Evolutionary Game Analysis and Stability Control Scenarios of Corporate Environmental Behavior Inspection in China

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Abstract. This paper explores the use of evolutionary game theory to describe the interactions between the stakeholders in China’s corporate environmental behavior inspection system, which includes the State Administration of the government, public participation, and enterprises in a tripartite game model for environmental pollution control exist in the process on the basis of information asymmetry. The simulation results show that the strategy selections of the three stakeholders fluctuate repeatedly, which indicates that the evolutionary stable strategy does not exist in the current interactions between the stakeholders. Therefore, the dynamic penalty control scenario and an optimized dynamic penalty-incentive control scenario were proposed to control the fluctuations and then simulated again. And the simulation results indicated that the dynamic penalty control scenario can effectively restrain the fluctuations and make stakeholder interactions more stable. The analysis and results of this paper are to help decision-support for environmental governance.

Introduction

The creation of enterprise pollution behavior is because of environmental negative externality, thus the key point of solving problem is turning the environmental negative externality into internalization. Meanwhile many scholars do the research of those two methods about enterprise pollution behavior influence\cite{1-3}. However, based on the current reality, pollution managing and environment protection go much less with the human expectation, enterprise pollution behavior is always exposed by the media, this also shows that Chinese directly administrative control exists the problem of control implementation, which is inefficient and incapable to control the environmental deterioration\cite{4-6}. Because of public participation, the enterprise environmental behavior becomes more complicated, therefore, it is necessary to use the game theory in order to build the various game theory model of enterprise environmental behavior main participation subject, it has significant reality influence designing efficient regulation and strategy to adjust enterprise environmental behavior and implement environmental protection efficiently.

Public participation in environmental protection measures> is passed by environmental protection department conference at 2nd July 2015 and is implemented from 1st September 2015 (The china environment statistical bulletin). Chinese government completely improves the environmental protection system and promotes public participates in the supervision. Public participation in environmental issues means that citizen has right to participate all environmental profit related decision making and environmental management through some procedures or methods, which owns obligation to supervise the governmental decision-making behavior, management behavior and the department and personal environmental resource using behavior in order to make each activity meet the public profits and be beneficial to the environmental protection\cite{7}. Public participation efficiently changes the bad situation of "government intervention" and "marketing mechanism" and also becomes the important factors of enterprise environmental behavior, especially in community belonged to the enterprise, by the method of democratic model, such as voting, electing, non-governmental organization, protesting and internet...
reporting to restrain the enterprise environmental behavior. According to the existed researches, the analyze of game theory between government and enterprise is a little more than others[8-9], some scholar uses game theory to analyze the enterprise pollution behavior relation between Chinese government and enterprise, builds some government-enterprise game theory model and analyzes each behavior and equilibrium strategy.

The Evolutionary Game Theory Analyze of Enterprise Environmental Behavior

Because of analyzing the dynamic progress of limited rational game theory, evolutionary game theory overcomes the shortcoming of the traditional game theory. It is more appropriate to analyze the dynamic evolutionary process through using evolutionary game theory.

The Design and Describe of Game Theory

It hypothesises different strategies as the different government, enterprise and social public profit and cost: Enterprise Profit $R$, if enterprise chooses to manage the pollution, aiming to satisfy the requirement of environmental protection the increase of cost $C_I$; when government monitors the enterprise, it gives rewards and allowance $S_g$ for managed enterprise, for enterprise which does not manage the pollution it gives penalty $P_s$, because enterprise does not manage the pollution, it will be suffered damage $L_s$ because social public report its bad behavior; for the government, positively regulatory creates supervision cost $C_g$; if government does not monitor the enterprise, it needs to deal with the pollution and pay the disposal fee $F_g$ and suffer the damage $L_g$ because the social public report that the government fails to perform the duty, such as the damage of governmental credibility, trust degree and social influence etc; for the public, based on the western cost-benefit analysis theory, the benefit includes the mode of direct and indirect. Indirect benefit uses the balance between public affordable paying cost and actual cost to express the psychological income. It hypothesizes that if social public supervises the enterprise, reports its bad behaviours, it creates supervisory cost $C_s$, because of reporting pollution enterprise, government gives the rewards $S_{go}$, it is direct benefit; when enterprise manages the pollution, public take participate in the supervision which is indirect benefit $H_s$; when enterprise has no willing to manage pollution, public take participation in the supervision which is indirect benefit $H_s$; $W$ represents enterprise implement the "no-managing" strategy which causes environmental degradation and it needs to be afforded by public, each parameter all greater than zero.

Figure 1. Enterprise Environmental Behavior Regulation Game Tree.

