The Tripartite Evolutionary Game Analysis of Collusive Behavior Regulation in EPR System

Li Ma, and Yunhui Wang

Abstract— In order to prevent possible environment damage due to industrial products' consumption and abandonment, Extended Producer Responsibility (EPR) institution has been widely adopted all over the world after it was firstly promoted by European scientists 30 years ago. Yet EPR institution has encountered many problems during its implementation, as it is human nature to quest for profits and escape punishment, collusive behavior may occurs between producers and auditors, likely to result in "Free-Rider" problem, and cause serious disadvantage to the whole system of EPR. Aiming at resolving collusive behavior problem, this article builds tripartite evolutionary game model which involves the producers, auditors and government authorities to analyze the important factors affect the tripartite game equilibrium, explores the creation conditions and elusion tactics of collusive behavior in EPR system and propose some countermeasures.

Keywords –Extended Producer Responsibility (EPR), collusive behavior, free rider, evolutionary game theory

I. Introduction

A LARGE number of abandoned industrial products lack of appropriate treatment cause serious resource waste and environmental pollution in our modern society. Environmental negative externality problem is not the incidental byproduct of a small number of economic activities, but a necessary result rooted in the economic decision-making framework formed by market, social and governmental forces [1]. In response to increasingly serious environmental problems, the Swedish environment economist Thomas Lindhquist proposed Extended Producer Responsibility (EPR) in 1988, which has been considered as one of the most promising means to solve waste products problem by the Organization for Economic Co-operation and Development (OECD) and the European Union (EU) [2]. EPR is a kind of environmental protection strategy based on the "polluter pays" logic and it advocates extending the responsibility of producers to recycling, processing and final disposal of the product in post-consumer stage, in order to achieve optimal product life cycle environmental performance [3].

Research on ERP has gained abundant achievements. Thomas' Ph.D. thesis in 2000 entitled "Extended Producer Responsibility in Clean Production" expounded the background, connotation, objectives, implementation methods, and some countries' EPR practical experiences [4].

Li Ma is with the School of Business, Dalian University of Technology, Panjin, China.

Yunhui Wang is with the School of Business, Dalian University of Technology, Panjin, China.

This work was supported by Major projects of the National Social Science Foundation under Grant 13& ZD147.

Subsequently a lot of research on EPR issues has emerged, OECD published "EPR: government work guideline", "EPR economic analysis" and "The cost-benefit assess analysis framework of EPR project" in 2001, 2004 and 2005 respectively. Thomas' original theoretical research and subsequent practical work of OECD laid the foundation of world EPR research and practice. Sander and Tojo et al. summed up the WEEE (Waste Electrical and Electronic Equipment) disposal practice in European Union [5]. Akenjin, Manomaivibool and Dwivedy et al. discussed the EPR practice in Thailand, India and some other Asian countries [6]-[8].

In 2008, China National People's Congress promulgated the "Circular Economy Promotion Law" and started the implementation of EPR institution in China. Before and after this policy kicked in, some scholars studied issues related to the implementation of EPR institution according to Chinese conditions. Zhao, Fu and Zhen et al. described the interactive relationship between the government and core enterprises, constructed static and dynamic evolutionary game models between the government and core enterprises in complete information situation and proposed countermeasures from different perspective [9]-[11]. Wang, Yin et al. pointed out that the recycling systems and regulations had a significant impact on the effect of waste product recycling [12]. Zhong et al. concluded that recycling vendors can be encouraged to participate in environmental dismantling if government impose environmental costs on illegal dismantling or raise the recycling price of qualified recycling business [13].

A common concern among EPR research scholars is the producers' "free rider" problem which may exist in the implementation of EPR. In EPR system, "Free rider" refers to the behavior that producers speculate to evade the extended responsibility so as to enjoy preference of levy policy without paying the corresponding costs, for instance, the German "Dual System" recycling system once suffered great losses due to the "free rider" behavior of the producers [3], Myanmar also regards "free rider" as the important factor influences the implementation effect of EPR institution.

