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Behavior choice mechanisms and tax incentive mechanisms in the game of construction safety

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Abstract: Improving the construction safety level requires the joint efforts of local governments, construction enterprises, and construction workers. To promote them to make efforts in construction safety, the paper first constructs an evolutionary game model composed of a local government, a construction enterprise, and a construction worker. Then the behavior choice mechanism of each player is analyzed. Finally, an incentive effect analysis method of incentive mechanism is put forward, and the incentive effects of different tax incentive mechanisms are analyzed. The research finds that the higher the tax rate, the more likely the construction enterprise chooses to make efforts. When the tax rate is small, the higher the tax rate, the more likely the local government chooses to make efforts. When the safety punishment imposed on the construction worker is large enough, the effort behavior of the local government and the construction enterprise can promote the construction worker to choose to make efforts. Reducing the proportion of tax allocated to the local government in case of accidents can promote the local government to choose to make efforts. Increasing the tax rate of the construction enterprise in case of accidents can promote the construction enterprise to choose to make efforts. Under certain conditions, these tax incentive mechanisms can promote the construction worker to choose to make efforts through the behavior interaction between the game players.

Keywords: Construction safety; Evolutionary game; Behavior choice; Tax incentive mechanism

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1. Introduction

Construction safety is an issue of great concern [1-10]. Improving the construction safety level requires the joint efforts of local governments, construction enterprises, and construction workers. Local governments' efforts in safety supervision will affect construction enterprises' efforts in safety investment and safety management. Construction enterprises' efforts will affect construction workers' efforts in construction safety. There is a behavior interaction between them. The behavior interaction process is also a behavior game process. Mastering the behavior choice mechanism of game players and designing the incentive mechanism according to players' behavior choice mechanism are conducive to the improvement of the construction safety level.

To analyze the safety efforts of the government and enterprises, Hausken constructed a game model and found that if the government can reduce the safety costs of enterprises in some way, or increase the negative impact of disasters on the company, the safety efforts of enterprises will be higher [11, 12]. Yang uses Stackelberg game model to analyze the safety level decision of enterprises in the supply chain and finds that revenue-sharing contracts and cost-sharing contracts can improve the work safety level [13].

The above researches assume that the game players are rational, but in practice, the game players are not completely rational. It is necessary to study the behavior of players under the condition of incomplete rationality. Since evolutionary game theory does not require the players to be completely rational, it has been widely used in coal mine safety research [14-16], food safety research [17-19], and other fields.

In the field of construction safety, Gong constructed an evolutionary game model between the government and two construction enterprises and found that the dynamic supervision mechanism can improve the safety supervision efficiency [20]. Pi constructed an evolutionary game model between the government and construction contractors and found that the safety information system helps to reduce the safety supervision cost of the government and the safety cost of the contractor [21]. Guo analyzed the game behavior among the government, construction enterprises, and construction workers by establishing an evolutionary game model [22].

The above researches based on evolutionary game theory mainly analyzed the stability of evolutionary game system and putted forward the reward and punishment mechanisms according to the influence of model parameters on the evolution process. However, under what condition will the player choose one behavior and under what condition will the player choose the other behavior? How to design the incentive mechanisms according to the behavior choice mechanism of players? These questions remain to be answered. To master the behavior choice mechanism of game players and design the incentive mechanism according to the behavior choice mechanism of game players, this paper has done the following work.

(1) An evolutionary game model consisting of a local government, a construction enterprise, and a construction worker is constructed.

(2) The behavior choice mechanisms of the local government, the construction enterprise, and the construction worker are analyzed.

(3) An incentive effect analysis method of incentive mechanism is designed, and different tax incentive mechanisms' incentive effect is analyzed.

The remainder of the research is structured as follows. The second section establishes the evolutionary game model. The third section analyses the behavior choice mechanisms of the local government, the construction enterprise, and the construction worker. The fourth section designs the incentive effect analysis method of incentive mechanisms and analyses the incentive effect of different tax incentive mechanisms. The fourth section is the conclusion.

2. Evolutionary Game Model

2.1. Model Symbols

The model symbols are as follows.

Table 1. Model symbols.

Model symbols	Mean
x	Probability of the local government choosing to make efforts.
y	Probability of the construction enterprise choosing to make efforts.
z	Probability of the construction worker choosing to make efforts.
C_G	Effort cost of the local government.
C_E	Effort cost of the construction enterprise.
C_W	Effort cost of the construction worker.
I	Income of the construction enterprise excluding the effort cost and the salary of the construction worker.
W	Salary of the construction worker.
r	Tax rate.
d	Proportion of tax allocated to the local government.
P_{GE}	Punishment imposed by the local government on the construction enterprise.
P_{EW}	Punishment imposed by the construction enterprise on the construction worker.

L_G	Accident loss expectation of the local government.
L_E	Accident loss expectation of the construction enterprise.
L_W	Accident loss expectation of the construction worker.

2.2. Model assumes

Assume 1: The game players are a local government, a construction enterprise, and a construction worker. The game players are all limited rationality. The local government can choose to make efforts or make no effort in the construction safety supervision. The probability of the local government choosing to make efforts is x, and the probability of choosing to make no effort is $1-x$. The construction enterprise can choose to make efforts or make no effort in the safety management. The probability of the construction enterprise choosing to make efforts is y, and the probability of choosing to make no effort is $1-y$. The construction worker can choose to make efforts or make no effort in the construction safety. The probability of the construction worker choosing to make efforts is z, and the probability of choosing to make no effort is $1-z$.

Assume 2: When the local government chooses to make efforts, the effort cost of the government is C_G, and the local government knows the behavioral choice of the construction enterprise and the construction worker. When the local government chooses to make no effort, the effort cost of the government is 0, and the local government don't know the behavioral choice of the construction enterprise and the construction worker. When the construction enterprise chooses to make efforts, the effort cost of the construction enterprise is C_E, and the construction enterprise knows the behavioral choice of the construction worker earlier than the government. When the construction enterprise chooses to make no effort, the effort cost of the construction enterprise is 0, and the construction enterprise don't know the behavioral choice of the construction worker. When the construction worker chooses to make efforts, the effort cost of the construction worker is C_W. When the construction worker chooses to make no effort, the effort cost is 0.

Assume 3: When the local government, the construction enterprise, and the construction worker all choose to make efforts, the income of the construction worker is $W-C_W$, the income of the construction enterprise is $(1-r)(I-W-C_E)$, and the income of the local government is $dr(I-W-C_E)-C_G$. Where W is the salary of the construction worker, r is the tax rate, I is the income of the construction enterprise excluding the effort cost and the salary of the construction worker, d is the proportion of tax allocated to the local government, and $I-W-C_E$ is the taxable income of the construction enterprise. Taxable income is the portion of an enterprise's gross income used to calculate how much tax enterprises owe in a given tax year. It can be described broadly as adjusted gross income (AGI) minus allowable itemized or standard deductions. The items allowed to be deducted from the income refer to the costs, expenses, and losses related to the taxpayer's income.

Assume 4: When the construction worker chooses to make no effort and his behavior is found by the construction enterprise, the construction enterprise will urge the construction worker to change their behavior in time through punishment. At this time, the income of the construction workers is $W-P_{EW}-C_W$. Where, P_{EW} refers to the punishment imposed by the construction enterprise on the construction worker. If the construction worker's behavior is not found by the construction enterprise, but by the local government, the construction enterprise will be punished by the local government. At this time, the construction enterprises will urge the construction worker to change his behavior in time through punishment. And the income of the construction enterprise is $(1-r)(I-W+P_{EW}-C_E)-P_{GE}$. Where, P_{GE} refers to the punishment imposed by the local government on the construction enterprise. When the construction enterprise chooses to make no effort and his behavior is found by the local government, the construction enterprise will be punished by the local government.

