



# Article Tripartite Dynamic Game among Government, Bike-Sharing Enterprises, and Consumers under the Influence of Seasons and Quota

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Abstract: After the cast ban on bike-sharing was lifted, bike-sharing entered the quota period. This notion means that the management of bike-sharing began to change from the unified to the diversified government governance, including all sectors of society. This work creates a dynamic game model based on the tripartite interest relationship among the government, bike-sharing enterprises, and consumers, and introduces the government quota policy and seasonal characteristics of bike-sharing into the game model. This model explores the multi-stage dynamic game process among the government, bike-sharing enterprises, and consumers. We draw the following conclusions. The government's quota policy was effective during peak demand for bike-sharing, but not before the off-peak season. Through the case studies, we verify the feasibility of the government to relax the regulation appropriately in the peak season. We also changed the punishment and reward intensity of bike-sharing enterprises to consumers in the case studies and analyzed the influence of regulation intensity of bike-sharing enterprises on consumer behaviors. The final suggestion is that the government should appropriately relax regulation during peak demand season to reduce costs and strengthen regulation before the off-season of bike-sharing demand. Bike-sharing enterprises should maintain a high level of regulation on consumers, and a low level of regulation has no constraint on consumer behaviors.

Keywords: dynamic game; bike-sharing; quotas administered; seasonal factor

## 1. Introduction

Bike-sharing has quickly entered people's lives as a new model integrating the internet and rental bikes in recent years, and it has provided numerous benefits to people. On the one hand, bike-sharing not only makes up for the lack of close connection between different modes of transportation, such as slow traffic and public transport [1], but also becomes an important tool to solve the last kilometer of the urban public transport. It can also become an alternative transportation mode during traffic interruptions, improving the resilience and robustness of the urban transport system [2]. On the other hand, bike-sharing has great environmental benefits and plays a positive role in reducing energy consumption and emissions [3], reflecting the five development concepts of "innovation, coordination, green, development, and sharing" [4]. In addition, bike-sharing offers healthy advantages, such as boosting people's physical fitness and lowering traffic-related fatalities [5]. In general, bike-sharing has significant positive externalities [6].

However, bike-sharing also brings many problems. Problems, such as random parking by consumers, excessive investment by bike-sharing enterprises, mismatch between the supply and the demand at various stations, and belated recycling of broken bike-sharing have emerged with the rapid development of bike-sharing, which have affected the public space and urban life [7]. Accordingly, the government issued a ban on investment, which required that centralized treatment and strict management should be carried out to alle-



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**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). viate the disorderly competition among bike-sharing enterprises. After several years of government management, only a few enterprises with good service quality remained in the bike-sharing industry [8]. At this time, the investment ban is extremely unfavorable to the development of the bike-sharing industry. Therefore, most cities began to try the fine management of bike-sharing. Some cities, including Hangzhou, Quanzhou, and Tianjin, have successively issued the "Internet Renting Bicycle Service Quality Assessment Measures", which regularly assessed the service quality of bike-sharing enterprises and adjusted the quota of bike-sharing according to the ranking of bike-sharing enterprises, to realize the scientific and dynamic regulation of bike-sharing enterprises [9]. On April 29, 2019, Guangzhou issued a quota tender for 400,000 shared bikes, identified three Internet rental bike operators and promoted the orderly development of the bike-sharing industry through the corresponding assessment methods [10]. Measures show that bike-sharing ushers a new situation and enters the quota era. Based on this situation, this study introduces the government quota policy into a multi-stage dynamic game model of the government, bike-sharing enterprises, and consumers. The effectiveness of the government quota policy in different seasons is also discussed, which is of great significance to improve the government policy and realize the scientific and dynamic regulation of the government on bike-sharing.

# 2. Literature Review

Since the first bike-sharing system was launched in 1965 in Amsterdam, the Netherlands, bike-sharing has been widely welcomed by people due to their green and convenient characteristics [11]. Statistics show that the travel distance of bike-sharing is within the range of 1–5 km [12,13], which makes up for the deficiency of the urban travel mode and plays an important role in urban traffic [14,15]. With the growing popularity of bikesharing, the application range of the sharing economy has expanded, and bike-sharing is receiving increasing academic attention. Scholars have studied bike-sharing from different theoretical approaches. Some studies have examined the effectiveness of credit supervision mechanism from the perspective of consumers. The authors believe that an effective credit supervision mechanism can alleviate the abuse of bike-sharing and promote its sustainable development [16]. Murphy analyzed the level of government best suited to regulate the sharing economy and argued that local governments can better understand the unique problems of their communities [17].

The use of bike-sharing is greatly affected by external factors. Its use is related to weather, built environment, land use, public transport, station level, sociodemographic attributes, time factor, and safety. If there is no precipitation at a temperature of 20-30 °C, then the use of bike-sharing may increase, and it has a negative effect on the demand for bike-sharing when the temperature is considerably high [18]. Kim studied the influence of weather conditions on the use of bike-sharing on the basis of system-level and station-level analysis. The study found that temperature was positively correlated with the number of trips, while relative humidity, precipitation, and wind speed were negatively correlated with the number of trips [19]. Seasonality changes the number of bike-sharing, and the seasonal demand for bike-sharing is caused by the weather [18]. Some studies have used an autoregressive moving average (ARMA) model to explain seasonal trends and correlations with previous periods of bike-sharing use [20,21]. The seasonal characteristics of bike-sharing are illustrated in the analysis of Gebhart et al. usage hour statistics. Weather patterns and seasonality are related to the usage and travel time of bike-sharing [22]. El-assi et al. analyzed the factors that influence bike-sharing travel in Toronto by using historical data throughout the year. They found a significant correlation between temperature and the number of bike-sharing trips. The distribution of trips in spring and summer is similar to that in autumn. However, the number of bike-sharing consumers decreased in winter [23]. In addition, a study of two years of data from Vienna's city bike-sharing system found that demand for bike-sharing in winter was significantly lower than in summer, even though stations were intensively used [24]. The analyze the

annual trend of bike-sharing must be analyzed because operating them all year round can produce better revenues [25]. Some studies have also studied the needs and expectations of women as consumers of bike-sharing services from the perspective of gender. The results show that far fewer women than men use Velib bike-sharing services (approximately 30% of the total number of consumers), supporting the definition of incorporating women's needs into the guidelines and policies for the design of future bike-sharing services [26].

The bike-sharing dilemma requires coordinated governance by all parties. The oversupply of bike-sharing has resulted in a large number of inferior bikes in many big cities in China [27]. By the end of 2015, bike-sharing had caused many unintended negative consequences to public spaces, such as abuse by bike users, many bikes on the streets, and an increase in the number of faulty bikes that must be removed [28]. Collaborative management is an umbrella term that refers to cross-border, multi-agency arrangements made by different actors from the public, private and private sectors to solve a public problem or promote a common goal [29]. Scholars have studied the governance of bike-sharing from the perspectives of all parties. The results show that the willingness of consumers to participate in the intelligent BSS governance is significant, and the factors that influence the willingness of consumers to governance are diversified. This finding provides multiple paths for the further coordinated governance of bike-sharing. Governments and city managers should optimize institutional arrangements, provide transparent and proactive oversight, maintain an iterative environment, define success indicators, prioritize planning goals over innovation, and strive for regional cooperation. The manner by which to adopt rational market behavior and improve the service level is the key for intelligent BSS enterprises. Bike-sharing enterprises should expect to be supervised by the government in exchange for the use of public right of way [30,31]. Bike-sharing governance should be achieved through the tripartite cooperation of the government, bike-sharing enterprises and consumers [32,33]. Therefore, the governance of bike-sharing must be studied.

Game theory has a wide range of applications in the governance of bike-sharing. Game theory is a mathematical study of the decision-making process. It simulates the behavior of individuals in specific situations to test the relationship between decisions and outcomes [34]. Furthermore, game theory is widely used to study economic, social, political, and biological phenomena [35]. In standard game theory, a game model consists of three parts: the set of players, the set of strategies for each player, and the payoff for each player [36]. Some studies proposed a game theory framework to represent the competition among bike-sharing enterprises and simulate the decision-making process of each enterprise through a two-stage multi-stage random program. Finally, they realize the optimization of the decision-making process of bike-sharing enterprises in competition and demand uncertainty [37]. In the game model between consumers and bike-sharing enterprises, it is highly effective for enterprises to choose the appropriate reward and punishment system to solve the parking problem of bike-sharing [37,38]. This conclusion is also applicable to the two-party game between the government and bike-sharing enterprises and the three-party game among the government, bike-sharing enterprises, and consumers [39-41]. Zhao et al. established a three-party game model among the government, bike-sharing enterprises and consumers to determine the balance between market expansion and sustainable development of bike-sharing enterprises. The results show that the number of bike-sharing placed on the market by bike-sharing enterprises is not proportional to their profits, and the government plays a leading role in the development of these enterprises [11]. Yang et al. established an evolutionary game model between the government and bike-sharing enterprises to explain the interaction and conflict between the government and bike-sharing enterprises and simulated the strategies to deal with evolutionary conflict by using system dynamics. The results show the conflict management strategy is a compromise mode, in which both parties sacrifice part of their own interests and adjust their strategies according to the benefits of the other party [42]. Scholars have studied the application of game theory in the governance of bike-sharing to expand the

possibility of game theory in governance optimization. However, most previous studies lack consideration of the seasonal characteristics of bike-sharing.

