sustainability

MDPI

Article

Research on Intercity Railway Subsidy Mechanism Optimization from the Perspective of a Government–Company Game Model: A Case Study of Henan Intercity Railway

Guoyong Yue [1,2], Zijian Zhao [1], Lei Dai [1,*] and Hao Hu [1]

[1] School of Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China; yueguoyong@sjtu.edu.cn (G.Y.); zhaozj_cliffer@sjtu.edu.cn (Z.Z.); hhu@sjtu.edu.cn (H.H.)
[2] Henan Railway Construction & Investment Group Co., Ltd., Zhengzhou 450046, China
* Correspondence: dailei1989@sjtu.edu.cn

Abstract: Intercity railway is an important part of public transportation, and the priority development of public transportation cannot be achieved without the support of government policies. This paper aims to find a more reasonable subsidy model for the governments and intercity railway companies. The paper analyzes the mechanism of intercity railway subsidy and uses the evolutionary game method to balance interests among governments, railway companies and social capitals. The main conclusions are as follows: (1) The introduction of performance subsidy into the traditional loss subsidy strategy can alleviate the conflict of interests between government and companies, and achieve a win-win conclusion: an annual revenue of 50 million RMB for the railway and 4 million RMB for the social capitals could be generated by the new subsidy model. (2) According to different intercity railways, reference performance standards are different, and operating mileage, pairs of trains and passenger flow are some of the factors that can be considered. The innovation of this paper is the introduction of a new dynamic subsidy model that combines performance and loss subsidies to intercity railways. For sustainable transportation development, it is significant for the government to develop a new reasonable intercity railway subsidy strategy.

Keywords: railway subsidy; intercity railway; evolutionary game; performance subsidy

Citation: Yue, G.; Zhao, Z.; Dai, L.; Hu, H. Research on Intercity Railway Subsidy Mechanism Optimization from the Perspective of a Government–Company Game Model: A Case Study of Henan Intercity Railway. *Sustainability* **2024**, *16*, 7631. https://doi.org/10.3390/su16177631

Academic Editors: Borna Abramović and Svetla Stoilova

Received: 10 June 2024
Revised: 17 August 2024
Accepted: 20 August 2024
Published: 3 September 2024

1. Introduction

For a long time, railway has undertaken the important task of personnel and materials transportation. Intercity railways are dedicated passenger railways connecting adjacent cities or urban agglomerations. In some countries, intercity railways have certain public interest in that they provide a transport service at a relatively low price for social benefit objectives [1,2]. However, this leads to a situation where many intercity railway companies have been in a long-term deficit [3]. Some researchers have focused on this problem and have suggested some solutions to help ease the deficit of railway companies. Loss subsidy was a widely used method by some governments to partly cover the financial losses of railway companies [4]. Some research has been conducted to identify the key factors affecting government subsidies and efficient assess to them, but it can be seen that, based on the current loss subsidy mechanism, the continuous deficit situation cannot be eased [5–7]. At present, the interests of governments and intercity railway companies for railway subsidies are in conflict:

(1) For the government, intercity railway operation requires long-term investment, but the subsidy efficiency is not good, which is not conducive to the sustainable development of the railway industry;
(2) For railway companies, the passenger transport income is far lower than the railway cost. The ticket revenue can hardly make up for the deficit gap. The balance of payments can only be maintained by government subsidies. At the same time,

railways may have problems such as a lack of enthusiasm and the reporting of false information to obtain more subsidies under the loss subsidy strategy.

Research has also found that the railway companies' performance cannot be substantially improved, thus there is a strong need for new subsidy ideas of government policy support to help improve the subsidy efficiency and reduce railway operation financial loss [6]. Taking the examples of state-owned intercity railway companies in China, for instance, provincial governments usually provide loss subsidies to them. However, after years of practice, this form of subsidy cannot mobilize railway companies as they know that no matter how good or bad the performance is, the government will help them fill the deficit gap. But little research has been focused on the subsidy innovation model or the new model efficiency assessment in the railway sector. Targeting this problem and research gap, this paper aims to (1) propose a new government subsidy mechanism that relies on intercity railway operators' efforts to stimulate, instead of relying on the traditional loss subsidy mechanism, and (2) quantify the potential effects of the newly proposed performance-based subsidy mechanism while considering the dynamic interactions and games between the government and railway companies. The new performance-based subsidy mechanism, or the performance subsidy model proposed in this paper, is a subsidy model according to which the subsidy amount paid from the government to the railway company is determined by the railway's performance, usually by operating mileage, pairs of trains and passenger-traffic flow. Only if the railway operator meets the set performance target can they get the full or part of the subsidy from the government. The performance evaluation model is a proposed quantified model to assess the outcome and efficiency of the performance subsidy model designed in this paper.

The paper contributes to the literature from the following two key aspects:

(1) We propose a performance subsidy model and compare the feasibility to the traditional loss subsidy. In addition, we formulate a performance evaluation method related to passenger flow and pairs of trains which are related to the characteristics of intercity railways, which could arouse the enthusiasm of railway companies.
(2) We also consider the game relationship between the government and the companies. Different from the traditional government's unilateral subsidies, a dynamic subsidy strategy is proposed, and the influence of social capitals is considered.

This structure of the paper is as follows: the second part is a literature review. Section 3 illustrates the game model between the government and the intercity railway companies. The game model results and discussions are analyzed in Section 4. Conclusion and policy suggestions are given in Section 5.

2. Literature Review

2.1. Research on the Optimization of the Railway Subsidy Mechanism

Currently, academic research on railway subsidies primarily focuses on the necessity and optimization of the subsidy mechanism. Thackway et al. mentioned that, due to the charging mechanism and rate of return, it is difficult to realize the market-oriented operation of public supply projects, and it requires co-ordinated participation of all parties and government subsidy support to achieve sustainable development [4]. Proost et al. showed that there are economies of scale in public rail transit. The optimal pricing in most transport markets is higher than the current fare price, which can only obtain limited benefits and is difficult to cover the optimal cost [5]. Ou Xinquan analyzed the problems of China's municipal railways and put forward the need for new development ideas and the introduction of innovative policy support [6]. Hu et al. used a multi-objective programming method, genetic algorithm and Monte Carlo simulation to make decisions with the goal of maximizing social welfare, maximizing private sector profits and maximizing consumer surplus [7]. Harrod discussed the train route pricing problem in North American rail networks and constructed a schedule optimization model to study the effect of absolute revenue maximization on railroad company revenue [8]. Xu et al. studied the influence of different railway fares and subsidy policies on urban form, residents' family behavior and developers' behavior [9]. Tsamboulas put forward a comprehensive method of railway investment project evaluation based on railway infrastructure and railway operation, and showed that in the case of negative financial evaluation, how to improve the financial situation through government subsidies is very important [10]. Yang et al. established a double-layer programming model to study the subsidy strategy of co-ordinated government for railways, and took container trade in Northeast Asia and Europe as an example to solve the problem [11]. Yuan et al. developed a system dynamics model of price and subsidy adjustment to balance the satisfaction of all relevant stakeholders [12]. Jiang et al. used the binary Logit model to discuss the selection probability of the two modes of railway express in China, and the influence of government subsidies on event probability [13]. Teng Jing et al. studied and analyzed the methodology and experience of RER operating subsidies by taking the example of the Paris Municipal Express Line, and proposed to increase the incentive and penalty system linked to railway-related parties [14].

Currently, railway investment and financing are facing some difficulties. The large gap between railway construction and operation costs and income has increased the operational difficulties of railway companies, requiring government subsidies to maintain operations. The government mainly uses loss subsidies to subsidize railway companies. With the development of the railway industry, this type of subsidy method needs to be changed and optimized. Subsidy models that take into account loss, satisfaction, environment, etc. are the more studied ones. The different railway subsidy mechanisms are summarized in Table 1.

Table 1. Summary of railway subsidy mechanism.

