

## Article

# Analysis of the Evolutionary Game between the Government and Urban Rail Transit Enterprises under the Loss-Subsidy Mode: A Case Study of Beijing

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**Abstract:** Most of the urban rail transit enterprises in China have high construction and operation costs, while the government imposes price control on their fares, making their revenues unable to cover their costs and thus causing certain losses. In order to ensure the economic sustainability of urban rail transit enterprises, the government then subsidizes their losses. In the context of loss subsidies as the main subsidy mode for urban rail transit, the government regulates whether urban rail transit enterprises waste cost in order to protect social welfare and reduce the financial pressure of subsidies. This paper constructs an evolutionary game model between government regulators and urban rail transit enterprises, establishes replicated dynamic equations to obtain the evolutionary stabilization strategies of the government and urban rail transit enterprises under different situations, and analyzes the effects of various parameters on the cost control behaviors of urban rail transit enterprises under different loss-subsidy modes through numerical simulations. The theoretical study and simulation results show the following: When only the regulatory policy is adopted, the optimal strategy of urban rail transit enterprises may be cost saving or cost wasting under different subsidy models; if only the penalty policy is adopted, the enterprises will choose the cost wasting strategy when the penalty is small, and the enterprises will choose the cost saving strategy when the penalty is large; if only the fixed proportion subsidy model is adopted, no matter how large the proportion  $k$  of government subsidies is, the urban the optimal strategy for rail transit enterprises is cost wasting. If only the regressive loss subsidy model is adopted, the different sizes of its various parameter settings will also lead to the enterprises' choice of cost wasting strategy or cost saving strategy. Therefore, the government should formulate corresponding policies according to different cost control objectives.



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**Keywords:** loss-subsidy mode; government regulation; urban rail transit enterprises' cost control; evolutionary game; Beijing; China

## 1. Introduction

The 2018 China Urban Rail Transit Annual Statistical Analysis Report released by the China Urban Rail Transit Association shows that China's urban rail transit is developing rapidly, with its 2018 operating line length increasing by 14.73% compared to 2017. By the end of 2018, a total of 35 cities in mainland China had opened urban rail transit, with a total operating line length of 5761.4 km, and the cumulative annual passenger volume of urban rail transit was 21.07 billion [1].

However, due to the high cost of urban rail transit construction and operation, as well as the government's price control on its fares, most of the urban rail transit enterprises in China are facing losses [1]. In order to maintain the sustainability of their operations, government subsidies are needed. The subsidy mode and the amount of subsidy in major Chinese cities are as follows: (1) special subsidy mode, such as Wuhan subsidizes the preferential part of fares for the military, disabled people, students, the elderly and other groups, which is about 160 million RMB in 2017, and Chongqing includes special subsidies such as preferential subsidies, fare differentials, and subsidies for remote lines, which

is about 800–900 million RMB per year. (2) The fixed amount subsidy mode, such as Suzhou subsidizing 300 million RMB per year. (3) The full subsidy mode for losses, for example, in Chengdu, after the fare adjustment in 2017, the annual loss was about 100 million RMB, which was fully subsidized by government financing [2]. (4) Beijing adopted the loss subsidy mode of “total amount control, itemized assessment, no compensation for excess loss and share of loss reduction” in 2015, and the subsidy amounted to 3.432 billion RMB [3].

From the current situation of rail transit subsidy modes and amounts in major cities in China, the Chinese subsidy mode is mainly the loss subsidy, supplemented by special subsidy, and loss subsidies can be divided into many different modes [2,3].

This study will focus on the loss subsidy mode and explore the advantages and disadvantages of different loss subsidy modes in urban rail transit subsidies, so as to provide suggestions for the government to select the appropriate loss subsidy modes and corresponding policy measures.

## 2. Literature Review

Chinese and foreign scholars have studied the following questions of government policies to subsidize urban public transportation enterprises such as urban rail transit. Why does the government subsidize urban public transportation enterprises? What are the ways in which the government subsidizes urban public transportation enterprises? What are the effects of government subsidies on urban public transportation enterprises? What are the games that arise when the government subsidizes urban public transport companies? The following subsection will review the literature for each question.

### 2.1. Reasons for Urban Public Transportation Subsidy

Some scholars have theoretically classified urban public transportation as a quasi-public good, that is, a public good with limited non-competitiveness or limited non-exclusivity [4,5], which makes the public transport enterprises have public welfare characteristics in addition to the general enterprise profitability. Losses caused by the public welfare characteristics of public transportation enterprises requiring low prices are called policy losses [6]. This loss is a reduction in revenue or increase in expenses related to rail transit fares that are limited by rail transit enterprises due to socially beneficial objectives set by policy and should be fully or partially compensated by government financial subsidies in order to ensure the sustainability of the enterprise's operations [7].

Other scholars argue that urban public transportation has economies of scale and therefore requires government subsidies to optimize the frequency of service for social welfare [8]. For example, when public transport companies monopolize the market, the frequency chosen by the vendor is too low and the price is too high compared to when the social welfare is optimal. Using a subsidy policy can make the operator choose the optimal price and frequency (in terms of welfare) [9]. Although it has been suggested that if operators are allowed to consider the demand effects of their pricing and frequency decisions, the profit-maximizing frequency is greater than or equal to the welfare-maximizing frequency. When consumers do not know the train schedules, the government does not need to subsidize for firms to reach the welfare maximizing frequency, and when consumers know the train schedules, a tax is even needed to bring the firm frequency down to the welfare maximizing frequency [10]. By modifying the assumption that demand is a function of price and frequency and that passengers' maximum willingness to pay is uniformly distributed, it can still be shown that government subsidies are needed to make the frequency of service optimal for social welfare [11,12]. The factor that leads to the two different conclusions is whether the firm is regulated by the government, and when it is regulated, the monopolistic public transportation firm requires government subsidies to achieve optimal welfare frequency of operation [13].

## 2.2. The Modes of Urban Public Transportation Subsidy

There are three main types of government subsidies for transportation operators: first, direct subsidies; second, indirect subsidies; and third, cross-subsidies [14]. Of these, direct subsidies can be divided into four main categories of models: the deficit subsidy mode, the incentive subsidy mode, the special subsidy mode and the franchise bidding mode.

The main idea of the loss subsidy mode is to find out the difference between the cost and the revenue of the enterprise [15], and then subsidize the difference in full or in part. The main loss subsidy modes are the fixed amount subsidy mode, the fixed percentage subsidy mode and the regressive loss subsidy mode. Under the fixed amount subsidy mode, the amount of subsidy is the difference between the determined reasonable cost and the actual revenue [16]. The fixed percentage subsidy mode means that the government subsidizes a certain percentage of the loss to the rail transit enterprise, and the rail transit enterprise settles the rest through other channels or methods [17]. The regressive loss subsidy mode is based on the subsidy principle of “total amount control, itemized assessment, no compensation for excess losses and share of loss reduction” [3].

The main incentive subsidy modes are the subsidy mode based on service quality and the subsidy mode based on passenger turnover. The subsidy mode based on service quality requires the government to first construct a performance evaluation system for urban rail transit enterprises so that subsidies can be made based on the performance of the enterprises. Constructing the index system needs to calculate the weight of each index, some scholars use a subjective weighting method based on the differential principle to calculate the weight, then use the fuzzy comprehensive evaluation method to assess the comprehensive performance, and finally determine the amount of subsidy based on the overall performance [18]. Some scholars have determined the weights of each indicator by using the distance entropy after translation correction and the tolerance of information loss, and also developed the entropy of priority order by TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) method [19]. The subsidy mode based on passenger turnover can link government subsidies to business performance, thus motivating rail transit companies to cultivate passenger traffic [17].

The special subsidy mode mainly focuses on fare discount subsidies for specific groups such as the military, the disabled, students and the elderly, as well as subsidies for specific, out-of-the-way routes [2]. In contrast, the franchise bidding mode discusses the situation where multiple investment entities do not participate in the operation and management of urban rail transit and only need to consider subsidies, specifically divided into the subsidy mode where the total subsidy amount during the contract period is the subject of the auction and the subsidy mode where the operating cost during the contract period is the subject of the auction [20].

Furthermore, different subsidy modes should be adopted in different operation stages of urban rail transit. For example, the loss subsidy mode can be chosen in the initial operation stage, the loss subsidy mode or special subsidy mode in the operation development stage, and the special subsidy mode or incentive subsidy mode in the operation stabilization stage [21]. Multiple subsidy modes can also be used in the same operation phase, for example, the subsidy can be divided into two parts: loss subsidy and incentive subsidy, with the loss subsidy set according to the amount of loss, while the incentive subsidy is linked to the performance of the enterprise [22].