Existing studies mostly focus on the bilateral game between bike-sharing stakeholders, while few studies have explored the tripartite game among the government, bike-sharing enterprises, and consumers. The innovation of this work lies in two aspects. On the one hand, the government's quota for bike-sharing, the seasonal characteristics of bike-sharing, and the game theory are combined to explore the multi-stage dynamic game process of the government, bike-sharing enterprises, and consumers, thereby achieving in a practical study. On the other hand, the changes of bike-sharing enterprise strategy selection in each stage are demonstrated through a case study, which provides a basis for the scientific management of bike-sharing by the government.

# 3. Model of the Multi-Stage Dynamic Game

The model is the core of this article, and its core structure is shown in Figure 1.



Figure 1. The structure of the core part of the article.

## 3.1. Model Assumptions

In the bike-sharing industry, bike-sharing involves multiple stakeholders, including the government, bike-sharing enterprises, consumers, investors, universities, competitors, suppliers, media, and property management. After the paired t-test and Mitchell scoring method are utilized, scholars finally determined that the potential stakeholders included property management, colleges, and universities, the expected stakeholders were suppliers, competitors, and media, and the deterministic stakeholders were the government, bikesharing enterprises, consumers, and investors. Based on the demands of stakeholders and their influence on bike-sharing management, scholars used the right/benefit matrix to determine that the government, bike-sharing enterprises, and consumers are the main influencing factors of bike-sharing management [43].

The government, bike-sharing enterprises, and consumers face different dilemmas when dealing with the bike-sharing governance. The government lacks relevant systems and governance, resulting in the control effect on bike-sharing. Bike-sharing enterprises lack the industry self-discipline, lagging management, and standards, which leads to problems such as disorderly competition and crowding out urban public space. Consumers lack public awareness, which leads to certain problems, such as random parking, vandalism, and locking shared bikes without permission. In this regard, scholars have conducted research on the governance dilemma and the governance path of bike-sharing. On this basis, the strategy of each participant needs to be further described [44].

In terms of the bike-sharing governance, the government formulated the bike-sharing service quality evaluation methods. They take the "Tianjin Internet Rental Bicycle Service Quality Assessment Method (Trial)" as an example [45]. The file showed the bike-sharing inspection cycle for every quarter, corresponding to the bike-sharing seasonal characteristics, which were described in the "Literature Review "section. The distribution of trips in spring and summer was similar to that in autumn, while the number of bike-sharing consumers decreased in winter. In this work, we combine the assessment cycle with the seasonal characteristics of bike-sharing.

We make the following five assumptions based on the above-presented statements.

**Hypothesis 1 (H1).** Suppose the main bodies that participate in the game are the government, bike-sharing enterprises, and consumers, and the tripartite game order is government–bike-sharing enterprises–consumers. The parties of the game are fully rational, and the information in the game is open among the parties. The government, bike-sharing enterprises, and consumers aim to maximize their own revenues.

**Hypothesis 2 (H2).** Suppose that participants are faced with two strategic choices. The government's strategy set consists of high and low regulation. The high regulation strategy means that the government invests manpower, material resources, and financial resources to strictly supervise bike-sharing enterprises, while the low regulation strategy means that the government relaxes the supervision for bike-sharing enterprises and intervenes less in the non-standardized operation of bike-sharing compared to the high regulation.

**Hypothesis 3 (H3).** Suppose that the bike-sharing enterprises' strategy set consists of a standardized operation and a non-standardized operation. The standardized operating strategy means that the bike-sharing enterprises engage in the optimization of governance cost, strengthen the management of daily operations, and follow the rules made by governments. The non-standardized operating strategy means that bike-sharing enterprises do not comply with the requirements of the government, try to reduce the management costs for bike-sharing, and neglect daily managements and rebalance for shared bikes.

**Hypothesis 4 (H4).** Suppose that the strategy set of consumers consists of the standard and nonstandard uses. The standard use strategy means that consumers are compliant with the rules for the use of shared bikes formulated by the government and the bike-sharing enterprises. Meanwhile, the non-standard use strategy means that consumers disobey the rules for the use of bike-sharing.

**Hypothesis 5 (H5).** Suppose that the government carries out regular service quality assessment on bike-sharing enterprises, and the assessment frequency is once every quarter. The peak seasons for bike-sharing demand are spring, summer, and autumn, while the off-peak season for the bike-sharing demand falls in winter. The theoretical basis is shown in Table 1. With regard to the transaction volume of bike-sharing, the market supply shall prevail when the demand for bike-sharing is high in the peak season; meanwhile, the consumer demand shall prevail when the demand for bike-sharing is low in the off-peak season.

Reference	Content
Godavarthy, R.P.; Taleqani, A.R. (2017).	The number of bike-sharing is affected by the seasons, with low utilization rate of bike-sharing in winter, and the passenger flow is expected to reach $10-30\%$ of the summer peak [25].
Gebhart, K.; Noland, R.B. (2014).	The authors studied the riding of bike-sharing on the 11th of each month (2010–2011). The study showed that the use of bike-sharing showed a waveform over time, reaching a peak in August and a trough in January [22].
Sun, F.Y.; Chen, P.; Jiao, J.F. (2018).	The estimated smoothing curve of the time measure has a large function value in July 2015 and 2016, and a small function value in January 2015 and January 2016. The curve reflecting the seasonal characteristics of bike-sharing [46].
El-Assi, W.; Mahmoud, M.S.; Habib, K.N. (2017).	Bike-sharing has a seasonal trend, with the distribution of trips in spring and summer similar to that in autumn, but with a slight increase in trips per hour in the afternoon peak (32%) and a corresponding decrease in trips per hour in the morning peak (19%), the proportion of trips per hour in winter drops to 19% as the weather gets colder [23].
Zhou, X.L.; Wang, M.S.; Li, D.Y. (2019).	The number of bike-sharing trips is affected by the weather, so it shows a seasonal distribution, with peak demand in summer and underestimation in winter [47].
Scott, D.M.; Ciuro, C. (2019).	Bike-sharing have seasonal characteristics, and the travel conditions of bike-sharing are relatively consistent with temperature changes. The travel conditions are better from March to September, but worse from October to February, and the travel conditions are the best from July to September [48].
Kim, H. (2020).	Use of bike-sharing is lowest in winter (December-February), usually less than 20,000 times per day, while it gradually increases in spring (March-May). Usage initially continued to increase during the summer (June to August), but declined in August. In autumn (September-November), bike sharing was the most used, with up to 60,000 trips per day, but it dwindled towards November [49].
Fournier, N.; Christofa, E.; Knodler, M.A. (2017).	Consumers of bike-sharing are highly responsive to many factors, especially seasonal weather, which is evident in locations with distinct seasons [50].
Bergstrom, A.; Magnusson, R. (2003).	Bike trips dropped 47 percent from summer to winter, with temperature and precipitation being the most important factors for seasonal riders [51].
Industry information network (2019).	According to the global/China weekly bike-share penetration trend, China and the world had a high weekly penetration rate from March to November 2019, and a low weekly penetration rate from December to February 2019, with obvious seasonal characteristics [52].

Table 1. Reference for seasonal characteristics of bike-sharing.

# 3.2. Parameter and Variable Setting

The goal of each player in the game is to maximize revenues. The revenues of the government, bike-sharing enterprises, and consumers depend on the strategic choices of all parties in the game. For example, government regulations affect bike-sharing enterprises' strategy choice, and bike-sharing enterprises' behavior will influence the government's decisions; meanwhile, consumers' behavior is influenced by bike-sharing enterprise rules. Therefore, the revenues of all parties in the game are an important part of the model. Next, we will set the revenues of all parties in the game.

1. When the government chooses the strategy of the high regulation, the cost of human, material and financial resources is  $C_1$ , and the improvement of the image of the government is  $R_1$ . The government rewards the bike-sharing enterprises for its standardized operation behavior, and the reward is denoted as  $A_1$ . Meanwhile, the government punishes the bike-sharing enterprises for its non-standardized operation behavior, and the punishment

is denoted as  $F_1$ . When the low regulation strategy is chosen, the input cost is zero. When bike-sharing enterprises and consumers regulate their behaviors, the improvement of government's image is  $R_2$ . When bike-sharing enterprises or consumers do not regulate their behaviors, the loss of the government's image is  $C_2$ .

