A Study of Three-Party Evolutionary Game in the Context of Carbon Disclosure

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Abstract. Given mandatory carbon info disclosure in construction and potential rent-seeking between enterprises and third-party agencies, this paper explores local gov't strategic choices using an evolutionary game model. MATLAB simulations analyze evolutionary paths and parameter sensitivities to establish a system without goverment review. Results suggest fines can enhance disclosure quality, but reducing disclosure costs and boosting third-party agencies' benefits are crucial. This study offers insights for improving carbon info disclosure quality.

Keywords: Carbon information disclosure; Rent-seeking behavior; Evolutionary game; Construction enterprises;

1 Introduction

The severity of environmental issues brought on by carbon emissions has increased recently. China's building industry grew from 3.5 billion to 14.9 billion in construction between 2005 and 2020, and carbon emissions kept rising[1]. Construction companies in China currently face challenges with their carbon information disclosure, including low information comparability and reliability, highly random data disclosure, a lack of coordination among information disclosure departments' roles and responsibilities, and inadequate oversight[2]. The primary explanation is the expense associated with disclosing carbon statistics, although it is also partially due to the challenge of acquiring data on carbon emissions and the lack of openness[3]. Businesses are motivated to misrepresent information to maximize profits; this leads to catering[4] and "greenwashing" [5]. Since carbon emission reduction cannot be effectively controlled by enterprises and government guidance alone [6] ecological and environmental authorities can entrust third-party verification agencies to provide verification services through government purchase of services [7]. However, at present, China's carbon trading mechanism adopts the mode of centralized implementation, and the carbon verification institutions have great work intensity, tight time, and heavy tasks, and the work of third-party verification institutions is often lax. Therefore, the three have an evolutionary game relationship [8], and rent-seeking collusion is difficult to avoid[9].

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In the existing research, most of the factors affecting carbon information disclosure will focus on the government's reward and punishment measures after the review, in fact, for the government, if the long-term review behavior, the government reward is lower than the rent-seeking income of enterprises and third-party verification agencies can not play a due role, if too high will increase the financial pressure of the government, the government will be weak[10]. If there are several high-carbon emission enterprises in the local area, the verification cost to be paid will also generate financial pressure on the local government[11]. In addition, the level of managers has a positive relationship with the carbon information disclosure of enterprises[12]. Therefore, this paper tries to use the evolutionary game method to shift the focus to the local government in the construction period of the construction enterprise's strong guidance, and weak supervision, from the "regulatory" government to the service-oriented government, dilute the role of incentives and penalties, and cede the right of supervision to the third-party verification agency, to achieve the ideal state.

2 Model Hypothesis and Parameter Setting

Hypothesis 1: The subjects in the process of carbon information disclosure government-led party, enterprise implementation party, and third-party verification organization are all limited rational decision-making subjects, and the information among the three is asymmetric and does not affect the decision-making of mutual interests.

Hypothesis 2: Carbon emissions from building construction are led by the government, entrusted to qualified third-party verification institutions to perform, responsible for supervising and checking whether the carbon information disclosure of construction enterprises is complete, and the three share the reality of the responsibility for the standardized development of monitoring and supervision of carbon emissions from building construction[13].

Hypothesis 3: The strategy choice of government supervision is the review or no review, and its probability is $x,(1-x)$ respectively; The strategic choice of the construction enterprise is low-quality carbon emission detection and high-quality carbon emission detection respectively as $y,(1-y)$, The strategy choice of the third-party verification institution is compliance reporting or violation reporting, and the probabilities is $z,(1-z)$, respectively, $0 \le x,y,z \le 1$.