Author	Methods	Using No-Subsidy for Comparison	References of Subsidy
Hu et al., 2018. [7]	Multi-objective programming model	No	- [1]
Harrod S., 2013 [8]	Schedule optimization model	Yes	Loss
Xu et al., 2018 [9]	Spatial equilibrium model	Yes	Ticket price
Tsamboulas D., 2014 [10]	Comprehensive evaluation method	Yes	-
Yang et al., 2020 [11]	Double-layer programming model	Yes	Loss, Environment
Yuan et al., 2019 [12]	System dynamics model	No	Loss, Satisfaction
Jiang et al., 2018 [13]	Binary Logit model	Yes	Loss

[1]—represents that the impact factor of subsidies is not taken into account.

2.2. Research on Game and Subsidy Mechanism Optimization

As demonstrated above, there is also guidance concerning the game relationship between the government and companies. Ho analyzed the post-compensation mechanism of the government in relation to the private sector by using dynamic game analysis [15]. Kundu et al. proposed a competition model based on game theory techniques to analyze the effect of government subsidies on shippers' mode-switching behavior [16]. Feng Fenling et al. used the non-co-operative game theory to analyze the influence of different subsidy amounts on the social benefits of local governments and the profits of railway express operators in China, considering the different goals of local governments and Chinese railway operators. The results showed that the optimal subsidy amount was between USD 2000 and USD 2500 per 40-foot equivalent unit (FEU) [17]. Liu et al. established a bargaining game model and discussed the influence of discount factors on the optimal subsidy [18]. Xie et al. analyzed the four-stage Stackelberg game among manufacturers, retailers and local governments under the same subsidy conditions of central government projects. In the case of consumer preference, township companies will choose online retail for product sales [19]. Zhang et al. established two Stackelberg game models of green tourism supply chain with and without government subsidy, and solved them by backward induction, finding that government subsidy can increase the demand for green tourism [20]. Ji et al. studied the interaction mechanism of complex behaviors between local governments and automobile manufacturers by using an evolutionary game model considering subsidy policy elimination and no subsidy policy elimination [21]. Zhang et al. analyzed the implementation mechanism of public transport subsidy policies from the perspective of carbon emissions, and explored the evolutionary stability strategy of the tripartite game model between the government, companies and residents under different circumstances [22]. Liu et al. set up an evolutionary game model between the government and the construction unit to solve the problem of poor subsidies from the government [23]. Zheng et al. constructed a tripartite evolutionary game model of fishermen, consumers and government, and analyzed the influence of the probability of each agent's behavior on the strategy of other agents and the stability of the system [24]. Zhang et al. established an evolutionary game model between farmers and herbivorous species, and studied the effects of different factors on the game process through model simulation [25]. Koryagin constructed coalition-free game among districts, passengers and public transport to study the problem of land distribution [26]. Stoilova used game theory and examined the strategic decisions of railway and road operators with different interests. She took into account the influence of profit and passenger traffic to determine the better decisions of both participants [27]. Ahmad et al. explored the application of game theory to transport systems, being able to analyze the behavior of individual travelers and transport providers to develop strategies to manage congestion, improve efficiency and reduce emissions [28,29]. Kotsi et al. combined system optimum principles with game theory and studied how the behavior of central governing authorities affected different stakeholders by making policies [30]. Many types of game models have made some progress in terms of case applications, with evolutionary games being less used in railways and not taking advantage of the benefits of such game models. The summary of different railway subsidies are listed in Table 2.

Table 2. Summary of railway subsidies.

Author	Methods	Using No-Subsidy for Comparison	References of Subsidy
Kundu et al., 2019 [7]	Non-cooperative game	Yes	Environment
Feng et al., 2020 [17]	Non-cooperative game	No	- [1]
Stoilova, 2020 [27]	Non-cooperative game	No	Profit, Passenger traffic
Xie et al., 2022 [19]	Stackelberg game	No	-
Zhang et al., 2023 [20]	Stackelberg game	Yes	Environment
Ji et al., 2019 [21]	Evolutionary game	Yes	Loss
Zhang et al., 2020 [22]	Evolutionary game	No	Loss

[1]—represents that the impact factor of subsidies is not taken into account.

2.3. Summary

At present, some research has confirmed that subsidies benefit railway development. Also, the game model has been applied to the research of city-wide railway subsidies. Some studies have considered the loss subsidy and performance subsidy, but these may not be applicable for intercity railways. Therefore, intercity railway subsidies need to be studied further by combining loss subsidy and performance subsidy. It is necessary to consider the characteristics of high cost, high station density and bus-like operation of intercity railways in the model, and to develop a new subsidy strategy specifically for intercity railways. Unlike the previous literature, this paper uses an evolutionary game to study the preferred model in the intercity railway subsidy problem, which integrates the relationship between the governments, railway companies and social participants, which is innovative compared to other research. In addition, we consider a performance subsidy, choose two influencing factors and combine the performance subsidy with the traditional loss subsidy to consider a new dynamic subsidy model.

3. Materials and Methods

3.1. Problem Description

Under the government–company co-operation relationship, decision-making behavior is affected by the positive externality, subsidy amount, incentive situation, operation situation, social capitals' investment and other factors. Their decision-making can be regarded as a process of continuous learning, and satisfies the key assumption of bounded rationality. Therefore, this problem can be studied by the evolutionary game model.

As mentioned above, this is a subsidy optimization issue related to the governments and railway companies. The governments seek the combination of social benefits and low costs, while the railway companies seek high revenue, so that the interests of the two will be contradictory to some extent. The governments' demand for social benefits will increase the economic pressure of railway companies. The demand for cost reduction and expenditure reduction conflicts with the companies' expectations of increased subsidies. The governments also hope to bring social capitals on board and improve the efficiency of the subsidies. Therefore, the new strategy needs to reach a balance between the two subjects' decisions, comprehensively meet the interests of both subjects and achieve a win-win outcome. This paper uses the method of an evolutionary game to solve this question.

Intercity railways are different from other kinds of railway: (1) They have faster speed, reaching 200 km/h to meet the needs of intercity transportation. (2) The station layout is denser and usually built in the city or around the city, making it convenient and meeting the short-distance transportation needs. (3) The cost is higher. Due to high technical requirements and operating standards, intercity railways require more advanced equipment and technology to ensure safety and reliability, resulting in higher construction and operating costs. (4) They are operated like buses, with high operating frequencies, lower ticket prices, high service quality and long operating hours to meet the commuting and business travel needs between cities. Some important features of intercity rail need to be considered in the model.

3.2. Model Assumption

(1) The three participants—governments, railway companies and social capitals—all have bounded rationality and lack the ability to predict. When making decisions, they usually use their reasoning abilities to constantly learn through trial and error according to existing information to maximize the benefits.

(2) Participants in decision-making have two behavioral strategies. The governments have "positive subsidy" and "conventional subsidy". The railway companies have "positive operation" and "negative operation". The social capitals have "invest" and "do not invest". The positive subsidy strategy of the government will have certain expectations of the behavior of railway companies, and is willing to pay a certain cost to supervise the operation of a railway company. The supervision cost is C_0. The conventional subsidy strategy will lead to the reduction of the basic subsidy to the railway company. Positive operation of a railway company can reduce operating loss on the condition that the number of running trains remains the same, and at the same time bring higher positive external railway benefits. Negative operation strategies lead to increased loss from improper operation, and this loss is likely to be included in the consideration of subsidies, and the increase in income is R_0. Social investment can bring a certain return R_1, assuming that the company and social capital are each allocated 50 per cent of the return, with the return being higher when the company is active, at α_3, and vice versa, at α_4 ($\alpha_4 < \alpha_3$).

(3) The positive external benefit of railways depends on the behavior of railway companies, which affects the income of the government. The positive external benefit of railways under the positive operation of companies is R, and the positive external benefit of railways under the negative operation of companies is $\alpha_1 R$ ($0 < \alpha_1 < 1$).

(4) The basic subsidy belongs to the category of loss subsidy, which is related to the loss of railway companies. It can be obtained from the difference between the income and

cost of railway companies by a certain loss subsidy ratio, and is related to government behavior. The basic subsidy under positive subsidy behavior is S, and the basic subsidy under conventional subsidy behavior is $\alpha_2 S$ $(0 < \alpha_2 < 1)$.

(5) The investment interest of social capitals changes according to government policies. Social capitals will invest more when the government is actively funding the project, and may invest conservatively when it is not. The discount factor is α_5 $(0 < \alpha_5 < 1)$.

(6) Performance subsidy has two influencing factors: passenger flow and pairs of trains.