2. When bike-sharing enterprises choose the standardized operating strategy, they invest  $C_3$  in the bike-sharing governance and obtain  $R_3$  in image benefits. Bike-sharing enterprises reward  $A_2$  for standard use behavior of consumers and penalize  $F_2$  for non-standard use behavior of consumers. When bike-sharing enterprises choose the non-standardized operating strategies, they invest  $C_4$  in bike-sharing governance ( $C_3 > C_4$ ). When consumers use bike-sharing in a non-standard way, the reputation loss of the operation and maintenance cost of the bike-sharing enterprises is  $C_5$ . The bike-sharing enterprise trading revenue is S in the peak season, while that in the off-peak season is D. In the peak season, the market is in short supply, and the profit is determined by the supply of bike-sharing. As the main profit of bike-sharing enterprises, S is much higher than other values. In the off-peak season, the market is in a state where the supply exceeds the demand, and D is determined by demand. When the government chooses the high regulation strategy, the market quota coefficient is  $U_1$  when the bike-sharing enterprises operate in a standardized way and  $U_2$  when they operate in a non-standardized manner ( $U_1 > U_2$ ).

3. When consumers choose the standard use strategy, the cost of its standard use is  $C_6$ . When consumers choose the non-standard use strategies, the cost of bike-sharing is  $C_7$ .

#### 3.3. Decision Variable Setting

This study assumes that the probabilities of the high and low government regulations in the first stage are  $P_1$  and  $1 - P_1$ , respectively. The probabilities of the high and low regulation are  $P_{11}$  and  $1 - P_{11}$  in the second stage, respectively. The probabilities of the high and low regulation are  $P_{12}$  and  $1 - P_{12}$  in the third stage, respectively. The probabilities of the high and low regulation are  $P_{12}$  and  $1 - P_{12}$  in the third stage, respectively. The probabilities of the high and low regulation are  $P_{13}$  and  $1 - P_{13}$  in the fourth stage.

Assume that the probabilities of the standardized and non-standardized operations operation by bike-sharing enterprises in the first stage are  $P_2$  and  $1 - P_2$ , respectively. Meanwhile, the probabilities of the standardized and non-standardized operations are  $P_{21}$  and  $1 - P_{21}$  in the second stage, respectively. The probabilities of the standardized and non-standardized operation are  $P_{22}$  and  $1 - P_{22}$  in the third stage, respectively. The probabilities of the standardized and non-standardized operation are  $P_{22}$  and  $1 - P_{22}$  in the third stage, respectively. The probabilities of the standardized and non-standardized operation are  $P_{23}$  and  $1 - P_{23}$  in the fourth stage, respectively.

Assume that the probabilities of the standard and non-standard use by consumers in the first stage are  $P_3$  and  $1 - P_3$ , respectively. The probabilities of the standard and non-standard use are  $P_{31}$  and  $1 - P_{31}$  in the second stage, respectively. The probabilities of the standard and non-standard use are  $P_{32}$  and  $1 - P_{32}$  in the third stage, respectively. The probabilities of the standard and non-standard use are  $P_{32}$  and  $1 - P_{33}$  in the fourth stage, respectively.

 $P_1$ ,  $P_2$ ,  $P_3$ ,  $P_{11}$ ,  $P_{21}$ ,  $P_{31}$ ,  $P_{12}$ ,  $P_{22}$ ,  $P_{32}$ ,  $P_{13}$ ,  $P_{23}$ ,  $P_{33} \in [0,1]$ . The tripartite game graph of the government, bike-sharing enterprises, and consumers is shown in Figure 2.

## 3.4. Tripartite Dynamic Game Evolution Model

This model is based on the quarterly assessment of the service quality of bike-sharing. The four stages are spring, summer, autumn, and winter. The strategy evolution of each player in different seasons is described, and the first stage is assumed to be in the initial state. Tables 1–4 describe the revenue value of each participant at different stages.



Figure 2. The tripartite game graph of government, bike-sharing enterprises, and consumers.

	Revenue Value of Government	Revenue Value of Bike-Sharing Enterprises	Revenue Value of Consumers
(1)	$R_1 + R_2 - C_1 - A_1$	$S + A_1 + R_3 - C_3 - A_2$	$A_2 - C_6$
(2)	$R_1 - C_1 - C_2 - A_1$	$S + A_1 + R_3 - C_3 - C_5 + F_2$	$-C_7 - F_2$
(3)	$R_1 - C_1 - C_2 + F_1$	$S - C_4 - F_1$	$-C_{6}$
(4)	$R_1 - C_1 - C_2 + F_1$	$S - C_4 - C_5 - F_1$	$-C_{7}$
(5)	$R_2$	$S + R_3 - C_3 - A_2$	$A_2 - C_6$
(6)	$-C_{2}$	$S + R_3 - C_3 - C_5 + F_2$	$-C_7 - F_2$
(7)	$-C_{2}$	$S - C_4$	$-C_{6}$
(8)	$-C_{2}$	$S - C_4 - C_5$	$-C_{7}$

	Revenue Value of Government	Revenue Value of Bike-Sharing Enterprises	Revenue Value of Consumers
(1)	$R_1 + R_2 - C_1 - A_1$	$U_1S + A_1 + R_3 - C_3 - A_2$	$A_2 - C_6$
(2)	$R_1 - C_1 - C_2 - A_1$	$U_1S + A_1 + R_3 - C_3 - C_5 + F_2$	$-C_7 - F_2$
(3)	$R_1 - C_1 - C_2 + F_1$	$U_2S - C_4 - F_1$	$-C_{6}$
(4)	$R_1 - C_1 - C_2 + F_1$	$U_2S - C_4 - C_5 - F_1$	$-C_{7}$
(5)	<i>R</i> <sub>2</sub>	$S + R_3 - C_3 - A_2$	$A_2 - C_6$
(6)	$-C_{2}$	$S + R_3 - C_3 - C_5 + F_2$	$-C_7 - F_2$
(7)	$-C_{2}$	$\mathrm{S}-C_4$	$-C_{6}$
(8)	$-C_{2}$	$S - C_4 - C_5$	$-C_{7}$

 Table 3. Tripartite game revenue (the second stage).

Table 4. Tripartite game revenue (the third stage).

	Revenue Value of Government	Revenue Value of Bike-Sharing Enterprises	Revenue Value of Consumers
(1)	$R_1 + R_2 - C_1 - A_1$	$U_1^2 S + A_1 + R_3 - C_3 - A_2, U_1 U_2 S + A_1 + R_3 - C_3 - A_2, U_1 S + A_1 + R_3 - C_3 - A_2$	$A_2 - C_6$
(2)	$R_1 - C_1 - C_2 - A_1$	$\begin{array}{c} U_1^2 S + A_1 + R_3 - C_3 - C_5 + F_2, \\ U_1 U_2 S + A_1 + R_3 - C_3 - C_5 + F_2, \\ U_1 S + A_1 + R_3 - C_3 - C_5 + F_2 \end{array}$	$-C_{7}-F_{2}$
(3)	$R_1 - C_1 - C_2 + F_1$	$U_{2}^{2}S - C_{4} - F_{1}, \\ U_{1}U_{2}S - C_{4} - F_{1}, \\ U_{2}S - C_{4} - F_{1}$	- <i>C</i> <sub>6</sub>
(4)	$R_1 - C_1 - C_2 + F_1$	$U_2^2 S - C_4 - C_5 - F_1, U_1 U_2 S - C_4 - C_5 - F_1, U_2 S - C_4 - C_5 - F_1$	- <i>C</i> <sub>7</sub>
(5)	<i>R</i> <sub>2</sub>	$S + R_3 - C_3 - A_2, U_1S + R_3 - C_3 - A_2, U_2S + R_3 - C_3 - A_2$	$A_2 - C_6$
(6)	-C <sub>2</sub>	$S + R_3 - C_3 - C_5 + F_2, U_1S + R_3 - C_3 - C_5 + F_2, U_2S + R_3 - C_3 - C_5 + F_2$	$-C_{7}-F_{2}$
(7)	$-C_{2}$	$S - C_4, U_1 S - C_4, U_2 S - C_4$	$-C_{6}$
(8)	$-C_{2}$	$S-C_4-C_5, U_1S-C_4-C_5, U_2S-C_4-C_5$	$-C_{7}$

In the first stage, the market quota coefficient has nothing to do with the revenues. The revenues of each party in the game are shown in Table 2.

In this stage, the market quota coefficient plays a role in the revenues. The revenues of this stage are related to the decisions made in the first stage, Table 3 presents the revenues of each party in the game.