Hypothesis 4: The government will obtain the corresponding tax revenue from the production activities of the construction enterprise B_1, When the government chooses to review, it is required to pay an additional review cost of B_2, In the process of carbon information disclosure, construction enterprises obtain net income C_1 when they choose low-quality carbon information disclosure, When selecting high-quality carbon information disclosure for construction enterprises, the additional cost of machinery, equipment and personnel is C_2, When the construction enterprise chooses to seek rent with the third-party verification agency, the rent-seeking cost required is C_3, $C_3 < C_2$,At this time, additional benefits such as government praise, media reports, public goodwill, etc., are C_4, The income of the third-party verification agency comes from the local government, the basic income is D_1 , the inspection cost is, a D_2 nd the additional income obtained by the compliance report is D_3 , including government support, media reports, reputation in society, etc. When the construction enterprise and the third-party verification agency engage in rent-seeking behavior, if the government chooses to review it, The rent-seeking behavior of construction enterprises will be fined n , and the rent-seeking behavior of third-party verification institutions will be fined $(0 < m,n)$. When a construction enterprise unilaterally has a fluke mind or fails to seek rent with a third-party verification institution and chooses to disclose low-quality carbon information, the government chooses to review and imposes a fine on the construction enterprise p ; when a third-party verification institution unilaterally neglects and chooses to report violations, the government chooses to review and imposes a fine on the third-party verification institution q .

Based on the above assumptions, parameters and variables under the three-way game of carbon information disclosure are set as follows Table 1:

Table 1. Payoff matrix

Government	Third party verification institution compliance report z		Third-party verification institutions report violations $(1-z)$	
	Low-quality carbon emission detection y	High-quality carbon emission detection $(1-y)$	Low-quality carbon emission detection y	High-quality carbon emission detection $(1-y)$
Review x	$B_1 - B_2 - D_1 + p$	$B_1 - B_2 - D_1$	$B_1 - B_2 - D_1 + m + n$	$B_1 - B_2 - D_1$
	$C_1 - p$	$C_1 - C_2 + C_4$	$C_1 - C_3 - n$	$C_1 - C_2 + C_4$
	$D_1 + D_3$	$D_1 + D_3$	$D_1 + D_2 + C_3 - m$	$D_1 + D_2 - q$
No review $(1-x)$	$B_1 - D_1 + p$	$B_1 - D_1$	$B_1 - D_1$	$B_1 - D_1$
	$C_1 - p$	$C_1 - C_2$	$C_1 - C_3$	$C_1 - C_2$
	$D_1 + D_3$	$D_1 + D_3$	$D_1 + D_2 + C_3$	$D_1 + D_2$

3 Model Analysis

3.1 Analysis of Strategic Stability of Government Departments

The expected returns and the average expected returns of the government departments conducting review or non-review are respectively calculated by the following formula:

$$E_1 = yz(B_1 - B_2 - D_1 + p) + y(1-z)(B_1 - B_2 - D_1 + m + n) + (1-y)z(B_1 - B_2 - D_1) + (1-y)(1-z)(B_1 - B_2 - D_1)$$

$$E_2 = yz(B_1 - D_1 + p) + y(1-z)(B_1 - D_1) + (1-y)z(B_1 - D_1) + (1-y)(1-z)(B_1 - D_1)$$

$$V_1 = xE_1 + (1-x)E_2$$

According to Malthusian, the government's dynamic equation is sorted out and the replicative dynamic equation is sorted out:

$$F(x) = \frac{dx}{dt} = x(x-1)(B_2 - my - ny + myz + nyz)$$

The first derivative of x and the set $G(y)$ are divided into: $d(F(x))/dx = (2x-1)(B_2 - my - ny + myz + nyz)$, Let $G(y) = B_2 - my - ny + myz + nyz$, according to the stability theorem of differential equations, the probability that the government chooses to conduct a review is stable must be satisfied: $F(x) = 0$ and $\frac{d(F(x))}{dx} < 0$, Because of $\frac{\partial G(y)}{\partial y} < 0$, $G(y)$ is y decreasing function with respect to y Therefore, when $y = B_2/[m(1-z) + n(1-z)] = y^*$, $G(y) = 0$, Then $\frac{d(F(x))}{dx} = 0$ and $F(x) = 0$ all x are in an evolutionarily stable state. When $y < y^*$, $G(y) > 0$, Then $d(F(x))/dx|_{x=0} < 0$, $x = 0$ is the evolutionary stability strategy that the government does not review; Conversely, $x = 1$ is the evolutionarily stable strategy for government review.