(7) Loss of railway companies includes loss during construction and operation, which is affected by company behaviors. Operating loss of positive railway companies is C and operating loss of negative railway companies is C_1.

(8) The subsidy methods considered by the model are loss subsidy and performance subsidy.

The parameters are listed in Table 3.

Table 3. Model parameters table.

Main Parameter	Meaning
S_0	Performance subsidy
R	Positive external benefits of positive railway
$\alpha_1 R$	Positive external benefits of negative railway
S	Basic subsidy under positive subsidy behavior
$\alpha_2 S$	Basic subsidy under conventional subsidy behavior
C	Operating loss of positive railway companies
C_1	Operating loss of negative railway companies
R_1	Social capitals' investment
α_3	Return on investment for positively operated projects
α_4	Return on investment for negatively operated projects
α_5	Investment income discount factor
C_0	Supervision cost
R_0	Income increase under negative operation of railway companies
N	Difference of passage flow between actual value and government expectation
n	Difference of pairs of trains between actual value and government expectation

3.3. Performance Subsidy

Considering the characteristics of intercity railways, passenger flow and pairs of trains were selected as influencing factors for performance subsidies. We used the difference between the actual value and the government expectations as the indicator.

$$S_0 = \beta_1 * N + \beta_2 * n \tag{1}$$

where β_1 and β_2 represent the coefficient of influence degree.

3.4. Model Framework

In the evolutionary game model, the governments grant basic subsidies according to the losses of companies and performance subsidies according to the railway operation. Government payoff refers to railways' positive external benefits net of subsidies. Supervision cost should be considered additionally if the governments choose positive subsidy strategy. Company payoff refers to basic subsidies, performance subsidies and social investment returns eliminating company loss. When companies operate negatively and the governments do not actively supervise, part of companies' improper operation loss is included in loss subsidy, so R_0 will increase. Accordingly, the government reduces the same amount of payoff. Social capital payoff refers to the investment returns.

Performance subsidy varies in parameters and variables according to government behavior and company behavior. The influence degree coefficient of the conventional government is reduced to β_1' and β_2'. The number of pairs of trains is reduced by the passive operation company, resulting in the change of the difference with the government's expected value, which is reduced to n'.

Suppose the proportion of governments with positive subsidy behavior is x $(0 \leq x \leq 1)$, and the proportion of governments with conventional subsidy behavior is $1 - x$. Suppose the proportion of railway companies with positive operation behavior is y $(0 \leq y \leq 1)$, and the proportion of railway companies with negative operation behavior is $1 - y$. Supposing the proportion of social capitals with investment behavior is z $(0 \leq z \leq 1)$, and the proportion of social capitals with no investment behavior is $1 - z$, these are the following decision relationships. The decision tree is shown in Figure 1.

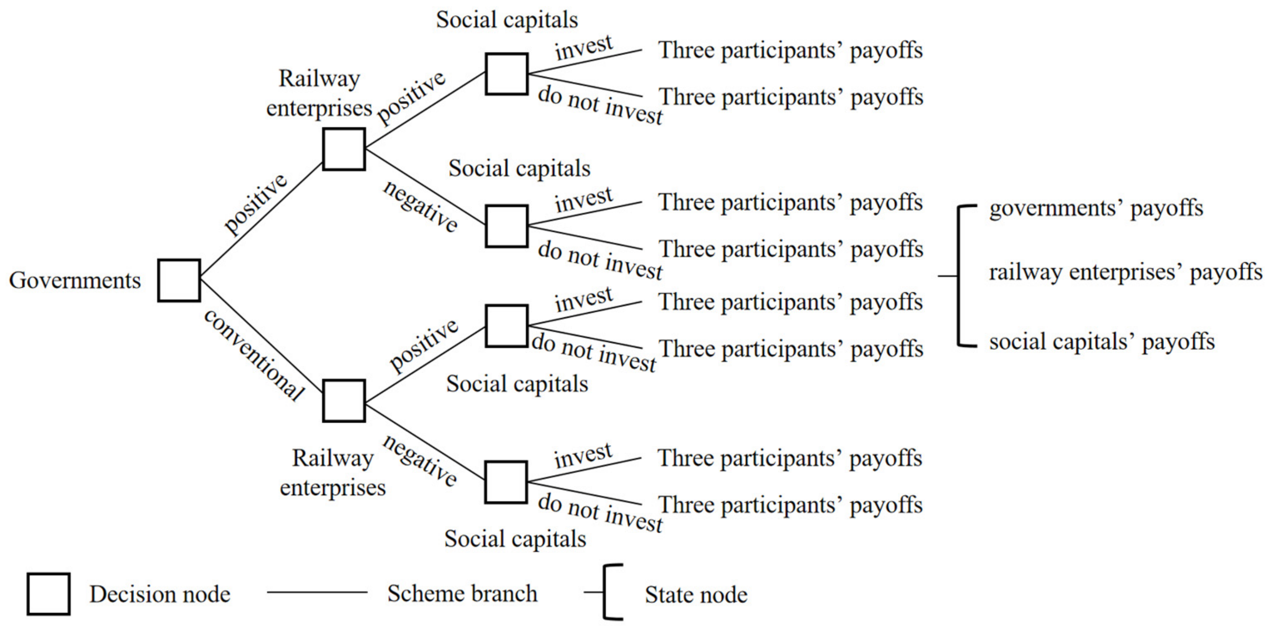


Figure 1. Decision tree.

Under the traditional loss subsidy policy, subsidy is only granted according to the loss amount of railway companies. When performance subsidy is considered, the behavior of railway companies is assessed, and the performance subsidy is calculated according to the operation status. The total subsidy is given is, therefore, more or less. The adjusted income matrix is shown as follows. The payoff matrices of investment and divestment are listed in Tables 4 and 5.

Table 4. Payoff matrix under social capitals' investment (z).

		Railway Companies	
		Positive Operation (y)	**Negative Operation (1 − y)**
Governments	Positive subsidy (x)	$R - S - C_0 - \beta_1 N - \beta_2 n$ $S - C + \beta_1 N + \beta_2 n + 0.5\alpha_3 R_1$ $0.5\alpha_3 R_1$	$\alpha_1 R - S - C_0 - \beta_1 N - \beta_2 n\prime$ $S - C_1 + \beta_1 N + \beta_2 n\prime + 0.5\alpha_4 R_1$ $0.5\alpha_4 R_1$
	Conventional subsidy (1 − x)	$R - \alpha_2 S - \beta_1' N - \beta_2' n$ $\alpha_2 S - C + \beta_1' N + \beta_2' n + 0.5\alpha_3\alpha_5 R_1$ $0.5\alpha_3\alpha_5 R_1$	$\alpha_1 R - \alpha_2 S - R_0 - \beta_1' \mathrm{N} - \beta_2' n'$ $\alpha_2 S - C_1 + \beta_1' N + \beta_2' n' + R_0 +$ $0.5\alpha_4\alpha_5 R_1$ $0.5\alpha_4\alpha_5 R_1$

Table 5. Payoff matrix under social capitals disinvestment (1 − z).

		Railway Companies	
		Positive Operation (y)	**Negative Operation (1 − y)**
Governments	Positive subsidy (x)	$R-S-C_0-\beta_1 N-\beta_2 n$ $S-C+\beta_1 N+\beta_2 n$ 0	$\alpha_1 R-S-C_0-\beta_1 N-\beta_2 n\prime$ $S-C_1+\beta_1 N+\beta_2 n\prime$ 0
	Conventional subsidy (1 − x)	$R-\alpha_2 S-\beta_1' N-\beta_2' n$ $\alpha_2 S-C+\beta_1' N+\beta_2' n$ 0	$\alpha_1 R-\alpha_2 S-R_0-\beta_1' N-\beta_2' n'$ $\alpha_2 S-C_1+\beta_1' N+\beta_2' n'+R_0$ 0

3.5. Calculation of Expected Payoff

Under the performance subsidy model, U_1, U_2, U_3 represent the expected payoff of governments, companies and social capitals. $U_{1a}, U_{1b}, U_{2a}, U_{2b}, U_{3a}, U_{3b}$ represent the payoff of different behavioral decisions of governments, companies and social capitals.