Assume 5: No accidents will happen when the construction worker chooses to make efforts. If the construction worker chooses to make no effort and the behavior is not found by the construction enterprise and the local government, accidents may occur. At this time, the loss expectation of the construction worker is L_W, the loss expectation of the construction enterprise is L_E, and the loss expectation of the local government is L_G。

According to the model assumptions, the income of the local government, the construction enterprise, and the construction worker under different game strategies are shown in Table 2.

Table 2. Income of the local government, the construction enterprise, and the construction worker under different game strategies.

{local government's strategy, construction enterprise's strategy, construction worker's strategy}	{local government's income, construction enterprise's income, construction worker's income}
{make efforts, make efforts, make efforts}	$\{dr(I-W-C_E)-C_G,\ (1-r)(I-W-C_E),\ W-C_W\}$
{make efforts, make efforts, make no effort}	$\{dr(I-W+P_{EW}-C_E)-C_G,\ (1-r)(I-W+P_{EW}-C_E),\ W-P_{EW}-C_W\}$
{make efforts, make no effort, make efforts}	$\{dr(I-W-C_E)+P_{GE}-C_G,\ (1-r)(I-W-C_E)-P_{GE},\ W-C_W\}$
{make efforts, make no effort, make no effort}	$\{dr(I-W+P_{EW}-C_E)+P_{GE}-C_G,\ (1-r)(I-W+P_{EW}-C_E)-P_{GE},\ W-P_{EW}-C_W\}$
{make no effort, make efforts, make efforts}	$\{dr(I-W-C_E),\ (1-r)(I-W-C_E),\ W-C_W\}$
{make no effort, make efforts, make no effort}	$\{dr(I-W+P_{EW}-C_E),\ (1-r)(I-W+P_{EW}-C_E),\ W-P_{EW}-C_W\}$
{make no effort, make no effort, make efforts}	$\{dr(I-W),\ (1-r)(I-W),\ W-C_W\}$
{make no effort, make no effort, make no effort}	$\{dr(I-W-L_E)-L_G,\ (1-r)(I-W-L_E),\ W-L_W\}$

2.3. Model construction

According to the replication dynamic equation in the evolutionary game theory [23-29], we can construct a tripartite evolutionary game model composed of the local government, the construction enterprise, and the construction worker. The model construction process is as follows.

When the local government chooses to make efforts, the income expectation of the local government is $u_1=[dr(I-W-C_E)-C_G]yz+[dr(I-W+P_{EW}-C_E)-C_G]y(1-z)+[dr(I-W-C_E)+P_{GE}-C_G](1-y)z+[dr(I-W+P_{EW}-C_E)+P_{GE}-C_G](1-y)(1-z)=dr(I-W-C_E)-C_G+drP_{EW}(1-z)+P_{GE}(1-y)$. Similarly, when the local government chooses to make no effort, the income expectation of the local government is $u_2=dr(I-W)-drC_Ey+drP_{EW}y(1-z)-drL_E(1-y)(1-z)-L_G(1-y)(1-z)$. The average income is $\bar{u}=xu_1+(1-x)u_2$.

When the construction enterprise chooses to make efforts, the income expectation of the construction enterprise is $v_1=(1-r)(I-W-C_E)+(1-r)P_{EW}(1-z)$. When the construction enterprise chooses to make no effort, the income expectation of the construction enterprise is $v_2=-(1-r)C_Ex+(1-r)(I-W)-P_{GE}x+(1-r)P_{EW}x(1-z)-(1-r)L_E(1-x)(1-z)$. The average income is $\bar{v}=yv_1+(1-y)v_2$.

When the construction worker chooses to make efforts, the income expectation of the construction worker is $w_1=W-C_W$. When the construction worker chooses to make no effort, the income expectation of the construction worker is $w_2=W-P_{EW}x-P_{EW}(1-x)y-C_Wx-C_W(1-x)y-L_W(1-x)(1-y)$. The average income is $\bar{w}=zw_1+(1-z)w_2$.

According to the income of the local government, the construction enterprise, and the construction worker, the following evolutionary game model can be obtained.

$$\begin{cases} \frac{dx}{dt} = x(u_1 - \bar{u}) = x(1-x)(u_1 - u_2) \\ \frac{dy}{dt} = y(v_1 - \bar{v}) = y(1-y)(v_1 - v_2) \\ \frac{dz}{dt} = z(w_1 - \bar{w}) = z(1-z)(w_1 - w_2) \end{cases} \tag{1}$$

where $u_1 - u_2 = G_1(y,z) = -C_G + (P_{GE} - drC_E)(1-y) + (drP_{EW} + drL_E + L_G)(1-y)(1-z)$, $v_1 - v_2 = E_1(x,z) = -(1-r)C_E(1-x) + P_{GE}x + (1-r)(P_{EW} + L_E)(1-x)(1-z)$, and $w_1 - w_2 = W_1(x,y) = (L_W - C_W)(1-x)(1-y) + [x + (1-x)y]P_{EW}$.

According to $\frac{dx}{dt} = 0$, $\frac{dy}{dt} = 0$, and $\frac{dz}{dt} = 0$, the equilibrium point of the evolutionary game model can be obtained as follows: (1,1,1), (1,1,0), (1,0,1), (1,0,0), (0,1,1), (0,1,0), (0,0,1), (0,0,0). The stability of the equilibrium point can be analysed by Jacobi matrix [23-29]. Through analysis, it is found that when $C_W < L_W$ and $C_G + drC_E > P_{GE}$, (0,0,1) is an evolutionary stability strategy. When $C_G + dr(C_E - P_{EW} - L_E) > P_{GE} + L_G$, $C_E > P_{EW} + L_E$, and $C_W > L_W$, (0,0,0) is an evolutionary stability strategy. Other equilibrium points are unstable.

The stability analysis of the equilibrium point makes us have an overall understanding of the evolutionary game system. However, the stability analysis cannot answer the behavior choice mechanism of each player. It is also inconvenient to analyse the incentive effect of the incentive mechanism on the players. To solve these problems, the following sections first analyse the behavior choice mechanism of each player, then design a method to analyse the incentive effect of incentive mechanisms.

3. Behavior Choice Mechanism of Players

3.1. Behavior choice mechanism of the local government

Let $F_1(x) = \frac{dx}{dt} = x(1-x)G_1(y,z)$. $F_1(x)$ is a first-order differential equation. $F_1{}'(x) = \frac{dF_1(x)}{dx} = (1-2x)G_1(y,z)$. According to the stability of first-order differential equations, the following proposition can be obtained.

Proposition 1. *When* $F_1(x_0) = 0$ *and* $F_1{}'(x_0) < 0$, x_0 *is the stable point of* $F_1(x)$.