## 2.3. The Impacts of Subsidies on Urban Public Transportation Companies

From a social perspective, subsidizing public transportation increases social welfare [23], while subsidizing private transportation decreases social welfare [24,25]. From a business perspective, government subsidies for public transport enterprises not only save inputs of transport enterprises [26], but also increase outputs [27]. Transportation companies that do not operate for profit must also rely on government subsidies to have sufficient funds to purchase vehicles [28]. However, as government subsidies increase year by year, the revenue-to-cost ratio of transportation enterprises decreases year by year,

indicating that unreasonable subsidies will instead reduce the operational efficiency of enterprises [29]. From a consumer perspective, consumer benefits generated by subsidized rail transit increase with the value of time, except for consumers with land ownership and low time value [30]. Public transport subsidies for specific groups can increase their use of public transport but may also increase the use of non-beneficiary groups [31]. The share of social benefits received by the lowest income group may be low [32] or high [33], but the reduction in their commuting burden is the most pronounced [34]. The impact on the welfare of the rich, on the other hand, depends on whether the rich take public transportation to work and who owns the land, as well as the size of the private transportation subsidy versus the public transportation subsidy [35]. Sometimes, the average subsidy per person may be similar for all income groups [36].

#### *2.4. The Games between Government and Urban Public Transportation Business*

The main methods of domestic and foreign scholars on the games between governments and transportation enterprises are the stage game and the evolutionary game. In the two-stage game, in which the government subsidizes public transport enterprises, whether considering carbon trading [37] or service level and pricing [38], the government should determine the optimal subsidy amount in the first stage of the game, while the public transport enterprises choose the optimal effort level in the second stage of the game. In the three-stage principal-agent game model between the government and the project company, government subsidies are the key to establishing the incentive constraint mechanism [39]. In the evolutionary game model between the government and transportation enterprises, some scholars study the new energy vehicle subsidy problem, mainly including the game strategy of regulation and fraud [40] and the influence of factors such as the strength of subsidy and punishment of fraud on the production game strategy of both sides [38]. Some scholars also study the carbon emission problem, mainly including the impact of factors such as the strength of government regulation, the success rate of investigation and the strength of third-party supervision on the low-carbon game strategy of both sides [41].

In general, the existing literature on the causes of loss-subsidy modes focuses on the revenue-based causes of losses, while the causes of cost control in transportation firms are rarely studied. Most of the studies on the classification of loss-subsidy modes are presented separately without focused comparison. The research on the impact of government subsidies on transportation enterprises is focused on inputs and outputs, while the impact of subsidy mode on such behavior of enterprise cost control is seldom studied. Meanwhile, the method of studying the game between the two in the process of subsidies is mainly a stage game, and the evolutionary game method is less used for studying government subsidies on transportation enterprises, especially rail transportation enterprises. Therefore, this paper will use the evolutionary game model supplemented by numerical simulation experiments to firstly determine the factors affecting the evolutionary stabilization strategy so as to obtain the evolutionary stabilization strategy under different situations, and then focus on analyzing the influence of various parameters on the cost control behavior of urban rail transit enterprises under different loss-making subsidy modes. Finally, the paper will draw conclusions and put forward relevant policy recommendations. Table 1 illustrates the shortcomings of the existing literature and the innovations of this paper.

**Table 1.** The shortcomings of the existing literature and the innovations of this paper.

Shortcomings of the Existing Literature	Innovations of This Paper
mainly focus on the revenue-based causes of losses	focus on the cost control
loss-subsidy modes are presented separately	there is a comparison of different loss subsidy modes
the impact of subsidies is focused on inputs and outputs	the impact of subsidies is focused on company behavior
the method of studying the game is mainly a stage game	the method of studying the game is an evolutionary game

### 3. Model and Analysis

#### 3.1. Model Assumptions

In this paper, we assume that without considering the differences between the government and urban rail transit enterprises as game participants, in the case of information asymmetry, all participants are finitely rational and do not know each other's strategies and benefit functions completely, and participants adjust their strategies in the game process until they find the optimal strategy. At the same time, all participants are risk neutral.

**Hypothesis 1 (H1).** *The government supervises and manages the operation of the project and subsidizes the loss-making enterprises to ensure social welfare. The urban rail transit enterprise is responsible for the operation of the project and is rewarded through the fare paid by consumers and the value-added service income subsidized by the government according to the enterprise's losses.*

**Hypothesis 2 (H2).** *Urban rail transit enterprises have two strategic choices—cost saving and cost wasting, cost saving means that all costs paid by the enterprises are necessary operating costs, and cost wasting means that in addition to necessary operating costs, enterprises also incur non-essential operating costs, such as higher than market prices of purchased items or redundancy of personnel, etc. The probability of choosing the cost saving strategy is  $x$ , and the probability of choosing the cost wasting strategy is  $1-x$ . Government regulators also have two strategic choices based on social benefits and their own costs—positive regulation and negative regulation, positive regulation means more frequent and conscientious regulation, and negative regulation means less frequent and conscientious regulation. It is assumed that if the government regulator chooses the positive regulation strategy, the problem of cost wasting of urban rail transit enterprises will be detected, while if the negative regulation strategy is chosen, there is a certain probability that the problem will not be detected. The probability of choosing the positive regulation strategy is  $y$ , and the probability of choosing the negative regulation strategy is  $1-y$ . Both  $x$  and  $y$  are functions of time  $t$ .*

**Hypothesis 3 (H3).** *The cost saving or wasting strategy chosen by urban rail transit enterprises only affects the government cost and subsidy amount, but not the enterprise revenue  $R_c$ .  $R_c$  consists of the fare revenue and the value-added service revenue. If an urban rail transit company chooses a cost wasting strategy, the operating cost is  $C_w$ , and it can obtain an operating loss subsidy  $S_w$ . However, it will definitely suffer a penalty (loss due to government fines) when the government actively regulates enterprises, and thus incur a loss  $L$ . While there is a 0.4 probability that it will suffer a penalty when the government negatively regulates enterprises, and thus incur a loss  $0.4L$ . If a cost-saving strategy is chosen, the operating cost is  $C_s$ ,  $C_s < C_w$ , and the operating loss subsidy  $S_s$  can be obtained,  $S_s < S_w$ . Furthermore,  $L > C_w - C_s$  so that the punishment is greater than the maximum amount of cost wasted by the enterprise when the Beijing Municipal Government finds that enterprise wastes cost, thus playing the effect that the enterprise does not dare to waste cost. As a public enterprise, urban rail transit enterprises cannot aim at profit maximization as private enterprises do, but more importantly, they should try to spend their costs on construction and operation to achieve the goal of scale maximization. Therefore, the revenue objective of urban rail transit enterprises is to maximize the sum of their own costs and government subsidies.*

**Hypothesis 4 (H4).** The producer surplus of urban rail transit firms can be expressed as the firm's profit, and CS represents the surplus of consumers who ride rail transit, independent of the government and firm strategies. Regardless of the government's choice of strategy, the social welfare of the firm choosing the cost saving strategy is  $R_c + S_s - C_s + CS$ . The social welfare of the government choosing the positive regulation strategy and the firm choosing the cost wasting strategy is  $R_c + S_w - C_w - L + CS$ , and the positive regulation requires that the regulatory cost is  $C_a$ . The social welfare of the government choosing the negative regulation strategy and the firm choosing the cost wasting strategy is  $R_c + S_w - C_w + CS$ , and the negative regulation requires that the regulatory cost is  $C_i$ . The government pursues the revenue objective of maximizing the difference between social welfare and its own costs.

According to the above assumptions, the evolutionary game payoff matrix between urban rail transit enterprises and the government is shown in Table 2.

**Table 2.** Payoff matrix for urban rail transit enterprises and government.

		Government	
		Active Regulation	Negative Regulation
Urban rail transit Enterprises	Cost saving	$C_s + S_s, R_c - C_s - C_a + CS$	$C_s + S_s, R_c - C_s - C_i + CS$
	Cost wasting	$C_w + S_w - L, R_c - C_w - C_a + CS$	$C_w + S_w - 0.4L, R_c - C_w - C_i + CS$

### 3.2. Model Building

According to the above payoff matrix, the expected benefits  $E_{11}$  for urban rail transit firms choosing cost saving strategy and the expected benefits  $E_{12}$  for firms choosing cost wasting strategies and the average expected benefits  $E_{\text{firm on average}}$  of the two strategies for firms are as follows:

$$E_{11} = y(C_s + S_s) + (1 - y)(C_s + S_s) = C_s + S_s \quad (1)$$

$$E_{12} = y(C_w + S_w - L) + (1 - y)(C_w + S_w - 0.4L) = C_w + S_w - 0.6Ly - 0.4L \quad (2)$$

$$E_{\text{firm on average}} = xE_{11} + (1 - x)E_{12} \quad (3)$$

The replication dynamic equation of urban rail transit enterprises is as follows:

$$F(x) = dx/dt = x(E_{11} - E_{\text{firm on average}}) = x(1 - x)(C_s - C_w + S_s - S_w + 0.6Ly + 0.4) \quad (4)$$