Table 4 shows the revenues of each party in the game.

In this stage, the bike-sharing enterprise trading revenue is *D*, and the supply of shared bikes exceeds the demand, Table 5 presents the revenues of each party in the game.

	Revenue Value of Government	Revenue Value of Bike-Sharing Enterprises	Revenue Value of Consumers
(1)	$R_1 + R_2 - C_1 - A_1$	$D + A_1 + R_3 - C_3 - A_2$	$A_2 - C_6$
(2)	$R_1 - C_1 - C_2 - A_1$	$D + A_1 + R_3 - C_3 - C_5 + F_2$	$-C_{7}-F_{2}$
(3)	$R_1 - C_1 - C_2 + F_1$	$D - C_4 - F_1$	$-C_{6}$
(4)	$R_1 - C_1 - C_2 + F_1$	$D - C_4 - C_5 - F_1$	$-C_{7}$
(5)	<i>R</i> <sub>2</sub>	$D + R_3 - C_3 - A_2$	$A_2 - C_6$
(6)	$-C_{2}$	$D + R_3 - C_3 - C_5 + F_2$	$-C_7 - F_2$
(7)	$-C_{2}$	$D - C_4$	$-C_{6}$
(8)	$-C_{2}$	$D - C_4 - C_5$	$-C_{7}$

Table 5. Tripartite game revenue (the fourth stage).

We determined the revenues of each party in each stage of the game, and the following is a description of the three-party dynamic game process.

# 3.4.1. First Stage

Dynamic Game Evolution of the Government

Assuming the expected revenues of the government adopting "high regulation" and "low regulation" strategies are  $LG_1$  and  $LG_2$ , we can obtain

$$LG_{1} = P_{2}P_{3}(R_{2} + R_{1} - C_{1} - A_{1}) + P_{2}(1 - P_{3})(R_{1} - C_{1} - C_{2} - A_{1}) + (1 - P_{2})P_{3}(R_{1} - C_{1} - C_{2} + F_{1}) + (1 - P_{2})(1 - P_{3})(R_{1} - C_{1} - C_{2} + F_{1})$$

$$= (R_{1} - C_{1} - C_{2} + F_{2}) + P_{2}P_{3}(R_{2} + C_{2}) - P_{2}(A_{1} + F_{1});$$
(1)

$$LG_{2} = P_{2}P_{3}R_{2} - P_{2}(1 - P_{3})C_{2} - (1 - P_{2})P_{3}C_{2} - (1 - P_{2})(1 - P_{3})C_{2}$$
  
=  $P_{2}P_{3}(R_{2} + C_{2}) - C_{2}.$  (2)

According to Malthusian equation, the dynamic replication equation of the government is:

$$F(P_1) = P_1(1 - P_1)\{R_1 - C_1 + F_1 - P_2(A_1 + F_1)\}.$$
(3)

According to the differential equation theorem, the government dynamic game must meet the following conditions to achieve the optimal state:  $F(P_1) = 0$ ,  $\frac{\partial F(P_1)}{\partial (P_1)} < 0$ .

According to  $F(P_1) = 0$ , we can get  $P_1 = 0$  or  $P_1 = 1$  or  $P_2 = \frac{R_1 - C_1 + F_1}{A_1 + F_1}$ . According to  $\frac{\partial F(P_1)}{\partial (P_1)} = (1 - 2P_1)\{R_1 - C_1 + F_1 - P_2(A_1 + F_1)\} < 0$ , we can draw the following conclusions. When  $\frac{R_1 - C_1 + F_1}{A_1 + F_1} < P_2 \le 1$ ,  $P_1 = 0$  is a steady state; when  $0 \le P_2 < \frac{R_1 - C_1 + F_1}{A_1 + F_1}, P_1 = 1$  is a steady state.

Dynamic Game Evolution of Bike-Sharing Enterprises

Assuming the expected revenues of bike-sharing enterprises adopting "standardized operation" and "non-standardized operation" strategies are  $LE_1$  and  $LE_2$ , we can obtain

$$LE_1 = S + R_3 - C_3 - C_5 + F_2 + A_1 P_1 + P_3 (C_5 - F_2 - A_2);$$
(4)

$$LE_2 = S - C_4 - C_5 + C_5 P_3 - F_1 P_1.$$
(5)

In the same way, when  $0 \le P_1 < \frac{P_3(A_2+F_2)-(F_2+R_3+C_4)+C_3}{A_1+F_1}$ ,  $P_2 = 0$  is a steady state; when  $\frac{P_3(A_2+F_2)-(F_2+R_3+C_4)+C_3}{A_1+F_1} < P_1 \le 1$ ,  $P_2 = 1$  is a steady state.

Dynamic Game Evolution of Consumers

Assuming the expected revenues of consumers adopting "standard use" and "nonstandard use" strategies are  $LC_1$  and  $LC_2$ , we can obtain

$$LC_1 = A_2 P_2 - C_6; (6)$$

$$LC_2 = -C_7 - F_2 P_2. (7)$$

In the same way, when  $0 \le P_2 < \frac{C_6-C_7}{A_2+F_2}$ ,  $P_3 = 0$  is a steady state; when  $\frac{C_6-C_7}{A_2+F_2} < P_2 \le 1$ ,  $P_3 = 1$  is a steady state.

# 3.4.2. Second Stage

Dynamic Game Evolution of Government

Assuming the expected revenues of the government adopting "high regulation" and "low regulation" strategies are  $LG_{11}$  and  $LG_{21}$ , we can obtain

$$LG_{11} = (R_1 - C_1 - C_2 + F_2) + P_{21}P_{31}(R_2 + C_2) - P_{21}(A_1 + F_1);$$
(8)

$$LG_{21} = P_{21}P_{31}(R_2 + C_2) - C_2.$$
(9)

We can draw the following conclusions. When  $\frac{R_1-C_1+F_1}{A_1+F_1} < P_{21} \le 1$ ,  $P_{11} = 0$  is a steady state; when  $0 \le P_{21} < \frac{R_1-C_1+F_1}{A_1+F_1}$ ,  $P_{11} = 1$  is a steady state.

# Dynamic Game Evolution of Bike-Sharing Enterprises

Assuming the expected revenues of bike-sharing enterprises adopting "standardized operation" and "non-standardized operation" strategies are  $LE_{11}$  and  $LE_{21}$ , we can obtain

$$LE_{11} = S + R_3 - C_3 - C_5 + F_2 + (U_1S - S)P_{11} + A_1P_{11} + P_{31}(C_5 - F_2 - A_2);$$
(10)

$$LE_{21} = S - C_4 - C_5 + (U_2 S - S)P_{11} + C_5 P_{31} - F_1 P_{11}.$$
(11)

In the same way, when  $0 \le P_{11} < \frac{(A_2+F_2)P_{31}-R_3+C_3-C_4-F_2}{U_1S-U_2S+A_1+F_1}$ ,  $P_{21} = 0$  is a steady state; when  $\frac{(A_2+F_2)P_{31}-R_3+C_3-C_4-F_2}{U_1S-U_2S+A_1+F_1} < P_{11} \le 1$ ,  $P_{21} = 1$  is a steady state.

# Dynamic Game Evolution of Consumers

Assuming the expected revenues of consumers adopting "standard use" and "nonstandard use" strategies are  $LC_{11}$  and  $LC_{21}$ , we can obtain

$$LC_{11} = A_2 P_{21} - C_6; (12)$$

$$LC_{21} = -C_7 - F_2 P_{21}. (13)$$

In the same way, when  $0 \le P_{21} < \frac{C_6-C_7}{A_2+F_2}$ ,  $P_{31} = 0$  is a steady state; when  $\frac{C_6-C_7}{A_2+F_2} < P_{21} \le 1$ ,  $P_{31} = 1$  is a steady state.

#### 3.4.3. Third Stage

Dynamic Game Evolution of Government

Assuming the expected revenues of the government adopting "high regulation" and "low regulation" strategies are  $LG_{12}$  and  $LG_{22}$ , we can obtain

$$LG_{12} = (R_1 - C_1 - C_2 + F_2) + P_{22}P_{32}(R_2 + C_2) - P_{22}(A_1 + F_1);$$
(14)

$$LG_{22} = P_{22}P_{32}(R_2 + C_2) - C_2.$$
<sup>(15)</sup>

We can draw the following conclusions. When  $\frac{R_1-C_1+F_1}{A_1+F_1} < P_{22} \le 1$ ,  $P_{12} = 0$  is a steady state; when  $0 \le P_{22} < \frac{R_1-C_1+F_1}{A_1+F_1}$ ,  $P_{12} = 1$  is a steady state.