3.6. Expected Payoff of Governments

$$\begin{aligned} U_{1a} = {} & yz(R-S-C_0-\beta_1 N-\beta_2 n)+(1-y)z(\alpha_1 R-S-C_0-\beta_1 N-\beta_2 n') \\ & +y(1-z)(R-S-C_0-\beta_1 N-\beta_2 n)+(1-y)(1-z)(\alpha_1 R-S-C_0-\beta_1 N-\beta_2 n') \end{aligned} \quad (2)$$

$$\begin{aligned} U_{1b} = {} & yz\left(R-\alpha_2 S-\beta_1' N-\beta_2' n\right)+(1-y)z\left(\alpha_1 R-\alpha_2 S-R_0-\beta_1' \mathrm{N}-\beta_2' n'\right) \\ & +y(1-z)\left(R-\alpha_2 S-\beta_1' N-\beta_2' n\right)+(1-y)(1-z)\left(\alpha_1 R-\alpha_2 S-R_0-\beta_1' N-\beta_2' n'\right) \end{aligned} \quad (3)$$

$$U_1 = xU_{1a}+(1-x)U_{1b} \quad (4)$$

$$F(1)=\frac{dx}{dt}=x(1-x)(U_{1a}-U_{1b})=x(1-x)\left[-(\Delta\beta_2\Delta n+R_0)y+R_0-C_0-\Delta S-\left(\Delta\beta_1 N+\Delta\beta_2 n'\right)\right] \quad (5)$$

where $\Delta\beta_1=\beta_1-\beta_1\prime$, $\Delta\beta_2=\beta_2-\beta_2\prime$, $\Delta n=n-n\prime$.

3.7. Expected Payoff of Railway Companies

$$\begin{aligned} U_{2a} = {} & xz(S-C+\beta_1 N+\beta_2 n+0.5\alpha_3 R_1)+(1-x)z\left(\alpha_2 S-C+\beta_1' N+\beta_2' n+0.5\alpha_3\alpha_5 R_1\right) \\ & +x(1-z)(S-C+\beta_1 N+\beta_2 n)+(1-x)(1-z)\left(\alpha_2 S-C+\beta_1' N+\beta_2' n\right) \end{aligned} \quad (6)$$

$$\begin{aligned} U_{2b} = {} & xz(S-C_1+\beta_1 N+\beta_2 n'+0.5\alpha_4 R_1)+(1-x)z\left(\alpha_2 S-C_1+\beta_1' N+\beta_2' n'+R_0+0.5\alpha_4\alpha_5 R_1\right) \\ & +x(1-z)(S-C_1+\beta_1 N+\beta_2 n')+(1-x)(1-z)\left(\alpha_2 S-C_1+\beta_1' N+\beta_2' n'+R_0\right) \end{aligned} \quad (7)$$

$$U_2 = yU_{2a}+(1-y)U_{2b} \quad (8)$$

$$F(2)=\frac{dy}{dt}=y(1-y)(U_{2a}-U_{2b})=y(1-y)\left[(\Delta\alpha_5\Delta R_1)xz+(\Delta\beta_2\Delta n+R_0)x+(\alpha_5\Delta R_1)z-R_0-\Delta C+\beta_2'\Delta n\right] \quad (9)$$

3.8. Expected Payoff of Social Capitals

$$U_{3a}=xy(0.5\alpha_3 R_1)+(1-x)y(0.5\alpha_3\alpha_5 R_1)+x(1-y)(0.5\alpha_4 R_1)+(1-x)(1-y)(0.5\alpha_4\alpha_5 R_1) \quad (10)$$

$$U_{3b}=xy(0)+(1-x)y(0)+x(1-y)(0)+(1-x)(1-y)(0)=0 \quad (11)$$

$$U_3 = zU_{3a}+(1-z)U_{3b} \quad (12)$$

$$F(3)=\frac{dz}{dt}=z(1-z)(U_{3a}-U_{3b})=z(1-z)[(\Delta\alpha_5\Delta R_1)xy+(0.5\alpha_4 R_1\Delta\alpha_5)x+(\alpha_5\Delta R_1)y+0.5\alpha_4\alpha_5 R_1] \quad (13)$$

3.9. Conclusion and Simplification

Therefore, the replicated dynamic equations are as follows:

$$\begin{cases} F(1) = x(1-x)[-(\Delta\beta_2\Delta n + R_0)y + R_0 - C_0 - \Delta S - (\Delta\beta_1 N + \Delta\beta_2 n')] \\ F(2) = y(1-y)[(\Delta\alpha_5\Delta R_1)xz + (\Delta\beta_2\Delta n + R_0)x + (\alpha_5\Delta R_1)z - R_0 - \Delta C + \beta_2'\Delta n] \\ F(3) = z(1-z)[(\Delta\alpha_5\Delta R_1)xy + (0.5\alpha_4 R_1\Delta\alpha_5)x + (\alpha_5\Delta R_1)y + 0.5\alpha_4\alpha_5 R_1] \end{cases} \quad (14)$$

where $\Delta S = (1-\alpha_2)S$, $\Delta C = C - C_1$, $\Delta R_1 = 0.5(\alpha_3 - \alpha_4)R_1$, $\Delta\alpha_5 = 1 - \alpha_5$.

4. Results and Discussion

4.1. Background

Henan Province has a total area of 167,000 square kilometers. In 2022, the resident population was 98.72 million people, the gross regional product was RMB 6.13 trillion and the railroad industry had a loss of RMB 1027 million. Figure 2 shows that the intercity railways undertake a large number of personnel transportation tasks every year. Henan Province has a large population base and a large annual loss in the railway industry, so there is a desperate need for railway subsidy optimization. Therefore, Henan Province was chosen as the research case for this paper. The annual passenger flows are shown in Figure. The subsidy relationship among the various parties is shown in Figure 3.

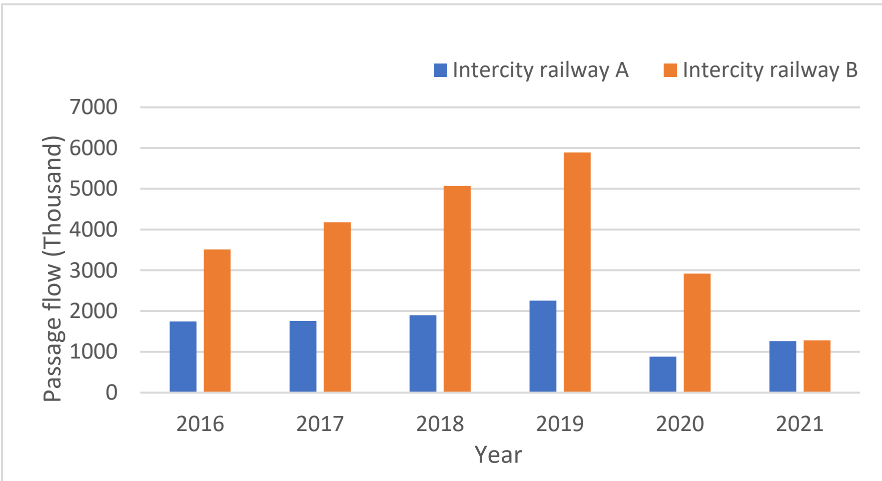


Figure 2. Annual passenger flows of two intercity railways in Henan Province, China.

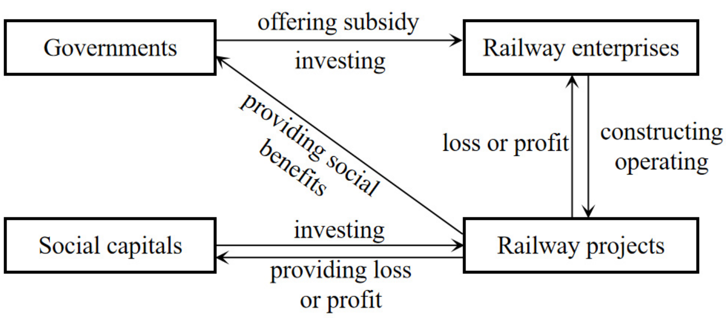


Figure 3. The subsidy relationship among participants.

Taking one of intercity railway of Henan Province as an example, the average annual passenger flow is 1.64 million, the average number of trains is 27.5 pairs and the annual loss is RMB 289 million.