The expected benefits  $E_{21}$  for active government regulation and the expected benefits  $E_{22}$  for negative regulation strategy and the average expected benefits  $E_{\text{government on average}}$  of the two strategies for government are as follows:

$$E_{21} = x(R_c - C_s - C_a + CS) + (1 - x)(R_c - C_w - C_a + CS) = R_c - C_a + CS - xC_s - (1 - x)C_w \quad (5)$$

$$E_{22} = x(R_c - C_s - C_i + CS) + (1 - x)(R_c - C_w - C_i + CS) = R_c - C_i + CS - xC_s - (1 - x)C_w \quad (6)$$

$$E_{\text{government on average}} = yE_{21} + (1 - y)E_{22} \quad (7)$$

The replication dynamic equation for the government can be obtained as follows:

$$G(y) = dy/dt = y(E_{21} - E_{\text{government on average}}) = y(1 - y)(C_i - C_a) \quad (8)$$

Let  $F(x)$  and  $G(y)$  be zero, respectively, to obtain the equilibrium points as (0,0), (0,1), (1,0), and (1,1). The Jacobi matrices of  $F(x)$  and  $G(y)$  are as follows:

$$J = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \quad (9)$$



The partial derivative of  $x$  and  $y$  for  $F(x)$  and  $G(y)$  gives  $A_{11} = (1 - 2x)(C_s - C_w + S_s - S_w + 0.6Ly + 0.4L)$ ,  $A_{12} = x(1 - x)0.6L$ ,  $A_{21} = 0$ ,  $A_{22} = (1 - 2y)(C_i - C_a)$ .

The equilibrium points for replicating the dynamic equations are the evolutionary stabilization strategy (ESS) if both of the following conditions are satisfied [42]:

$$\text{tr}J = A_{11} + A_{22} < 0$$

$$\text{det}J = A_{11}A_{22} - A_{12}A_{21} > 0$$

The values within the Jacobi matrix at the four equilibrium points are shown in Table 3.

**Table 3.** Values within the Jacobi matrix at the equilibrium points.

Equilibrium Points	$A_{11}$	$A_{12}$	$A_{21}$	$A_{22}$
(0,0)	$C_s - C_w + S_s - S_w + 0.4L$	0	0	$C_i - C_a$
(0,1)	$C_s - C_w + S_s - S_w + L$	0	0	$C_a - C_i$
(1,0)	$-(C_s - C_w + S_s - S_w + 0.4L)$	0	0	$C_i - C_a$
(1,1)	$-(C_s - C_w + S_s - S_w + L)$	0	0	$C_a - C_i$

For  $C_i - C_a < 0$ ,  $C_a - C_i > 0$ , the equilibrium points that have the potential to make  $A_{11}$  less than zero and that have the potential to become evolutionary stable strategies (ESS) are (0,0) and (1,0).

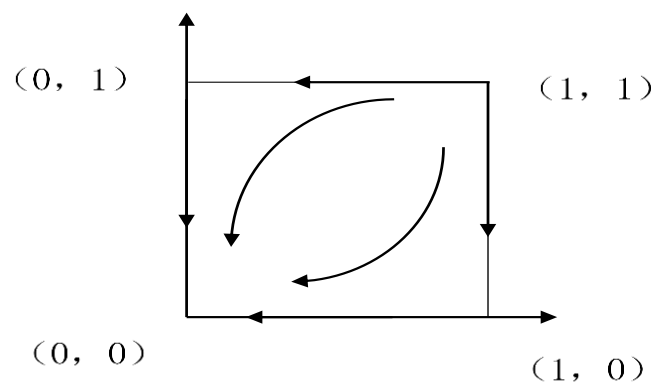
The stability of each equilibrium point can be discussed in the following cases.

**Case 1:** When  $C_s - C_w + S_s - S_w < -L$ , the evolutionary stability strategy (ESS) is (0,0). The results of stability analysis of each equilibrium point are shown in Table 4.

**Table 4.** Stability analysis results of each equilibrium point for case 1.

Equilibrium Points	trJ	detJ	Stability
(0,0)	-	+	ESS
(0,1)	?	-	Saddle Point
(1,0)	?	-	Saddle Point
(1,1)	+	+	Unstable point

The phase diagram of the replication dynamics of the evolutionary game at this time can be obtained according to Table 4, as shown in Figure 1.



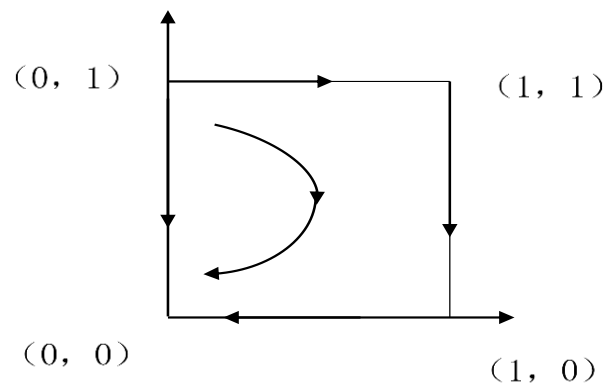
**Figure 1.** Replicated dynamic phase diagram for case 1.

**Case 2:** When  $-L < C_s - C_w + S_s - S_w < -0.4L$ , the evolutionary stability strategy (ESS) is (0,0). The results of stability analysis of each equilibrium point are shown in Table 5.

**Table 5.** Stability analysis results of each equilibrium point for case 2.

Equilibrium Points	trJ	detJ	Stability
(0,0)	−	+	ESS
(0,1)	+	+	Unstable Point
(1,0)	?	−	Saddle Point
(1,1)	?	−	Saddle point

The phase diagram of the replication dynamics of the evolutionary game at this time can be obtained according to Table 5, as shown in Figure 2.

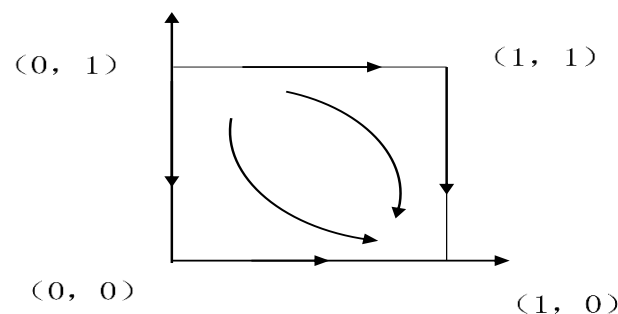
**Figure 2.** Replicated dynamic phase diagram for case 2.

**Case 3:** When  $C_s - C_w + S_s - S_w > -0.4 L$ , the evolutionary stability strategy (ESS) is (1,0). The results of stability analysis of each equilibrium point are shown in Table 6.

**Table 6.** Stability analysis results of each equilibrium point for case 3.

Equilibrium Points	trJ	detJ	Stability
(0,0)	?	−	Saddle Point
(0,1)	+	+	Unstable Point
(1,0)	−	+	ESS
(1,1)	?	−	Saddle point

The phase diagram of the replication dynamics of the evolutionary game at this time can be obtained according to Table 6, as shown in Figure 3.

**Figure 3.** Replicated dynamic phase diagram for case 3.

### 3.3. Data and Related Calculations

This study will take the Beijing Subway as the research object. The Beijing Subway is a large, wholly state-owned enterprise with a total of 15 operating lines under its jurisdiction in 2016 (including Line 1, Line 2, Line 5, Line 6, Line 7, Line 8, Line 9, Line 10, Line 13, Line



15, Batong Line, Airport Line, Fangshan Line, Changping Line and Yizhuang Line), with a total of 274 operating stations and 460 kilometers of operation. Figure 2 shows all the subway lines that have been opened in Beijing in 2021.

The Beijing Subway's operation data are all obtained from its official website. Its main operation data in 2016 (excluding the airport line) are shown in Table 7.

**Table 7.** Key operational data of Beijing Subway in 2016.

Items	Data for 2016
Total costs and expenses	RMB 8266 million
Ticket revenue	RMB 6772 million
Annual passenger volume	3.026 billion
Line length as a percentage of the whole network	83.03%
Annual passenger volume percentage of the whole network	82.42%
Passenger entries	1.581 billion
Average ticket price	RMB 4.28 per passenger
Kilometers traveled	446.05 million vehicle kilometers
Administrative and financial expenses	RMB 602 million

The Beijing Subway's cost amounts and other data by category for 2017–2019 are shown in Table 8.