# Dynamic Game Evolution of Bike-Sharing Enterprises

Assuming the expected revenues of bike-sharing enterprises adopting "standardized operation" and "non-standardized operation" strategies are  $LE_{12}$  and  $LE_{22}$ , we can obtain

$$LE_{12} = (1 - P_{11})S + P_{11}P_{21}U_1S + P_{11}(1 - P_{21})U_2S + R_3 - C_3 - C_5 + F_2 + P_{12} \left\{ \begin{pmatrix} P_{11} P_{21}U_1^2S + P_{11} (1 - P_{21})U_1U_2S \\ + (1 - P_{11})U_1S \end{pmatrix} + A_1 \\ - (1 - P_{11})S - P_{11}P_{21}U_1S - P_{11}(1 - P_{21})U_2S \right\} - P_{32}(A_2 - C_5 + F_2);$$
(16)

$$LE_{22} = (1 - P_{11})S + P_{11}P_{21}U_1S + P_{11}(1 - P_{21})U_2S - C_4 - C_5 + P_{12} \{ (P_{11}(1 - P_{21})U_2^2S + P_{11}P_{21}U_1U_2S + (1 - P_{11})U_2S) - F_1 - (1 - P_{11})S - P_{11}P_{21}U_1S - P_{11}(1 - P_{21})U_2S \} + P_{32}C_5.$$
(17)

In the same way, when  $0 \le P_{12} < \frac{(A_2+F_2)P_{32}-R_3+C_3-C_4-F_2}{\{P_{11}P_{21}U_1+P_{11}(1-P_{21})U_2+1-P_{11}\}(U_1-U_2)+A_1+F_1}$ ,  $P_{22} = 0$  is a steady state; when  $\frac{(A_2+F_2)P_{32}-R_3+C_3-C_4-F_2}{\{P_{11}P_{21}U_1+P_{11}(1-P_{21})U_2+1-P_{11}\}(U_1-U_2)+A_1+F_1} < P_{21} \le 1$ ,  $P_{22} = 1$  is a steady state.

## Dynamic Game Evolution of Consumers

Assuming the expected revenues of consumers adopting "standard use" and "nonstandard use" strategies are  $LC_{12}$  and  $LC_{22}$ , we can obtain

$$LC_{12} = A_2 P_{22} - C_6; (18)$$

$$LC_{22} = -C_7 - F_2 P_{22}. (19)$$

In the same way, when  $0 \le P_{22} < \frac{C_6-C_7}{A_2+F_2}$ ,  $P_{32} = 0$  is a steady state; when  $\frac{C_6-C_7}{A_2+F_2} < P_{22} \le 1$ ,  $P_{32} = 1$  is a steady state.

# 3.4.4. Fourth Stage

Dynamic Game Evolution of Government

Assuming the expected revenues of the government adopting "high regulation" and "low regulation" strategies are  $LG_{13}$  and  $LG_{23}$ , we can obtain

$$LG_{13} = (R_1 - C_1 - C_2 + F_2) + P_{23}P_{33}(R_2 + C_2) - P_{23}(A_1 + F_1);$$
(20)

$$LG_{23} = P_{23}P_{33}(R_2 + C_2) - C_2.$$
<sup>(21)</sup>

We can draw the following conclusions. When  $\frac{R_1-C_1+F_1}{A_1+F_1} < P_{23} \le 1$ ,  $P_{13} = 0$  is a steady state; when  $0 \le P_{23} < \frac{R_1-C_1+F_1}{A_1+F_1}$ ,  $P_{13} = 1$  is a steady state.

# Dynamic Game Evolution of Bike-Sharing Enterprises

Assuming the expected revenues of bike-sharing enterprises adopting "standardized operation" and "non-standardized operation" strategies are  $LE_{13}$  and  $LE_{23}$ , we can obtain

$$LE_{13} = D + R_3 - C_3 - C_5 + F_2 + A_1 P_{13} + P_{33} (C_5 - F_2 - A_2);$$
(22)

$$LE_{23} = D - C_4 - C_5 + C_5 P_{33} - F_1 P_{13}.$$
(23)

In the same way, when  $0 \le P_{13} < \frac{P_{33}(A_2+F_2)-(F_2+R_3+C_4)+C_3}{A_1+F_1}$ ,  $P_{23} = 0$  is a steady state; when  $\frac{P_{33}(A_2+F_2)-(F_2+R_3+C_4)+C_3}{A_1+F_1} < P_{13} \le 1$ ,  $P_{23} = 1$  is a steady state.

Dynamic Game Evolution of Consumers

Assuming the expected revenues of consumers adopting "standard use" and "nonstandard use" strategies are  $LC_{13}$  and  $LC_{23}$ , we can obtain

$$LC_{13} = A_2 P_{23} - C_6; (24)$$

$$LC_{23} = -C_7 - F_2 P_{23}.$$
 (25)

In the same way, when  $0 \le P_{23} < \frac{C_6 - C_7}{A_2 + F_2}$ ,  $P_{33} = 0$  is a steady state; when  $\frac{C_6 - C_7}{A_2 + F_2} < P_{23} \le 1$ ,  $P_{33} = 1$  is a steady state.

# 3.5. Specification of the Model

The stable state refers to the optimal state of the dynamic game. In this state, all parties in the game will not change their strategy. When either party changes its strategy, its revenues at this stage will be smaller. In this model, the conditions that should be met to realize the optimal state of dynamic game among the government, bike-sharing enterprises, and consumers are calculated according to the differential equation theorem. When this state is reached, the government, bike-sharing enterprises, and consumers will not change their strategies, and the strategy combination is in a stable state.

In the first stage, the government allows the licensed bike-sharing enterprises to enter the market with a certain investment volume. When the government chooses the high regulation strategy, it will assess the service quality of the bike-sharing enterprises at the end of the quarter and increase or decrease the investment of the bike-sharing enterprises in the next stage based on the assessment results. When the government chooses the low-regulation strategy, it will not place great cost into the regulation of bike-sharing enterprises, and the investment volume of bike-sharing enterprises will remain unchanged in the next stage. The government's strategy choice has no influence on consumers.

When the government chooses the high regulation strategy in the second stage, it will increase or decrease the investment volume for bike-sharing enterprises according to the strategy selection of bike-sharing enterprises in the first stage. In comparison with the first stage, bike-sharing enterprises that choose a standardized operation will gain more revenues, while those that select a non-standardized operation will have less revenue. When the government chooses low regulation, the number of bike-sharing enterprises will not significantly change.

In the third stage, the investment volume of bike-sharing enterprises is interrelated with the strategy selection by the government and bike-sharing enterprises in the first two stages, with a variety of possible outcomes. At this point, the revenue of bike-sharing enterprises can only be expressed by the weighted average. However, the revenue value of bike-sharing enterprises choosing the standardized operating strategies increases under the high regulation condition. Meanwhile, the revenue value of bike-sharing enterprises choosing the non-standardized operating strategies decreases. In the case of low government regulation, the number of shared bikes will prevail in the previous stage and remain unchanged.

In the fourth stage, the market demand is less than the market supply due to the seasonal characteristics of bike-sharing. In this case, the reduced investment volume can still meet the market demand even if the bike-sharing enterprises are reduced due to the non-standardized operation. The government's quota policy becomes ineffective, and the state of the initial stage is returned.

#### 3.5.1. Potential Boundary

In this model, the investment volume of bike-sharing is determined by the behavior of the government and the bike-sharing enterprises. The quantity of bike-sharing is in various states at different stages. The time range of our model study is 1 year. Next, we will elaborate on the potential boundary of bike-sharing quantity in the model under the quota policy.

When the government chooses low regulation, the investment volume of bike-sharing corresponds to the trading revenue *S*. The investment volume is in the middle value in the model; hence, we will not consider it. When the government chooses high regulation, bike-sharing enterprises choose a standardized operation, and the investment volume of bike-sharing increases. When bike-sharing enterprises choose a non-standardized operation, the investment volume of bike-sharing decreases. The investment volume in each state is the same in the initial stage. The volume of investment in bike-sharing will increase or decrease with time due to the behavior of the bike-sharing enterprise. Given that the whole process is cumulative, the minimum volume of investment in bike-sharing is most likely to appear in the fourth stage, that is, the amount of investment corresponding to the trading revenue  $U_2{}^3S$  ( $U_2{}^3S$  is the ideal income that cannot be obtained in practice).

Considering the seasonal characteristics of bike-sharing into the model, the usage of bike-sharing will significantly decline in the fourth stage. At this point, bike-sharing enterprises may choose not to standardize the operation, and the investment volume of bike-sharing will decrease. The maximum investment volume of bike-sharing appears in the third stage, which is the corresponding investment volume of trading revenue  $U_1^2S$ . If the bike-sharing enterprises always maintain a standardized operation, the maximum investment volume of bike-sharing is in the fourth stage. This volume corresponds to the transaction revenue  $U_1^3S$  ( $U_1^3S$  is the ideal income that cannot be obtained in practice).

