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Evolutionary Game Analysis on the Coordinated Application of Incentive and Punitive Policies in Urban Public Transport Development for Small Cities

Abstract. *In China, small cities are currently heavily relying on fiscal incentives to develop urban public transport, leading to unsustainable economic conditions. This paper proposes a coordinated approach combining incentive and punitive policies and constructs a tripartite evolutionary game model involving the government, public transport enterprises, and travellers. By categorising small cities into four scenarios based on fiscal capacity and existing public transport infrastructure, we analyse stakeholders' strategies and the effectiveness of policy combinations. The analysis indicates: (1) both incentives and penalties significantly promote cooperation; (2) in cities with weaker fiscal capacity or poorer transport infrastructure, incentives alone fail to stabilise cooperative behaviour—moderate punitive measures become necessary; (3) particularly for cities with poor transport foundations, introducing moderate punitive measures proves more effective than escalating incentives. These findings offer important implications for policy design, ensuring economically sustainable public transport systems in small cities.*

Keywords: *small cities, urban public transport, incentive policies, punitive policies, evolutionary game, simulation analysis.*

JEL Classification: C70, H20, R40.

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1. Introduction

The public transit priority development strategy has consistently served as a crucial initiative in advancing new-type urbanisation construction in China's small cities. In recent years, governments in small cities have continuously increased fiscal investments to support and subsidise urban public transportation development. (Wang

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et al., 2024; Giagnorio et al., 2024; Hu et al., 2024). However, amid practical constraints such as declining ridership, rising operational costs, and limited subsidies, public transit enterprises have faced worsening financial losses, struggling to sustain normal operations. Since 2023, small cities in Henan, Hunan, Guangdong, and other regions have experienced multiple public transport service suspensions. The economic unsustainability caused by excessive reliance on government incentives has emerged as a critical issue hindering the healthy development of public transportation systems (Rizzi et al., 2025).

Economic sustainability in transportation requires the industry to maintain competitive capabilities, reasonable costs, and financial viability. Examining the underlying causes of economic unsustainability issues: The first is the unsustainability of large-scale subsidies. Small cities in China currently face uneven regional economic development (Sogbe et al., 2025; Yang et al., 2023; Zannat et al., 2024). Some cities struggle with relatively low fiscal revenue levels, shrinking land-based fiscal income, and mounting debt pressures, making it increasingly difficult for local governments to sustain sufficient financial support for public transportation infrastructure and operations. Second, the problem of unprofitability of public transit enterprises caused by declining ridership has not been effectively resolved over time. The transportation characteristics of small cities include short travel distances and low costs, where public transport struggles to compete with private cars and other transportation modes (Rasca et al., 2022). Unlike big cities, most small cities have not implemented restrictions on private vehicle ownership or usage. Consequently, public transit ridership is easily replaced by alternative transport modes, leading to a continuous decline in its modal share. Neither state-owned nor market-oriented public transit enterprises can achieve stable profitability. Under limited subsidy allocations, the system is trapped in a negative cycle: shrinking demand → reduced profitability → service deterioration → further demand decline (Moslem et al., 2023; Suryani et al., 2023).

To address the above issues, researching how to use diverse policy instruments to optimise supply-demand dynamics in the transit system and guide the development of economically sustainable public transportation models for small cities is of significant practical importance. Behaviour can be effectively shaped through positive reinforcement and negative reinforcement, while penalty-derived gains are reinvested into supplement positive incentives, thereby forming a closed-loop regulatory mechanism (Skinner et al., 1966). Considering the practical limitations of small cities, resolving the issues still requires addressing the fundamental imbalance in the supply-demand structure by comprehensively applying incentive and punitive measures, establish a positive feedback loop, and ultimately guide the system toward sustainable development.

Inspired by this, this paper proposes that small cities could consider introducing punitive policies alongside incentive polices to break the negative cycle of economic unsustainability. Based on the requirements for economically sustainable, this paper construct a tripartite evolutionary game model involving the government, public transport enterprises, and travellers, using theoretical analysis and simulation, examine the implementation effects and applicable conditions of incentive and punitive polices, providing theoretical support and practical recommendations for addressing public transit development challenges in various scenarios of small cities.

2. Literature review

In recent years, a growing number of scholars have investigated public transit development in small cities, with research primarily concentrated on fiscal subsidy efficiency and systemic service efficiency.

For the study of fiscal subsidy efficiency, the existing studies mainly focus on maximising subsidy effectiveness through exploration of subsidy implementation methods. Coulombel et al. (2023) found that subsidisation of urban public transportation systems is often motivated by economies of scale and second-best considerations. Börjesson et al. (2019) revealed that larger optimal subsidy amounts prove more effective both as financial support mechanisms and redistributive policy tools in small cities. Ling et al. (2019) presented an incentive subsidy mechanism that is based on the service level of a bus line to overcome the problem of information asymmetry. Asplund et al. (2020) evaluated the welfare effects of optimising bus service fares and frequencies in small cities by modelling street congestion and crowding in public transport vehicles.

For the study of systemic service efficiency, the existing studies has explored planning models such as integrated land development and coordinated urban-rural development from a planning perspective. Nigro et al. (2019) extended the conceptualisation and implementation of integrating land use with public transport planning to small and low-density cities. Verge et al. (2023) analysed the complexities of redevelopment and renewal measures in already urbanised areas.