**Table 8.** Cost and other data for 2017–2019 (Unit: RMB million).

Cost Category	2017	2018	2019	Average
Wages and wage related costs	4488	4819	5259	4855
Direct repair costs and operating expenses	2359	2754	3043	2719
Security inspection costs	526	1015	1207	916
Direct electricity costs	1169	1187	1229	1195
Management and finance costs	693	762	763	739
Total costs	9235	10,537	11,501	10,424
Kilometers traveled (million vehicle kilometers)	469.64	485.71	535.38	496.91
Passenger entries (billion)	1.607	1.632	1.676	1.638

When adopting the regressive loss subsidy mode, the government is required to approve a reasonable cost  $C_n$  for the enterprise, and  $n$  is the year. The reasonable cost of the Beijing Subway in 2016 can be approved based on the average cost of the year before 2016, but because the Beijing urban rail transit enterprises only started to disclose their costs and expenses in 2015, this paper uses the average cost of the 2017–2019 years to invert 2016's reasonable cost, calculated as follows.

$$C_{\text{average}} = C_{2016} (1 + \gamma_{\text{average}})^2 (1 + \text{CPI}_{\text{average}})^2 \quad (10)$$

where  $\gamma$  denotes the adjustment factors, and CPI denotes consumer price index.

This formula comes from a study report on financial subsidies for rail transit operations in Beijing jointly issued by the School of Economics of Peking University and the Institute of Economics and Resource Management of Beijing Normal University (not publicly available). Adjustment factors can be divided into five categories based on cost characteristics: first, wages and wage related costs are considered according to the 2017–2019 average wage growth rate of non-private workers in Beijing; second, the direct repair costs and operating costs are measured according to the 2017–2019 average travel kilometer increase rate minus the price index; third, the security inspection costs are measured according to the 2017–2019 average passenger entry rate; fourth, the direct power costs are measured according to the 2017–2019 average travel kilometer increase rate and the electricity price adjustment (the direct electricity costs, measured by the average increase in kilometers traveled in

2017–2019 and the electricity tariff adjustment, can be considered as zero); the fifth category, administrative and financial costs, is determined by the average annual growth rate of the operating companies in 2017–2019. The adjustment factors corresponding to each year and each cost category of the Beijing Subway obtained from the internet search and the calculation of Table 8 are shown in Table 9.

**Table 9.** The adjustment factors corresponding to each year and each cost category.

Cost Category	2017		2018		2019	
	CPI	Other Factors	CPI	Other Factors	CPI	Other Factors
Wages and wage related costs	0	9.9%	0	10.7%	0	14.4%
Direct repair costs and operating costs	1.9%	5.3%	2.5%	3.4%	2.3%	10.2%
Security inspection costs	0	1.6%	0	1.6%	0	2.7%
Direct power costs	0	5.3%	0	3.4%	0	10.2%
Administrative and financial costs	0	15.1%	0	10%	0	0.1%

#### 4. Results and Discussions

Since the value-added service revenue of the Beijing Subway is not publicly available, this paper uses the average value-added service revenue per line estimated by other literature of RMB 7.261 million [43], which yields a total value-added service revenue of RMB 102 million for 14 lines in 2016 (the cost of the airport line is not publicly available, so it is not included in the discussion of this paper), and finally adds the ticket revenue to get  $R_c = \text{RMB } 6.874$  billion. If we assume that the 2016 cost of the Beijing Subway is in the middle value of cost saving and cost wasting, and its ability to save or waste again is 0.5% of the cost, the initial value is  $C_s = \text{RMB } 8.225$  billion and  $C_w = \text{RMB } 8.307$  billion. Assuming that the initial value  $x = 0.1$ ,  $y = 0.1$ ,  $C_a = \text{RMB } 200$  million,  $C_i = \text{RMB } 50$  million and  $L = \text{RMB } 300$  million.

When  $S_s - S_w < -2.18$ , the evolutionary stabilization strategy is consistent with Case 1; when  $-2.18 < S_s - S_w < -0.38$ , the evolutionary stabilization strategy is consistent with Case 2; when  $S_s - S_w > -0.38$ , the evolutionary stabilization strategy is consistent with Case 3. Thus, with other values fixed, the firm's evolutionary stabilization strategy depends on the difference between subsidies when cost is saved and when cost is wasted.

If a fixed amount of the loss subsidy mode is adopted,  $S_s = S_w$ ,  $S_s - S_w = 0 > -0.38$ , the evolutionary stabilization strategy is consistent with Case 3. Since  $S_s - S_w = 0$ , it is not necessary to consider what the initial amount of the fixed-loss subsidy is for the time being.

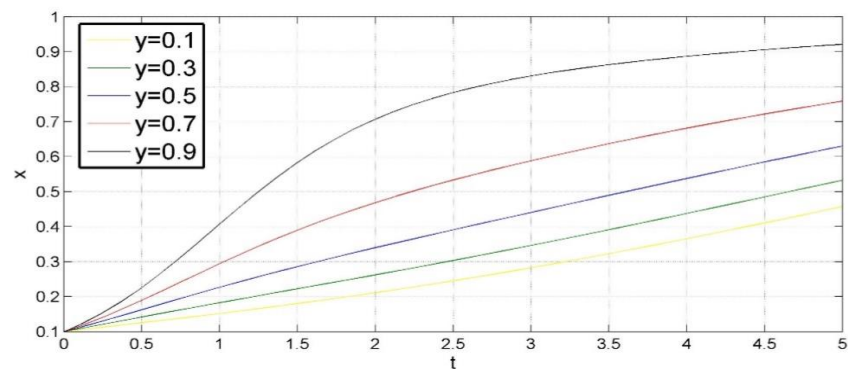
If a fixed percentage loss subsidy mode is used,  $S_s = k(C_s - R_c)$ ,  $S_w = k(C_w - R_c)$ , where  $k$  denotes the ratio of subsidy to loss,  $0 < k < 1$ , which gives  $S_s - S_w = k(C_s - C_w) = -0.82k$ . When  $0.46 < k < 1$ ,  $-0.82 < S_s - S_w < -0.38$ , the evolutionary stabilization strategy is consistent with Case 2; when  $0 < k < 0.46$ ,  $-0.38 < S_s - S_w < 0$ , the evolutionary stabilization strategy is consistent with Case 3. However, since the case of a lower percentage subsidy of  $0 < k < 0.46$  is very rare in reality, this paper only discusses the case of a higher percentage subsidy of  $0.46 < k < 1$ , assuming that the initial  $k = 0.8$ .

If the regressive loss subsidy mode is adopted, according to Tables 7 and 8 and the calculation Formula (10), we can get the reasonable total cost in 2016  $C_{2016} = \text{RMB } 8487$  million. Assuming that the initial over-loss subsidy ratio  $\varepsilon = 0.2$ , decreasing range  $\alpha = 0.05$ , over-loss number segmentation interval  $\beta = \text{RMB } 50$  million, the over-loss reaches RMB 200 million, then there is no more subsidy, and the loss reduction share ratio is  $z = 0.5$ . When  $C_s \leq C_{2016}$ , the urban rail transit enterprises belong to the loss reduction stage, and the government fully subsidizes the reasonable loss while also dividing 50% of the loss reduction amount, that is,  $S_s = (C_{2016} - R_c) - 0.5(C_{2016} - C_s)$ ; when  $C_{2016} < C_s \leq C_{2016} + 0.5$ ,  $S_s = (C_{2016} - R_c) + 0.2(C_s - C_{2016})$ ; when  $C_{2016} + 0.5 < C_s \leq C_{2016} + 1$ ,  $S_s = (C_{2016} - R_c) + 0.15(C_s - C_{2016})$ ; when  $C_{2016} + 1 < C_s \leq C_{2016} + 1.5$ ,  $S_s = (C_{2016} - R_c) + 0.1(C_s - C_{2016})$ ; when  $C_{2016} + 1.5 < C_s \leq C_{2016} + 2$ ,  $S_s = (C_{2016} - R_c) + 0.05(C_s - C_{2016})$ ; when  $C_s > C_{2016} + 2$ , urban rail transit enterprises belong to the stage of over-loss without compensation. At this time, the government will not subsidize the over-loss part, that is,  $S_s = (C_{2016} - R_c)$ . Similarly,  $C_w$  and  $S_w$

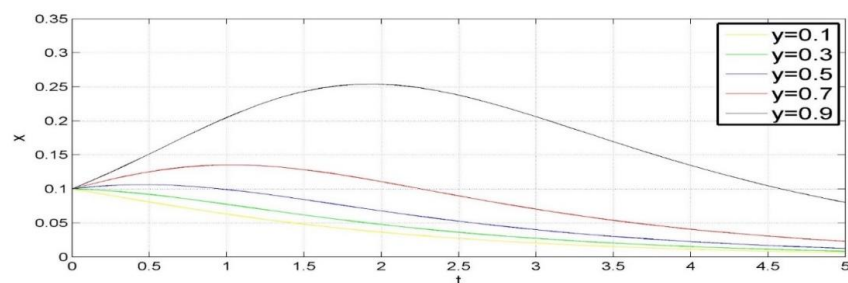
are also segmented according to this criterion. Because  $C_{2016}$  in this paper is obtained by back-projecting the average cost of the 2017–2019 years, and the cost growth rate of the 2017–2019 years is increasing year by year, there is thus a possibility that the reasonable cost of 2016 obtained is overestimated, so this paper assumes that the reasonable cost of 2016 may also be less than  $C_s$  or  $C_w$ . Assuming that the first adjusted reasonable cost for FY16 is RMB 8287 million,  $C_s$  is in the loss reduction stage and  $C_w$  is in the excess loss stage. Assuming the second adjusted reasonable cost for FY16 is RMB 8187 million, both  $C_s$  and  $C_w$  are in the over-loss stage.