3.2 Analysis of Strategic Stability of Construction Enterprises

The expected revenue and average expected revenue (E_3, E_4, V_2) of high-quality or low-quality carbon emission monitoring for construction enterprises are calculated by the following formula:

$$E_3 = (C_1 - p)xz + (C_1 - C_3 - n)x(1-z) + (C_1 - p)z(1-x) + (C_1 - C_3)(1-x)(1-z)$$

$$E_4 = (C_1 - C_2 + C_4)xz + (C_1 - C_2 + C_4)x(1-z) + (C_1 - C_2)(1-x)z + (C_1 - C_2)(1-x)(1-z)$$

The dynamic equation of replication is: $F(y) = y(y-1)(C_3 - C_2 + C_4x - C_3z + nx + pz - nxz)$ The first derivative of y and the set x are respectively $d(F(y))/dy = (2y-1)(C_3 - C_2 + C_4x - C_3z + nx + pz - nxz)$, the stability theorem of differential equation, and the probability that a construction enterprise chooses to carry out high-quality carbon emission monitoring is in a stable state must meet: $F(y) = 0$ and $\frac{d(F(y))}{dy} < 0$, Because of $\frac{\partial G(x)}{\partial x} > 0$, $G(x)$ is x increasing function with respect to x .Therefore, when $x = (C_2 - C_3 + zC_3 - pz)/(C_4 + n - nz) = x^*$, $G(x) = 0$, Then $\frac{d(F(y))}{dy} = 0$, and $F(y) = 0$ all y are in an evolutionarily stable state.when $x > x^*$, $G(x) > 0$, then $d(F(y))/dy|_{x=0} > 0$, $y = 0$ is the evolution and stability strategy of high-quality carbon emission monitoring of construction enterprises; On the contrary, $y = 1$ selects the evolutionarily stable strategy of low-quality carbon emission monitoring for construction enterprises.

3.3 Analysis of the Strategic Stability of Third-Party Verification Institutions

The formula for calculating the expected return and average expected return of the third-party verification institution for compliance reporting or non-compliance reporting is as follows:

$$E_5 = xy(D_1 + D_3) + x(1-y)(D_1 + D_3) + (1-x)y(D_1 + D_3) + (1-x)(1-y)(D_1 + D_3)$$

$$E_6 = xy(D_1 + D_2 + C_3 - m) + x(1-y)(D_1 + D_2 - q) + (1-x)y(D_1 + D_2 + C_3) + (1-x)(1-y)(D_1 + D_2)$$

The dynamic equation of replication is: $F(z)=z(z-1)(D_2-D_3+C_3y-qx-mxy+qxy)$

The first-order function of z and the set $H(x)$ are respectively $d(F(z))/dz=(2z-1)(D_2-D_3+C_3y-qx-mxy+qxy)$. According to the stability theorem of differential equation, the probability of $H(x)=D_2-D_3+C_3y-qx-mxy+qxy$ and the third-party verification institution choosing compliance reporting to be in a stable state must meet: $F(z)=0$ and $\frac{d(F(z))}{dz}<0$, Because of $\frac{\partial H(x)}{\partial x}<0$, Therefore, the relation of $H(x)$ to x is a decreasing function. Therefore, when $x=D_2-D_3+yC_3/q+my-qy=x*$, $H(x)=0$, then $\frac{d(F(z))}{dz}=0$,and $F(z)=0$ all z are in an evolutionarily stable state. when $x<x*$, $H(x)<0$, then $d(F(z))/dz|_{x=0}<0$, $z=0$ is an evolutionary and stable strategy for third-party verification agencies to report violations; Conversely, $z=1$ is ESS.

Corollary: Reducing the cost of government review helps to ensure that the government enforces the review behavior, and the higher the fines for rent-seeking behavior of construction companies and third-party verifiers, the more likely it is that the government will actively conduct the review.

For rent-seeking behaviors, increasing the fines for rent-seeking behaviors of construction companies, the fines for construction companies, when the government reviews problems, occur, and the rent-seeking costs for rent-seeking behaviors can reduce the probability of rent-seeking behaviors of construction companies, increase the additional benefits from high-quality disclosure of carbon information, and decreasing the extra costs of high-quality disclosure can promote the probability of high-quality disclosure of carbon information of construction companies. information disclosure behavior.

When the third-party verification agency chooses to comply with the report to be able to obtain additional revenue will greatly increase its work enthusiasm, its rent-seeking behavior gain is directly proportional to the probability of rent-seeking behavior, the higher the cost of verification behavior, the higher the probability of non-compliance with the report.

