Through a survey campaign, Ampudia-Renuncio et al. found how the quality attributes of free-floating carsharing depend strongly on car availability and on the limit time and distance tolerated by each user to wait and walk in search of a free car [18].

Along with the development of the computer technology, scholars began to analyze carsharing travel behavior based on service system data. Morency et al. classified carsharing users according to their temporal patterns of carsharing use frequency, traveled distance, and week use variability [24]. Based on real transaction data sets, Morency et al. proposed a dynamically ordered probability model to analyze behaviors of carsharing users [25]. Kawajiri et al. used carsharing operator data to reveal the travel purpose and the typical use pattern [26]. Schmöller et al. analyzed carsharing booking data for temporal and spatial aspects. The temporal and spatial facets were combined by applying cluster analysis to identify groups of days with similar spatial booking patterns and showed asymmetries in the spatio-temporal distribution of vehicle supply and demand [27]. Combined with points of interest, Willing et al. analyzed the booking data from a carsharing company in Amsterdam to predict carsharing demand in Berlin [28]. Wielinski et al. investigated the carsharing members' behaviors over time in a free-floating system, including service usage and activity space [29]. Ampudia-Renuncio et al. designed a Web-based platform to collect operators' data in Madrid and estimated real carsharing flows, which could clearly show the prevalence of spontaneous and short-distance free-floating car-sharing trips [30].

The literature review indicates that carsharing has been highlighted. Some recognized that comparative analysis between carsharing mode and private car mode is important to carsharing development [31–35]. However, comparative studies of carsharing mode and private car mode under the influence of policies were rarely seen, which need to be further studied. In particular, numerous previous studies have indicated that travel choice is profoundly influenced by government policy [36–38].

Meanwhile, in the research field of travel choice behavior, scholars realized that travel mode choice behavior is a strategy adjustment process made by travelers based on bounded rationality, which is not completely rational [39]. Scholars began to pay attention to travel choice behavior under bounded rationality. Among these research approaches, an evolution game model is one of the most widely applied theoretical methods to analyze travel mode choice in metropolitan [40–42]. The evolution game model, a methodology developing based on evolutionary theory and game theory, is conducted on the premise of the bounded rationality, which is a long-term repetitive game within a certain size-specific group [43, 44]. Research subjects in the evolution game model are individuals with thought and calculation [43, 44], which is consistent with travel behavior. Compared with traditional models, bounded rationality theory can better describe travel decision behavior. Especially, evolutionary game theory has been proven to the applicability to traffic choice behavior analysis [45], which has adaptability in assumptions, research object, analysis method, game mode, and expected output. The evolutionary game theory provides an effective way to dynamically describe the competition optimization between carsharing and private car.

Therefore, this paper focuses on the competitive choice process between carsharing and private car under government policy by using an evolution game model, which provides government and private sectors a more precise basis for decision-making. The flow of the overall research framework is shown in Figure 2, which consists of the research steps of this paper.

3. Methodology

3.1. Research Assumptions. Carsharing is an alternative mode of transportation, which shifts private mobility from ownership to service use. Previous studies have shown carsharing could reduce the demands on private cars [46–48], which could reduce the environmental pressure of car use [48]. Therefore, if carsharing could replace more private cars, carsharing could make more contribution to sustainable cities. Normally, the carsharing can be seen as a bridge between private car trips and taxi trips. However, taxis belong to the public transport in a broad sense [49], not private cars. Besides, both private car and carsharing require travelers to have a driving license, while there are no requirements for taxi trips on driving license. Taking these aspects into consideration, this paper focuses on this kind of travelers, who make choice between carsharing and private car. Assume that this kind of travelers is confronted with choosing the carsharing or private car.

Meanwhile, travel choice is profoundly influenced by government policy [36–38]. A government policymaker is the government. Hence, the government is confronted with
whether implement policies to the traveler, which includes positive-incentive and negative-incentive.

In summary, two game players are determined: the traveler and government. Before constructing the evolution game model, some assumptions are made as follows:

Assumption 1. The traveler’s behavior is primarily a choice between carsharing and private car. The government’s behavior is primarily a choice between implement policy and not. For the traveler \((T)\), suppose the possibility of choosing carsharing is \(x\), then the possibility of choosing private car is \(1 - x\). For the government \((G)\), suppose the possibility of implementing policies is \(y\), then the possibility of choosing not to implement policies is \(1 - y\).