In summary, regarding the public transport development problem in small cities, the existing studies primarily focus on enhancing government subsidy efficiency, promoting market-oriented reforms, and implementing scientific transportation planning. Solutions predominantly emphasise expanding funding sources and enhancing incentive efficiency. Rarely studies have considered introducing punitive policies, particularly in terms of exploring the coordinated application of incentive and punitive policies in small cities. There remains a significant gap in theoretical research on related topics.

3. Model specification

3.1 Problem Description

The main stakeholders in the public transportation market of small cities include the government, public transport enterprises, and travellers. In this game-theoretic framework, the government aims to maximise social welfare. Public transport enterprises, meanwhile, seek to maximise corporate profits. Travelers, as the end-users of urban transportation, aim to maximise their travel utility. For small cities, achieving economic sustainability necessitates that governments implement fiscal subsidy policies within budgetary constraints. Concurrently, public transport enterprises must satisfy profitability requirements to maintain long-term viability. This paper proposes a policy framework integrating incentives and punitive polices, as shown in Figure 1, as detailed below.

(1) Incentive policies: For enterprises, these policies primarily involve fiscal subsidies and tax incentives to create positive incentives for active operations. For bus travellers, incentive policies mainly consist of fare discounts and green travel rewards for frequent bus passengers.

(2) Punitive policies: For enterprises, these policies primarily involve revoking incentives or imposing fines on enterprises that receive incentive benefits but engage in passive operations. For private car travellers, these policies focus on internalising external costs such as congestion and pollution by implementing parking fees, fuel taxes, and vehicle usage levies on relevant travellers, with revenue allocated to improve public transport systems.

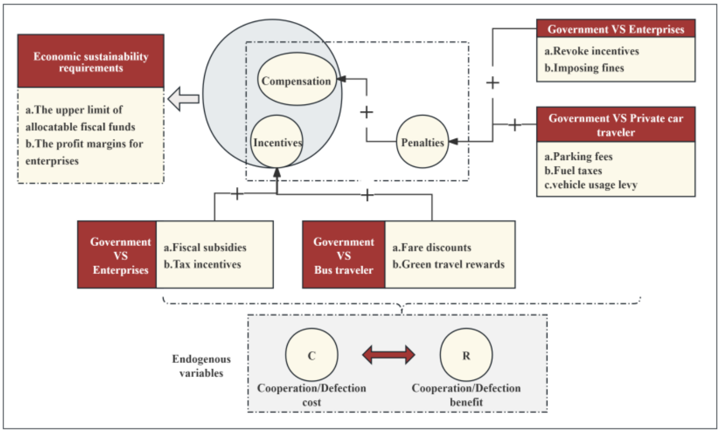


Figure 1. Impacts of Government Policies Under Economic Sustainability Requirements

Source: Authors' own creation.

3.2 Model establishment and symbol description

Evolutionary game theory integrates game-theoretic analysis with dynamic evolutionary processes, requiring neither complete behavioural rationality nor perfect information among participants. In small cities' public transport systems, interactions among governments, enterprises, and travellers occur under conditions of bounded rationality and imperfect information, the following assumptions are made.

Assumption 1. Government is assumed to have two behavioural strategies: active management and passive management. While x represents the probability of active management and (1-x) represents the probability of passive management. Under the active management strategy, the government implements both incentive and punitive policies. Due to prevalent fiscal constraints in these cities, CV_i must remain below the allocable fiscal fund ceiling C_{max}. When travelers choose bus travel, the government will receive additional social benefits recorded as RV_i .RV_i include not only the increase in consumer surplus but also environmental benefits from green travel and other economic benefits, which aligns with the government's practical objectives of actively promoting public transportation development and increasing its mode share. Under the passive management strategy, the market self-regulates through the self-interest motivations of enterprises and travellers, achieving supply-demand equilibrium without governmental intervention.

Assumption 2. Public transport enterprises are assumed to have two behavioural strategies: active operation and passive operation. While y represents the probability of an active operation and (1-y) represents the probability of a passive operation. Under the active operation strategy, the public transport enterprises enhance operational efficiency and service quality, increasing bus travellers' utility but incur relatively higher operational costs. Under the passive operation strategy, enterprises maintain baseline service levels with essential operational costs.

Assumption 3. Travelers are assumed to have two behavioural strategies: taking a bus or taking private car. While z represents the probability of taking bus and (1-z) represents the probability of taking a private car.

Based on the model assumptions, the tripartite game model's payoff matrix is presented in Table 1, and the parameters symbols and descriptions are shown in Table 2.