The prospective earnings $U_1$ and $U_2$ represent that government supervises the environmental management and does not supervise the environmental management respectively, and the government average revenue is $U$ dynamic equation as follows:

$$U_1 = p_1(F_g - P_{sb} - S_{sb}) + P_{sb} - F_g - C_g - p_2 S_{go}$$  \hspace{1cm} (1)$$

$$U_2 = p_2 F_g - p_2 L_g - F_g$$  \hspace{1cm} (2)$$
\[ U = p_1 U_1 + (1 - p_1) U_2 \]  
\[ dp_1/dt = p_1 (U_1 - U) = p_1 (1 - p_1) [p_2 (P_{gb} + S_{gb} - C_g - p_2 S_{go} + p_2 L_g)] \]

By the same token, the available duplicator dynamic equation of pollutant discharging enterprises and the public.

\[ dp_1/dt = p_1 (V_1 - V) = p_1 (1 - p_1) [p_2 (S_{gb} - C_s + p_2 P_{gb} + p_2 L_g)] \]

\[ dp_1/dt = p_1 (H_1 - H) = p_1 (1 - p_1) [p_2 (H_g - H_s) + p_2 S_{go} - C_s + H_s] \]

The connect equation (4), (5) and (6) the duplicator dynamic equation between government, public and enterprise:

\[
\begin{cases}
    dp_1/dt = p_1 (1 - p_1) [p_2 S_{gb} - C_g + p_2 P_{gb} + p_2 L_g] \\
    dp_2/dt = p_2 (1 - p_2) [p_1 (H_g - H_s) + p_2 S_{go} - C_s + H_s] \\
    dp_3/dt = p_3 (1 - p_3) [P_{gb} - p_1 (P_{gb} + S_{gb}) - C_g - p_2 S_{go} + p_2 L_g] 
\end{cases}
\]

Based on mentioned above kinetic equation (7), the strategy adjustment of velocity and direction are represented between government surveillance department, public and enterprise. When it equals zero, it reflects the velocity of strategy adjustment is equal to a zero and evolutionary game system, which aims to reach a stable equilibrium state. Therefore, by analyzing Jacobi matrix determinant and tracing game to get the stable equilibrium solution, it also represents the existence of evolutionary game stable strategy. However, it is difficult to analyze Jacobi matrix determinant which is equation (7). Thus, getting strategy option by means of the computer numerical simulation, it is also appropriate for the complex dynamic game of various factors.

**Game Analysis Based on System Dynamics**

In the evolutionary game model, system dynamics is applied to research the stability of equilibrium solution and analyze the monitored and supervised feedback model of enterprise environmental behavior. Besides, according to the above game hypothesis and analysis, game system is made of three subsystems, which are government supervision, public participation management and enterprise, Vensim PLE 6.0 is used to build the SD model of evolutionary game, see Fig. 2.

**Figure 2.** The Evolutionary Game SD model of Enterprise Environmental Behavior Supervision.

Based on above replicator dynamics equation (7), which is defined the functional relationship between game system, level variable, rate variable and auxiliary variable. Let \( C_b = 4, R = 10, P_{gb} = 4, S_{gb} = 2, L_b = 1, C_s = 2, F_g = 2, L_g = 1, C_w = 5, S_{go} = 2, H_g = 3, H_s = 2, W = 2 \). Thus, it gets the balanced strategy combinations of replicator dynamics equation(10), which is eight balanced pure strategy combinations and two mixed strategy combinations, as
below: $P_1(0,0,0)^T$, $P_2(0,1,0)^T$, $P_3(0,0,1)^T$, $P_4(1,0,0)^T$, $P_5(1,1,0)^T$, $P_6(0,1,1)^T$, $P_7(1,0,1)^T$, $P_8(1,1,1)^T$, $P_9(1,6,1,1/2)^T$, $P_{10}(0,3,0,2/3)^T$. Therefore, $P_9$, for instance, is simulated in the above evolutionary game SD model and game result shows as Fig.3. The simulation shows that those three profit related subjects do not initially changed the original strategy, none of them adopt a new strategy, meanwhile it also reflects a relatively balanced status. Similarly, the initial mixed strategy $P_{10}$ and other initial pure strategy $(P_i - P_j)$ have the same simulation result with above result.

![Figure 3. The Game Result of Initial Strategy $P_i$.](image1)

![Figure 4. Strategy $P_i(P_j)$ Changed Game Result.](image2)

However, those relative balanced status is not stable. Take $P_j$ as example, if public gently changes its initial strategy, which is modified the rate of $p_2$ from 1 to 0.999, and then simulating the game system again, the results shows as Fig.4. The result demonstrates that $P_j$ balanced status is not stable. Especially, public strategy trend gently develops to zero, and other two game subjects’ strategy goes repeating fluctuation. Similarly, initial mixed strategy $P_{10}$ and other initial pure strategy $(P_i - P_j)$ have the same simulation with above result. Therefore, the application of system dynamics solves the evolutionary game balanced problem between government, public and enterprise and it is an efficiently solution to analyze the model stability. Besides, numerical simulation result shows that three profit related subject have a fluctuant strategy selection, also demonstrates that the stable evolutionary strategy does not exist.