Proof of Proposition 1. When x_0 satisfies $F_1(x_0) = 0$, x_0 is the equilibrium point of $F_1(x)$. If $F_1(x)$ is expanded by Taylor at x_0 and only one term is taken, the approximate equation of $\frac{dx}{dt} = F_1(x)$ is $\frac{dx}{dt} = F_1{}'(x_0)(x - x_0)$. The general solution of $\frac{dx}{dt} = F_1{}'(x_0)(x - x_0)$ is $x(t) = ce^{F_1{}'(x_0)t} + x_0$. Where c is a constant determined by the initial condition. When $F_1{}'(x_0) < 0$, $\lim_{t\to\infty} x(t) = x_0$, x_0 is a stable point. □

According to $G_1(y,z) = 0$, $z_1^*(y) = 1 - \frac{drC_E - P_{GE}}{drP_{EW} + drL_E + L_G} - \frac{C_G}{(drP_{EW} + drL_E + L_G)(1-y)}$ or $y_1^*(z) = 1 - \frac{C_G}{(P_{GE} - drC_E) + (drP_{EW} + drL_E + L_G)(1-z)}$.

According to $\frac{\partial G_1(y,z)}{\partial z} = -(drP_{EW} + drL_E + L_G)(1-y) < 0$, $G_1(y,z)$ is a monotonous decrease function of z. When $z > z_1^*(y)$, $G_1(y,z) < 0$, $F_1(0) = 0$, and $F_1{}'(0) < 0$. At this time, $x = 0$ is the stable point of $F_1(x)$. When $z < z_1^*(y)$, $G_1(y,z) > 0$, $F_1(1) = 0$, and $F_1{}'(1) < 0$. At this time, $x = 1$ is the stable point of $F_1(x)$.

According to the above analysis, the behavior evolution direction of the local government can be obtained, as shown in Figure 1.

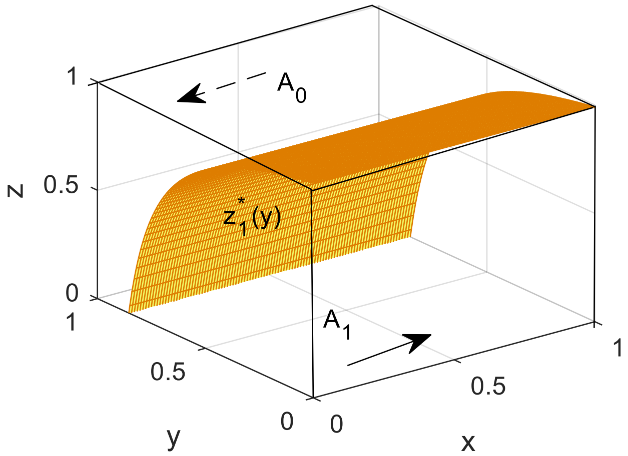


Figure 1. Behavior evolution direction of the local government.

The cube in Figure 1 is surrounded by the planes of $x = 0$, $x = 1$, $y = 0$, $y = 1$, $z = 0$, and $z = 1$. In the cube, $0 \le x \le 1$, $0 \le y \le 1$, and $0 \le z \le 1$. In Figure 1, the area bounded by the cube and the upper side of $z_1^*(y)$ is marked as A_0, and the area bounded by the cube and the lower side of $z_1^*(y)$ is marked as A_1. In the area of A_0, $z > z_1^*(y)$, the local government will choose to make no effort. In the area of A_1, $z < z_1^*(y)$, the local government will choose to make efforts. As can be seen from Figure 1, the greater $z_1^*(y)$, the more likely the local government is to choose to make efforts.

According to the relationship between the local government's behavior choice and $z_1^*(y)$ or $y_1^*(z)$, the following proposition can be obtained.

Proposition 2. *The larger C_G, the more likely the local government is to choose to make no effort. The larger P_{GE}, the more likely the local government is to choose to make efforts. When $r < 1 + \frac{P_{GE}(1-y)-C_G}{dC_E(1-y)}$, the larger r, the more likely the local government is to choose to make efforts. When $r > 1 + \frac{P_{GE}(1-y)-C_G}{dC_E(1-y)}$, the larger r, the more likely the local government is to choose to make no effort. The larger y, the more likely the local government is to choose to make no effort. When $z < 1 - \frac{drC_E-P_{GE}}{drP_{EW}+drL_E+L_G}$, the larger z, the more likely the local government is to choose to make no effort. Where C_G is the effort cost of the local government, P_{GE} is the punishment imposed by the local government on the construction enterprise, and r is the tax rate.*

Proof of Proposition 2. According to $\frac{\partial z_1^*(y)}{\partial C_G} = -\frac{1}{(drP_{EW}+drL_E+L_G)(1-y)} < 0$, the larger C_G, the smaller $z_1^*(y)$. According to $\frac{\partial z_1^*(y)}{\partial P_{GE}} = \frac{1}{drP_{EW}+drL_E+L_G} > 0$, the larger P_{GE}, the larger $z_1^*(y)$. According to $\frac{\partial z_1^*(y)}{\partial r} = \frac{C_G-[d(1-r)C_E+P_{GE}](1-y)}{(drP_{EW}+drL_E+L_G)(1-y)}$, when $r < 1 + \frac{P_{GE}}{dC_E} - \frac{C_G}{dC_E(1-y)}$, $\frac{\partial z_1^*(y)}{\partial r} < 0$, the larger r, the smaller $z_1^*(y)$. when $r > 1 + \frac{P_{GE}}{dC_E} - \frac{C_G}{dC_E(1-y)}$, $\frac{\partial z_1^*(y)}{\partial r} > 0$, the larger r, the larger $z_1^*(y)$. The smaller $z^*(y)$, the more likely z is greater than $z^*(y)$, and the more likely the local government is to choose to make no effort. The larger $z^*(y)$, the more likely z is smaller than $z^*(y)$, and the more likely the local government is to choose to make efforts. When $z < 1 - \frac{drC_E-P_{GE}}{drP_{EW}+drL_E+L_G}$, $\frac{\partial G_1(y,z)}{\partial y} = drC_E - P_{GE} - (drP_{EW} + drL_E + L_G)(1-z) < 0$, $G_1(y,z)$ is a monotonous decrease function of y. When $y > y_1^*(z)$, $G_1(y,z) < 0$, $F_1(0) = 0$, and $F_1{}'(0) < 0$. $x = 0$ is the stable point of $F_1(x)$. When $y < y_1^*(z)$, $G_1(y,z) > 0$, $F_1(1) = 0$, and $F_1{}'(1) < 0$. $x = 1$ is the stable point of $F_1(x)$. The smaller $y_1^*(z)$, the more likely y is greater than $y_1^*(z)$, and the more likely the local government is to choose to make no effort. According to $\frac{\partial y_1^*(z)}{\partial z} = -\frac{C_G(drP_{EW}+drL_E+L_G)}{[(P_{GE}-drC_E)+(drP_{EW}+drL_E+L_G)(1-z)]^2} < 0$, the larger z, the smaller $y_1^*(z)$. The smaller $y_1^*(z)$, the more likely y is larger than $y_1^*(z)$, and the more likely the local government is to choose to make no effort. □

3.2. Behavior choice mechanism of the construction enterprise

Let $F_2(y)=\frac{dy}{dt}=y(1-y)E_1(x,z)$, $F_2{}'(y)=\frac{dF_2(y)}{dy}=(1-2y)E_1(x,z)$. According to $E_1(x,z)=0$, $z_1^{**}(x)=1-\frac{C_E}{P_{EW}+L_E}+\frac{P_{GE}x}{(1-r)(P_{EW}+L_E)(1-x)}$ or $x_1^{**}(z)=1-\frac{P_{GE}}{(1-r)C_E+P_{GE}-(1-r)(P_{EW}+L_E)(1-z)}$.