Table 1. Payoff matrix of evolutionary game model

Strategy Combinations	Benefit for the government	Benefit for the public transport enterprises	Benefit for the travellers
Active management, Active operation, Taking bus	$R_g + RV_1 - CV_1 - C_g$	$PV_1 + \beta CV_1 - CF_1$	$V_1(R_b - P) + \gamma CF_1 +(1-\beta)CV_1$
Active management, Active operation, Taking private Car	$R_g - C_0 - C_g$	$C_0 + T - CF_1$	$R_p - C_p - T$
Active management, Passive operation, Taking bus	$RV_2 - (1-\beta)CV_2 - C_g$	$PV_2 - CF_2 - F$	$V_2(R_b - P) + F +(1-\beta)CV_2$
Active management, Passive operation, Taking private Car	$F + T - C_g$	$-CF_2 - F$	$R_p - C_p - T$
Passive management, Active operation, Taking bus	$R_g + RV_3 - W_g$	$PV_3 - CF_1$	$V_3(R_b - P) + \gamma CF_1$
Passive management, Active operation, Taking private Car	$R_g - W_g$	$-CF_1$	$R_p - C_p$
Passive management, Passive operation, Taking bus	$RV_4 - W_g$	$PV_4 - CF_2$	$V_4(R_b - P)$

Strategy Combinations	Benefit for the government	Benefit for the public transport enterprises	Benefit for the travellers
Passive management, Passive operation, Taking private Car	$-W_g$	$-CF_2$	$R_p - C_p$

Source: Authors' own creation.

Table 2. Parameters symbols and descriptions

Symbols	Descriptions
R_g	The additional social benefits brought by the public transport enterprises' active operations.
V_i	V_1, V_2, V_3, V_4 respectively represent the bus passenger flow volume under different strategic combinations adopted by the government and public transport enterprises.
RV_i	RV_1, RV_2, RV_3, RV_4 respectively represent the additional social benefits brought by the shift of travellers to public transport, related to the bus passenger flow volume under different strategic combinations.
CV_i	CV_1, CV_2 respectively represent the government's cost expenditure for implementing incentives, related to the bus passenger flow volume under different strategic combinations.
C_g	The regulatory costs brought by the active management strategies of government.
C_0	The government's basic subsidy expenditure for actively operating enterprises when travellers choose private car travel.
W_g	The reputation loss caused by the government's passive management.
β	The distribution coefficient of government incentives between public transport enterprises and bus travellers.
R_b	The basic unit travel benefit generated when travellers choose bus travel.
P	The basic unit fare of bus travel, assumed to remain constant within a certain period.
CF_1	The public transport enterprises' cost expenditure when providing bus services under active operation strategies.
CF_2	The public transport enterprises' cost expenditure when providing bus services under passive operation strategies.
T	The relevant fees imposed by the government on private car travellers, including parking fees, fuel taxes, and vehicle usage taxes.
F	The fines levied by the government on passively operating enterprises.
γ	The conversion coefficient of the cost expenditure of public transport enterprises' active operation into the improvement of bus travellers' benefits.
R_p	The basic travel benefit generated when travellers choose private car travel.
C_p	The basic travel cost incurred when travellers choose private car travel.

Source: Authors' own creation.

3.3 The model analyses

(1) Strategy stability analysis of government

For government, the expected benefit of choosing active management is

$$U_{11} = yz(R_g + RV_1 - CV_1 - C_g) + y(1-z)(R_g - C_0 - C_g) + z(1-y)(RV_2 - CV_2 + \beta CV_2 - C_g) + (1-z)(1-y)(F + T - C_g) \tag{1}$$

The expected benefit of choosing passive management is

$$U_{12} = yz(R_g + RV_3 - W_g) + y(1-z)(R_g - W_g) + z(1-y)(RV_4 - W_g) + (1-z)(1-y)(-W_g) \quad (2)$$

Therefore, the expected average benefit of government is

$$\overline{U_1} = xU_{11} + (1-x)U_{12} \quad (3)$$

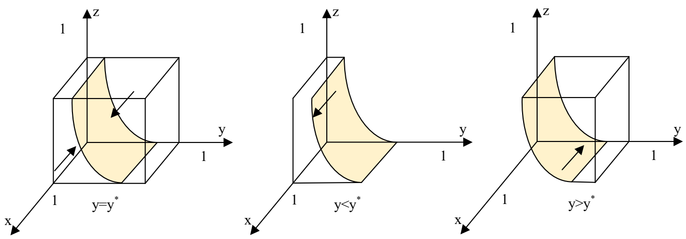
According to the Malthusian equation (Xu et al., 2024), the replicator dynamic equation for government active management is:

$$F(x) = dx/dt = x(U_{11} - \overline{U_1}) = x(1-x)\{[(CV_2 - \beta CV_2 + F + RV_1 - RV_2 - RV_3 + RV_4 + T + C_0 - CV_1)y + \beta CV_2 - CV_2 - F + RV_2 - RV_4 - T]z + (-F - T - C_0)y + F + T - C_g + W_g\} \quad (4)$$

Analyse the stability of the strategy evolution based on the replicator dynamic equation of the strategy adopted by the government. Let

$$y = y^* = -\frac{CV_2\beta z - CV_2 z - Fz + RV_2 z - RV_4 z - Tz - C_g + F + T + W_g}{-CV_2\beta z + C_0 z - CV_1 z + CV_2 z + Fz + RV_1 z - RV_2 z - RV_3 z + RV_4 z + Tz - C_(} \quad (5)$$

When $y = y^*$,we have $F(x) = 0$,all x are in steady state. Evolutionary strategies remain unaffected by the government's strategy selection probabilities. When $y \neq y^*$, let $F(x) = 0$,it can be obtained that $x = 1$ and $x = 0$ are equilibrium points. When $y < y^*$, $dF(x)/dx|_{x=0} > 0$, $dF(x)/dx|_{x=1} < 0$, $x = 1$ is the evolutionary stability point. When $y > y^*$, $dF(x)/dx|_{x=0} < 0$, $dF(x)/dx|_{x=1} > 0$, $x = 0$is the evolutionary stability point. The mathematical conclusions derived above are demonstrated in Figure 2.