Assumption 2. The two players, the traveler and the government, are bounded rational players with bounded rational behaviors. The two players will adequately calculate and compare all the possible outcomes to protect their own interests and identify the strategy that can best serve these interests.

Assumption 3. When the traveler chooses a travel model, he will receive the corresponding benefit (social norm factors, sense of achievement, and so on) and pay considerable cost. Thus, assume that when the traveler chooses the carsharing and private car, he will gain the benefit, \(P_1\) and \(P_2\), respectively, and pay the cost, \(C_1\) and \(C_2\), respectively. Besides, whether the traveler chooses to travel by private car or carsharing, he would suffer some losses, such as time, comfort, and convenience losses. Because the carsharing development is in the initial stage, the ancillary facilities are incomplete, such as unreasonable station layout and lack of charging stalls. Moreover, the key technology of service platform needs further improvement. Oppositely, private cars have quite mature technologies and supporting services. Thus, if the traveler chooses the carsharing, he will suffer the losses, \(P_0\). \(P_0\) is a relative value, not an absolute value.

Assumption 4. Suppose that the government’s policy of encouraging carsharing (positive-incentive) is a retrograde mechanism, i.e., the incentive intensity decreases year by year. The majority of carsharing vehicles are electric vehicles in China. Meanwhile, the purchase subsidy of electric vehicles is a retrograde mechanism in China. So the government’s policy of encouraging carsharing (positive-incentive) is set as a retrograde mechanism in this paper. Thus, the traveler’s earning from government encourage policies is \(f(s)S\), which is given by the government. \(f(s)\) represents how the economic subsidy from the government encourages policies changes over time \(t\). Besides, \(0 < f(s) < f'(s) < 0\). If the traveler chooses to use carsharing right now, he will receive a full reward, \(S\). If the traveler chooses to use carsharing in the future, the rewards will decrease year by year. The stimulate rewards from the government subsidies will approach zero in extreme cases in the future. Oppositely, when the traveler chooses private car, he will accept punishment cost (negative-incentive) \(D\), which is given to the government, too. In addition, when the government chooses to implement policies, it will spend a certain administrative cost. Assume the administrative cost is \(A\).
Assumption 5. When the traveler chooses the carsharing, the government will obtain the social benefit, \( R_1 \). Oppositely, when the traveler chooses the private car, the government will obtain the social benefit, \( R_2 \).

Table 1 summarizes the parameters, variables, and abbreviations mentioned above to describe travel choice processes and evolution game theory.

3.2. Model Construction. Based on research assumptions, the model is constructed by analyzing the different choice processes of the traveler and government.

As shown in Figure 3, when the traveler chooses the carsharing while the government decides to implement policies, the traveler’s total interest is \( P_1 - C_1 - P_0 + f(s)S \). When the traveler chooses the carsharing while the government chooses not to implement policies, the traveler’s total interest is \( P_1 - C_1 - P_0 \). When the traveler chooses the private car while the government chooses to implement policies, the traveler’s total interest is \( P_2 - C_2 - D \). When the traveler chooses the private car while the government chooses not to implement policies, the traveler’s total interest is \( P_2 - C_2 \). As shown in Figure 3(b), when the traveler chooses the carsharing while the government chooses to implement policies, the government’s total interest is \( R_1 - f(s)A - D \). Oppositely, when the traveler chooses the private car while the government chooses to implement policies, the government’s total interest is \( R_2 + D - A \). If the government chooses not to implement policies while the traveler chooses the carsharing, the government’s total interest is \( R_1 \). When the traveler chooses the private car, the government’s total interest is \( R_2 \).

According to the above analysis, payoff bimatrix of traveler-government is constructed, as shown in Table 2.

3.3. Model Solution. According to evolution game theory [50–52], the expected payoff of the traveler chooses the carsharing is as follows:

\[
E_{t_1} = yP_1 - C_1 - P_0 + f(s)S + (1 - y)(P_1 - C_1 - P_0),
\]

which is reduced to

\[
E_{t_1} = P_1 - C_1 - P_0 + yf(s)S.
\]

The expected payoff of the traveler chooses the private car is as follows:

\[
E_{t_2} = yP_2 - C_2 - D + (1 - y)(P_2 - C_2),
\]

which is reduced to

\[
E_{t_2} = P_2 - C_2 - yD.
\]

The average expected payoff is as follows:

\[
E_t = xE_{t_1} + (1 - x)E_{t_2}.
\]