According to $\frac{\partial E_1(x,z)}{\partial z}=-(1-r)(P_{EW}+L_E)(1-x)<0$, $E_1(x,z)$ is a monotonous decrease function of z. When $z>z_1^{**}(x)$, $E_1(x,z)<0$, $F_2(0)=0$, and $F_2{}'(0)<0$. At this time, $y=0$ is the stable point of $F_2(y)$. When $z<z_1^{**}(x)$, $E_1(x,z)>0$, $F_2(1)=0$, and $F_2{}'(1)<0$. At this time, $y=1$ is the stable point of $F_2(y)$.

According to the above analysis, the behavior evolution direction of the construction enterprise can be obtained, as shown in Figure 2.

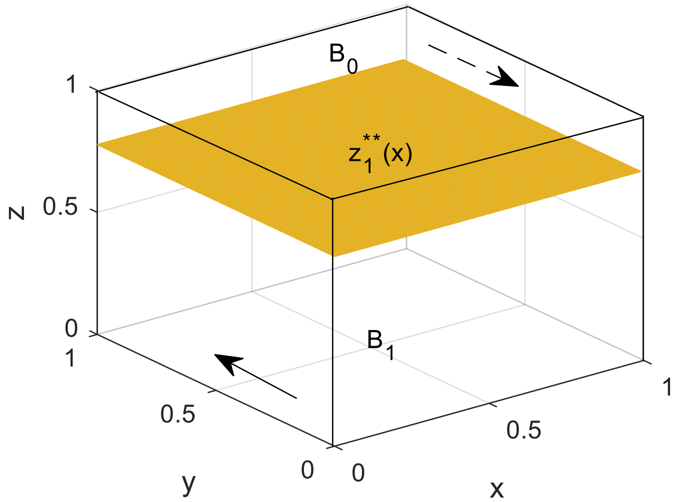


Figure 2. Behavior evolution direction of the construction enterprise.

According to the relationship between the construction enterprise's behavior choice and $z_1^{**}(x)$ or $x_1^{**}(z)$, the following proposition can be obtained.

Proposition 3. *The larger C_E, the more likely the construction enterprise is to choose to make no effort. The larger P_{GE} and r, the more likely the construction enterprise is to choose to make efforts. The larger x, the more likely the construction enterprise is to choose to make efforts. When $z>1-\frac{(1-r)C_E+P_{GE}}{(1-r)(P_{EW}+L_E)}$, the larger z, the more likely the local government is to choose to make no effort.*

Proof of Proposition 3. According to $z_1^{**}(x)$, $\frac{\partial z_1^{**}(x)}{\partial C_E}=-\frac{1}{P_{EW}+L_E}<0$, $\frac{\partial z_1^{**}(x)}{\partial P_{GE}}=\frac{x}{(1-r)(P_{EW}+L_E)(1-x)}>0$, $\frac{\partial z_1^{**}(x)}{\partial r}=\frac{P_{GE}x}{(1-r)^2(P_{EW}+L_E)(1-x)}>0$, and $\frac{\partial z_1^{**}(x)}{\partial x}=\frac{P_{GE}}{(1-r)(P_{EW}+L_E)(1-x)^2}>0$. The larger C_E, the smaller $z_1^{**}(x)$. The smaller $z_1^{**}(x)$, the more likely z is greater than $z_1^{**}(x)$, and the more likely the construction enterprise is to choose to make no effort. The larger P_{GE}, the larger $z_1^{**}(x)$. The larger r, the larger $z_1^{**}(x)$. The larger x, the larger $z_1^{**}(x)$. The larger $z_1^{**}(x)$, the more likely z is smaller than $z_1^{**}(x)$, and the more likely the construction enterprise is to choose to make efforts. When $z>1-\frac{(1-r)C_E+P_{GE}}{(1-r)(P_{EW}+L_E)}$, $\frac{\partial E_1(x,z)}{\partial x}=(1-r)C_E+P_{GE}-(1-r)(P_{EW}+L_E)(1-z)>0$, $E_1(x,z)$ is a monotonous increase function of x. When $x<x_1^{**}(z)$, $E_1(x,z)<0$, $F_2(0)=0$, and $F_2{}'(0)<0$. $y=0$ is the stable point of $F_2(y)$. When $x>x_1^{**}(z)$, $E_1(x,z)>0$, $F_2(1)=0$, and $F_2{}'(1)<0$. $y=1$ is the stable point of $F_2(y)$. According to $\frac{\partial x_1^{**}(z)}{\partial z}=\frac{P_{GE}[(1-r)(P_{EW}+L_E)]}{[(1-r)C_E+P_{GE}-(1-r)(P_{EW}+L_E)(1-z)]^2}>0$, the larger z, the larger $x_1^{**}(z)$. The larger $x_1^{**}(z)$, the more likely x is smaller than $x_1^{**}(z)$, and the more likely the construction enterprise is to choose to make no effort. □

3.3. Behavior choice mechanism of the construction worker

Let $F_3(z) = \frac{dz}{dt} = z(1-z)W_1(x,y)$, $F_3'(z) = \frac{dF_3(z)}{dz} = (1-2z)W_1(x,y)$. According to $W_1(x,y) = 0$, $x_1^*(y) = 1 - \frac{P_{EW}}{(C_W+P_{EW}-L_W)(1-y)}$ or $y_1^*(x) = 1 + \frac{P_{EW}}{(L_W-C_W)(1-x)-P_{EW}(1-x)}$.

When $C_W < L_W - P_{EW}$, $\frac{\partial W_1(x,y)}{\partial x} = (C_W + P_{EW} - L_W)(1-y) < 0$, $W_1(x,y)$ is a monotonous decrease function of x. When $x > x_1^*(y)$, $W_1(x,y) < 0$, $F_3(0) = 0$, and $F_3'(0) < 0$. At this time, $z = 0$ is the stable point of $F_3(z)$. When $x < x_1^*(y)$, $W_1(x,y) > 0$, $F_3(1) = 0$, and $F_3'(1) < 0$. At this time, $z = 1$ is the stable point of $F_3(z)$.

When $C_W > L_W - P_{EW}$, $\frac{\partial W_1(x,y)}{\partial x} > 0$, $W_1(x,y)$ is a monotonous increase function of x. When $x > x_1^*(y)$, $W_1(x,y) > 0$, $F_3(1) = 0$, and $F_3'(1) < 0$. At this time, $z = 1$ is the stable point of $F_3(z)$. When $x < x_1^*(y)$, $W_1(x,y) < 0$, $F_3(0) = 0$, and $F_3'(0) < 0$. At this time, $z = 0$ is the stable point of $F_3(z)$.

When $C_W > L_W - P_{EW}$, the behavior evolution direction of the construction worker is shown in Figure 3.

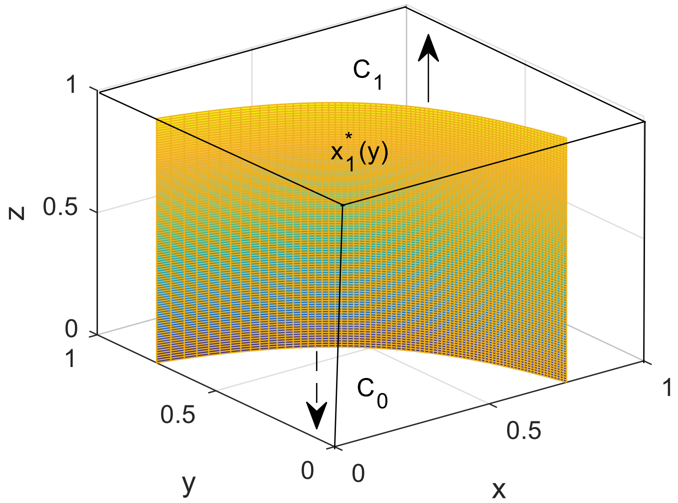


Figure 3. Behavior evolution direction of the construction worker under the condition of $C_W > L_W - P_{EW}$.