(a) (b) (c)

Figure 2. Dynamic replication phase diagram of the decision-making evolution for government

Source: Authors' own creation.

(2) Strategy stability analysis of public transport enterprise

Similarly, the replicator dynamic equation for public transport enterprises active operation is:

$$F(y) = dy/dt = y(U_{21} - \overline{U_2}) = y(1 - y)\{[(PV_1 - PV_2 - PV_3 + PV_4 + \beta CV_1 - T - C_0)z + F + T + C_0]x + P(V_3 - V_4)z - CF_1 + CF_2\} \quad (6)$$

Analyse the stability of strategy evolution based on the replicator dynamic equation for the strategies adopted by public transport enterprises. Let

$$x = x^* = \frac{P(V_4 - V_3)z + CF_1 - CF_2}{(PV_1 - PV_2 - PV_3 + PV_4 + \beta CV_1 - T - C_0)z + F + T + C_0} \quad (7)$$

When $x = x^*$,we have $F(y) = 0$,all y are in steady state. When $x \neq x^*$, let $F(y) = 0$,it can be obtained that $y = 1$and $y = 0$ are equilibrium points. When $x < x^*$, $dF(y)/dy|_{y=0} < 0$, $dF(y)/dy|_{y=1} > 0$, $y = 0$is the evolutionary stability point. When $x > x^*$, $dF(y)/dy|_{y=0} > 0$, $dF(y)/dy|_{y=1} < 0$, $y = 1$ is the evolutionary stability point. The mathematical conclusions derived above are demonstrated in Figure 3.

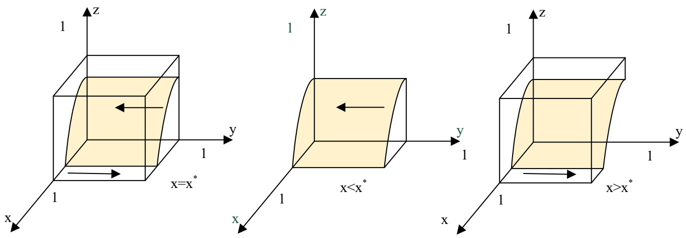


Figure 3. Dynamic replication phase diagram of the decision-making evolution for public transport enterprises
Source: Authors' own creation.

(3) Strategy stability analysis of travellers

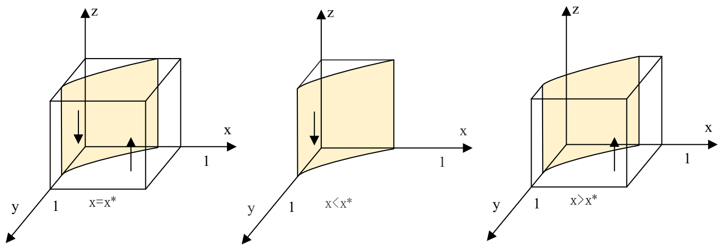
Similarly, the replicator dynamic equation for travellers taking bus is:

$$F(z) = dz/dt = z(U_{31} - \overline{U_3}) = z(1 - z)\{[(V_1 - V_2 - V_3 + V_4)(R_b - P)y + (\beta - 1)(CV_2 - CV_1)y - Fy + (V_2 - V_4)(R_b - P) + (1 - \beta)CV_2 + F + T]x + [(R_b - P)(V_3 - V_4) + \gamma CF_1]y + V_4(R_b - P) - R_p + C_p\} \quad (8)$$

Analyse the stability of the strategy evolution based on the replicator dynamic equation of the strategy adopted by the travellers. Let

$$x = x^* = -\frac{[(R_b - P)(V_3 - V_4) + \gamma CF_1]y + V_4(R_b - P) - R_p +}{[(V_1 - V_2 - V_3 + V_4)(R_b - P)y + (\beta - 1)(CV_2 - CV_1)y - Fy + (V_2 - V_4)(R_b} \quad (9)$$

When $x = x^*$,we have $F(z) = 0$,all z are in steady state. When $x \neq x^*$, let $F(z) = 0$,it can be obtained that $z = 1$and $z = 0$ are equilibrium points. When $x < x^*$, $dF(z)/dz|_{z=0} < 0$, $dF(y)/dy|_{y=1} > 0$, $z = 0$is the evolutionary stability point. When $x > x^*$, $dF(z)/dz|_{z=0} > 0$, $dF(y)/dy|_{y=1} < 0$, $z = 1$ is the evolutionary stability point. The mathematical conclusions derived above are demonstrated in Figure 4.



(a) (b) (c)

Figure 4. Dynamic replication phase diagram of the decision-making evolution for travellers

Source: Authors' own creation.