#### 4.1. The Effect of $y$ on $x$

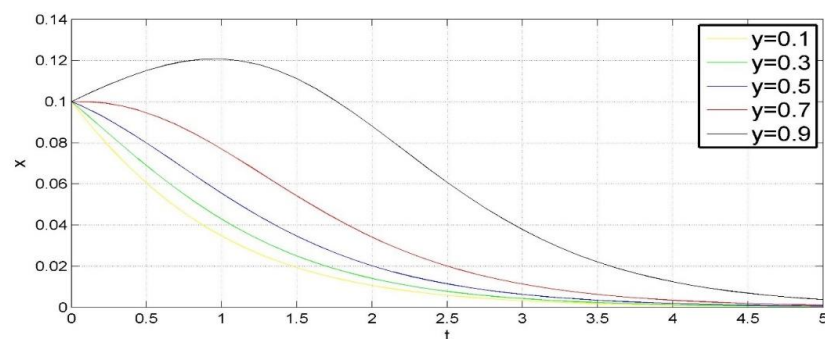
To study the influence of the initial condition  $y$  on the strategy choice of urban rail transit enterprises in five cases of three loss-subsidy modes, the interference of the saddle point on the stability of the model is excluded, and other values are taken as the initial values. Because  $0 < y < 1$ , the values of 0.1, 0.3, 0.5, 0.7 and 0.9 are taken for  $y$ , the value interval is 0.2, and the results are shown in Figure 4.



(a) fixed amount subsidy mode

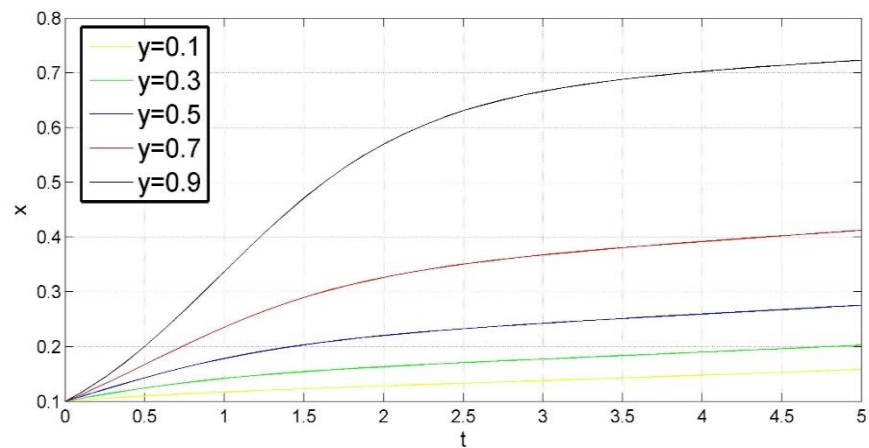


(b) fixed percentage subsidy mode

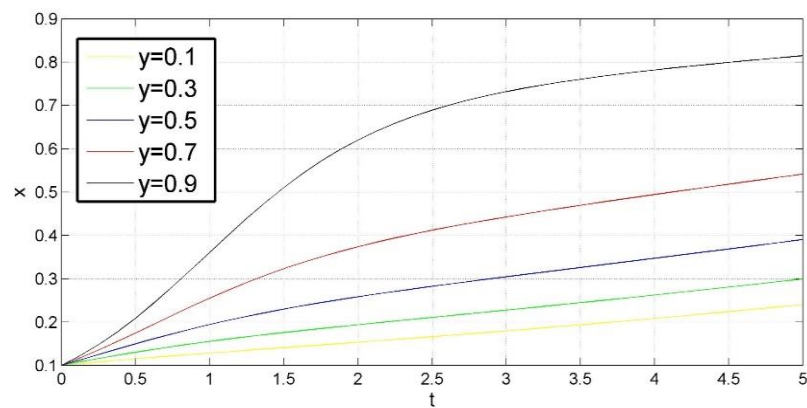


(c)  $C_s$  and  $C_w$  are in the loss reduction stage

Figure 4. Cont.



(d)  $C_s$  is in the loss reduction phase while  $C_w$  is in the over-loss



(e) both  $C_s$  and  $C_w$  are in the over-loss phase

Figure 4. The effect of  $y$  on  $x$ .

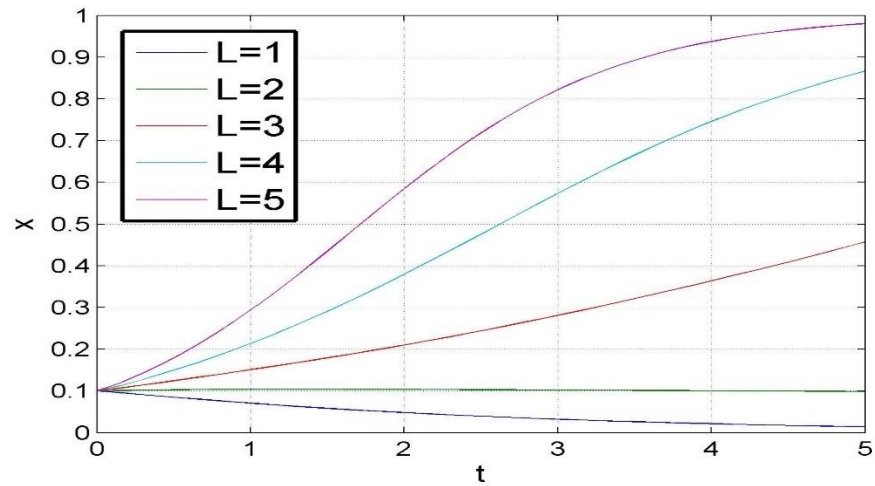
According to Figure 4a–e, when the regressive loss subsidy mode is used and both  $C_s$  and  $C_w$  are in the over-loss phase, the impact of  $y$  taking values on  $x$  is similar to that of the fixed amount subsidy mode and  $C_s$  is in the loss reduction phase while  $C_w$  is in the over-loss phase, and the optimal urban rail transit firms’ strategy for both is cost saving. The government’s best effect in making enterprises save costs with the same probability of active regulation is the fixed amount subsidy mode. When the regressive loss subsidy mode is used and both  $C_s$  and  $C_w$  are in the loss reduction stage, the impact of  $y$  taking values on  $x$  is similar to the fixed percentage subsidy mode, the optimal strategy for urban rail transit firms is both cost wasting. The same probability of active government regulation that results in better cost saving for the firm is the fixed percentage subsidy mode. The results of various comparisons are shown in Table 10.

Table 10. Comparison of the results of the influence of  $y$  on  $x$ .

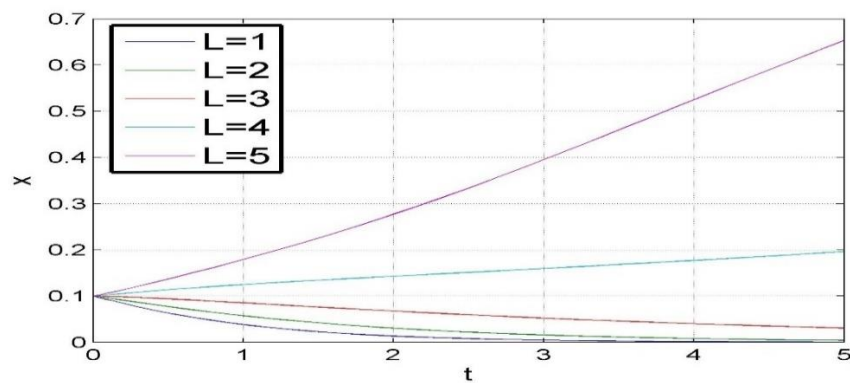
Subsidy Mode	Urban Rail Transit Firms’ Strategy	Evolutionary Speed	Evolutionary Acceleration
Fixed amount subsidy mode	Cost saving	Fastest	Large
Fixed percentage subsidy mode	Cost wasting	Slowest	Small
$C_s$ and $C_w$ are in the loss reduction stage	Cost wasting	Slow	Minimum
$C_s$ is in the loss reduction phase while $C_w$ is in the over-loss phase	Cost saving	Fast	Maximum
Both $C_s$ and $C_w$ are in the over-loss phase	Cost saving	Faster	Very large