Besides, the expected payoff of the government chooses to implement policies is as follows:

\[
E_{g_1} = x(R_1 - f(t)S - D) + (1 - x)(R_2 + D - A),
\]

which is reduced to

\[
E_{g_1} = x(R_1 - R_2) + R_2.
\]

The expected payoff of the government chooses not to implement policies is as follows:

\[
E_{g_2} = xR_1 + (1 - x)R_2,
\]

which is reduced to

\[
E_{g_2} = x(R_1 - R_2) + R_2.
\]

The average expected payoff is as follows:

\[
E_g = yE_{g_1} + (1 - y)E_{g_2}.
\]

Thus, the replicator dynamics equation of the traveler is as follows:

\[
\frac{dx}{dt} = x(E_{t_1} - E_t),
\]

which is reduced to

\[
\frac{dx}{dt} = x(1 - x)[P_1 - C_1 - P_0 - (P_2 - C_2) + y(fS + D)].
\]

The replicator dynamics equation of the government is as follows:

\[
\frac{dy}{dt} = y(E_{g_1} - E_g),
\]

which is reduced to

\[
\frac{dy}{dt} = y(1 - y)[x(- f(s)S - D) + D - A].
\]

The evolutionary stable strategy (ESS) is akin to the Nash equilibrium in classical game theory, but with mathematically extended criteria [44, 50–52]. According to the replicator dynamics equation stability theorem and ESS, when \( F(x) = 0 \) and \( F'(x) < 0 \), \( x^* \) becomes ESS. Stability analysis of replicator dynamics equation of the traveler and government is conducted as follows: when

\[
F(x) = \frac{dx}{dt} = 0,
\]

then

\[
x_1^* = 0, x_2^* = 1, y^* = \frac{P_1 - C_1 - P_0 - (P_2 - C_2)}{fS + D},
\]

\[
taking the derivative
\]

\[
F'(x) = \frac{dx/dt}{dx} = (1 - 2x)[P_1 - C_1 - P_0 - (P_2 - C_2) + y(fS + D)],
\]
\[ F(y) = \frac{dy}{dt} = 0, \quad (18) \]
\[ y_1^* = 0, y_2^* = 1, x^* = \frac{D - A}{fsS + A} = 1 - \frac{fsS + A}{fsS + D}. \quad (19) \]
taking the derivative
\[ F'(y) = \frac{dx}{dt} = (1 - 2y)\{x[-f(s)S - D] + D - A\}. \] (20)

The analysis results of ESS are shown as follows:

As shown in Table 3, when \( y^* = P_2 - C_2 - (P_1 - C_1 - P_0)/fS + D \), the ESS is a certain value between 0 and 1. When \( y^* > P_2 - C_2 - (P_1 - C_1 - P_0)/fS + D \), the ESS is equal to 1. When \( y^* < P_2 - C_2 - (P_1 - C_1 - P_0)/fS + D \), the ESS is equal to 0. The corresponding replicator dynamics phase diagram is drawn, as shown in Figure 4(a). When \( x^* = D - A/fS + D \), the ESS is a certain value between 0 and 1. When \( x^* > D - A/fS + D \), the ESS is equal to 1. When \( x^* < D - A/fS + D \), the ESS is equal to 0. The corresponding replicator dynamics phase diagram is drawn, as shown in Figure 4(b).

\[ J = \begin{pmatrix} (1 - 2x)\{P_1 - C_1 - P_0 - (P_2 - C_2) + y[fS + D]\} & -x(1 - x)[fS + D] \\ -y(1 - y)[fS + D] & (1 - 2y)\{x[-f(s)S - D] + D - A\} \end{pmatrix}. \] (21)

Therefore, the determinant and trace of this Jacobian matrix in the system are as follows:

\[ \text{Det}(J) = (1 - 2x)\{P_1 - C_1 - P_0 - (P_2 - C_2) + y[fS + D]\} \times (1 - 2y)\{x[-f(s)S - D] + D - A\}, \]
\[ \text{Tr}(J) = (1 - 2x)\{P_1 - C_1 - P_0 - (P_2 - C_2) + y[fS + D]\} + (1 - 2y)\{x[-f(s)S - D] + D - A\}. \] (22)

The corresponding \( \text{Det}(J) \) and \( \text{Tr}(J) \) of the above-mentioned five equilibrium points are shown in Table 4.