According to the relationship between the construction worker's behavior choice and $x_1^*(y)$ or $y_1^*(x)$, the following proposition can be obtained.

Proposition 4. *When $C_W < L_W + P_{EW}\frac{y}{(1-y)}$, no matter what behavior the local government and the construction enterprise choice, the construction worker will choose to make efforts. When $C_W > L_W + P_{EW}\frac{y}{(1-y)}$, the larger C_W, the more likely the construction worker is to choose to make no effort, and the larger L_W and P_{EW}, the more likely the construction worker is to choose to make efforts. When $P_{EW} > L_W - C_W$, the larger x and y, the more likely the construction worker is to choose to make efforts.*

Proof of Proposition 4. When $C_W < L_W - P_{EW}$, $x_1^*(y) > 1$. For any x and y, $x < x_1^*(y)$. When $C_W < L_W - P_{EW}$, $z = 1$ is the stable point of $F_3(z)$ under the condition of $x < x_1^*(y)$. When $L_W - P_{EW} < C_W < L_W + P_{EW}\frac{y}{(1-y)}$, $x_1^*(y) < 0$. For any x and y, $x > x_1^*(y)$. When $C_W > L_W - P_{EW}$, $z = 1$ is the stable point of $F_3(z)$ under the condition of $x < x_1^*(y)$. Thus, When $C_W < L_W + P_{EW}\frac{y}{(1-y)}$, for any x and y, $z = 1$ is the stable point of $F_3(z)$. When $C_W > L_W + P_{EW}\frac{y}{(1-y)}$, $\frac{\partial x_1^*(y)}{\partial C_W} > 0$, $\frac{\partial x_1^*(y)}{\partial L_W} < 0$, $\frac{\partial x_1^*(y)}{\partial P_{EW}} = \frac{-C_W+L_W}{(C_W+P_{EW}-L_W)^2(1-y)} < 0$. The larger C_W, the larger $x_1^*(y)$. When $C_W > L_W + P_{EW}\frac{y}{(1-y)} > L_W - P_{EW}$, the larger $x_1^*(y)$, the more likely x is smaller than $x_1^*(y)$, and the more likely the construction worker is to choose to make no effort. The larger L_W and P_{EW}, the smaller $x_1^*(y)$. When $C_W > L_W - P_{EW}$, the smaller $x_1^*(y)$, the more likely x is larger than $x_1^*(y)$, and the more likely the construction worker is to choose to make efforts. When $P_{EW} > L_W - C_W$ or

$C_W > L_W - P_{EW}$, $\frac{\partial x_1^*(y)}{\partial y} = -\frac{P_{EW}}{(C_W+P_{EW}-L_W)(1-y)^2} < 0$ and $\frac{\partial y_1^*(x)}{\partial x} = -\frac{P_{EW}}{(C_W+P_{EW}-L_W)(1-x)^2} < 0$. The larger x and y, the smaller $x_1^*(y)$. The smaller $x_1^*(y)$, the more likely the construction worker is to choose to make efforts. □

4. Tax incentive mechanisms

4.1. Incentive effect analysis method of incentive mechanisms

According to the behavior choice mechanism of the local government, when $G_1(y,z)$ is a monotonous decrease function of z, the greater $z_1^*(y)$, the more likely the local government is to choose to make efforts. Based on this, through analyzing the impact of the incentive mechanism on the monotonicity of $G_1(y,z)$ and the size of $z_1^*(y)$, we can analyze the incentive effect of the incentive mechanism on the local government.

According to the behavior choice mechanism of the construction enterprise, when $E_1(x,z)$ is a monotonous decrease function of z, the greater $z_1^{**}(x)$, the more likely the construction enterprise is to choose to make efforts. Based on this, through analyzing the impact of the incentive mechanism on the monotonicity of $E_1(x,z)$ and the size of $z_1^{**}(x)$, we can analyze the incentive effect of the incentive mechanism on the construction enterprise.

According to the behavior choice mechanism of the construction worker, when $W_1(x,y)$ is a monotonous decrease function of x, the smaller $x_1^*(y)$, the more likely the construction worker is to choose to make efforts. Based on this, through analyzing the impact of the incentive mechanism on the monotonicity of $W_1(x,y)$ and the size of $x_1^*(y)$, we can analyze the incentive effect of the incentive mechanism on the construction worker.

According to Proposition 2, Proposition3, and Proposition4, the behavior influence mechanism among the local government, the construction enterprise, and the construction worker under the action of the incentive mechanism is shown in Figure 4. According to the behavior influence mechanism, we can analyze the incentive effect of the incentive mechanism for one player on other players.

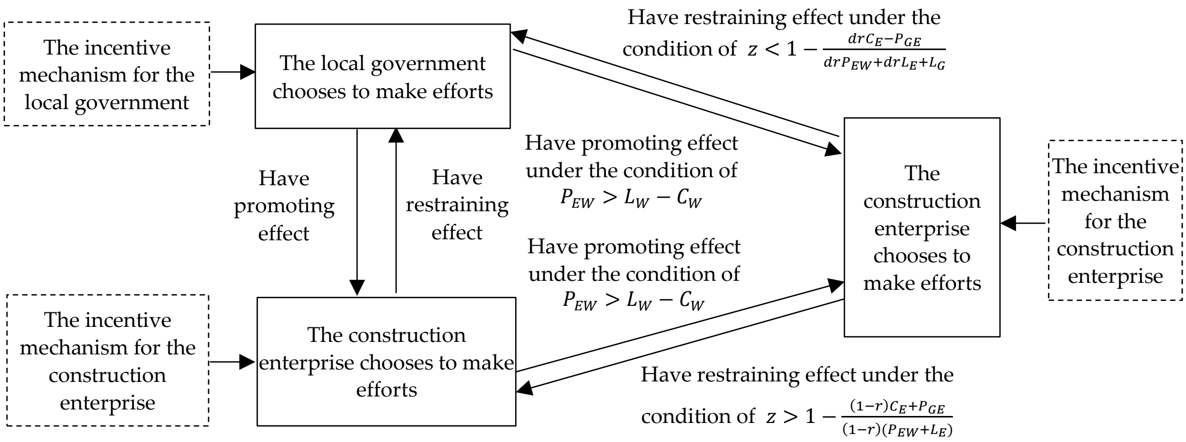


Figure 4. Behavior influence mechanisms among the local government, the construction enterprise, and the construction worker.

As tax is an important factor affecting the behavior choice of the local government and the construction enterprise, the following uses the above method to analyse the incentive effects of different tax incentive mechanisms on the local government, the construction enterprise, and the construction worker.

4.2. Tax mechanism that encourages the local government to make efforts

It is assumed that the tax mechanism that encourages the local government to make efforts is as follows. If an accident occurs, the central government will punish the local government by reducing the proportion of tax distribution. According to the assumption of the model, accidents may occur when the local government, the construction enterprise, and the construction worker all choose to make no effort. At this time, the local government's income, the construction enterprise's income, and the construction worker's income are $(d-d_0)r(I-W-L_E)-L_G$, $(1-r)(I-W-L_E)$, $W-L_W$ respectively. Where d_0 is the expectation of the tax distribution proportion reduction. According to their income, $u_1-u_2=G_2(y,z)=-C_G+P_{GE}(1-y)-drC_E(1-y)+(drP_{EW}+drL_E+L_G)(1-y)(1-z)+d_0r(I-W-L_E)(1-y)(1-z)$, $v_1-v_2=E_2(x,z)=E_1(x,z)$, and $w_1-w_2=W_2(x,y)=W_1(x,y)$.