The potential boundary of the quota policy must be understood because it helps the government in regulating the overall quantity of bike-sharing and realizing a scientific and accurate operation of bike-sharing.

## 3.5.2. Evolution Path

The government, bike-sharing enterprises, and consumers are three parties that work together. The eight types of strategies are (0, 0, 0), (1, 0, 0), (0, 1, 0), (0, 0, 1), (1, 1, 0), (1, 0, 1), (0, 1, 1), and (1, 1, 1). A concrete analysis is as follows.

S is much larger than the other revenue parameters of bike-sharing enterprises; hence, when the government chooses high regulation, as a rational economic man, the bike-sharing enterprises will inevitably choose a standard operation. Therefore, state (1, 0, 0) (1, 0, 1) is not true. We assume that once the government chooses a high-regulation strategy, it stays there because the government's quota regulation behavior is ongoing. We know  $\frac{C_6-C_7}{A_2+F_2} < 0$  is not true, when bike-sharing enterprises choose a non-standardized operating strategy, consumers will only choose such a strategy; hence, (0, 0, 1) is not established. When the government chooses a low regulation strategy, bike-sharing enterprises will freely compete in accordance with the market rules. The bike-sharing enterprises will have greater benefits when they choose a non-standardized operation. The (0, 1, 0) and (0, 1, 1) state do not match in reality. We conclude the following possible evolutionary paths based on the above analysis.

The city's public space is managed by multiple departments, such as the transportation department, which divides the right of way and the traffic police, who regulate bike-sharing riding. When bike-sharing was just emerging, the disorderly occupation of public space by bike-sharing was a new problem, which belongs to the blind area of governance [53]. At this time, the government's regulatory regulations are yet perfect. The government's regulatory costs are high,  $R_1 - C_1 + F < 0$  and the government tends to have low supervision. The bike-sharing market is in a state of free competition due to the imperfect supervision of the government. Bike-sharing enterprises launch large-scale shared bikes in the market and grab the opportunity to reduce marginal cost and attract consumers at a low price [54]. The non-standard operation of bike-sharing enterprises increases the cost of standardized use by consumers, who are more inclined to non-standard use strategies; therefore, state (0, 0, 0) is satisfied. Imperfect laws and regulations are major challenges to the sustainable development of bike-sharing. The sustainable development of bike-sharing can be realized

through mandatory legislation and supervision on the problems of bike-sharing and the incentive and punishment mechanism of operators [55]. Bike-sharing have greatly damaged public interests with the advancement of time [56]. The regulatory regulations of the bike-sharing industry have been improved with the aggravation of social conflicts. The cost of government regulation is reduced. At this time,  $R_1 - C_1 + F > 0$ , the government tends to choose the high supervision strategy, and bike-sharing enterprises choose a standardized operation. The behavior of bike-sharing enterprises has a significant positive effect on consumers' awareness of uncivilized behavior and civilized use intention [57]. Consumers' decisions change according to the behavior of bike-sharing enterprises. If  $C_6 - C_7 > A_2 + F_2$ , it goes from (0, 0, 0) to (1, 1, 0). On the contrary, if  $C_6 - C_7 < A_2 + F_2$ , it goes from (0, 0, 0) to (1, 1, 0). On the game are in a stable state. In the fourth stage, the government's quota policy becomes invalid. Although the government is in a state of high supervision, the strategic choices of bike-sharing enterprises and consumers return to the initial state. The evolutionary path of the whole process may be (0,0,0) (1,1,0) (1,1,0) (1,0,0) or (0,0,0) (1,1,1) (1,1,1) (1,0,0).

When the government's regulatory laws and regulations are gradually improved, and the regulatory costs are reduced,  $R_1 - C_1 + F > 0$  the government tends to have high supervision. Hence, bike-sharing enterprises choose a standardized operation. If  $C_6 - C_7 < A_2 + F_2$ , then all parties in the game remain in the state of (1, 1, 1), the evolutionary path is (1,1,1) (1,1,1) (1,1,1) (1,1,1). If  $C_6 - C_7 > A_2 + F_2$ , then all parties in the game keep the state of (1, 1, 0), the evolutionary path is (1,1,0) (1,1,0) (1,1,0).

From the perspective of evolutionary path, the implementation of government quota policy is very effective for the governance of bike-sharing. As long as the government ensures appropriate regulatory intensity, the strategic choices of other players will evolve in the desired direction, reflecting the dominant position of the government in the governance of bike-sharing. The following case studies will be used for further verification.

## 4. Case Studies

This example is carried out in the context of the government's choice of high supervision strategy. When the government chooses high supervision, the benefits of bike-sharing can only be maximized by a standardized operation. When the government chooses low supervision, and enterprises select a non-standard operation, consumers can only minimize their losses by non-standard use.

In the case analysis, the following conditions should be met  $R_1 - C_1 + F_1 > 0$ ,  $C_6 - C_7 < A_2 + F_2$ , *S* is obviously larger than other parameters, and  $C_3 > C_4$ ,  $U_1 > U_2$ .

 $C_1 = 8, R_1 = 12, A_1 = 3, F_1 = 4, R_2 = 5, C_2 = 6, C_3 = 7, R_3 = 4, A_2 = 2, F_2 = 2.5, C_4 = 3.5, C_5 = 7, S = 20, D = 8, U_1 = 1.2, U_2 = 0.8, C_6 = 2, C_7 = 1.5.$ 

## 4.1. Multi-Stage Evolution of Tripartite Revenue

The parameter values are substituted into Tables 2–5, yielding Tables 6–9. The result showed that the effect of quota policy on bike-sharing enterprise revenue value is evident. In the first three stages (spring, summer, and autumn), under the environment of high government supervision, the more stages of standardized and continuous operations of bike-sharing enterprises, the greater their revenue value will be. Meanwhile, the more stages of non-standardized operation, the smaller their revenue value will be, indicating the effectiveness of the government quota policy. However, the revenue value of bike-sharing enterprises returned to the initial state in the fourth stage (winter) when the transaction volume of bike-sharing decreased, demonstrating the ineffectiveness of the policy at this stage. The government's quota policy still needs to be improved.

In different stages of the quota policy, the revenue value of the government and consumers remains unchanged, which indicates that the quota policy mainly affects bikesharing enterprises and has nothing to do with the revenue value of the government and consumers.

#### 16 of 24

#### 4.1.1. First Stage

We can obtain the result shown in Table 6 based on Table 2.

	Revenue Value of Government	Revenue Value of Bike-Sharing Enterprises	Revenue Value of Consumers
(1)	6	18	0
(2)	-5	15.5	-4
(3)	2	12.5	-2
(4)	2	5.5	-1.5
(5)	5	15	0
(6)	-6	12.5	-4
(7)	-6	16.5	-2
(8)	-6	9.5	-1.5

Table 6. Tripartite game revenue (the first stage).

The table illustrates that the government's revenue will be affected by the decisions of bike-sharing enterprises and consumers. For example, the possible revenues of the government are 6, -5, 2, and 2 when it selects a high regulation strategy due to the different strategy combinations of bike-sharing enterprises and consumers. Meanwhile, bike-sharing enterprises' revenue will be affected by the government and consumers' behaviors. Nevertheless, the revenue of consumers is only relevant to the bike-sharing enterprises' behaviors. For example, the revenue of standardized use by consumers is zero, and that of non-standard use by consumers is -2 when bike-sharing enterprises choose a standardized operation. By contrast, consumers' decisions will affect the revenues of the government and bike-sharing enterprises.

#### 4.1.2. Second Stage

We can obtain the result shown in Table 7 based on Table 3.

Tab	le 7.	Tripartite	game revenue	(th	e second	stage	).
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	Revenue Value of Government	Revenue Value of Bike-Sharing Enterprises	Revenue Value of Consumers
(1)	6	22	0
(2)	-5	19.5	-4
(3)	2	8.5	-2
(4)	2	1.5	-1.5
(5)	5	15	0
(6)	-6	12.5	-4
(7)	-6	16.5	-2
(8)	-6	9.5	-1.5

In the table, the possible revenue of the government is 22 or 19.5, which is higher than 18 and 15.5 in the previous stage, when the government always maintains a high regulation strategy, and the bike-sharing enterprises choose a standardized operation. In the case of non-standard operation, the revenue is 8.5 or 1.5, which is lower from 12.5 and 5.5 in the previous phase. At this point, the revenues for governments and consumers remain the same in each state, which we will not discuss at a later stage.