#### 4.2. The Effect of $L$ on $x$

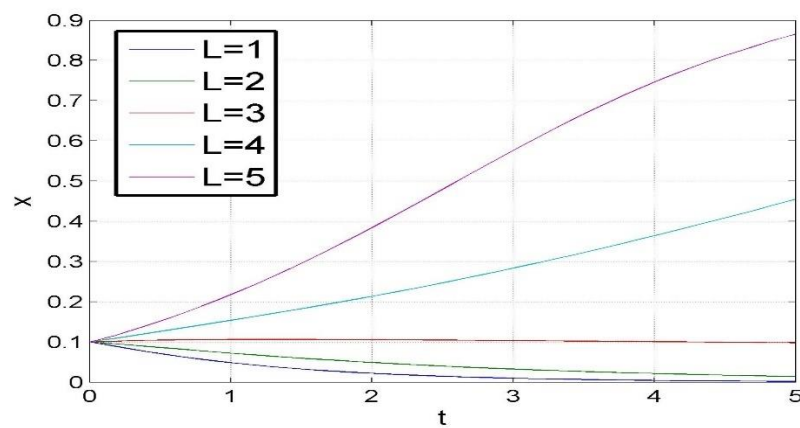
To study the influence of the initial condition  $L$  on the strategy choice of urban rail transit enterprises in five cases of three loss-subsidy modes, the interference of the saddle point on the stability of the model is excluded, and other values are taken as the initial values. Because  $L > C_w - C_s$ , the values of 1, 2, 3, 4 and 5 are taken for  $L$ , the value interval is 1, and the results are shown in Figure 5 (unit of  $L$ : RMB 100 million).



(a) fixed amount subsidy mode



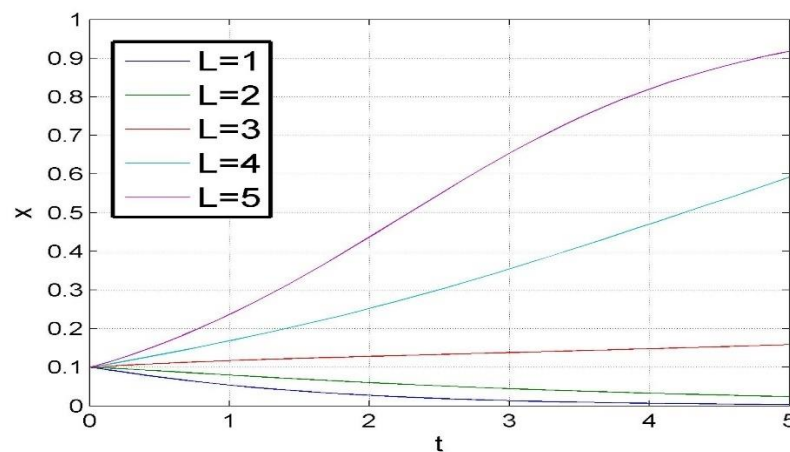
(b) fixed percentage subsidy mode



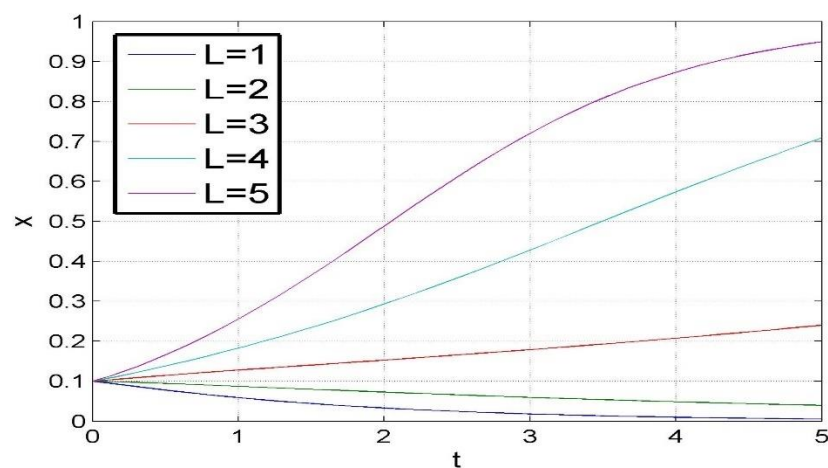
(c)  $C_s$  and  $C_w$  are in the loss reduction stage

Figure 5. Cont.





(d)  $C_s$  is in the loss reduction phase while  $C_w$  is in the over-loss phase



(e) both  $C_s$  and  $C_w$  are in the over-loss phase

Figure 5. The effect of L on x.

According to the Figure 5a–e, the effect of L on x is similar for all loss-subsidy modes. When the government finds that the penalties for cost wasting of urban rail transit enterprises are small, the enterprises will choose the cost wasting strategy, and when the penalties are large, the enterprises will choose the cost saving strategy. Specifically, when the regressive loss subsidy mode is used and both  $C_s$  and  $C_w$  are in the over-loss stage, the effect of L taking value on x is similar to that of the fixed amount subsidy mode. When  $C_w$  is in the loss reduction stage and  $C_w$  is in the over-loss stage, as the government’s cost wasting penalties increase, firms will tend to save costs quickly at first, but then the incentive to save cost increases will decrease. When the regressive loss subsidy mode is used and both  $C_s$  and  $C_w$  are in the loss reduction stage, the effect of L on x is similar to that of the fixed percentage subsidy mode. As the penalty increases, the faster the firm tends to save costs. The results of various comparisons are shown in Table 11.

Table 11. Comparison of the results of the influence of L on x.

Subsidy Mode	Urban Rail Transit Firms’ Strategy	Evolutionary Speed	Evolutionary Acceleration
Fixed amount subsidy mode	When the penalties for cost wasting of urban rail transit enterprises are small, the enterprises will choose the cost wasting strategy, and when the penalties are large, the enterprises will choose the cost saving	Fastest	Increase and then decrease as L increases
Fixed percentage subsidy mode		Slowest	Increase as L increases
$C_s$ and $C_w$ are in the loss reduction stage		Slow	Increase as L increases
$C_s$ is in the loss reduction phase while $C_w$ is in the over-loss phase		Fast	Increase and then decrease as L increases
Both $C_s$ and $C_w$ are in the over-loss phase		Faster	Increase and then decrease as L increases

#### 4.3. The Effect of $k$ on $x$

The size of the subsidy under the fixed amount subsidy mode has no effect on the probability  $x$  of choosing a cost saving strategy for urban rail transit enterprises, so its amount is not discussed in this paper. To study the influence of the initial condition  $k$  on the strategy choice of urban rail transit enterprises in the fixed percentage subsidy mode, the interference of the saddle point on the stability of the model is excluded, and other values are taken as the initial values. The values of 0.9, 0.8, 0.7, 0.6 and 0.5 are taken for  $k$ , the value interval is 0.1, and the results are shown in Figure 6.

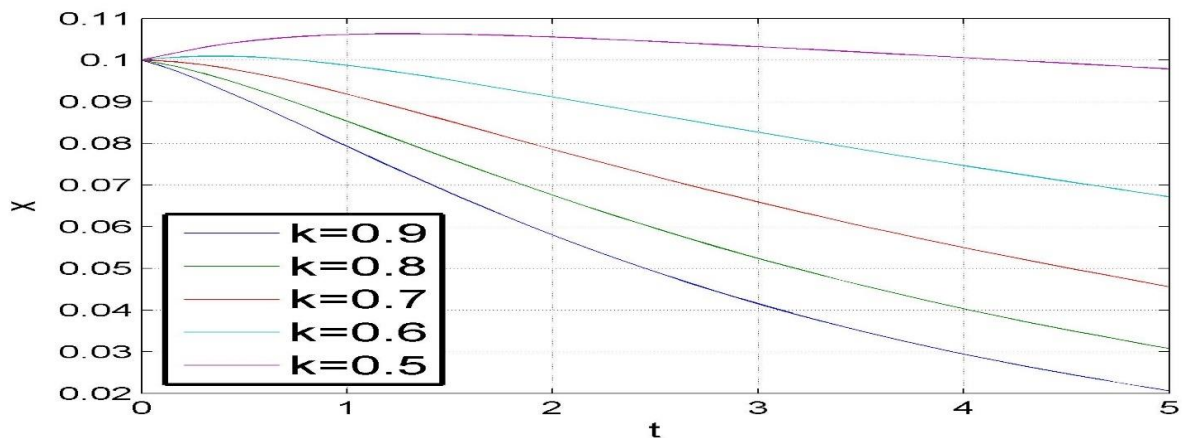


Figure 6. The effect of  $k$  on  $x$ .

According to Figure 6, the optimal strategy of urban rail transit enterprises under the fixed percentage subsidy mode is cost wasting no matter how large the proportion  $k$  of government subsidies is, and the larger the subsidy proportion is, the faster the urban rail transit enterprises choose cost wasting. When the subsidy ratio is relatively low, increasing the subsidy ratio will make the enterprises accelerate the speed of cost wasting rapidly. When the subsidy ratio is relatively high, then increasing the subsidy ratio will result in the enterprises' speed of cost wasting slowing down.