4.2. Simulation Results without Performance Subsidy

Consider first the case where there is no performance subsidy and only loss subsidy. MATLAB R2022a was used to simulate the model. Some parameters are set as follows:

$$R_1 = 1,\ \alpha_3 = 0.1,\ \alpha_4 = -0.2,\ \alpha_5 = 0.8,\ C_0 = 0.01,\ R_0 = 1,\ \alpha_2 = 0.8,\ S = 2,\ C = 2.89,\ C_1 = 3.5.$$

Three initial value co-ordinates $[0.4, 0.4, 0, 4]$, $[0.5, 0.5, 0, 5]$, $[0.6, 0.6, 0, 6]$ were selected for calculation, and the simulation results were obtained as shown in the figure below. The final results converged at $[x^*, y^*, z^*]$.

According to Figure 4, with the progress of the simulation, the decisions of the two players finally converge to a point. This means that the stability point is not reached, and under the policy of loss subsidy, the railway project cannot benefit by itself and it cannot bring benefits to the social capital, so this type of loss subsidy is not suitable for investment from the practical point of view, and it cannot work as an incentive for the railway company.

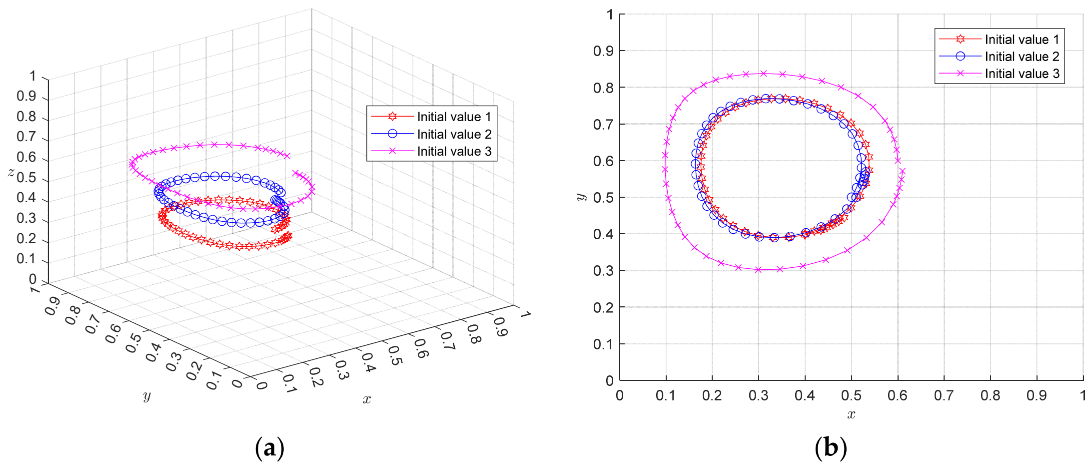


Figure 4. Dynamic evolution process. (**a**) 3D view; (**b**) x–y view.

Performance subsidy can link the revenue of companies to their own operation conditions. It is also related to the positive external benefits of railways that governments are most concerned about, thus affecting the social benefits of the government. This kind of subsidy can arouse the enthusiasm of companies and increase the benefits of the governments at the same time. Therefore, it is necessary to combine performance subsidy with traditional loss subsidy to form an innovative means of subsidy.

4.3. Simulation Results with Performance Subsidy

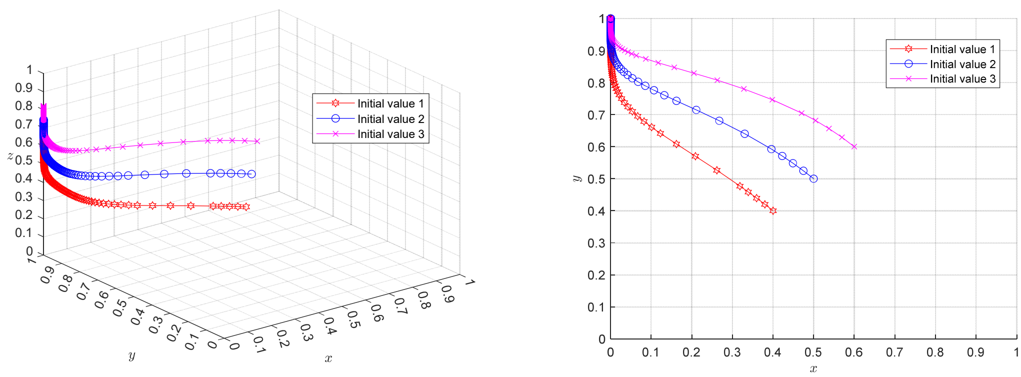
Parameters are set as follows:

$$N = 10,\ n = 7.5,\ n\prime = 0,\ \beta_1 = 0.2,\ \beta_2 = 0.2,\ \beta_1' = 0.1,\ \beta_2' = 0.1.$$

Three initial values co-ordinates $[0.4, 0.4, 0, 4]$, $[0.5, 0.5, 0, 5]$, $[0.6, 0.6, 0, 6]$ were selected for calculation, and the simulation results were obtained as shown in the figure below. The final results converged at $[0, 1, 1]$.

In Figure 5, all initial cases converge at $[0, 1, 1]$. The payoffs of companies and social capitals are 0.5 and 0.04, respectively. The payoff of governments is related to R. This indicates that the introduction of performance appraisal into the subsidy policy can arouse the enthusiasm of companies. Under the condition that the government expectation of passenger flow and pairs of trains remains unchanged, railway companies tend to choose positive operation strategies to obtain higher performance subsidies. The governments only need conventional subsidies, which can bring a win-win situation for both players.

Railway companies gain higher subsidies and revenue from positive operation, and the governments do not need high performance subsidy parameters or supervision costs, thus saving fiscal expenditure. Social capitals are also willing to invest in railway projects, bringing more liquidity to railway projects.



(**a**) (**b**)

Figure 5. Dynamic evolution process (considering performance subsidy). (**a**) 3D view; (**b**) x–y view.

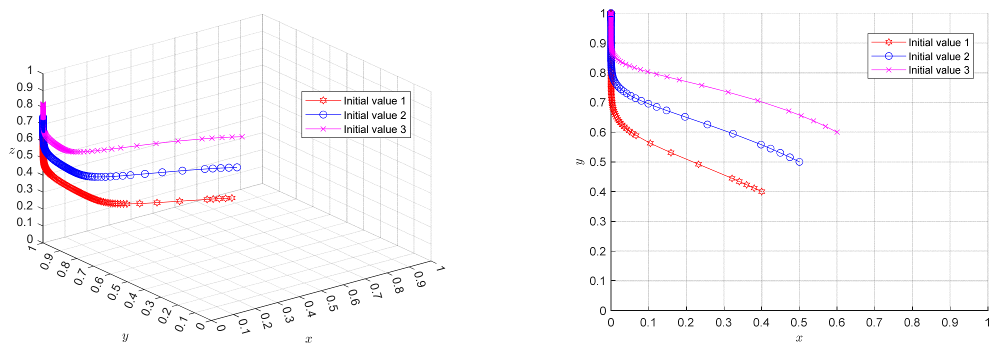
Compared to the approach without performance subsidy, this new approach links the revenue of railway companies with their behaviors, and fully arouses their enthusiasm. The governments implement the conventional investment strategy, which can save unnecessary expense while obtaining the guarantee of social benefits.

4.4. Sensitivity Analysis and Discussion

A sensitivity analysis of variables and parameters in the model was carried out to determine the changes in decisions of three participants under different scenarios.