At present, China has implemented EPR institution in WEEE, automobile, packaging and so on. But in view of China's conditions, how to manage and respond to the collusive behavior issues between producers and auditors in EPR system, the discussion is far away from sufficiency. Therefore, this paper uses the analysis tool of evolutionary game theory to build the tripartite game model which involves the producers, auditors and governmental authorities, through analyzing game equilibrium conditions, so as to put forward corresponding countermeasures and suggestions

II. Evolutionary Game Modeling

A. The Basic Assumptions and Payoff Matrix Modeling

Since EPR institution has extended the responsibility of producers to the post-consumer stage, these enterprises are required to perform their corresponding duty. The auditors assigned by the related government authorities will examine the producers' EPR implementation situation and report to the government authorities. If the producers are found to have well fulfilled their obligations, of course they should have paid additional costs to do that, usually they will be subsidized to a certain percentage by the government. On the contrary, the producers will be required to pay waste products handling funds or even be fined if they cannot pass the inspection, if this happens, their production costs will be forced to improve accordingly. Therefore, in order to be entitled to enjoy subsides without bearing the costs brought by fulfilling EPR obligations, some producers might collude with auditors. To avoid this risk, government authorities may need to pay additional human, financial costs to supervise activities of the producers and auditors, thus form a tripartite game relationship among the producers, auditors and government authorities. Based on game theory, we try to model this relationship. The basic assumptions of the tripartite game model are listed below and the meanings of the parameters are shown in Table I.

TABLE I
THE MAIN PARAMETERS MEANING IN THE MODEL

Parameters	Parameters' connotations
C	Costs producers pay by ERP implementation
R	Benefits producers can get by ERP implementation
E_b	Fines imposed on producers if fail to fulfill EPR
E_d	Costs of the producers if collude with auditors
E_r	Penalty to the auditors' collusion behavior
E_p	Penalty to the producers' collusion behavior
C_g	Government authorities' regulatory cost

(a) Producers' collusion cost E_d must be less than the additional cost $\mathrm{C} + E_b - R$ caused by being forced to carry out EPR obligations if their undone tasks are found by inspection, that is, $E_d < \mathrm{C} + E_b - R$, otherwise the producers have no motivation to collude with auditors.

(b) If the government authorities were well-functioned, no weaknesses and loopholes in the regulation, they must be able to find out the collusion behavior between the producers and auditors.

(c) When government authorities select to engage in regulatory strategy, if collusive behavior between the producers and auditors are found, then the producers should be ordered to fulfill the EPR obligations and pay fine E_b, in addition, fine E_p, E_r should be imposed to the producers and auditor respectively; if the collusion behavior does not occur between the producers and auditors, then it means that the government authorities waste regulation cost C_g, but get confiscated income E_b for the producers' failing to fulfill EPR obligations[13].

(d) When government authorities choose not to regulate, if the producers and auditors occur collusion behavior, "free riders" effects take place, government authorities will be forced to bear the cost C of recycling waste products; and if the producers and auditors do not collude, the auditors report the truth to the government authorities according to actual situation, then the producers which fail to fulfill EPR obligations will be forced to do that and pay fine E_b, meanwhile government authorities will obtain confiscated income E_b.

Game tripartite pay-off matrix of the three parties is shown in Table II.

TABLE II
TRIPARTITE GAME PAY-OFF MATRIX

Profits		Regulation	Non Regulation
Collusion	Government authorities	$-C_g + E_d + E_b + E_p + E_r$	$-C$
	Producers	$-E_r$	E_d
	Auditors	$-E_d - E_b - C + R - E_p$	$-E_d$
Non collusion	Government Authorities	$-C_g + E_b$	E_b
	Producers	0	0
	Auditors	$-E_b - C + R$	$-E_b - C + R$