If the traveler’s total interest of choosing the carsharing is greater than choosing the private car without the government policies, the traveler’s total interest of choosing the carsharing inevitably is greater than choosing the private car with the government policies. Thus, when \( P_1 - C_1 - P_0 > P_2 - C_2 \), then \( P_1 - C_1 - P_0 + fS < P_2 - C_2 - D \). Similarly, if the traveler’s total interest of choosing the carsharing is less than choosing the private car with the government policies, then the traveler’s total interest of choosing the carsharing inevitably is less than choosing the private car without the government policies. Thus, when \( P_1 - C_1 - P_0 + fS < P_2 - C_2 - D \), then \( P_1 - C_1 - P_0 < P_2 - C_2 \). Hence, the local stability analysis of this traveler-govern-ment only needs to analyze the results under conditions of \( P_1 - C_1 - P_0 > P_2 - C_2 \) and \( P_1 - C_1 - P_0 + fS < P_2 - C_2 - D \). The results are shown in Table 5.

From the stability analysis of local equilibrium points, some discussions are carried out. When \( P_2 - C_2 - (P_1 - C_1 - P_0)/fS + D < 0 \), that is \( P_1 - C_1 - P_0 > P_2 - C_2 \), it means the traveler’s total interest of choosing the carsharing is greater than choosing the private car without the government policies. At this time, no matter how powerful the government’s policies are, the traveler tends to use carsharing. And this strategy is stable. \( P_1 - C_1 - P_0 > P_2 - C_2 \) is equivalent to \( P_1 - P_0 - P_2 > C_1 - C_2 \). The inequity

3.4. Model Analysis and Discussion. Consider the strategy of traveler and government as a dynamic system: there are five local equilibrium points in the plane \( S = y(x, y)[0 \leq x, y \leq 1] \), a dynamical system consisting of replicator dynamics equation. These five local equilibrium points are \( O(0,0), A(1,0), B(1,1), C(0,1), D \) \( (D - A/fS + D, P_2 - C_2 - (P_1 - C_1 - P_0)/fS + D) \), as shown in Figure 5.

Among them, point \( (x^* = D - A/fS + D, y^* = P_2 - C_2 - (P_1 - C_1 - P_0)/fS + D) \) sets up only in case of \( x^* = D - A/fS + D > 0 \) \( \in [0,1] \), \( y^* = P_2 - C_2 - (P_1 - C_1 - P_0)/fS + D \in [0,1] \). For a group dynamic described by a differential equation system, the stability of its equilibrium point is obtained by the local stability analysis of the Jacobi matrix obtained by the system [53]. The Jacobi matrix combining formulas (17) and (20) is as follows:

\[ A \begin{pmatrix} -x(1 - x)[fS + D] & 0 \\ -y(1 - y)[fS + D] & (1 - 2y)\{x[-f(s)S - D] + D - A\} \end{pmatrix} \]

shows the traveler gets the benefit from using carsharing, \( P_1 \), minus losses when traveler chooses the carsharing, \( P_0 \), continue minus the traveler gets the benefit from using private car, that is \( P_1 - P_0 - P_2 \), should be greater than the difference between the cost of using carsharing and cost of using private car, \( C_1 - C_2 \). In this case, regardless of whether the government chooses financial incentive to the carsharing traveler or how powerful financial incentive is, or whether the government chooses to punish the private car traveler or how powerful financial punishment, the traveler will choose to use the carsharing. In addition, the traveler’s choice strategy is not dependent on government policy changes. Hence, after a learning and evolution of traveler and government in the game system, the traveler chooses carsharing, and the government chooses not to implement policies. Finally, the evolution game of system tends to be the local stable equilibrium (1,0).

When \( P_2 - C_2 - (P_1 - C_1 - P_0)/fS + D > 1 \), that is \( P_1 - C_1 - P_0 + fS < P_2 - C_2 - D \), and \( D > A \), meaning the traveler’s total interest of choosing the carsharing is less than choosing the private car with the government policies, the traveler tends to choose private car. \( P_1 - C_1 - P_0 + fS < P_2 - C_2 - D \) is equivalent to \( fS + D < P_2 - C_2 - (P_1 - C_1 - P_0) \). At this time, the policy intensity \( (fS + D) \), which including reward, \( fS \), and punishment, \( D \), is less than the traveler’s total interest difference between choosing carsharing and private car, \( (P_2 - C_2 - (P_1 - C_1 - P_0)) \). It shows
Table 3: Analysis of ESS.