The Stability Analysis and Test under the Optimal Dynamic Rewards and Punishments Control Project

Therefore, it also mentions the dynamic awards and punishment project, the project performs optimizations[10], which means government launches the dynamic awards and punishment project based on the no managing pollution rate of enterprise, as follows: $P_{10} = P_{10}(1 - p_3) + C_3/p_3$, $S_{10} = S_{10}p_1 + p_1/C_3$. Therefore, it summarizes the dynamic award and punishment projects of replicator dynamic equation between government, public and enterprise.

$$\begin{align*}
\frac{dp_1}{dt} &= p_1(1 - p_1)[2p_1p_3 + p_1^2/4 + 4p_3 - 4p_1p_3 + p_3] \\
\frac{dp_2}{dt} &= p_2(1 - p_2)[p_2 + 2p_3 - 3] \\
\frac{dp_3}{dt} &= p_3(1 - p_3)[2 - 8p_1 + 4/p_3 + 2p_1^2 - 4p_3 - p_1p_3]/4 - p_3]
\end{align*}$$

(8)

![Figure 5. Evolutionary Game SD model of Enterprise Environmental Behavior under Dynamic Award and Punishment Control Project.](image3)
Therefore, the game SD model (Fig. 2) has been optimized and changes into following Fig. 5 by dynamic award and punishment project.

Eq. (8) calculates the Jacobi matrix of duplicator dynamic equation, as follows:

\[
J = \begin{pmatrix}
P_1(1-p_1) & P_1(1-p_1)/p_1(2+2p_1) \\
p_1(1-p_1)/[p_1+2p_1-3] & 2p_1(1-p_1) \\
p_1(1-p_1)/[1-2p_1] & -p_1(1-p_1)
\end{pmatrix}
\]

where

\[
A = (1-2p_1)(2p_1p_1 + p_1^2/4 + 4p_1 - 4p_1 + 3p_1 - p_1 + 3p_1 - p_1 - 3p_1 + 1 - p_1),
\]

\[
B = -8 + 4p_1 - 4p_1 - p_1/4,
\]

\[
N = (1-2p_1)(2-8p_1 + 4p_1 + 2p_1^2/4 - 4p_1 - p_1 - 3p_1 - 4p_1 - 3p_1 + 1 - p_1)[4p_1 - p_1^2/4 - 4p_1 - p_1/4].
\]

It simulates evolutionary game progress under the optimized dynamic award and punishment control situation. When randomly considering the initial strategy of \(P_t(0.5,0.5,0.5)^T\) and \(P_t(0.2,0.7,0.8)^T\), the simulation results show as Fig.6 and Fig.7 respectively.

The simulation result shows that the evolutionary game strategy stabilizes at \(P_3(1,0,0)^T\). Finally, it fully demonstrates that dynamic reward and punishment project have been optimized the system, which not only effectively restrains the fluctuation but also affords an ideal evolutionary stable strategy, enterprise takes almost all of selected pollution managing progress as the optimal strategy. Thus, evolutionary stable strategy is \(P_3(1,0,0)^T\), it is also the evolutionary result when \(p_t \neq 0\) in the case of \(\lim p_t \rightarrow 0\). Similarly, it is also necessary to solve the evolutionary game model and analyze its equilibrium solutions to verify the above simulation results. In order to analyze conveniently, it only analyzes the evolutionary stable strategy, which is \(P_3(1,0,0)^T\) according to the above simulation result. Moreover, the Jacobi matrix as follows:

\[
J(P^*) = \begin{pmatrix}
-[2p_1 + p_1^2/4] & 0 & 0 \\
0 & -2 & 0 \\
p_1(1-p_1)(-4/p_1) & -p_1(1-p_1)(1-2p_1)/4 & -p_1(1-p_1)/4
\end{pmatrix}
\]

Then its characteristic values were obtained below:

\[
\lambda_1 = -2 + p_1^2/4 < 0, \lambda_2 = -2 < 0, \lambda_3 = 3p_1^2/4 - p_1/2 - 4 < 0.
\]

Based on the characteristic values, it gets the evolutionary stable result \(P_3(1,0,0)^T\), it also matches the above result of simulation. Thus, application SD model simulates the progress evolutionary game which is an effective method to solve the stable analysis of equilibrium solution. Besides, optimizing dynamic award and punishment project can effectively restrain the current game, not only makes game to reach a stable status but also affords an ideal evolutionary stable strategy, enterprise choose almost all of pollution managing strategy as the optimal strategy.

**Conclusion**

In the enterprise environmental behavior game, the paper analyzes the game between government, pollution enterprise and public participation, and uses the SD model to analyze the sable equilibrium solution. The simulation result shows that dynamic award and punishment method can effectively maintain the fluctuation, stabilize the game. Besides dynamic award and punishment method has been optimized that not only restrain fluctuation but also affords an ideal evolutionary stable strategy, enterprise chooses to deal with the pollution as the optimal strategy.

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