4. Equilibrium and stability analysis

First, construct the Jacobian matrix:

$$J = \begin{bmatrix} \frac{\partial F(x)}{dx} & \frac{\partial F(x)}{dy} & \frac{\partial F(x)}{dz} \\ \frac{\partial F(y)}{dx} & \frac{\partial F(y)}{dy} & \frac{\partial F(y)}{dz} \\ \frac{\partial F(z)}{dx} & \frac{\partial F(z)}{dy} & \frac{\partial F(z)}{dz} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \tag{10}$$

Through calculation, we obtain:

$$a_{11} = (1-2x)\{[(CV_2 - \beta CV_2 + F + RV_1 - RV_2 - RV_3 + RV_4 + T + C_0 - CV_1)y + \beta CV_2 - CV_2 - F + RV_2 - RV_4 - T]z + (-F - T - C_0)y + F + T - C_g + W_g\} \tag{11}$$

$$a_{22} = (1-2y)\{[(PV_1 - PV_2 - PV_3 + PV_4 + \beta CV_1 - T - C_0)z + F + T + C_0]x + P(V_3 - V_4)z - CF_1 + CF_2\} \tag{12}$$

$$a_{33} = (1-2z)\{[(V_1 - V_2 - V_3 + V_4)(R_b - P)y + (\beta - 1)(CV_2 - CV_1)y - Fy + (V_2 - V_4)(R_b - P) + (1-\beta)CV_2 + F + T]x + [(R_b - P)(V_3 - V_4) + \gamma CF_1]y + V_4(R_b - P) - R_p + C_p\} \tag{13}$$

Stability is determined by eigenvalues (Friedman et al., 1991; Cao et al., 2023). The stability analysis of the above eight evolutionary equilibrium points is shown in Table 3.

Table 3. Stability analysis of equilibria based on Jacobian matrix

Equilibrium point	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3	Stability
$E_1(0,0,0)$	$-C_g + F + T + W_g$	$-CF_1 + CF_2$	$C_p - PV_4 + R_bV_4 - R_p$	Unstable
$E_2(1,0,0)$	$C_g - F - T - W_g$	$C_0 - CF_1 + CF_2 + F + T$	$-CV_2\beta + CV_2 + C_p + F - PV_2 + R_bV_2 - R_p + T$	Unstable
$E_3(0,1,0)$	$-C_0 - C_g + W_g$	$CF_1 - CF_2$	$CF_1\gamma + C_p - PV_3 + R_bV_3 - R_p$	Unstable
$E_4(0,0,1)$	$CV_2\beta - CV_2 - C_g + RV_2 - RV_4 + W_g$	$-CF_1 + CF_2 + PV_3 - PV_4$	$-- C_p + PV_4 - R_bV_4 + R_p$	Unstable
$E_5(1,1,0)$	$C_0 + C_g - W_g$	$-C_0 + CF_1 - CF_2 - F - T$	$CF_1\gamma - CV_1\beta + CV_1 + C_p - PV_1 + R_bV_1 - R_p + T$	ESS with conditions
$E_6(1,0,1)$	$-CV_2\beta + CV_2 + C_g - RV_2 + RV_4 - W_g$	$-CF_1 + CF_2 + CV_1\beta + F + PV_1 - PV_2$	$CV_2\beta - CV_2 - C_p - F + PV_2 - R_bV_2 + R_p - T$	ESS with conditions
$E_7(0,1,1)$	$-CV_1 - C_g + RV_1 - RV_3 + W_g$	$CF_1 - CF_2 - PV_3 + PV_4$	$- CF_1\gamma - C_p + PV_3 - R_bV_3 + R_p$	ESS with conditions
$E_8(1,1,1)$	$CV_1 + C_g - RV_1 + RV_3 - W_g$	$CF_1 - CF_2 - CV_1\beta - F - PV_1 + PV_2$	$-CF_1\gamma + CV_1\beta - CV_1 - C_p + PV_1 - R_bV_1 + R_p - T$	ESS with conditions

Source: Authors' own creation.

Considering the practical realities, $CF_1 > CF_2$. When the government adopts passive management and public transport enterprises implement passive operations, bus travel travel utility is lower than that of private cars, i.e.$V_4(R_b - P) < R_p - C_p$. The reputational losses incurred by small city government's passive management outweigh the regulatory costs of active management, i.e.$W_g > C_g$.Based on the above analysis, $E_1(0,0,0)$, $E_3(0,1,0)$, $E_4(0,0,1)$ exhibit partially positive eigenvalues, rendering these equilibrium points unstable. The payoff function of the public transport enterprises corresponding to $E_2(1,0,0)$ fails to satisfy the profitability constraint, and therefore, it is also an unstable point. The remaining five equilibrium points $E_2(1,0,0)$, $E_5(1,1,0)$, $E_6(1,0,1)$, $E_7(0,1,1)$, $E_8(1,1,1)$ may potentially evolve into system-stable points.

5. Simulation analysis

To intuitively visualise the evolutionary stabilisation process under various development scenarios in small cities, MATLAB software is utilised to simulate the equilibrium strategies of all stakeholders (Wang et al., 2023; Hu et al., 2024; Xu et al., 2024; Acko et al., 2024).