(a) Analysis of ESS (traveler)

<table>
<thead>
<tr>
<th>Range</th>
<th>$F(0)$</th>
<th>$F(1)$</th>
<th>$F'(0)$</th>
<th>$F'(1)$</th>
<th>ESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y^* = P_2 - C_2 - (P_1 - C_1 - P_0)/f sS + D$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>[0.1]</td>
</tr>
<tr>
<td>$y^* \neq P_2 - C_2 - (P_1 - C_1 - P_0)/f sS + D$</td>
<td>$P_2 - C_2 - (P_1 - C_1 - P_0)/f sS + D &lt; 0$</td>
<td>0</td>
<td>0</td>
<td>&gt;0</td>
<td>&lt;0</td>
</tr>
<tr>
<td></td>
<td>$P_2 - C_2 - (P_1 - C_1 - P_0)/f sS + D &gt; 1$</td>
<td>0</td>
<td>0</td>
<td>&lt;0</td>
<td>&gt;0</td>
</tr>
<tr>
<td></td>
<td>$0 &lt; P_2 - C_2 - (P_1 - C_1 - P_0)/f sS + D &lt; 1$</td>
<td>$y^* &lt; P_2 - C_2 - (P_1 - C_1 - P_0)/f sS + D$</td>
<td>0</td>
<td>0</td>
<td>&lt;0</td>
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<tr>
<td></td>
<td></td>
<td>$x^* &gt; P_2 - C_2 - (P_1 - C_1 - P_0)/f sS + D$</td>
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<td>0</td>
<td>&gt;0</td>
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</table>

(b) Analysis of ESS (government)

<table>
<thead>
<tr>
<th>Range</th>
<th>$F(0)$</th>
<th>$F(1)$</th>
<th>$F'(0)$</th>
<th>$F'(1)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x^* = D - A/ f sS + D$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td></td>
<td>$D - A/ f sS + D &gt; 0$</td>
<td>0</td>
<td>0</td>
<td>&lt;0</td>
</tr>
<tr>
<td>$x^* \neq D - A/ f sS + D$</td>
<td>$x^* &gt; D - A/ f sS + D$</td>
<td>0</td>
<td>0</td>
<td>&gt;0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0 &lt; D - A/ f sS + D &gt; 1$</td>
<td>$x^* &gt; D - A/ f sS + D$</td>
<td>0</td>
</tr>
</tbody>
</table>
the government’s policy intensity is not enough, currently the evolution game of system tends to the local stable equilibrium point \((0, 1)\).

When \(0 < P_2 - C_2 - (P_1 - C_1 - P_0)/fsS + D < 1\), that is \(P_1 - C_1 - P_0 + fsS > P_2 - C_2 - D\) and \(P_1 - C_1 - P_0 < P_2 - C_2\), the traveler’s total interest of choosing the carsharing is greater than choosing the private car with government policies and the traveler’s total interest of choosing the carsharing is less than choosing the private car without government policies. According to the \(x^*\) value, there are two situations.

\(\textcircled{a}\) When \(x^* < D - A/\fsS + D\), the equilibrium point is \((0, 0)\). The government would choose not to implement policies, and the traveler will choose to use the private car.

Thus, when \(0 < P_2 - C_2 - (P_1 - C_1 - P_0)/fsS + D < 1\), both the traveler of choosing carsharing and private car do coexist. The traveler’s behavior is uncertain, and the equilibrium point \((1, 1)\) and \((0, 0)\) are not stable.