According to $G_2(y,z)=0$, $z_2{}^*(y)=1-\frac{C_G+drC_E(1-y)-P_{GE}(1-y)}{(drP_{EW}+drL_E+L_G)(1-y)+d_0r(I-W-L_E)(1-y)}$. $\frac{\partial G_2(y,z)}{\partial z}=-[(drP_{EW}+drL_E+L_G)(1-y)+d_0r(I-W-L_E)](1-y)$. When $C_G>(P_{GE}-drC_E)(1-y)$ and $I-W-L_E>0$, $G_2(y,z)$ is a monotonous decrease function of z, and $z_2{}^*(y)>z_1{}^*(y)$. The behavior evolution direction of the local government is shown in Figure 5.

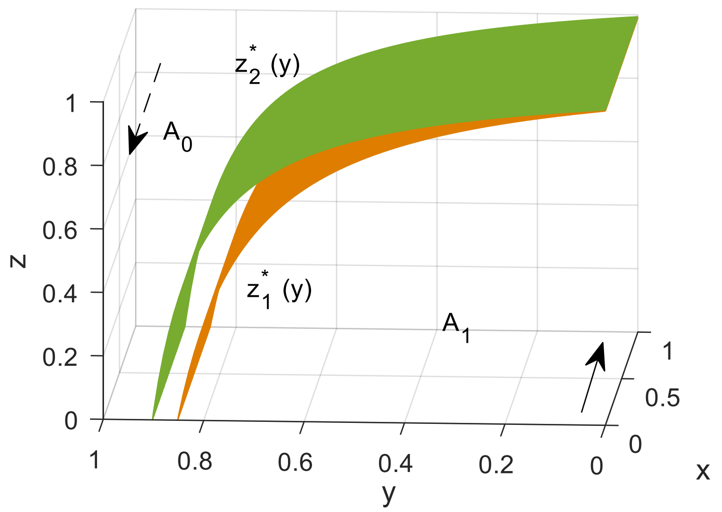


Figure 5. Behavior evolution direction of the local government under the tax mechanism.

As can be seen from Figure 5, the local government is more likely to choose to make efforts under the tax incentive mechanism. And the greater $z_2{}^*(y)-z_1{}^*(y)$, the stronger the incentive effect.

Because $E_2(x,z)=E_1(x,z)$ and $W_2(x,y)=W_1(x,y)$, the tax incentive mechanism that encourages the local government will not directly affect the behavior of the construction enterprise and the construction worker, but it will indirectly affect their behavior through the behavior interaction between the players.

4.2. Tax mechanism that encourages the construction enterprise to make efforts

It is assumed that the tax mechanism that encourages the construction enterprise to make efforts is as follows. If an accident occurs, the government will punish the construction enterprise by raising the tax rate. According to the assumption of the model, accidents may occur when the local government, the construction enterprise, and the construction worker all choose to make no effort. At this time, the local government's income, the construction enterprise's income, and the construction worker's income are $d(r+r_0)(I-W-L_E)-L_G$, $(1-r-r_0)(I-W-L_E)$, $W-L_W$ respectively. Where r_0 is the expectation of the tax rate raising. According to their income, $u_1-u_2=G_3(y,z)=-C_G+P_{GE}(1-y)-drC_E(1-y)+(drP_{EW}+drL_E+L_G)(1-y)(1-z)-dr_0(I-W-L_E)(1-y)(1-z)$, $v_1-v_2=E_3(x,z)=-(1-r)C_E(1-x)+P_{GE}x+(1-r)(P_{EW}+L_E)(1-x)(1-z)+r_0(I-W-L_E)(1-x)(1-z)$, and $w_1-w_2=W_3(x,y)=W_1(x,y)$.

According to $E_3(x,z)=0$, $z_3{}^{**}(x)=1-\frac{(1-r)C_E(1-x)-P_{GE}x}{(1-r)(P_{EW}+L_E)(1-x)+r_0(I-W-L_E)(1-x)}$. $\frac{\partial E_3(x,z)}{\partial z}=-(1-r)(P_{EW}+L_E)(1-x)-r_0(I-W-L_E)(1-x)<0$. When $C_E>\frac{P_{GE}x}{(1-r)(1-x)}$ and $I-$

$W - L_E > 0$, $z_3^{**}(x) > z_1^{**}(x)$. The behavior evolution direction of the construction enterprise is shown in Figure 6.

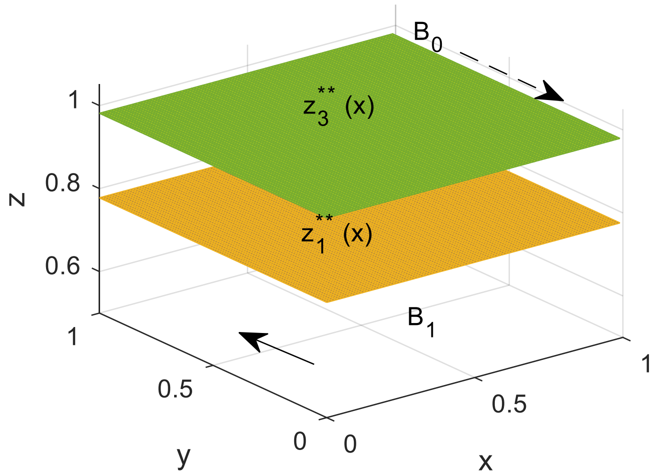


Figure 6. Behavior evolution direction of the construction enterprise under the tax mechanism.

As can be seen from Figure 6, the construction enterprise is more likely to choose to make efforts under the tax incentive mechanism. And the greater $z_3^{**}(x) - z_1^{**}(x)$, the stronger the incentive effect.

According to $G_3(y,z) = 0$, $z_3^{*}(y) = 1 - \frac{C_G + drC_E(1-y) - P_{GE}(1-y)}{(drP_{EW} + drL_E + L_G)(1-y) - dr_0(I - W - L_E)(1-y)}$. $\frac{\partial G_3(y,z)}{\partial z} = -[(drP_{EW} + drL_E + L_G) - dr_0(I - W - L_E)](1-y)$. When $\frac{\partial G_3(y,z)}{\partial z} < 0$, $z_3^{*}(y) < z_1^{*}(y)$ under the condition of $C_E > \frac{P_{GE}x}{(1-r)(1-x)}$ and $I - W - L_E > 0$. This shows that the tax incentive mechanism for the construction enterprise will reduce the possibility for the local governments to choose to make efforts under the above conditions.

5. Impact of tax incentive mechanisms on the behavior evolution

When the local government or the construction enterprise are encouraged by the tax incentive mechanism, they will affect the behavior of other players through their own behavior, and will also be affected by the behavior of other players. The following is an example to analyze the impact of the above two tax incentive mechanisms on the behavior evolution process of the local government, the construction enterprise, and the construction worker.

The values of each parameter are as follows. $I = 20$, $W = 4$, $C_G = 2$, $C_E = 4$, $C_W = 4$, $L_G = 1$, $L_E = 1$, $L_W = 1$, $P_{GE} = 2$, $P_{EW} = 2$, $r = 0.25$, $d = 0.3$. Where $P_{EW} > L_W - C_W$.