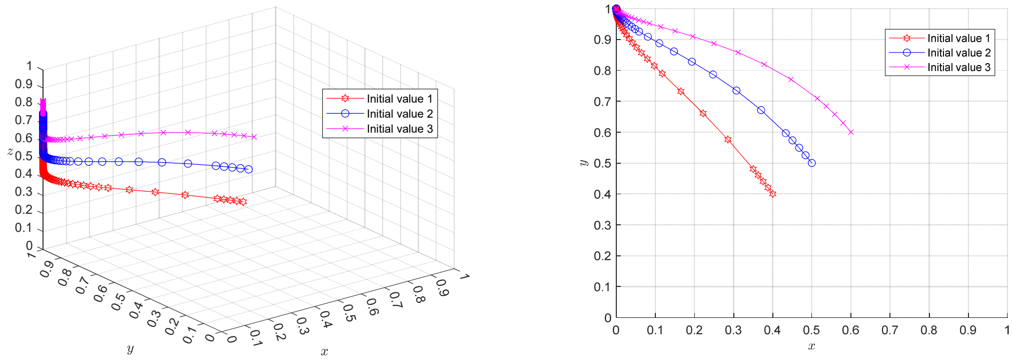
(1) The coefficient of influence degree β_1, β_2

With other parameters unchanged, the value of performance subsidy coefficient is changed. The results are shown in Figures 6 and 7.



(**a**) (**b**)

Figure 6. $\beta_1 = \beta_2 = 0.3, \beta_1' = \beta_2' = 0.1$. (**a**) 3D view; (**b**) x–y view.



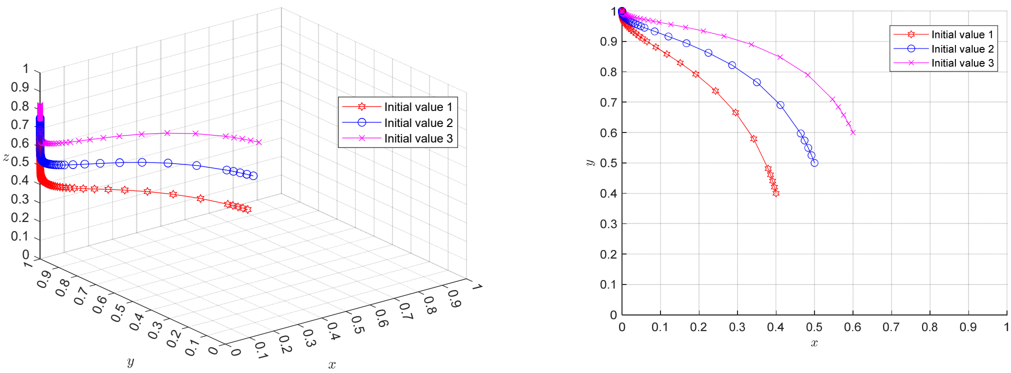
(**a**) (**b**)

Figure 7. $\beta_1 = \beta_2 = 0.3, \beta_1' = \beta_2' = 0.2$. (**a**) 3D view; (**b**) x–y view.

The results are unchanged, converging to $[0,1,1]$. The payoffs of companies are 0.5 and 2.21, respectively. The payoffs of social capitals are 0.04 and 0.04, respectively. However, increasing the performance subsidy coefficient under the positive subsidy strategy exerts no great change on the convergence process, which has little impact on their behavior. At the same time, by increasing both performance subsidy coefficients under the positive subsidy strategy and negative subsidy strategy, the result converges to the equilibrium point faster. It can be seen that increasing the intensity of performance subsidy while maintaining the same performance difference between the two government subsidy strategies can increase the enthusiasm of railway companies and make them choose positive operation strategies faster. For social capital, the change in willingness to invest is not obvious.

(2) Difference of passage flow between actual value and government expectation R_0

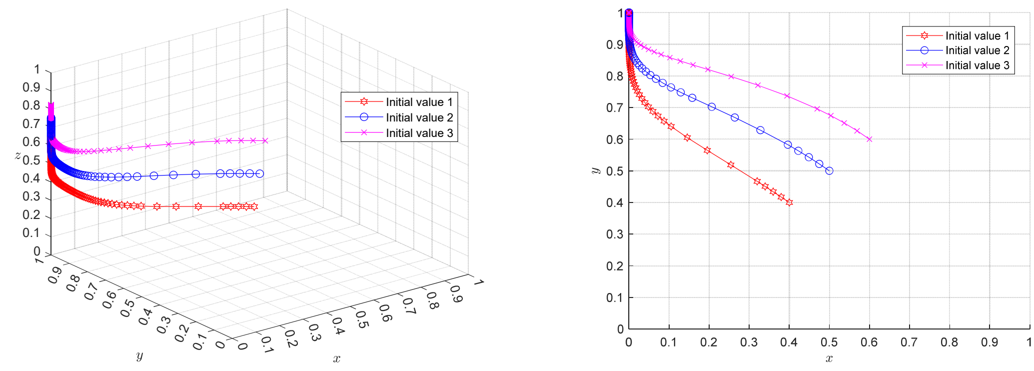
With other parameters unchanged, under the negative operation strategy difference of passage flow between actual value and government expectation is changed. The results are shown in Figures 8 and 9.



(**a**) (**b**)

Figure 8. $N = 5$. (**a**) 3D view; (**b**) x–y view.

The results are unchanged. The payoffs of companies are 0 and 1.5, respectively. The payoffs of social capitals are 0.04 and 0.04, respectively. As N increases, the governments choose the conventional funding strategy more quickly, and the companies choose a positive operational strategy immediately afterwards. This reflects the fact that if the passenger flow of a particular railway is sufficiently high in itself, and its level of revenue and performance is sufficient, the government can save time and effort, and it is easier for governments and railway companies to achieve a win-win result.

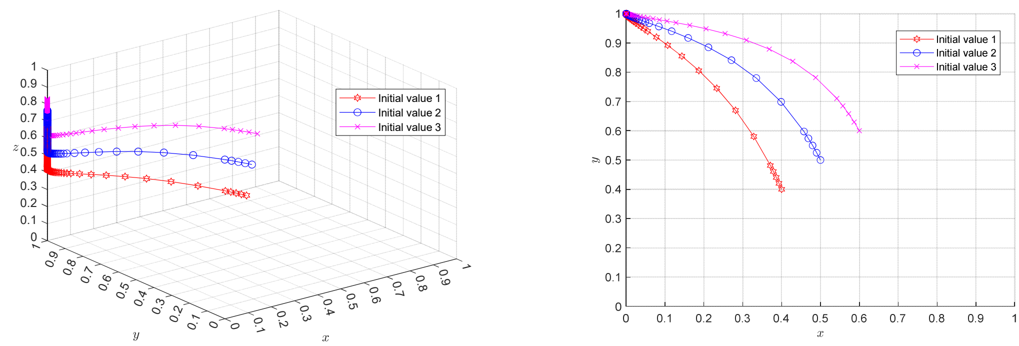


(**a**) (**b**)

Figure 9. $N = 20$. (**a**) 3D view; (**b**) x–y view.

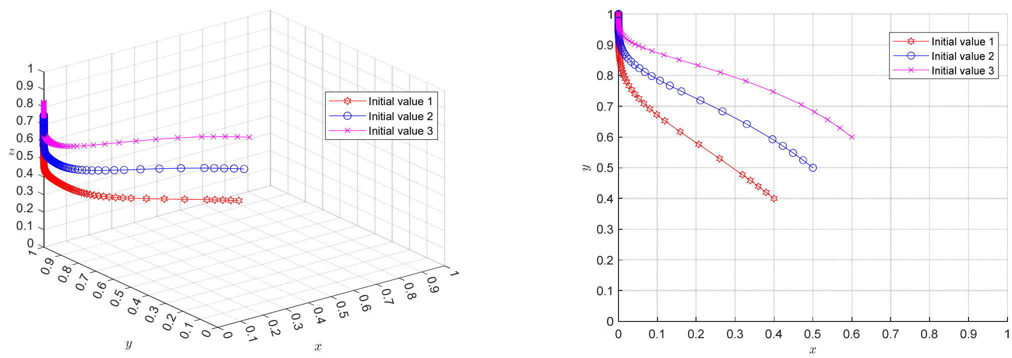
(3) Difference of pairs of trains between actual value and government expectations $n, n\prime$

Change the government expectation of pairs of trains, which changes the performance subsidy evaluation index. The results are shown in Figures 10 and 11.



(**a**) (**b**)

Figure 10. $n = 15, n' = 0$. (**a**) 3D view; (**b**) x–y view.