From the analysis of system, it is found that there are some key factors influencing the evolutionary game dynamic system. The traveler will choose the carsharing during the
<table>
<thead>
<tr>
<th>Equilibrium points</th>
<th>Det $(J)$</th>
<th>Tr $(J)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x = 0, y = 0$</td>
<td>$[P_1 - C_1 - P_0 - (P_2 - C_2)](D - A)$</td>
<td>$P_1 - C_1 - P_0 - (P_2 - C_2) + D - A$</td>
</tr>
<tr>
<td>$x = 1, y = 0$</td>
<td>$[P_1 - C_1 - P_0 - (P_2 - C_2)][f(s)S + A]$</td>
<td>$-[P_1 - C_1 - P_0 - (P_2 - C_2)] - f(s)S - A$</td>
</tr>
<tr>
<td>$x = 0, y = 1$</td>
<td>$[P_1 - C_1 - P_0 - (P_2 - C_2) + fS + D](A - D)$</td>
<td>$P_1 - C_1 - P_0 - (P_2 - C_2) + fS + A$</td>
</tr>
<tr>
<td>$x = 1, y = 1$</td>
<td>$-[P_1 - C_1 - P_0 - (P_2 - C_2) + fS + D] \times [f(s)S + A]$</td>
<td>$-[P_1 - C_1 - P_0 - (P_2 - C_2) + D - A]$</td>
</tr>
<tr>
<td>$x^* = D - A/fS + D, y^* = P_2 - C_2 - (P_1 - C_1 - P_0)/fS + D$</td>
<td>$0$</td>
<td>$0$</td>
</tr>
</tbody>
</table>
The traveler eventually evolves into the strategy of using the market, which can maximize the social welfare. Moreover, the market adjustment should play a dominant role in the traveling reward and eventually withdraw the reward mechanism. If the government would gradually reduce the magnitude of carsharing is a retrograde mechanism. In the next few years, the government’s awarding policy of carsharing could only be a likely to lead to diminishing social welfare \[54\]. Hence, the equilibrium point compared with private car. However, the equilibrium point \((1, 1)\) is not a stable equilibrium point. According to Hirte and Tscharktschiew’s research, financial subsidies for vehicles are likely to lead to diminishing social welfare \[54\]. Hence, the government’s awarding policy of carsharing could only be a short term. Thus, the government’s policy of encouraging carsharing is a retrograde mechanism. In the next few years, the government would gradually reduce the magnitude of the reward and eventually withdraw the reward mechanism. The market adjustment should play a dominant role in the traveling market, which can maximize the social welfare. Moreover, the improvement of carsharing technology and service quality is the key to win the traveling market.

### 3.5. Sensitivity Analysis of Policies

The state of center point, \(D = (x^*, y^* = P_2 - C_2 - (P_1 - C_1 - P_0)/f_sS + D)\), in evolutionary game is affected by the parameters. To analyze the impact of policy, it is necessary to study the sensitivity of \(S\) (full reward) and \(D\) (punishment cost).

#### 3.5.1. Sensitivity Analysis of \(S\) (Full Reward).

\[
\frac{\partial x^*}{\partial S} = \frac{f_s(A - D)}{(f_sS + D)^2} \\
\frac{\partial y^*}{\partial S} = \frac{[P_1 - C_1 - P_0 - (P_2 - C_2)]f_s}{(f_sS + D)^2}
\]

There are four possibilities:

1. When \(A > D\), and \(P_1 - C_1 - P_0 > P_2 - C_2\), then \(\frac{\partial x^*}{\partial S} > 0\), \(\frac{\partial y^*}{\partial S} > 0\).

2. When \(A > D\), and \(P_1 - C_1 - P_0 < P_2 - C_2\), then \(\frac{\partial x^*}{\partial S} < 0\), \(\frac{\partial y^*}{\partial S} < 0\).

3. When \(A < D\), and \(P_1 - C_1 - P_0 > P_2 - C_2\), then \(\frac{\partial x^*}{\partial S} < 0\), \(\frac{\partial y^*}{\partial S} > 0\).

4. When \(A < D\), and \(P_1 - C_1 - P_0 < P_2 - C_2\), then \(\frac{\partial x^*}{\partial S} > 0\), \(\frac{\partial y^*}{\partial S} > 0\).

Full reward has an impact on the choice behavior of both the traveler and government. With the increase of full reward, the traveler tends to choose the strategy of carsharing and the government tends to choose the strategy of implementing policies.

Full reward has an impact on the choice behavior of both the traveler and government. With the increase of full reward, the traveler tends to choose the strategy of carsharing and the government tends to choose the strategy of not implementing policies.
of full reward, the traveler tends to choose the strategy of private car and the government tends to choose the strategy of implementing policies.

(4) When \( A < D \), and \( P_1 - C_1 - P_0 < P_2 - C_2 \), then
\[
\frac{\partial x^*}{\partial S} < 0, \\
\frac{\partial y^*}{\partial S} < 0.
\] (27)

Punishment cost has an impact on the choice behavior of the traveler. With the increase of punishment cost, the traveler tends to choose the strategy of carsharing. Besides, the punishment cost has an impact on the choice behavior of the government too, which has two possibilities:

(1) When \( P_1 - C_1 - P_0 > P_2 - C_2 \), then
\[
\frac{\partial y^*}{\partial D} > 0.
\] (29)

With the increase of punishment cost, the government tends to choose the strategy of implementing policies.