5.1. Impact of the tax mechanism that encourages the local government to make efforts on the behavior evolution

When $x_0 = 0.5$, $y_0 = 0.5$, and $z_0 = 0.5$, the impact of the tax mechanism that encourages the local government to make efforts on the behavior evolution process is shown in Figure 7. Where x_0, y_0, and z_0 are the behavior choices of the local government, the construction enterprise, and the construction worker at the initial time.

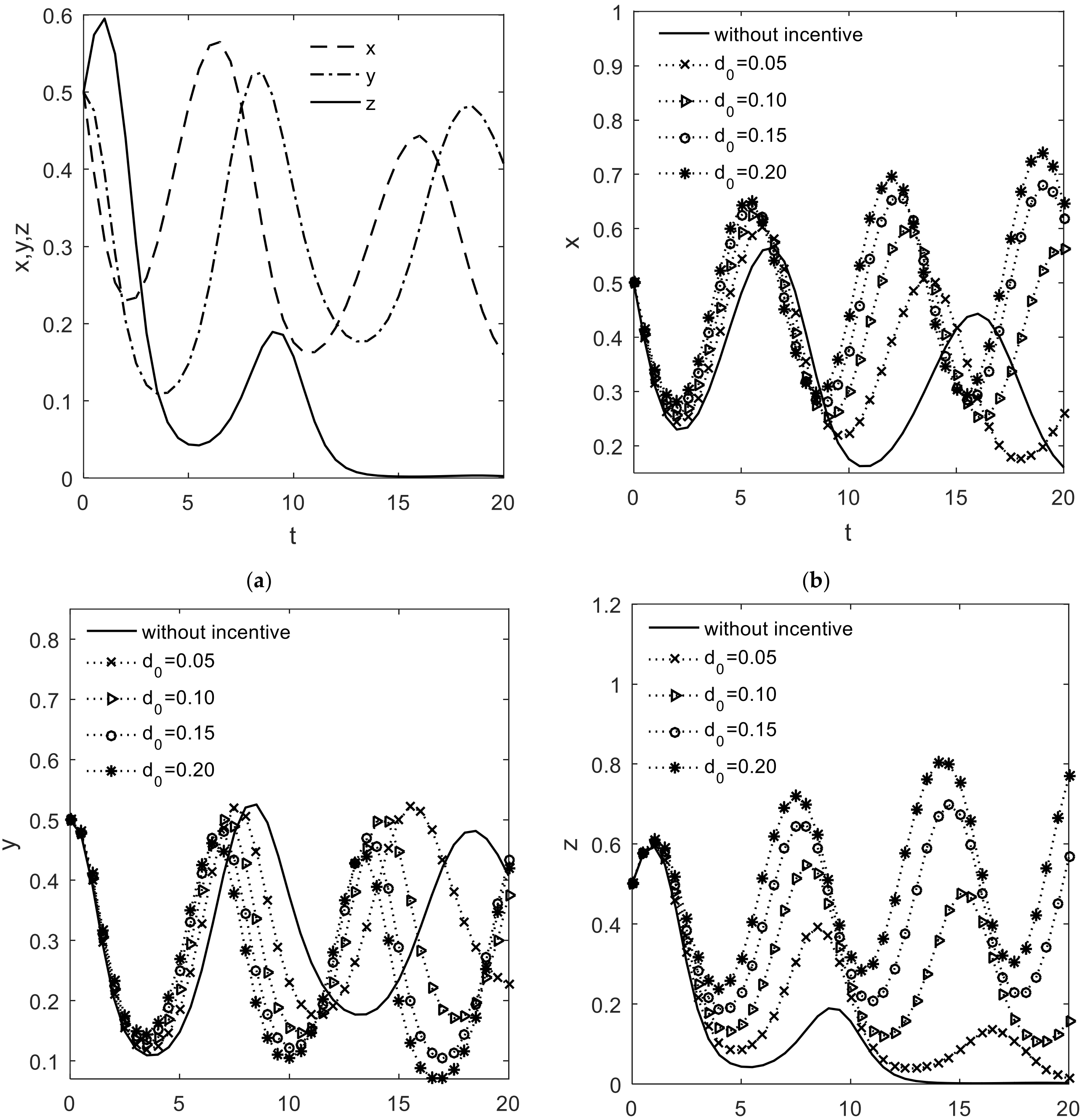


Figure 7. The impact of the tax mechanism that encourages the local government to make efforts on the behavior evolution process. (**a**) Evolution process without tax incentive mechanism; (**b**) The behavior evolution process of the local government under different tax incentive mechanisms; (**c**) The behavior evolution process of the construction enterprise under different tax incentive mechanisms; (**d**) The behavior evolution process of the construction worker under different tax incentive mechanisms.

As can be seen from Figure 7(b), the tax mechanism that encourages the local government to make efforts makes the highest and lowest points of x higher, which shows that the mechanism can promote the effort of the local government. And the greater d_0, the more obvious the incentive effect. The mechanism makes the lowest point of y lower, which indicates that the mechanism has a certain restraining effect on the effort of the construction enterprise. And the greater d_0, the more obvious the restraining effect. The mechanism makes z larger, which shows that the mechanism can promote the effort of the construction worker. And the greater d_0, the more obvious the incentive effect.

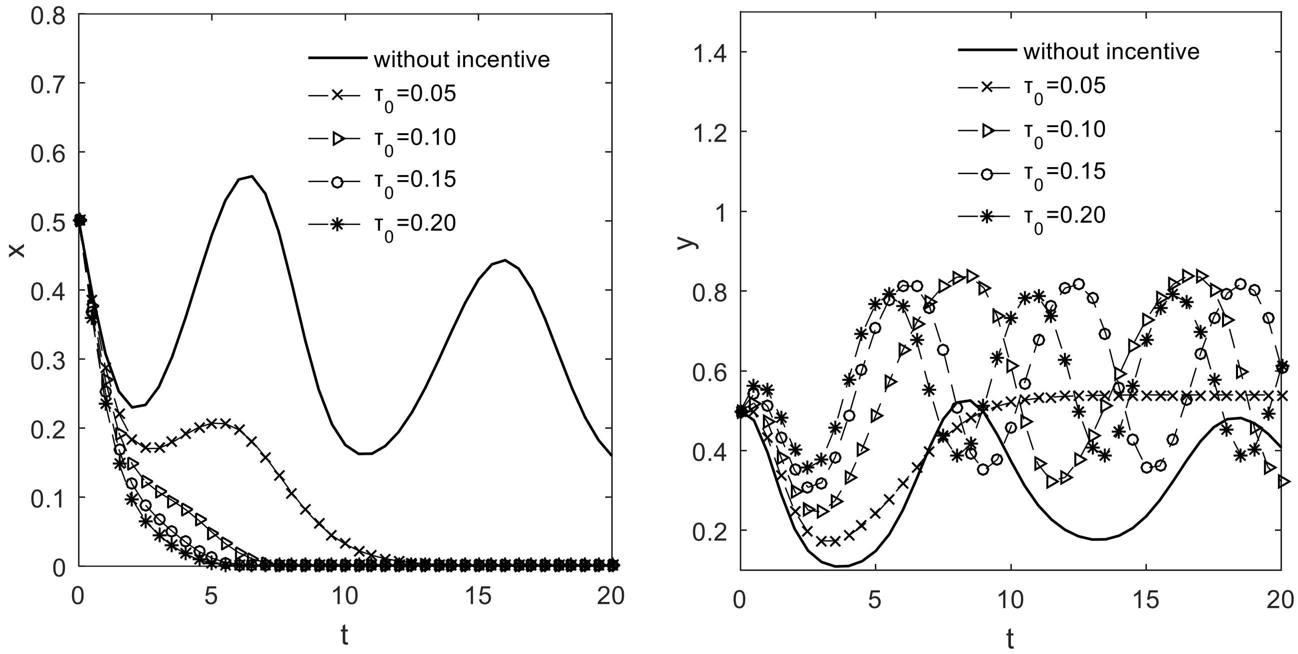
According to the behavior influence mechanism among the local government, the construction enterprise, and the construction worker shown in Figure 4, the reason the local government is more likely to choose to make efforts under the tax mechanism is that the incentive effect of the tax mechanism exceeds the restraining effect of the construction enterprise’s effort and the construction worker's effort on the local government's effort.