5.1 Simulation Analysis of evolutionary equilibrium paths for (0,1,1) and (1,1,1)

Numerical simulation analyses are conducted for the stable points (0, 1, 1) and (1, 1, 1). With an initial parameter assignment of $\mathbf{R_g}$=15, $\mathbf{V_1}$=15, $\mathbf{V_2}$=12, $\mathbf{V_3}$=9, $\mathbf{V_4}$=6, $\mathbf{RV_1}$=50, $\mathbf{RV_2}$=45, $\mathbf{RV_3}$=40, $\mathbf{RV_4}$=35, $\mathbf{CV_1}$=20, $\mathbf{CV_2}$=16, $\mathbf{C_0}$=8, $\mathbf{C_g}$=10, $\mathbf{W_g}$=15, $\boldsymbol{\beta}$=0.5, $\mathbf{R_b}$=5, $\mathbf{P}$=2, $\mathbf{CF_1}$=12, $\mathbf{CF_2}$=8, $\mathbf{T}$=10, $\mathbf{F}$=3, $\boldsymbol{\gamma}$=0.5, $\mathbf{R_p}$=50, $\mathbf{C_p}$=20, the evolutionary outcomes are simulated in Fig.5. When adjusting the values of variables influencing government decisions (while holding other parameters constant) to $\mathbf{RV_2}$=40, $\mathbf{RV_3}$=30, $\mathbf{RV_4}$=20, $\mathbf{W_g}$=20, the evolutionary outcomes are simulated in Fig.6. It shows that when the sum of incentive costs and regulatory costs becomes smaller than the sum of reputational losses and the reduction in social benefits caused by passive management-induced ridership declines. This indicates a strategic shift in government behavior from passive management to active management. The comparative analysis of Figure 5 and Figure 6 reveals a significant acceleration in the convergence speed of enterprises and travelers toward cooperation. The simulations demonstrate that active government management substantially enhances urban transit service levels and rationalise travel mode structures.

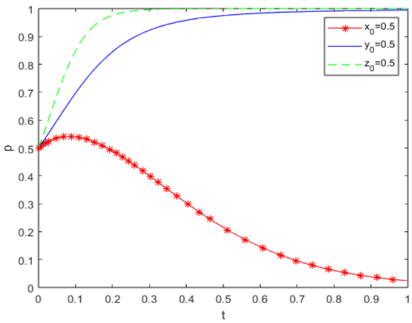


Figure 5. Schematic diagram of evolutionary outcomes for (0,1,1)

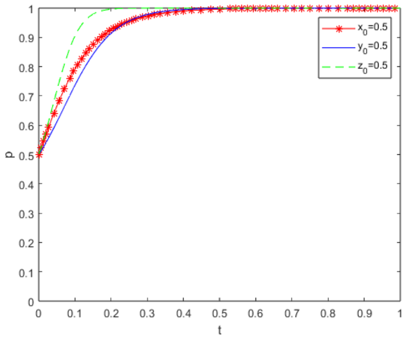


Figure 6. Schematic diagram of evolutionary outcomes for (1,1,1)

Source: Authors' own creation.

5.2 Comparative simulation analysis under four development scenarios

China has many small cities with wide geographic distribution, exhibiting significant disparities in fiscal capacity and urban built environments. These differences create distinct foundational scenarios for public transportation development. This paper categorises public transportation development scenarios in small cities into four quadrants based on fiscal capacity (stronger/weaker) and public transportation development foundations (better/poorer). The fiscal capacity of small city government affects the ceiling of allocable fiscal funds C_{max}, thereby influencing CV_i. The public transportation development foundation is reflected in the differential between the base travel utilities of bus travel and private car travel (i.e.the difference between $V_i(R_b - P)$ and $R_p - C_p$). In small cities with stronger public transportation foundations, improved infrastructure and service levels provide bus transport with competitive advantages over private car travel. Simulation analyses of system evolution under different scenarios are as follows.

(1) **Scenario 1:** Small cities with stronger fiscal capacity and better public transportation development foundations.

Let R_g=15, V_1=15, V_2=12, V_3=9, V_4=6, RV_1=50, RV_2=40, RV_3=30, RV_4=20, C_0=8, C_g=10,W_g=20,β=0.5,R_b=5,P=2,CF_1=21,CF_2=10,γ=0.5,R_p=60,C_p=20. Under scenario 1, the parameters for incentive policies, CV_1 and CV_2, are assigned two sets of values (20, 16) and (25, 20), corresponding to low-intensity and high-intensity incentive policies respectively. The punitive policies parameters T and F are set to 5 and 4, reflecting moderate penalties. Initial probabilities for cooperative strategies among the government, public transport enterprises, and travelers are defined as (x, y, z) = (0.5, 0.5, 0.5). Based on these parameterisations, simulations are conducted under four conditions: (1) no incentive or punitive policies, (2) low-intensity incentive policies only, (3) high-intensity incentive policies only, and (4) low-intensity incentive policies combined with moderate punitive policies. The simulation results are shown in Figure 7.

From Figure 7, we observe that without governmental active management, y and z gradually decline to 0, stabilising the evolutionary game at (1, 0, 0) by t = 1.8. In this scenario, enterprises face net losses due to the absence of subsidies and fare revenue, rendering sustainable operations unviable. However, with low-intensity incentive policies alone, y and z gradually increase to 1, stabilising the system at (1, 1, 1) by t=1.6. When high-intensity incentives are implemented, y and z rise more rapidly to 1, achieving stability at (1, 1, 1) by t = 1.1. Combining low-intensity incentive policies with moderate punitive policies further accelerates this trend, stabilising y and z at (1, 1, 1) by t = 0.8. These simulations demonstrate that in small cities with stronger fiscal capacity and better public transportation foundations, the government can enhance cooperative probabilities by strategically increasing incentive subsidies for enterprises and travellers within fiscal fund ceilings. When introducing moderate punitive policies, the cooperative probability of evolutionary game participants will reach (1,1,1); more rapidly, this indicates that punitive policies have a positive effect as well.