(2) When \( P_1 - C_1 - P_0 < P_2 - C_2 \), then
\[
\frac{\partial y^*}{\partial D} < 0.
\] (30)

With the increase of punishment cost, the government tends to choose the strategy of not implementing policies.

4. Case Study

4.1. Carsharing Development in Beijing. Beijing is China’s capital, with 21.53 million people and 6.37 million vehicles by 2019. Carsharing started in Beijing in 2013 and had only four or five companies in 2014. The citizens with driving license but no cars have been growing under the capital’s vehicle restriction scheme. As travelers who do not possess private cars show excessive demand on cars, especially under the haze, rainfall, and other inclement weather, carsharing has been developing rapidly in Beijing in the past five years. There are more than 20 carsharing companies in Beijing, including Youche, GreenGo, GoFun, and other platforms. The Beijing municipal government expressed the support for EV (electric vehicle) carsharing. For example, “Action Plan of Electric Vehicles Widespread Use in Beijing (2014–2017)” was proposed to conduct the demonstration application of EV carsharing involving constructing an EV carsharing network and incorporating EV carsharing into the urban multidimensional traffic system. However, there is no financial measure of carsharing travelers in Beijing. In the case study, through the proposed model, the impacts of policies on relationship between carsharing and private car in Beijing are analyzed.

4.2. Numerical Analysis. Questionnaire survey and numerical analysis have been widely used in the transportation research field [55, 56]. Thus, parameters and variables were investigated through a questionnaire. This study put out 120 investigating questionnaires, and 116 questionnaires were recovered. Excluding the missing or erroneous questionnaires, this study got 112 valid questionnaires. The calculation of each questionnaire question is shown as follows:

\[
Q_i = \frac{Q_{i1} + Q_{i2} + \cdots + Q_{in}}{n},
\]

(31)

where \( Q_i \) is the value of question \( i \), \( n \) is the number of valid questionnaires, and \( Q_{in} \) is the value of the answer of respondent \( n \) to question \( i \). The survey results are shown in Table 6.

According to above study results, in existing case, \( F(x) = dx/dt = -0.84x(x - 1), F(y) = dy/dt = 0 \), and \( F'(x) = -0.84(2x - 1), F'(y) = 0 \). To the traveler, \( F(0) = F(1) = 0, F'(0) < 0, F'(1) > 0 \). Thus, \( X = 0 \) is ESS. To the government, \( F(0) = F(1) = F'(0) = F'(1) = 0 \). Thus, the ESS is a certain value between 0 and 1. At present, under circumstance of there are no financial measures of carsharing in Beijing, and \( P_1 - C_1 - P_0 < P_2 - C_2 \), the traveler’s total interest of choosing the carsharing is less than choosing the private car. The game playing system will eventually evolve into that the traveler chooses the private car. To increase the use of carsharing, implementing policies could be considered, social norm factors and sense of achievement when the traveler chooses carsharing should be increased, and losses when the traveler chooses carsharing should be
decreased. Thus, in hypotheses 1 and 2, policies are considered. In hypothesis 2, except policies are considered, $P_1$ is increased, and $P_0$ is decreased.

Numerical analysis results of hypotheses 1 and 2 are shown in Figures 6 and 7, respectively. Under hypothesis 1, $P_1 - C_1 - P_0 + fS < P_2 - C_2 - D$, and hence the traveler ultimately chooses the private car. The results indicate that, despite implementing policies, there is not enough strength. Under hypothesis 2, $P_1 - C_1 - P_0 > P_2 - C_2$, and hence the traveler ultimately chooses the carsharing. Besides, the results of hypothesis 2 indicate that when $P_1$ is increased and $P_0$ is decreased, leading to $P_1 - C_1 - P_0 > P_2 - C_2$, the traveler ultimately chooses the carsharing. During the long-term evolution process, carsharing infrastructure is developing well, and the carsharing market is gradually leading evolution. Thus, the traveler ultimately chooses the carsharing.

The government policies of a full reward and punishment cost are fixed that cannot show how the policy changes affect users’ mode choice. Thus, to quantitatively analyze the impact of the policy of $S$ and $D$, the sensitivity analysis on the two parameters ($S$ and $D$) is conducted.

![Figure 6: $dx/dt - t$ in hypothesis 1 value under different initial values.](image6)

![Figure 7: $dx/dt - t$ in hypothesis 2 value under different initial values.](image7)
The initial values are randomly set as (0.1, 0.9) and (0.2, 0.8).