According to the first method of Ly Bpunov, the stable state of the system can be judged by the symbols of the eigenvalues. In the matrix, when every eigenvalue calculated is negative, the equilibrium point is the stable point of the system; when there are positive eigenvalues calculated, the equilibrium point is not the stable point of the system. The equilibrium point stability analysis is shown in Table 2:

Table 2. Equilibrium point stability point analysis

Equalization point	eigenvalue		Stable conclusion	ESS condition
	eigenvalue	symbol		
$(0,0,0)$	$[-B_2,C_2-C_3,D_3-D_2]$	$(-,+,x)$	Unstable point	
$(0,1,0)$	$[m-B_2+n,C_3-C_2,D_3-D_2-C_3]$	$(X,X,-)$	ESS or instability	when $B_2>(m+n)$, $D_3<D_2+C_3$

$(0,0,1)$	$[-B_2, C_2 - p, D_2 - D_3]$	$(-, X, X)$	ESS or instability	when $p > C_2$ $D_3 > D_2$
$(0,1,1)$	$[-B_2, p - C_2, C_3 + D_2 - D_3]$	$(-, X, X)$	ESS or instability	when $p < C_2$ $D_3 > D_2 + C_3$
$(1,0,0)$	$[B_2, C_2 - C_3 - C_4 - n, D_3 - D_2 + q]$	$(+, X, X)$	Unstable point	
$(1,1,0)$	$[B_2 - m - n, C_3 - C_2 + C_4 + n, D_3 - D_2$	$(X, +, X)$	Unstable point	
$(1,0,1)$	$[B_2, C_2 - C_4 - p, D_2 - D_3 - q]$	$(+, -, x)$	Unstable point	
$(1,1,1)$	$[B_2, C_4 - C_2 + p, C_3 + D_2 - D_3 - m]$	$(+, X, X)$	Unstable point	

Corollary 2: When $p > C_2$, $D_3 > D_2$, $(0,0,1)$ is the equilibrium point, that is, the fixed fine imposed by the government on the construction enterprise for the problem review will be greater than the additional cost incurred by the enterprise for high-quality disclosure of carbon information, and the additional income obtained by the third-party verification institution for compliance reporting will be greater than the inspection cost of the third-party verification institution.

Corollary 2 shows that The government actively guides the third-party verifiers so that the additional benefits of compliance reporting by the third-party verifiers are greater than the cost of inspection by the third-party verifiers. For building construction enterprises, when the government reviews the problem and imposes a fixed fine on the building construction enterprise that is higher than the additional cost that the enterprise needs to spend to make high-quality disclosure of carbon information, the building construction enterprise will choose to make high-quality disclosure of carbon information, and at this time the third-party verification agency will refuse to co-opt both of them so that the government can still choose not to carry out the act of reviewing though.

The equilibrium point (0,1,0) indicates that the government will choose not to conduct a review when the cost of the review is higher than the fine imposed by the government for rent-seeking behavior, the cost of rent-seeking is lower than the additional cost of high-quality disclosure of carbon information, and the cost of inspection by the third-party verifier is higher than the additional benefit of compliance reporting, and the cost of inspection by the third-party verifier is higher than the additional benefit of rent-seeking. When the cost of inspection and rent-seeking benefits are higher than the additional benefits of complying with the reporting requirements, the construction company and the third-party verifier will choose to engage in rent-seeking behavior.

The equilibrium point (0,1,1) indicates that when the cost of government review is less than the benefit of fines, the government will choose not to review, and the additional benefit of the third-party verifier's compliance reporting is greater than the sum of the cost of inspection and the benefit of rent-seeking behaviors, so the third-party verifier will choose to conduct compliance reporting. When the fixed fine imposed on a construction company by the government for reviewing the problem is less than the additional cost of the strategy to make a high-quality carbon disclosure, the construction company will choose to make a low-quality carbon disclosure, and to avoid this, the government should increase the penalty for the construction company.