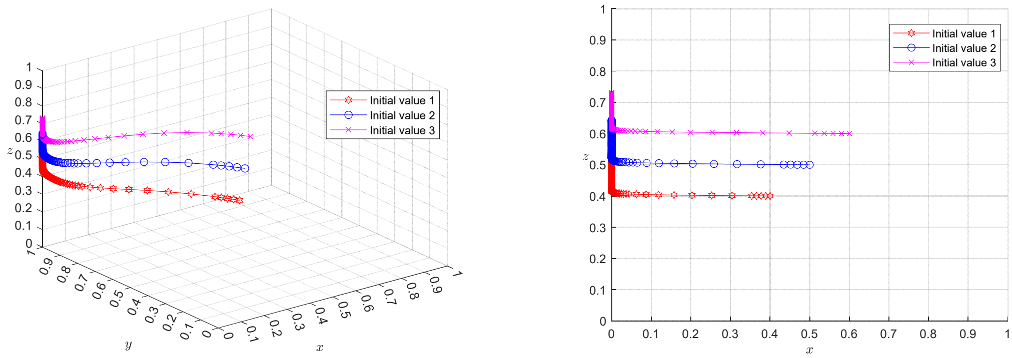
(**a**) (**b**)

Figure 11. $n = 15, n' = 7.5$. (**a**) 3D view; (**b**) x–y view.

The payoffs of companies are 1.25 and 1.25, respectively. The payoffs of social capitals are 0.04 and 0.04, respectively. When the difference between the actual value and government expectations of pairs of trains under a positive subsidy strategy is changed, the convergence speed is accelerated, and the railway companies will choose the positive operation strategy more quickly. After the introduction of performance subsidy, railway companies are more willing to increase the number of train pairs to increase the revenue from performance subsidy, and an appropriate increase in the number of train pairs has a positive effect on all participants in the game. The larger the revenue gap brought by active operation, the more willing the railway companies are to operate actively, which can also improve the social benefits. If the governments' expectation of the number of train pairs is reduced, it will not have a significant effect on the results.

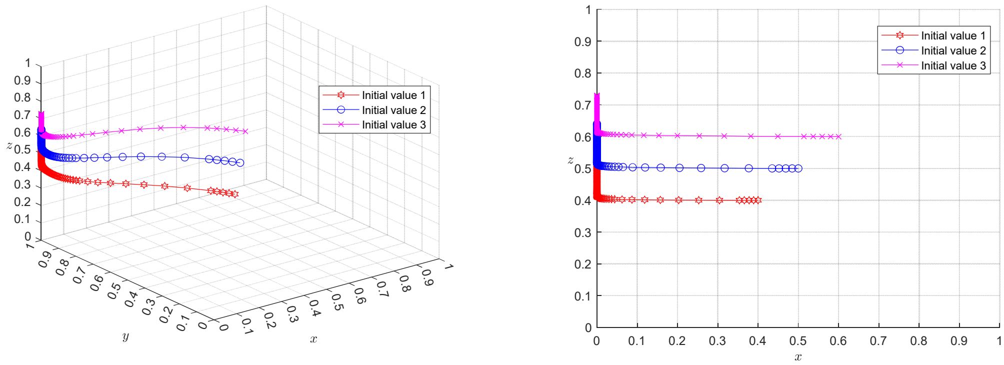
(4) Returns on investment α_3, α_4

With other parameters unchanged, change the returns on investment. The results are shown in Figures 12 and 13.



(**a**) (**b**)

Figure 12. $\alpha_3 = 0.1, \alpha_4 = 0$. (**a**) 3D view; (**b**) x–z view.



(**a**) (**b**)

Figure 13. $\alpha_3 = 0.1, \alpha_4 = -0.1$. (**a**) 3D view; (**b**) x–z view.

The payoffs of companies are 0.5 and 0.5, respectively. The payoffs of social capitals are 0.04 and 0.04, respectively. No matter how the rate of return on social investment is changed, it will have little impact on the overall railway project, or on the choice of social capitals. After considering whether social capitals participate in railway projects, and after introducing performance subsidies, social capitals are willing to invest, even if the willingness to invest changes little at first. The rate of return on investment may have a certain impact on how much social capitals invest in other similar projects in the future. When social capitals have gained a good return on existing railway projects, they will have higher expectations for the construction of other public welfare projects in the future, which is conducive to the benign development of society.

According to the simulation results, adding performance subsidies to the existing subsidy policy can significantly increase the benefits of the governments and companies. Their behavioral decisions will also be changed accordingly. With a passenger flow of 1.64 million, a train pair count of 27.5 and an annual loss of RMB 289 million, a combination of performance subsidy and loss subsidy is used. Assuming a basic subsidy of RMB 2 million, a coefficient of influence degree of 0.2, a discounted coefficient of influence degree of 0.1 and a social return on investment of 0.1, the final results are obtained. The payoff of companies is RMB 50 million, which has some revenue and is sustainable. The payoff of social capitals is RMB 4 million, which can attract more social capitals to participate and reduce the pressure on government funding. The governments only need to choose conventional subsidy strategies and introduce a performance-based subsidy, which increases earnings for railway companies at a modest cost. Also, this kind of subsidy can improve and guarantee social benefits. Under the new subsidy approach of government, railway companies will choose positive operation strategies to improve the reward of performance subsidies through better operation decisions, and the positive operation strategies would also improve the earnings for companies, compared to blindly relying on the governments' loss subsidies. Social capitals are willing to invest in projects as long as they are actively funded by the government and have substantial returns. Finally, it is helpful for social public welfare projects.

5. Conclusions and Policy Suggestion

5.1. Conclusions

There are two main conclusions:

(1) The performance and loss subsidy models can be combined to introduce a more dynamic subsidy model that maximizes the benefits to subsidy participants according to the actual situation. In the general case presented in the paper, when passenger traffic is at 1.64 million, the number of train pairs is at 27.5 and the annual loss of the company is at RMB 280 million, this new subsidy model still generates an annual revenue of RMB 50 million for the railway company and RMB 4 million for the social capitals. An increase in subsidy can even increase this value.

(2) Varying the size of the parameters of the performance allowance affects the final choice of participants, and choosing other parameters not mentioned may also have a role in assessing performance, depending on the different circumstances of different intercity railways. In the case in this paper, if the coefficients for the influence of passenger flow and the number of train pairs are all chosen to be 0.2, and after discounting they are all chosen to be 0.1, the payoff of companies will be RMB 50 million. If the coefficients are changed to 0.3 and 0.1, the payoff will be stable. If the coefficients are changed to 0.3 and 0.2, the payoff of companies will be 2.21.

The new approach brings positive effects. On the one hand, the enthusiasm of railway companies is improved. Reasonable subsidy policies can optimize the overall benefits of railway companies, which is conducive to the healthy development of the railway industry in the long run. On the other hand, through an innovative subsidy approach, the governments provide guaranteed benefits for railway companies and optimize the behavior of railway companies. Also, this drives the positive development of the railway industry and improves the convenience of intercity railway operation for residents. The governments do not need to bear too much financial pressure and regulatory pressure, and the subsidy efficiency has been greatly improved. Exactly how to set the indicators and intensity of performance subsidies needs to be determined according to different intercity railways, and the governments can also formulate policies according to different intercity railway operations to attract and guide the healthy participation of social capitals.

Railway subsidies play a very important role in the sustainable development of intercity railways, and provide an important source of funds for such public welfare projects. This paper considered a performance subsidy approach for intercity railways, in addition to the existing railway subsidy approach—loss subsidy. Considering the characteristics of high costs, high frequency and public transport of intercity railways, this paper chose passage flow and pairs of trains as the performance subsidy indicators and provided a more reasonable subsidy approach for intercity railway government subsidies. The research results show that after introducing performance evaluation, the interests of participants were improved, and their behaviors tend to develop in a healthy direction, which is beneficial for the long-term operation of the railway industry.

At the same time, this paper had some limitations. On the one hand, the selection of data may have been subjective, and subsequent validation and repeated experiments are needed. On the other hand, the model was a simplification of the real situation, ignoring many environmental factors, and so specific problems should be analyzed specifically.

5.2. Policy Suggestions

(1) Innovate subsidy approach

Under the subsidy approach, combining performance subsidy and loss subsidy, the government only needs conventional investment subsidies to bring a win-win situation for both sides. In the future, the new subsidy policy can consider introducing the subsidy approach of performance reward, stipulating operation boundary conditions, formulating assessment indicators, and providing additional rewards or penalties for the operation of railway companies, so as to stimulate the enthusiasm of the operators.