At this stage, the optimal state of the dynamic game is (1, 1, 1). All parties in the game will not change their strategy to maximize their own revenues. If the government changes its strategy, its revenue will change from 6 to 5. If the bike-sharing enterprise changes its strategy, its profit will change from 22 to 8.5; if the consumer changes its strategy, its profit will change from 0 to -4, then it is in a steady state at this time.

#### 4.1.3. Third Stage

We can obtain the result shown in Table 8 based on Table 4.

	Revenue Value of Government	Revenue Value of Bike-Sharing Enterprises	Revenue Value of Consumers
(1)	6	26.8, 17.2, or 22	0
(2)	-5	24.3, 14.7, or 19.5	-4
(3)	2	5.3, 11.7, or 8.5	-2
(4)	2	-1.7, 4.7, or 1.5	-1.5
(5)	5	15, 19, or 11	0
(6)	-6	12.5, 16.5, or 8.5	-4
(7)	-6	16.5, 20.5, or 12.5	-2
(8)	-6	9.5, 13.5, or 5.5	-1.5

Table 8. Tripartite game revenue (the third stage).

In the table, the revenue of this stage is affected by the decisions of the previous two stages. Three possible revenue scenarios exist for bike-sharing enterprises. When the bike-sharing enterprises maintain a standardized operation, their revenues are highest, accounting for 26.8.

# 4.1.4. Fourth Stage

We can obtain the result shown in Table 9 based on Table 5.

Table 9. Tripartite game revenue (the fourth stage).

	Revenue Value of Government	Revenue Value of Bike-Sharing Enterprises	Revenue Value of Consumers
(1)	6	6	0
(2)	-5	3.5	-4
(3)	2	0.5	-2
(4)	2	-6.5	-1.5
(5)	5	3	0
(6)	-6	0.5	-4
(7)	-6	4.5	-2
(8)	-6	-2.5	-1.5

The table shows that the demand of consumers for bike-sharing is greatly reduced due to the winter, and the market supply still can meet the market demand even if the bike-sharing enterprises cut supply. The existing bike-sharing enterprises will lose the advantage of the accumulated during the first few stages. The revenue of selecting high regulation decreases from 26.8 to 6, and the quota policy becomes invalid.

# 4.2. Multi-Stage Tripartite Probability Evolution

We substituted the parameter values according to the equations in the model, and the results were as follows:

#### 4.2.1. First Stage

We can draw the following conclusions according to the dynamic game model above: Government:

When  $\frac{8}{7} < P_2 \le 1$ ,  $P_1 = 0$ , there exists a steady state.  $P_1$  cannot be zero because the case is carried out under the background of high government regulation; hence, this state is omitted. In the following analysis, we will also omit this state; when  $0 \le P_2 < \frac{8}{7}$ ,  $P_1 = 1$ , there exists a steady state.

Bike-sharing enterprises:

When  $0 \leq P_1 < \frac{4.5P_3-3}{7}$ ,  $P_2 = 0$ , there exists a steady state; when  $\frac{4.5P_3-3}{7} < P_1 \leq 1$ ,  $P_2 = 1$ , there exists a steady state.

Consumers:

When  $0 \le P_2 < \frac{1}{9}$ ,  $P_3 = 0$ , there exists a steady state; when  $\frac{1}{9} < P_2 \le 1$ ,  $P_3 = 1$ , there exists a steady state.

According to the changes in the revenue values of the participants in each stage above, the probability of the government and consumers in the following three stages will be consistent with that in the first stage. Therefore, we will focus on calculating the probability evolution of bike-sharing enterprises in the following stages.

#### 4.2.2. Second Stage

We can draw the following conclusions according to the dynamic game model above: Government:

When  $0 \le P_{21} < \frac{8}{7}$ ,  $P_{11} = 1$ , there exists a steady state.

When  $0 \leq P_{11} < \frac{4.5P_{31}-3}{15}$ ,  $P_{21} = 0$ , there exists a steady state; when  $\frac{4.5P_{31}-3}{15} < P_{11} \le 1, P_{21} = 1$ , there exists a steady state.

Consumers:

Bike-sharing enterprises:

When  $0 \le P_{21} < \frac{1}{9}$ ,  $P_{31} = 0$ , there exists a steady state; when  $\frac{1}{9} < P_{21} \le 1$ ,  $P_{31} = 1$ , there exists a steady state.

#### 4.2.3. Third Stage

We can draw the following conclusions according to the dynamic game model above: Government:

When  $0 \le P_{22} < \frac{8}{7}$ ,  $P_{12} = 1$ , there exists a steady state.

Bike-sharing enterprises:

When  $0 \le P_{12} < \frac{4.5P_{32}-3}{7+8(0.4P_{11}P_{21}-0.2P_{11}+1)}$ ,  $P_{22} = 0$ , there exists a steady state; when  $\frac{4.5P_{32}-3}{7+8(0.4P_{11}P_{21}-0.2P_{11}+1)} < P_{12} \le 1, P_{22} = 1, \text{ there exists a steady state.}$ 

Consumers:

When  $0 \le P_{22} < \frac{1}{9}$ ,  $P_{32} = 0$ , there exists a steady state; when  $\frac{1}{9} < P_{22} \le 1$ ,  $P_{32} = 1$ , there exists a steady state.

## 4.2.4. Fourth Stage

We can draw the following conclusions according to the dynamic game model above: Government:

When  $0 \le P_{23} < \frac{8}{7}$ ,  $P_{13} = 1$ , there exists a steady state.

Bike-sharing enterprises:

When  $0 \leq P_{13} < \frac{4.5P_{33}-3}{7}$ ,  $P_{23} = 0$ , there exists a steady state; when  $\frac{4.5P_{33}-3}{7} < P_{13} \le 1, P_{23} = 1$ , there exists a steady state.

Consumers:

When  $0 \le P_{23} < \frac{1}{9}$ ,  $P_{33} = 0$ , there exists a steady state; when  $\frac{1}{9} < P_{23} \le 1$ ,  $P_{33} = 1$ , there exists a steady state.

The revenue value of the government and consumers remains unchanged in each stage. Meanwhile, the probability of the government and consumers also remains unchanged in each stage of the game, that is  $P_1 = P_{11} = P_{12} = P_{13}$ ,  $P_3 = P_{31} = P_{32} = P_{33}$ . Quota policy has the most obvious influence on the probability of the strategy selection of bike-sharing enterprises. For bike-sharing enterprises, when  $P_2 = P_{21} = P_{22} = P_{23} = 1$ , the value range of  $P_1$ ,  $P_{11}$ ,  $P_{12}$ , and  $P_{13}$  are respectively  $(\frac{4.5P_3-3}{7}, 1)$ ,  $(\frac{4.5P_{31}-3}{15}, 1)$ ,  $(\frac{4.5P_{32}-3}{7+8(0.4P_{11}P_{21}-0.2P_{11}+1)}, 1)$ ,  $(\frac{4.5P_{33}-3}{7}, 1)$ . In the case of government quota, the probability of bike-sharing enterprises choosing a standardized operation in the first three stages is improved in each stage. In the fourth stage, the probability of bike-sharing enterprises choosing a standardized operation

decreases and returns to the initial state.

The strategy selection of bike-sharing enterprises in the previous stage affects the strategy selection in the next stage. When the probability of bike-sharing enterprises choosing a standardized operation in the second stage is greater than a certain value, the probability of bike-sharing enterprises choosing a standardized operation in the third stage 4.3. Other Examples

(1) U1 = 1.05, U2 = 0.95, the government reduces supervision. Given that the changes of  $U_1$  and  $U_2$  only affect the earnings of bike-sharing enterprises, the following table only shows the earnings changes of bike-sharing enterprises.

 $C_1 = 8, R_1 = 12, A_1 = 3, F_1 = 4, R_2 = 5, C_2 = 6, C_3 = 7, R_3 = 4, A_2 = 2, F_2 = 2.5, C_4 = 3.5, C_5 = 7, C_6 = 10, C_7 = 10, C_8 = 10, C$  $S = 20, D = 8, U_1 = 1.05, U_2 = 0.95, C_6 = 2, C_7 = 1.5.$ 

> Table 10 shows that when the government reduces the regulation, the possible revenue in the second stage is 19 or 16.5 if the bike-sharing enterprises choose to standardize the operation. Such value is higher than the revenue in other states in the second stage. The same is true in the third stage, indicating that the government's quota policy is still effective at this time.

Table 10. Revenues of bike-sharing enterprises.