1. Sensitivity analysis of $S$ (full reward)
   $S$ set as 1, 5, 10, 15, and 20, respectively. Other parameters are the same as hypothesis 2. As shown in Figure 8, with the increase of full reward, to the traveler, the probability of choosing carsharing is increasing, which is consistent with the analysis in Section 3.5.

2. Sensitivity analysis of $D$ (punishment cost)
   $D$ set as 1, 5, 10, 15, and 20, respectively. Other parameters are the same as hypothesis 2. As shown in Figure 9, with the increase of punishment cost, to the traveler, the probability of choosing carsharing is increasing, which is consistent with the analysis in Section 3.5 too.

4.3. Discussion and Recommendation. At present, the case study in Beijing shows the ESS is $X = 0$. That is to say, bounded rational travelers would eventually choose to use the private car. To increase the use of carsharing, implementing policies could be considered, social norm factors and sense of achievement when the traveler chooses carsharing should be increased, and losses when the traveler chooses carsharing should be decreased. Therefore, the following measures can be adopted to improve the interest of using carsharing in Beijing, so that the dynamic system formed by the traveler and the government will converge to the ideal stable equilibrium strategy.

1. Rationalize the $S$ value. Implement different policy of $S$ in different stages. According to the sensitivity analysis of $S$, when $A > D$, the full reward should be increased. When $A < D$, the full reward should be decreased. It should cancel the fiscal subsidy mechanism to carsharing travelers in the long term. Direct long-time fiscal subsidies may be inefficient, and carsharing travelers may be dependent on subsidies. Improving the benefits of carsharing themselves is the key to improve the competitive advantage of carsharing. (2)
Increase the $S$ value. According to the sensitivity analysis of $D$, with the increase of punishment cost, the traveler tends to choose the strategy of carsharing. (3) Reduce the $P_0$ value. Except direct motivating the carsharing traveler, the government could actively guide enterprises to invest in the construction of carsharing infrastructure. Completed carsharing facilities provide convenience for carsharing travelers, which could reduce losses due to the inconvenience of hardware facilities and increase the total interests that the travelers can get from carsharing. Finally, the traveler’s total interest of choosing the carsharing is greater than choosing the private car. Furthermore, the travelers’ total interest of choosing carsharing will be improved, and people will give greater emphasis to improve air quality. Through publicity means, carsharing could be bonded together by energy conservation, emission reduction, reducing smog, and improving air quality. Through enhance the knowledge and preferences of the travelers to carsharing, carsharing would be further popularized.

5. Conclusions

To study the competitive choice process between carsharing and private car, an evolution game model with incomplete information is constructed to analyze the travel choice process between carsharing and private car, of which the influences of government policy is taken into consideration. The ESS solution of model is derived from replicator dynamics, and a discussion about stable point and condition is presented. A case in Beijing illustrates the application and potential of the approaches to serve as tools. The results prove that, during the long-term evolution process, the traveler’s total interest of choosing the carsharing is greater than choosing the private car without government policies $(P_1 - C_1 - P_0 + fSS < P_2 - C_2 - D)$, regardless of the government’s strategic choice, bounded rational travelers would eventually choose to use carsharing. Moreover, the travelers’ total interest of choosing the carsharing is less than choosing the private car with government policies $(P_1 - C_1 - P_0 + fSS > P_2 - C_2 - D)$, regardless of the government’s strategic choice, bounded rational travelers would eventually choose to use private car. Furthermore, the travelers’ total interest of choosing the carsharing is greater than choosing the private car with government policies, and the travelers’ total interest of choosing the carsharing is less than choosing the private car without government policies $(P_1 - C_1 - P_0 + fSS > P_2 - C_2 - D$ and $P_1 - C_1 - P_0 < P_2 - C_2)$, and there is no ESS. The final state is determined by the learning adjustment speed of the traveler and government. At last, to increase the use of carsharing and replace of private car in Beijing, implementing policies could be considered, social norm factors and sense of achievement of choosing carsharing should be increased, and losses of choosing the carsharing should be decreased.

The findings of this study are conducive for agencies to improve the current carsharing strategy. It should be pointed out that the variability of the cost for travel mode and its effect on the evolution game model have not been considered. In fact, it may not be easy for travelers to accurately predict. Besides, the punishment cost is considered as fixed, which is a limitation in this study. In the future, the impact of fixed punishment and time-varying decline punishment on travel choice will be compared. Additionally, further research may focus on the application and improvement of the proposed model for carsharing and other travel modes.

Data Availability

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

Conflicts of Interest

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

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