4 Simulation Analysis

In order to verify the validity of the evolutionary stability analysis, the model was assigned according to the actual situation, and numerical simulation was carried out by MATLAB2021a. The assignment is as follows: $B_2 = 5$, $C_2 = 4$, $C_3 = 2$, $C_4 = 1$, $D_2 = 2$, $D_3 = 1$, $m = 3$, $n = 3$, $p = 2$, $q = 2$.

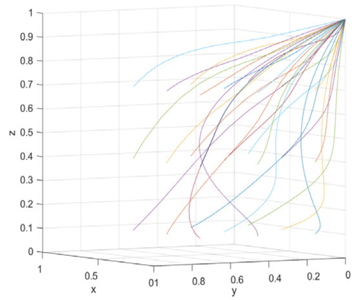

Fig. 1. System evolution path

Through the above evolution results Figure 1, we can see that the numerical simulation verifies the correctness of the theoretical analysis. When the government tends to choose not to review, the enterprise chooses high-quality carbon information disclosure, and the third-party verification institution chooses compliance reporting, the system stability is in an ideal state, and the stability point is, condition ① $p > C_2$ must be met, that is, the fixed fine imposed by the government on the construction enterprise for problems in the review is greater than the additional cost required by the construction enterprise for high-quality carbon information disclosure. After the failure of rent-seeking with the third-party environmental testing agency, the construction enterprise may still choose to disclose low-quality information and commit data fraud. In this case, the government chooses to review and imposes a fine on the construction enterprise that is higher than the additional cost of high-quality carbon information disclosure. Condition ② $D_3 > D_2$, that is, the additional income obtained by the third-party verification institution from compliance reporting is greater than the inspection cost of the third-party verification institution. The additional income of the third-party verification institution can come from the government's praise, resource inclination, continued employment relationship, etc., or from the society, such as mass media reports, to improve the visibility of the third-party verification institution in this city and province. So as to get more cooperation opportunities.In order to achieve the ideal stability point $(0,0,1)$, the parameters are adjusted and numerical sensitivity analysis and simulation are discussed as follows:

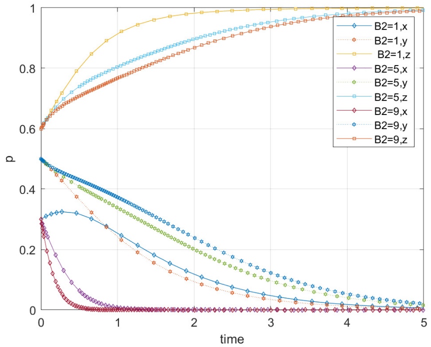

Fig. 2. Tripartite behavior evolution of variable review costs

Figure 2 illustrates that when review cost B_2 is 1, 5, or 7, it serves as a negative incentive for the government. As the cost of review rises, the expected benefits of the government's review decrease. This is because the cost directly reduces the government's net income, dampening their enthusiasm for conducting reviews. Conversely, for construction enterprises, the increased cost of review is a positive incentive. With a lower probability of government review, the risk of being caught for disclosing low-quality carbon information decreases, increasing the potential benefits of low-quality carbon emission monitoring. This trend may increase the difficulty and risk of compliant reporting for third-party verification institutions.

In conclusion, the increasing cost of review may hinder the effectiveness of the carbon emission monitoring and reporting system. Therefore, it's crucial for the government, construction enterprises, and third-party verification institutions to collaborate in reducing review costs and enhancing efficiency to ensure the accuracy and fairness of the system.

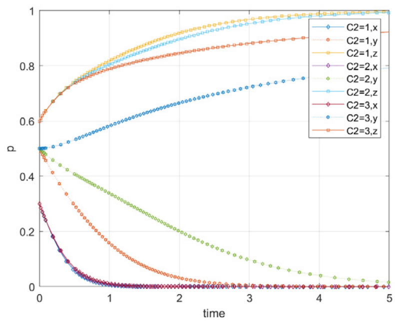

Fig. 3. When a variable building construction enterprise makes high-quality disclosure of carbon information tripartite behavior evolution curve with additional cost required.