#### 4.4. The Effect of Regressive Loss Subsidy Mode on $x$

##### 4.4.1. The Effect of $z$ on $x$

To study the influence of  $z$  on the strategy choice of urban rail transit enterprises when both  $C_s$  and  $C_w$  are in the deficit reduction stage, the interference of the saddle point on model stability is excluded, and other values are taken as initial values. The values of 0.1, 0.3, 0.5, 0.7 and 0.9 are taken for  $z$ , the value interval is 0.2, and the results are shown in Figure 7.

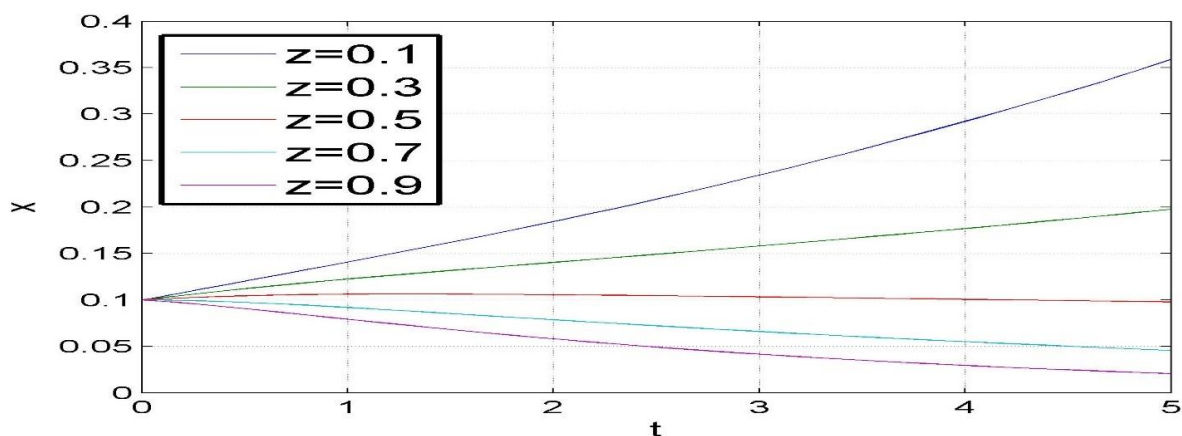


Figure 7. The effect of  $z$  on  $x$ .



According to Figure 7, using the regressive loss subsidy mode and both  $C_s$  and  $C_w$  are in the loss reduction stage, when the government loss reduction share ratio  $z$  is small, firms will choose the cost saving strategy, and the smaller the loss reduction share ratio, the faster firms choose the cost saving strategy. When the loss reduction share ratio is larger, firms will choose the cost wasting strategy and the loss reduction share ratio. The larger the share of loss reduction, the faster the enterprises choose the cost wasting strategy. At the same time, when the government's share of loss reduction is small, the effect of reducing the same share to make enterprises save cost is better than when the share of loss reduction is large.

#### 4.4.2. The Effect of $\alpha$ on $x$

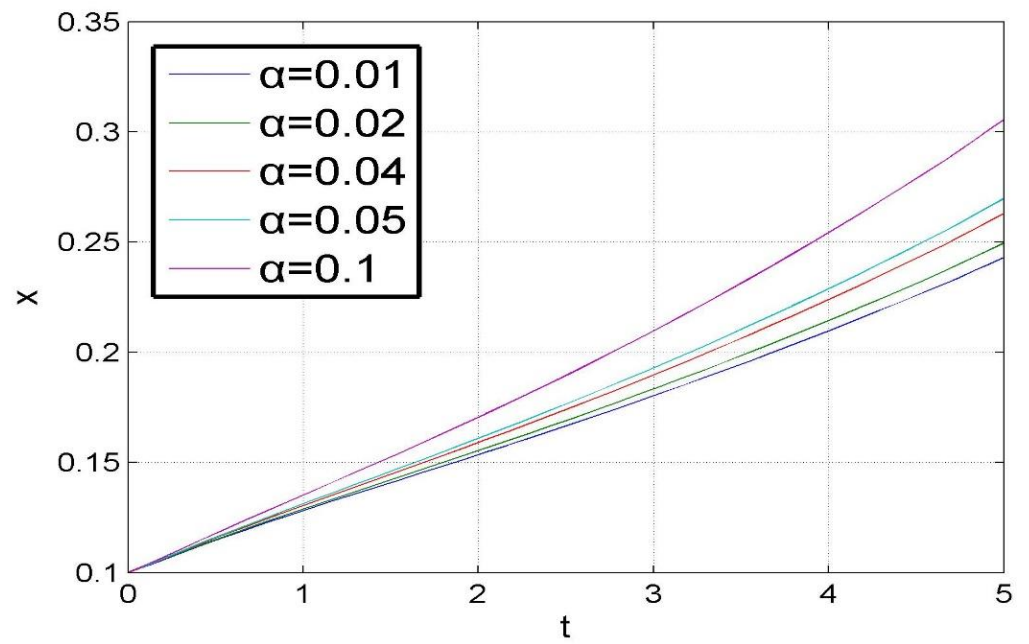
In order to study the influence of  $\alpha$  on the strategy choice of urban rail transit enterprises when  $C_w$  is in the over-loss stage, the interference of saddle point on the model stability is excluded, and other values are taken as initial values. Because  $\varepsilon = 0.2$ , the values of 0.01, 0.02, 0.04, 0.05 and 0.1 are taken for  $\alpha$  so that it can be divisible by 0.2. If the number of the over-loss segment interval  $\beta$  remains unchanged, the corresponding over-loss non-subsidies are 10, 5, 4, 2 and 1, but because the difference between  $C_w$  and the first adjusted reasonable cost of 2016 is  $0.2 < 0.5$ , the change of  $\alpha$  does not affect the subsidy of the over-loss stage when using the function of the first segment of the excess loss. Therefore, the third adjustment of the 2016 reasonable cost is RMB 8237 million, and thus the subsidies of the excess loss stage are all using the function of the second segment of the excess loss. The results are shown in Figure 8.

According to Figure 8a,b, when the regressive loss subsidy mode is used and both  $C_s$  and  $C_w$  are in over-loss phase, the effect of  $\alpha$  taking values on  $x$  is similar to that when  $C_s$  is in the loss reduction phase and  $C_w$  is in the over-loss phase. No matter how large the decreasing over-loss subsidy ratio is, the firm will eventually choose the cost saving strategy, and the larger the decreasing percentage of over-loss subsidy, the faster the cost saving strategy will be reached. The main difference is that when both  $C_s$  and  $C_w$  are in the over-loss stage, the government adopts the same decreasing over-loss ratio to make the firm save costs better than when  $C_s$  is in the loss-reducing stage and  $C_w$  is in the over-loss stage.

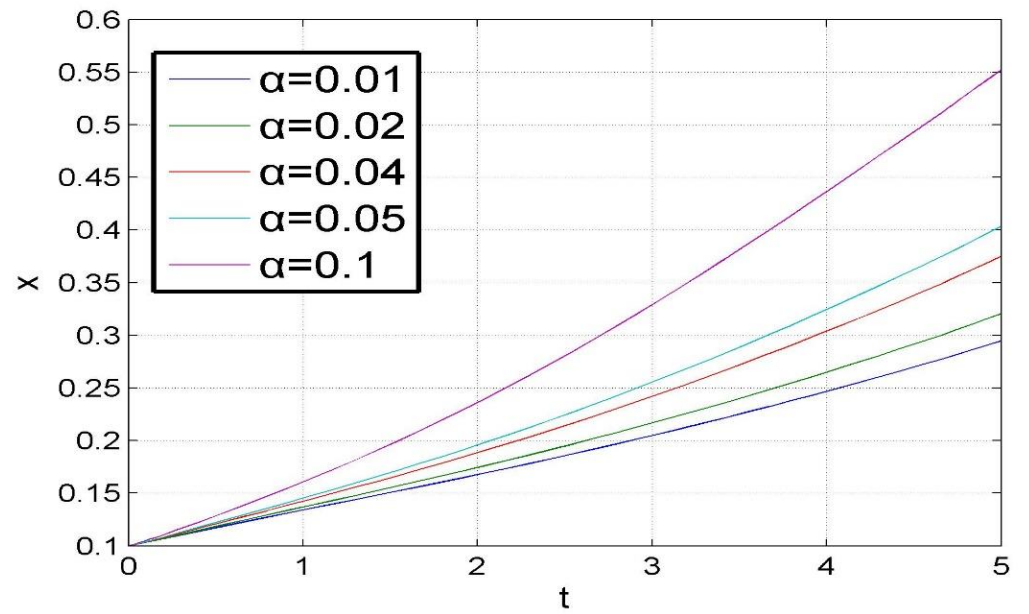
#### 4.4.3. The Effect of $\beta$ on $x$

In order to study the influence of  $\beta$  on the strategy choice of urban rail transit enterprises when  $C_w$  is in the over-loss phase and to exclude the interference of the saddle point on the model stability, other values are taken as initial values. The values of 0.1, 0.2, 0.3, 0.4 and 0.5 are taken for  $\beta$  with a value interval of 0.1, but because the second segmentation function of the over-loss phase is used after  $\beta$  is taken as 0.4 and before 0.7, 0.5 is turned into 0.7. If  $\varepsilon$  and  $\alpha$  are kept constant, the corresponding over-loss non-replacement amounts are 0.4, 0.8, 1.2, 1.6 and 2.8, and the results are shown in Figure 9 (unit of  $\beta$ : 100 million RMB).