The reason the construction enterprise's effort is restrained under the tax mechanism is that the restraining effect of the construction worker's effort on the construction enterprise's efforts exceeds the promoting effect of the government’s effort on the construction enterprise's efforts.

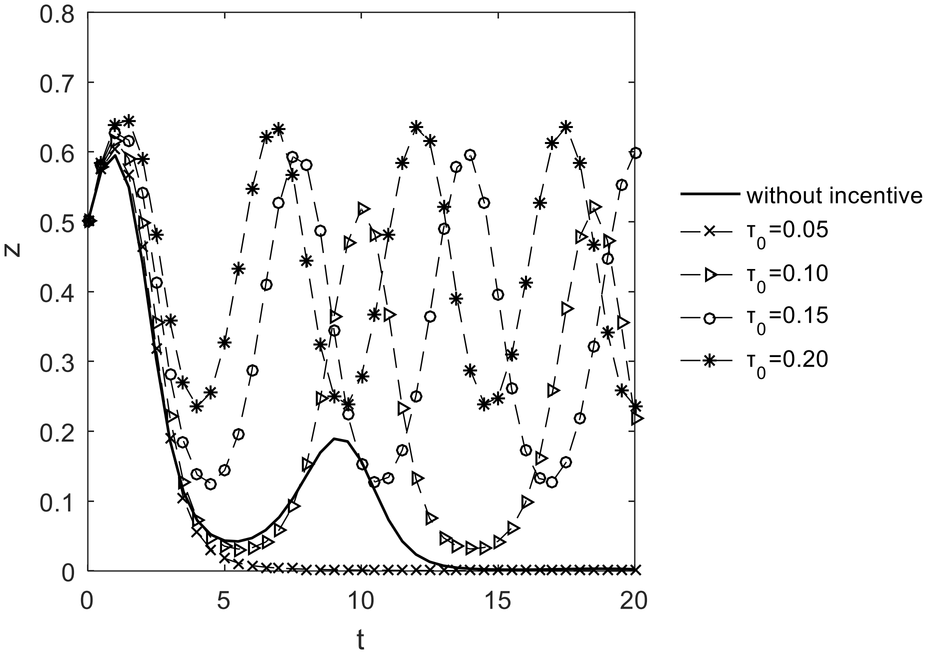
The reason the construction worker is more likely to choose to make efforts under the tax mechanism is that the effort of the local government can promote the effort of the construction worker under the condition of $P_{EW} > L_W - C_W$.

5.2. Impact of the tax mechanism that encourages the construction enterprise to make efforts on the behavior evolution

The impact of the tax mechanism that encourages the construction enterprise to make efforts on the behavior evolution process is shown in Figure 8.



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



(**c**)

Figure 8. The impact of the tax mechanism that encourages the construction enterprise to make efforts on the behavior evolution process. (**a**) The behavior evolution process of the local government under different tax incentive mechanisms; (**b**) The behavior evolution process of the construction enterprise under different tax incentive mechanisms; (**c**) The behavior evolution process of the construction worker under different tax incentive mechanisms.

As can be seen from Figure 8, the tax mechanism that encourages the construction enterprise to make efforts makes x smaller. This shows that the mechanism has a restraining effect on the efforts of the local government. The tax mechanism that encourages the construction enterprise to make efforts makes y bigger. This shows that the mechanism can promote the effort of the construction enterprise. When r_0 is small, the tax mechanism makes z smaller. When r_0 is large, the tax mechanism makes z larger. This shows that only when r_0 is large, the tax mechanism that encourages the construction enterprise to make efforts can promote the effort of the construction worker.

According to the behavior influence mechanism among the local government, the construction enterprise, and the construction worker shown in Figure 4, the reason the local government is more likely to choose to make no effort under the tax mechanism that encourages the construction enterprise to make efforts is that the effort of the construction enterprise has a restraining effect on the effort of the local government.

The reason the construction enterprise is more likely to choose to make efforts is that the incentive effect of the tax mechanism is more than the restraining effect of the construction worker's effort on the construction enterprise's effort.

It can be seen from Figure 8 (b), when r_0 is small, the tax mechanism that encourages the construction enterprise to make efforts plays a weak role in promoting the effort of the construction enterprise. This weak promoting effect has a weak promoting effect on the effort of the construction worker. On the other hand, it has a certain restraining effect on the efforts of the local government. This restraining effect also inhibits the effort of the construction worker. And the restraining effect on the effort of the construction worker exceeds the promoting effect, which makes the construction worker more likely to choose to make no effort. When r_0 is large, the tax mechanism that encourages the construction enterprise has a greater incentive effect on the effort of the construction enterprise. The effort of the construction enterprise promotes the effort of the construction worker. This kind of promoting effect exceeds the restraining effect, making the construction worker more likely to choose to make efforts.

6. Conclusions

To master the behavior choice mechanism of the local government, the construction enterprise, and the construction worker in the construction safety game, and design the incentive mechanism according to the behavior choice mechanism, an evolutionary game model is constructed, and an incentive effect analysis method of the incentive mechanism is proposed. According to the behavior choice mechanism of game players, the following conclusions are obtained.

(1) Reducing the cost of effort and increasing punishment can promote the local government, the construction enterprise, and the construction worker to choose to make efforts.

(2) Raising the tax rate can promote the construction enterprise to choose to make efforts. When the tax rate is small, raising the tax rate can promote the local government to choose to make efforts. When the tax rate is large, reducing the tax rate can promote the local government to choose to make efforts.

(3) The efforts of the local government, the construction enterprise, and the construction worker promote and restrain each other. When the punishment imposed on the construction worker is large, the efforts of the local government and the construction enterprise can promote the construction worker to choose to make efforts. Under certain conditions, the effort of the construction worker can inhibit the efforts of the local government and the construction enterprise. The effort of the local government can promote the construction enterprise to choose to make efforts. The effort of the construction enterprise has a restraining effect on the effort of the local government.

(4) The tax incentive mechanism of reducing the tax distribution proportion of the local government in case of accidents can promote the local government to choose to make efforts. However, this mechanism has a certain restraining effect on the efforts of the construction enterprise. This mechanism can promote the construction worker to choose to make efforts through the behavior interaction between the players.

(5) The tax incentive mechanism of raising the tax rate of the construction enterprise in case of accidents can promote the construction enterprise to choose to make efforts. However, this mechanism has a restraining effect on the efforts of the local government. Only when the expectation of the tax rate raising is large, this tax mechanism can promote the construction worker to choose to make efforts through the behavior interaction between the players.

The behavior choice mechanism of the players in the construction safety game and the incentive effect analysis method of the incentive mechanism provide ideas for the design of the construction safety mechanisms. This also provides ideas for the design of coal mine safety mechanisms, food safety mechanisms, and chemical safety mechanisms.

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