As can be seen from Figure 3, when the additional cost C_2 required for high-quality carbon information disclosure of construction enterprises is assigned as 1, 2, and 3, the increase of additional cost is a positive incentive for the government and construction enterprises, and a negative incentive for third-party verification institutions. When the assignment value is 1 or 2, although the evolution rate of construction enterprises will slow down, construction enterprises are willing to pay appropriate cost for high-quality disclosure of carbon information, and the evolution result can evolve towards the ideal equilibrium point (0,0,1). However, when the assignment value is too large, the additional cost required by construction enterprises exceeds the range that enterprises can accept in the long run. Construction enterprises will choose to save costs and disclose low-quality carbon information. At the same time, they will try to conduct rent-seeking behavior, which will also affect the evolution rate of compliance reporting by third-party verification institutions.

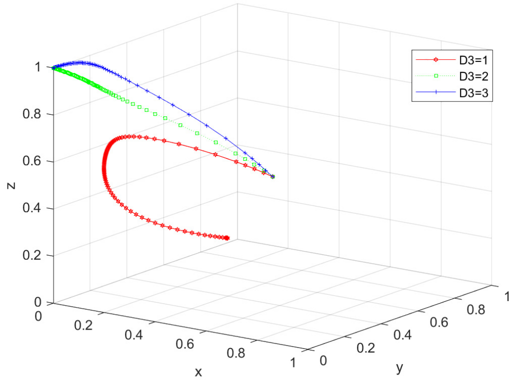

Fig. 4. Results of compliance reporting by third-party verification agencies sensitivity analysis of additional income to each subject

The extra benefits D_3 received by third-party verification institutions for compliant reporting, when set at 1, 2, or 3, can clearly be seen in Figure 4 to have a positive incentive effect on their behavior. Simultaneously, the attitude of these institutions positively encourages construction enterprises to adopt a more favorable stance towards carbon information disclosure. When third-party verification institutions actively comply with reporting requirements, their professionalism and credibility are recognized by the market, which in turn prompts construction enterprises to prioritize the quality of carbon information disclosure in order to maintain their reputation.

However, if the extra benefits received for compliant reporting are too low or non-existent, third-party verification institutions may choose to violate reporting regulations or overlook crucial carbon information due to a lack of economic incentives. This would result in a decline in the quality of carbon information disclosure. At the same time, construction enterprises, lacking external supervision, may tend to disclose carbon information with lower quality in order to save costs. Such behavior driven by self-interest can severely damage the effectiveness and credibility of the entire carbon information disclosure system.

5 Conclusions and Suggestions

Based on the perspective of interests of each subject of carbon information disclosure quality of construction enterprises, this paper constructs a tripartite evolutionary game model of the government, construction enterprises, and third-party regulators, and uses the simulation model to conduct a detailed analysis of interest demands, evolutionary behaviors and sensitivity of influencing factors among each subject.

In the equilibrium point (0,0,1), although the government did not conduct the review, it did not give up its social responsibility but chose to better improve the management of third-party verification institutions, fully mobilize the enthusiasm of third-party verification institutions, and increase the number of fines for construction enterprises to disclose low-quality carbon information. The transfer of the regulatory power to the third-party verification institutions enables the third-party verification institutions to obtain more additional benefits when reporting compliance, and the simulation results of participants reach the ideal state, providing the optimal strategic choice for the government to achieve carbon information management.To promote the coordinated development of various stakeholders in the high-quality disclosure of carbon information, this paper puts forward the following suggestions:

(1) The government should actively assist enterprises to reduce the cost of carbon information collection; Encourage building construction enterprises to actively cooperate with universities or scientific research institutions to promote the research of related low-carbon technologies, promote the innovation of technical methods based on building construction sites, and change the status quo that most of the building construction sites are still in high energy consumption and high emissions. Better promote the sustainable development of the region and maintain a virtuous cycle.

(2) To ensure the effective operation of the carbon information disclosure system and the healthy development of the market, the government and relevant institutions need to formulate reasonable incentive policies to ensure that third-party verification agencies can obtain sufficient additional benefits through compliant reporting. At the same time, it is also necessary to strengthen supervision and punishment for irregular behaviors to maintain fair competition and order in the market.

(3) As the direct person in charge of carbon information disclosure, construction units should improve their carbon emission reduction capacity, realize the potential value of carbon information disclosure, reduce the cost of carbon emission reduction, strengthen the awareness of carbon emission reduction, and change from passive carbon disclosure to active carbon disclosure.

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