	The First Stage	The Second Stage	The Third Stage	The Fourth Stage
(1)	18	19	20.05, 17.95, or 19	6
(2)	15.5	16.5	17.55, 15.45, or 16.5	3.5
(3)	12.5	11.5	10.55, 12.45, or 11.5	0.5
(4)	5.5	4.5	3.55,5.45, or 4.5	-6.5
(5)	15	15	15, 16, or 14	3
(6)	12.5	12.5	12.5, 13.5, or 11.5	0.5
(7)	16.5	16.5	16.5, 17.5, or 15.5	4.5
(8)	9.5	9.5	9.5, 10.5, or 8.5	-2.5

(2)  $C_6 - C_7 > A_2 + F_2$ , In other words, bike-sharing enterprises have less supervision

over consumers.  $C_1 = 8, R_1 = 12, A_1 = 3, F_1 = 4, R_2 = 5, C_2 = 6, C_3 = 7, R_3 = 4, A_2 = 0, F_2 = 0.4, C_4 = 3.5, C_5 = 7,$ (26) $S = 20, D = 8, U_1 = 1.2, U_2 = 0.8, C_6 = 2, C_7 = 1.5.$ 

> Table 11 shows that the cost of non-standardized use by consumers is always less than that of standardized use when bike-sharing enterprises reduce their regulation on consumers, regardless of whether the bike-sharing enterprises choose a standardized operation or not. When bike-sharing enterprises choose a standardized operation, the cost -2 of standard use by consumers is less than the cost -1.9 of non-standard use. When bike-sharing enterprises choose a standardized operation, the cost -2 of standard use by consumers is less than the cost -1.5 of non-standard use. Consumers will always choose non-standard use strategies, indicating that the supervision of bike-sharing enterprises on consumers is invalid at this time. Therefore, bike-sharing enterprises should grasp the supervision of consumers to achieve coordinated governance of bike-sharing.

	The First Stage		The Second Stage		The Third Stage		The Fourth Stage	
(1)	20	-2	24	-2	28.8, 19.2, or 24	-2	8	-2
(2)	13.4	-1.9	17.4	-1.9	22.2, 12.6, or 17.4	-1.9	1.4	-1.9
(3)	12.5	-2	8.5	-2	5.3, 11.7, or 8.5	-2	0.5	-2
(4)	5.5	-1.5	1.5	-1.5	-1.7, 4.7, or 1.5	-1.5	-6.5	-1.5
(5)	17	-2	17	-2	17, 21, or 13	-2	5	-2
(6)	10.4	-1.9	10.4	-1.9	10.4, 14.4, or 6.4	-1.9	-1.6	-1.9
(7)	16.5	-2	16.5	-2	16.5, 20.5, or 12.5	$^{-2}$	4.5	-2
(8)	9.5	-1.5	9.5	-1.5	9.5,13.5, or 5.5	-1.5	-2.5	-1.5

Table 11. Revenues of bike-sharing enterprises and consumers.

According to the analysis of case studies, the government's quota policy is effective in the governance of bike-sharing, and the social welfare is maximum in state (1, 1, 1). The government can relax regulation to a certain extent in some states due to the seasonal changes in the use of bike-sharing, which can not only reduce costs but also maintain the market order of bike-sharing. However, regulation should be strengthened in advance when the demand decreases during winter to prevent the market from getting out of control. Bike-sharing enterprises should grasp the regulatory intensity of consumers. When the regulatory intensity is considerably low, consumers have no constraint.

#### 4.4. Discussion and Policy Implications

The maximization of social welfare is the ultimate goal of bike-sharing governance. In this work, we translate the maximization of social welfare into the analysis of the minimization of the total cost of the government, bike-sharing enterprises, and consumers to determine the balance among the three parties in the maximization of social welfare. The three stable states established under high government supervision are (1, 1, 0), (1, 1, 1), and (1, 0, 0). According to the first calculation example in this article, in state (1, 1, 0), the total cost of the three parties is  $C_1 + C_2 + C_3 + C_5 + C_7 = 29.5$ . In state (1, 1, 1), the total cost for all three parties is  $C_1 + C_3 + C_6 = 17$ . In state (1, 0, 0), the total cost of three parties is  $C_1 + C_2 + C_4 + C_5 + C_7 = 26$ . By contrast, the total cost is the smallest when the state is (1, 1, 1). When the government maintains high supervision, the bike-sharing enterprises standardize their operation and consumers standardize their use, the social welfare is the optimal. All parties in society should aim toward this state. In real life, the relevant factors with positive effects should be improved, and the influence of negative factors should be reduced. According to the expressions of relevant parameters in the model, the government quota policy is effective in the peak season, but invalid in the low season.

Analyzing the model, we know that at each stage, when  $0 \le P_{2(i)} < \frac{R_1 - C_1 + F_1}{A_1 + F_1}$ ,  $P_{1(i)} = 1$  (i = 1, 2, 3) is a steady state. Therefore, government image and punishment have a positive effect on the promotion of high government regulation probability. Meanwhile, the input cost of high government regulation has a negative effect on the promotion of high government regulation probability. The government should improve the relevant laws and policies on standardizing the operation of bike-sharing, solicit opinions from all walks of life, realize the diversified governance of bike-sharing, and improve the government image. The government should gradually loosen the regulation in spring, summer, and autumn and strengthen the regulation in advance in winter to realize the scientific and dynamic regulation of the government but also achieves precise regulation. On the one hand, the government should mainly punish the bike-sharing enterprises and supplement them with rewards. On the other hand, it can reduce the regulation cost and promote the standardized operation of the bike-sharing enterprises. The government should consider incorporating bike-sharing into the urban transport system and improve urban transport planning with the support of cycling data. Moreover, the government should strengthen the

connection between bike-sharing and other modes of transport and improve the resilience and robustness of the urban transport system.

Similarly, bike-sharing trading revenues, government rewards and punishments, bikesharing enterprise punishments, and quota coefficient difference have a positive effect on the improvement of standardized operation probability of bike-sharing enterprises. Governance costs have a negative effect on the improvement of standardized operation probability of bike-sharing enterprises. Bike-sharing enterprises should consider cooperating with the government to establish a more perfect consumer credit evaluation system, evaluate and record consumers' consumption behaviors according to their credit rating reward and penalize consumers to improve consumers' awareness of standard use. Bikesharing enterprises should improve the comfort and convenience of using bike-sharing and reduce the cost of standard use. Bike-sharing enterprises should have good moral quality and sense of responsibility, actively participate in the governance of bike-sharing, supervise each other and cooperate with the government and consumers to improve their corporate image. Bike-sharing enterprises should have a long-term vision of development and identify the strategies conducive to their sustainable development under the regulation of the government. Furthermore, such enterprises should not restrict their future development because of temporary revenues.

For the same reason, the rewards and punishments of bike-sharing enterprises have a positive effect on the improvement of standard use probability of consumers. Meanwhile, the cost of standard use has a negative effect on the improvement of standard use probability of consumers. Relevant departments should strengthen the publicity of standard use of bike-sharing, explain the disadvantages of non-standard use of bike-sharing, and strengthen the social identity of consumers. Consumers should improve their moral quality, regulate the use of bike-sharing, give full play to their supervisory role, and provide suggestions for the development of bike-sharing.

## 5. Conclusions and Future Directions

The work creates a dynamic multi-stage game model among the government, bikesharing enterprises, and consumers and verifies it through an example. The research finds that:

(1) The quota policy of the government only affects the strategic choice of bike-sharing enterprises and has no effect on the strategic choice of the government and consumers. In the case of quota policy and multi-stage dynamic game, the strategy choice of bike-sharing enterprises in the previous stage will have an influence on the strategy choice of the next stage.

(2) In the first three stages, the bike-sharing enterprises' strategy selection tends to standardize the operation and validated the effectiveness of government quota policy. However, in the fourth stage, bike-sharing transaction volume is sharply reduced, and the bike-sharing enterprises' strategy selection tends to the initial state. Accordingly, the government's quota policy will be in a state of failure.

(3) When the government ease regulation appropriately during peak demand for bike-sharing, the government's quota policy is still in effect. When bike-sharing enterprises have too few regulations on consumers, the regulation of bike-sharing enterprises has no binding force on consumers' behaviors.

The government's quota policy has opened up a new situation for the development of bike-sharing, which means that bike-sharing will move toward fine operation and diversified governance and has a good development prospect. This work is based on the government, bike-sharing enterprises, and consumers of the multi-stage tripartite game model aims to explore the effectiveness of the government's quota policy in different seasons, and has very important significance. However, the game analysis is based on an ideal state and only considers the government's quarterly assessment of bike-sharing enterprises, ignoring the other regions to examine every six months or a year. Moreover, the article conclusions lack universality. Future studies will focus on strengthening the link between model and reality. On the one hand, the basic assumptions of the model will be gradually relaxed, that is, it assumes that the participants are bounded rational, and the information mastered by each participant is incomplete. On the other hand, the quota parameters of the model should be reasonably set to maintain the total market investment volume, and the content of the model will be further enriched. The exit mechanism of bike-sharing enterprises in government documents will be introduced into the model to extensively verify the effectiveness of government policies and provide theoretical support for government regulation.

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