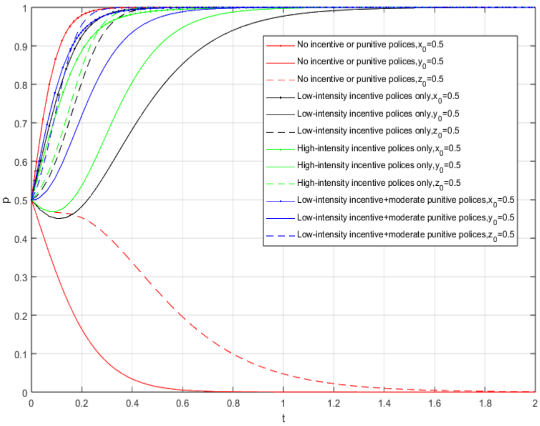


Figure 7. Schematic diagram of evolutionary outcomes for scenario 1

Source: Authors' own creation.

(2) **Scenario 2:** Small cities with stronger fiscal capacity and poorer public transportation development foundations.

Let R_g=15, V_1=12, V_2=9, V_3=6, V_4=3, RV_1=50, RV_2=40, RV_3=30, RV_4=20, C_0=8, C_g=10, W_g=20, β=0.5, R_b=5, P=2, CF_1=21, CF_2=10, γ=0.5, R_p=75, C_p=20. Under scenario 2, the parameters for incentive policies, CV_1 and CV_2, are assigned two sets of values (20, 16) and (25, 20), corresponding to low-intensity and high-intensity incentive policies respectively. The punitive policy parameters T and F are set to 5 and 4, reflecting moderate penalties. Similarly, let (x, y, z) = (0.5, 0.5, 0.5). Based on these parameterisations, simulations are conducted under four conditions, same as scenario 1. The simulation results are shown in Figure 8.

From Figure 8, we observe that without governmental active management, y and z gradually decrease to 0, stabilising the evolutionary game at (1, 0, 0) by t=0.6. Similarly, under low-intensity incentive policies alone, y and z decline to 0, stabilising at (1, 0, 0) by t=1.6. Even with high-intensity incentives, y and z continue to diminish to 0, converging to (1, 0, 0) by t = 2.0. However, combining low-intensity incentives with moderate punitive policies results in y gradually rising to 1 and z first decreasing then rebounding to 1, stabilising the system at (1, 1, 1) by t = 1.8. These simulations demonstrate that for small cities with stronger fiscal capacity but poorer public transportation foundations, punitive policies are more directly effective than escalating incentives in enhancing cooperative probabilities among enterprises and travellers.

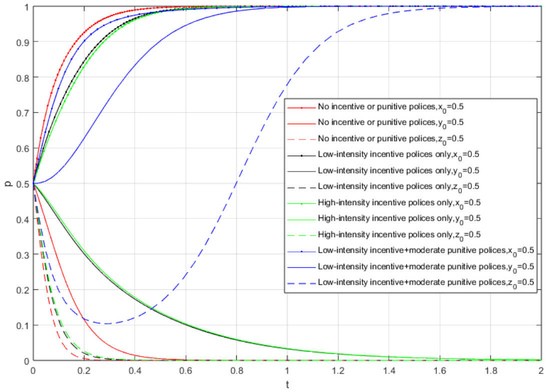


Figure 8. Schematic diagram of evolutionary outcomes for scenario 2
Source: Authors' own creation.

(3) **Scenario 3:** Small cities with weaker fiscal capacity and better public transportation development foundations.

Let R_g=15, V_1=15, V_2=12, V_3=9, V_4=6, RV_1=50, RV_2=40, RV_3=30, RV_4=20, CV_1=8, CV_2=4, C_0=4, C_g=10, W_g=20, β=0.5, R_b=5, P=2, CF_1=21, CF_2=10, γ=0.5,R_p=60,C_p=20. Under scenario 3, The parameters for punitive policies, T and F, are assigned two sets of values (5, 4) and (12, 6), corresponding to low-intensity and high-intensity punitive policies respectively. Similarly, let (x, y, z) = (0.5, 0.5, 0.5). Based on these parameterisations, simulations are conducted under four conditions: (1) no incentive or punitive policies, (2) low-intensity incentive policies only, (3) low-intensity incentive policies combined with moderate punitive policies, and (4) low-intensity incentive policies combined with stringent punitive policies. The simulation results are shown in Figure 9.

From Figure 9, we observe that without governmental active management, y and z gradually decline to 0, stabilising the evolutionary game at (1, 0, 0) by t = 1.8. When only incentive policies are implemented, y similarly decreases to 0, while z initially rises before declining to 0, stabilising the system at (1, 0, 0) by t=4.5. However, combining incentives with moderate penalties results in y and z gradually increasing to 1, stabilising at (1, 1, 1) by t = 2.1. When incentives are paired with stringent penalties, y and z rise rapidly to 1, converging to (1, 1, 1) by t =1.2. These simulations demonstrate that for small cities with weaker fiscal capacity but better public transportation foundations, governments constrained by fiscal fund ceilings can enhance cooperative probabilities by introducing punitive policies when further increasing incentives is infeasible. Escalating the severity of punitive policies exerts a significant positive effect. As the intensity of punitive policies increases, the cooperative probabilities of evolutionary game participants converge to (1, 1, 1) at a faster rate.