(2) Consider performance subsidy indicators from different aspects

Set performance subsidy standards that are consistent with the characteristics of the intercity railway itself. Selectable criteria include the passage flow, the number of train pairs and the number of kilometers traveled. At the same time, according to the actual situation of different intercity railways, the standards and assessment system can be changed appropriately.

Author Contributions: Conceptualization, L.D. and H.H.; methodology, G.Y.; software, G.Y.; validation, L.D.; formal analysis, G.Y. and Z.Z.; investigation, G.Y. and Z.Z.; resources, L.D. and H.H.; data curation, G.Y. and Z.Z.; writing—original draft preparation, G.Y. and Z.Z.; writing—review and editing, L.D. and H.H.; visualization, G.Y. and Z.Z.; supervision, L.D. and H.H.; project administration, L.D. and H.H.; funding acquisition, G.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Henan Railway Construction & Investment Group Co., Ltd. and Henan Province Philosophy and Social Science Key Project, grant number 2022DWT014. The APC was funded by 2022DWT014.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to restrictions.

Acknowledgments: Thanks go to the reviewers for giving us insightful comments.

Conflicts of Interest: Author Guoyong Yue was employed by the company Henan Railway Construction & Investment Group Co., Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Tang, L. *Research on Public Welfare Measurement and Subsidy Mechanism of Public Welfare Railway*; Southwest Jiaotong University: Chengdu, China, 2021.
2. Dai, L. *Research on Incentive Subsidy Model of Municipal Railway*; Southwest Jiaotong University: Chengdu, China, 2021.
3. Wang, Z.; Li, Y. Analysis on subsidy mechanism of railway public welfare transportation based on mixed strategy game model. *J. Chongqing Jiaotong Univ. (Soc. Sci. Ed.)* **2022**, *22*, 42–51.
4. Thackway, R.; Olsson, K. Public/private partnerships and protected areas: Selected Australian case studies. *Landsc. Urban Plan.* **1999**, *44*, 87–97. [CrossRef]
5. Proost, S.; Dender, K.V. Optimal urban transport pricing in the presence of congestion, economies of density and costly public funds. *Transp. Res. Part A* **2008**, *42*, 1220–1230. [CrossRef]
6. Ou, X. Research on Development Situation and Policies of Urban (Suburban) Railways in China. *Railway Transport and Economy*. pp. 1–6. Available online: http://kns.cnki.net/kcms/detail/11.1949.U.20230920.1608.008.html (accessed on 16 October 2023).
7. Hu, Y.; Wang, J.; Sun, H. Optimization of pricing and subsidies for urban rail transit PPP projects based on satisfaction of main stakeholders. *J. Environ. Prot. Ecol.* **2018**, *19*, 435–449.

8. Harrod, S. Auction pricing of network access for North American railways. *Transp. Res. Part E Logist. Transp. Rev.* **2013**, *49*, 176–189. [CrossRef]
9. Xu, S.X.; Liu, T.L.; Huang, H.J.; Liu, R. Mode choice and railway subsidy in a congested monocentric city with endogenous population distribution. *Transp. Res. Part A Policy Pract.* **2018**, *116*, 413–433. [CrossRef]
10. Tsamboulas, D. Evaluation of rail infrastructure investments related to the new rail regulatory environment in some countries. *Transp. Res. Rec.* **2014**, *2411*, 1–9. [CrossRef]
11. Yang, J.; Luo, M.; Shi, M. Optimal subsidies for rail containers: A bi-level programming solution. *Marit. Policy Manag.* **2020**, *47*, 172–187. [CrossRef]
12. Yuan, J.; Ji, W.; Guo, J.; Skibniewski, M.J. Simulation-based dynamic adjustments of prices and subsidies for transportation PPP projects based on stakeholders' satisfaction. *Transportation* **2019**, *46*, 2309–2345. [CrossRef]
13. Jiang, Y.; Sheu, J.-B.; Peng, Z.; Yu, B. Hinterland patterns of China Railway (CR) express in China under the Belt and Road Initiative: A preliminary analysis. *Transp. Res. Part E Logist. Transp. Rev.* **2018**, *119*, 189–201. [CrossRef]
14. Teng, J.; Wu, T.; Yang, Y.; Li, H. Analysis and Revelation of Operating Subsidy Method for Regional Expressed Railway. *Railw. Transp. Econ.* **2022**, *44*, 29–35.
15. Ho, S.P. Model for financial renegotiation in public-private partnership projects and its policy implications: Game theoretic view. *J. Constr. Eng. Manag.* **2006**, *132*, 678–688. [CrossRef]
16. Kundu, T.; Sheu, J.-B. Analyzing the effect of government subsidy on shippers' mode switching behavior in the Belt and Road strategic context. *Transp. Res. Part E Logist. Transp. Rev.* **2019**, *129*, 175–202. [CrossRef]
17. Feng, F.; Zhang, T.; Liu, C.; Fan, L. China Railway Express Subsidy Model Based on Game Theory under "the Belt and Road" Initiative. *Sustainability* **2020**, *12*, 2083. [CrossRef]
18. Liu, Y.; Wang, X.; Guo, S.; Chen, J. Using Bargaining Game Model to Negotiate Government Subsidy for PPP Infrastructure Projects. In Proceedings of the Construction Research Congress 2020, Tempe, AZ, USA, 8–10 March 2020.
19. Xie, N.; He, H.; Tong, Y. Game Model of Green Financial Supply Chain Based on Government Subsidy Analysis. *IEEE Access* **2022**, *10*, 60929–60945. [CrossRef]
20. Zhang, R.; Li, Z. Stackelberg game model of green tourism supply chain with governmental subsidy. *Inf. Syst. Oper. Res.* **2023**, *61*, 141–168. [CrossRef]
21. Ji, S.; Zhao, D.; Luo, R. Evolutionary game analysis on local governments and manufacturers' behavioral strategies: Impact of phasing out subsidies for new energy vehicles. *Energy* **2019**, *189*, 116064. [CrossRef]
22. Zhang, L.; Long, R.; Huang, Z.; Li, W.; Wei, J. Evolutionary game analysis on the implementation of subsidy policy for sustainable transportation development. *J. Clean. Prod.* **2020**, *267*, 122159. [CrossRef]
23. Liu, Y.; Cai, D.; Guo, C.; Huang, H. Evolutionary Game of Government Subsidy Strategy for Prefabricated Buildings Based on Prospect Theory. *Math. Probl. Eng.* **2020**, *10*, 1–10.
24. Zheng, S.; Yu, L. The government's subsidy strategy of carbon-sink fishery based on evolutionary game. *Energy* **2022**, *254 Pt B*, 124282. [CrossRef]
25. Zhang, X.; Wang, L.; Zhao, N.; Dunn, D.W.; Yu, X.; Ye, X. How to promote terrestrial herbivores' conservation in areas where small-scale agriculturalists set up fences−An analysis based on evolutionary game theory. *Glob. Ecol. Conserv.* **2023**, *43*, e02457. [CrossRef]
26. Koryagin, M. Urban planning: A game theory application for the travel demand management. *Period. Polytech. Transp. Eng.* **2018**, *46*, 171–178. [CrossRef]
27. Stoilova, S. Application of game theory in planning passenger rail and road transport on parallel routes. Engineering for Rural Development. In Proceedings of the International Scientific Conference (Latvia), Jelgava, Latvia, 20–22 May 2020.
28. Ahmad, F.; Almarri, O.; Shah, Z.; Al-Fagih, L. Game theory applications in traffic management: A review of authority-based travel modelling. *Travel Behav. Soc.* **2023**, *32*, 100585. [CrossRef]
29. Ahmad, F.; Al-Fagih, L. Game Theory Applications in Micro and Macroscopic Simulation in Transportation Network: A Comprehensive Review. *IEEE Access* **2023**, *11*, 93635–93663. [CrossRef]
30. Kotsi, A.; Politis, I.; Mitsakis, E. The Impacts of Centralized Control on Mixed Traffic Network Performance: A Strategic Games Analysis. *Sustainability* **2024**, *16*, 6343. [CrossRef]