According to Figure 9a,b, when using the regressive loss subsidy mode and  $C_s$  is in the loss reduction stage while  $C_w$  is in the excess loss stage. If the government excess loss number segment interval is small, then the firm will choose the cost saving strategy, and the smaller the excess loss number segment interval is, the faster the firm will choose the cost saving strategy. If the excess loss number segment interval is large, the firm will choose the cost wasting strategy, and the larger the interval between segments of excess losses, the faster the enterprises choose the cost wasting strategy. In contrast, when the regressive loss subsidy mode is used and both  $C_s$  and  $C_w$  are in the over-loss stage, the firm will choose the cost saving strategy regardless of the government's over-loss number segment interval. When the over-loss number segmentation interval is small, increasing the over-loss number segmentation interval will speed up the cost saving of the firm, but when the over-loss number segmentation interval is large, increasing the over-loss number segmentation interval will slow down the cost saving of the firm.

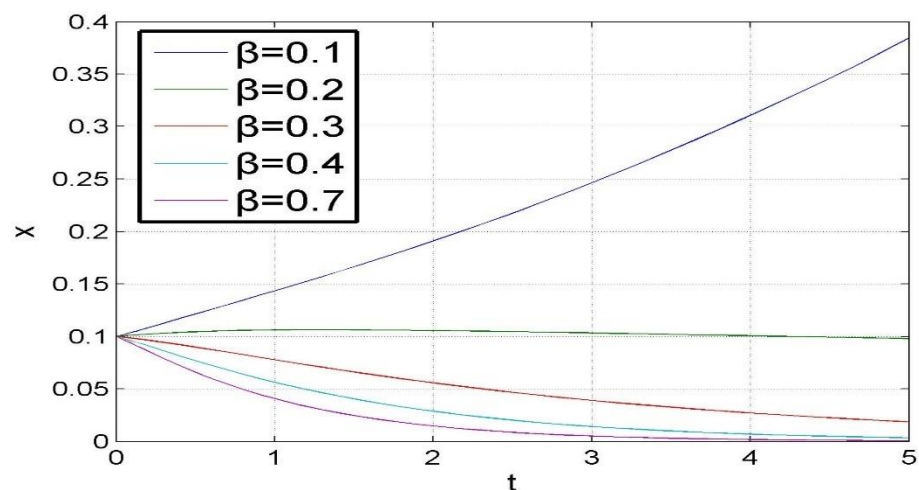


(a)  $C_s$  is in the loss reduction phase while  $C_w$  is in the over-loss phase

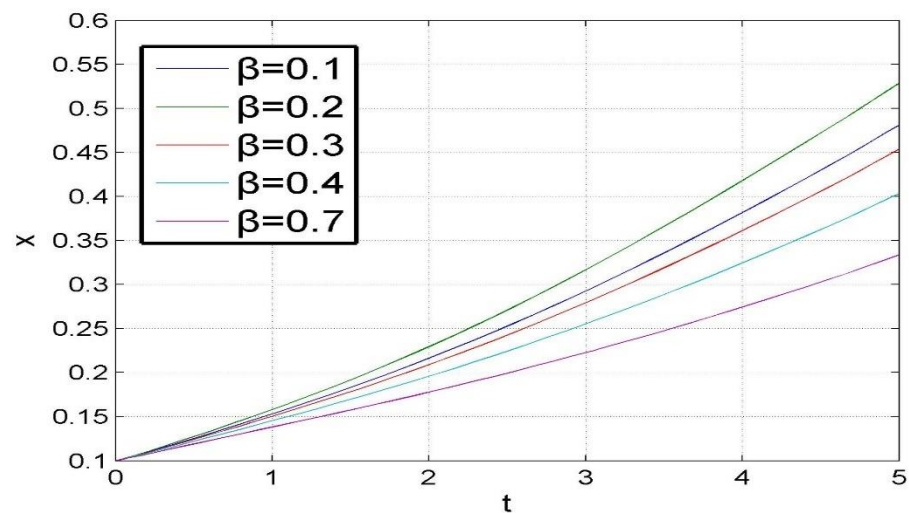


(b) both  $C_s$  and  $C_w$  are in the over-loss stage

Figure 8. The effect of  $\alpha$  on  $x$ .



(a)  $C_s$  is in the loss reduction phase while  $C_w$  is in the over-loss phase



(b) both  $C_s$  and  $C_w$  are in the over-loss stage

Figure 9. The effect of  $\beta$  on  $x$ .

## 5. Conclusions

This paper concludes that the factors affecting the government evolutionary stabilization strategy are the positive regulatory cost  $C_a$  to be paid and the negative regulatory cost  $C_i$ , because  $C_i < C_a$ , the government evolutionary stabilization strategy is negative regulation. The factors that affect the evolutionary stabilization strategy of urban rail transit enterprises are the loss  $L$  caused by government fines, the initial probability  $y$  of government regulators choosing the positive regulation strategy and the pattern of loss subsidies. The factor of the loss subsidy mode specifically includes the fixed amount loss subsidy mode, the subsidy proportion  $k$  of fixed percentage loss subsidy mode, the reasonable cost  $C_n$  of the enterprise estimated by the government under the regressive loss subsidy mode, the decreasing percentage of over-loss subsidy  $\alpha$ , the interval of over-loss number segments  $\beta$  and the percentage of loss reduction share  $z$ .

Based on the above research, this paper can provide the following suggestions for government departments to adopt appropriate policies.

(1) If we only want to urge enterprises to save costs more frequently and quickly through regulatory policies, then the government can adopt a fixed amount subsidy mode. If we consider not only the speed at which firms eventually choose cost saving, but also the effect of increasing the probability of positive regulation to increase the speed of cost saving, then the government should most likely adopt a regressive loss subsidy mode

and determine a smaller reasonable cost  $C_n$ , so that both  $C_s$  and  $C_w$  are in the over-loss stage, at which point it is also necessary to strengthen regulation if we want to continue to increase firms' incentives to save cost. The initial probability of positive regulation can be set lower so that the effect of government strengthening regulation will become more and more obvious.

(2) If the government only considers to urge the enterprises to save cost through the punishment policy of cost wasting, a relatively high punishment amount should be determined. If only the speed at which the enterprises eventually choose cost saving is considered, then the government should most likely adopt a fixed amount subsidy mode. If, in addition to considering the speed at which enterprises eventually choose cost saving, it also considers the effect of increasing the penalties to make the speed of cost saving increase, then the government should most likely adopt a regressive loss subsidy mode and determine a larger reasonable cost  $C_n$  so that both  $C_s$  and  $C_w$  are in the loss reduction stage.

(3) If we determine to adopt a fixed amount subsidy mode, the determination of the subsidy amount will not have an impact on the cost strategy, so only factors such as financial constraints need to be considered. If the government determines to adopt a fixed percentage subsidy mode, the optimal strategy of the enterprise is cost wasting. If only slowing down the speed of the final cost wasting of the enterprise is considered, the government should set a lower subsidy ratio. If only considering the effect of changing the subsidy ratio on slowing down the speed of cost wasting, the government should set a higher subsidy ratio.

(4) When we determine to adopt regressive loss subsidy mode and approve a larger reasonable cost  $C_n$ , so that both  $C_s$  and  $C_w$  are in the stage of loss reduction, if it only wants to adjust the speed of enterprises' cost saving by changing the loss reduction share ratio, then the loss reduction share ratio should be set relatively small. If it only wants to adjust the speed of enterprises' cost saving by changing the decreasing ratio of over-loss subsidy, then the government should determine a smaller reasonable cost  $C_n$ , so that both  $C_s$  and  $C_w$  are in the over-loss stage. At the same time, a larger percentage of decreasing over-loss subsidy should be set. If it only wants to adjust the speed of cost saving of enterprises by changing the interval of over-loss number segments, the government should determine a smaller reasonable cost  $C_n$  so that both  $C_s$  and  $C_w$  are in the over-loss stage. A smaller over-loss number segmentation interval should also be developed, but it should not be developed too small, otherwise the speed of reaching the cost saving strategy will be reduced.

In conclusion, the government should consider all available policies to achieve cost control of urban rail enterprises based on the final result of cost control, speed and acceleration.

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