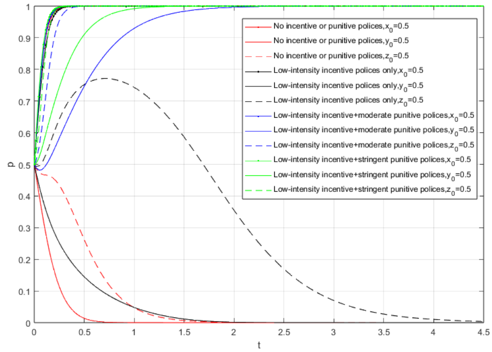


Figure 9. Schematic diagram of evolutionary outcomes for scenario 3
Source: Authors' own creation.

(4) **Scenario 4**: Small cities with weaker fiscal capacity and poorer public transportation development foundations.

Let R_g=15, V_1=12, V_2=9, V_3=6, V_4=3, RV_1=50, RV_2=40, RV_3=30, RV_4=20, CV_1=8, CV_2=4, C_0=4, C_g=10, W_g=20, β=0.5, R_b=5, P=2, CF_1=21, CF_2=10, γ=0.5, R_p=75,C_p=20. Under scenario 4, the parameters for punitive policies, T and F, are assigned two sets of values (5, 4) and (12, 6), corresponding to low-intensity and high-intensity punitive policies, respectively. Similarly, let (x, y, z) = (0.5, 0.5, 0.5). Based on these parameterisations, simulations are conducted under four conditions, same as scenario 4. The simulation results are shown in Figure 10.

From Figure 10, we observe that without governmental active management, y and z gradually decline to 0, stabilising the evolutionary game at (1, 0, 0) by t = 0.6. Similarly, under incentive policies alone, y and z decrease to 0, stabilising at (1, 0, 0) by t = 0.9. When combining incentives with moderate punitive policies, y initially decreases slightly before rising to 1, while z declines to 0, stabilising the system at (1, 1, 0) by t = 3. In contrast, combining incentives with stringent punitive policies results in y gradually rising to 1 and z first decreasing then rebounding to 1, converging to (1, 1, 1) by t = 1.2.

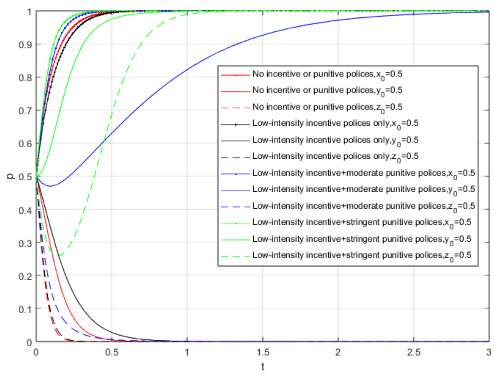


Figure 10. Schematic diagram of evolutionary outcomes for scenario 4
Source: Authors' own creation.

Simulation results indicate that for small cities with weaker fiscal capacity and poorer public transportation foundations, economic sustainability requirements impose more direct limitations. It is necessary to introduce and escalate punitive policies to further enhance cooperative probabilities between public transport enterprises and travellers, ensuring the system meets economic sustainability requirement and resolves developmental bottlenecks.

6. Conclusions

Based on the analysis of public transport development challenges in small cities, this paper establishes a tripartite evolutionary game model involving the government, public transport enterprises, and travellers. By categorising cities into four quadrants based on fiscal capacity and public transportation development foundations, we systematically investigate how incentive and punitive policies influence public transportation development across different scenarios.

Key conclusions are as follows:

1. Active government management significantly enhance cooperative probabilities among enterprises and travellers, accelerating service improvements and rationalising travel mode structures. When the sum of incentive policy costs and regulatory expenditures is smaller than the reputational losses and the social benefit reductions caused by passive management, government stabilise at active management strategies. Policy expectations and implementation costs are key determinants, with fiscal fund ceilings acting as critical constraints.

2. Strengthening incentive policies has a pronounced positive effect on accelerating cooperation. For small cities with stronger fiscal capacity and better public transportation foundations, government can strategically increase incentives within fiscal limits to boost cooperative probabilities and expedite system development.

3. Both incentive and punitive policies enhance cooperation, but incentives alone may fail to stabilise cooperative strategies in some scenarios, explaining the unsatisfactory outcomes of subsidy policies in certain cities. For small cities with stronger fiscal capacity and poorer public transportation foundations, moderate punitive policies are more effective than further escalating incentives.

4. Incentive policy intensity is heavily constrained by local fiscal capacity. For small cities with weaker fiscal capacity and better public transportation foundations, introducing moderate punitive policies can compensate for limited incentives, accelerating convergence to (1, 1, 1) as punitive policies severity increases.

5. For small cities with weaker fiscal capacity and poorer public transportation foundations – constrained by ceilings on allocable fiscal funds and low fare revenue bases – economic sustainability requirements impose more direct limitations. It is necessary to introduce and escalate punitive policies to further enhance cooperative probabilities between public transport enterprises and travellers, ensuring the system meets economic sustainability requirement and resolves developmental bottlenecks.

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