B. The Model

In reality, the producers, auditors, and government authorities are not guaranteed to get accurate judgement of each other's strategy choice, and they are more likely to adopt mixed strategy, namely, all parties determine their own action plan by a certain probability distribution, so as to achieve hybrid strategy equilibrium. Under the equilibrium condition, any party is not likely to gain extra benefits by changing its own tactics. We use evolutionary game theory to solve the equilibrium point. Assume that the producers and the auditors' collusion ratio is x, then non collusion ratio is $1 - x$; the probability of the government authorities to select regulation is y, then non regulation probability is $1 - y$. According to the tripartite game pay-off matrix, the expected profit of the producers who select to collude with the auditors is :

$$C_Y = y(-E_d - E_b - C + R - E_p) + (1 - y)(-E_d) = y(-E_b - C + R - E_p) - E_d \quad (1)$$

The expected profits of the producers who select not to collude with the auditors is:

$$C_N = y(-E_b - C + R) + (1 - y)(-E_b - C + R) = -E_b - C + R \quad (2)$$

Average profit of the producers' hybrid strategy is:

$$\bar{C} = xC_Y + (1 - x)C_N = xy(-E_b - C + R - E_p) - x(E_d - E_b - C + R) + (-E_b - C + R) \quad (3)$$

The Expected profits of the government authorities who select to engage in regulatory strategy is:

$$G_Y = x(-C_g + E_d + E_b + E_p + E_r) + (1 - x)(-C_g + E_b) = x(E_d + E_p + E_r) + (-C_g + E_b) \quad (4)$$

The Expected profits of the government authorities who select not to regulate is:

$$G_N = x(-C) + (1 - x)E_b = E_b + x(-E_b - C) \quad (5)$$

The average profit of the government authorities' hybrid strategy is:

$$\bar{G} = yG_Y + (1 - y)G_N = xy(E_d + E_p + E_r + E_b + C) +$$

$$y(-C_g) + x(-E_b - C) \quad (6)$$

III. Evolutionary Game Equilibrium Analysis

A. The Producers and Auditors' Collusion Probability Replicator Dynamics Equation

The producers and auditors' collusion Probability replicator dynamics equation is:

$$F(x) = \frac{dx}{dt} = x(C_Y - \bar{C}) = x(x-1)\left[y\left(E_b + E_p + C - R\right) + \left(E_d - E_b - C + R\right)\right] \quad (7)$$

When $y = \frac{E_b+C-R-E_d}{E_b+E_p+C-R}$, $F(x) \equiv 0$, no matter x takes any value, the game is in a state of equilibrium.

When $y \neq \frac{E_b+C-R-E_d}{E_b+E_p+C-R}$, let $F(x) = 0$, then $x_1 = 0, x_2 = 1$ are the two equilibrium points.

Take the derivative of $F(x)$.

$$\frac{dF(x)}{dx} = (2x-1)\left[y\left(E_b + E_p + C - R\right) + \left(E_d - E_b - C + R\right)\right] \quad (8)$$

Evolutionary stable strategy (ESS) requires $\frac{dF(x)}{dx} < 0$.

When $y > \frac{E_b+C-R-E_d}{E_b+E_p+C-R}$, $y\left(E_b + E_p + C - R\right) + \left(E_d - E_b - C + R\right) > 0$, so $\frac{dF(x)}{dx}|_{x=1} > 0, \frac{dF(x)}{dx}|_{x=0} < 0$, therefore $x = 0$ is the equilibrium point, the producers tend to choose not to collude with the auditors;

When $y < \frac{E_b+C-R-E_d}{E_b+E_p+C-R}$, $y\left(E_b + E_p + C - R\right) + \left(E_d - E_b - C + R\right) < 0$,so$\frac{dF(x)}{dx}|_{x=1} < 0, \frac{dF(x)}{dx}|_{x=0} > 0$, therefore $x = 1$ is an equilibrium point, the producers tend to choose to collude with the auditors.

Dynamic trend and stability of the producers and auditors' strategic choices under the condition of three kinds of different Y values is shown in Fig.1.

B. The Government Authorities' Regulation Probability Replicator Dynamics Equation

The Government Authorities' Regulation Probability Replicator Dynamics Equation is:

$$F(y) = \frac{dy}{dt} = y(G_Y - \bar{G}) = y(1-y)\left[x\left(E_d + E_b + E_p + E_r + C\right) - C_g\right] \quad (9)$$

When $x = \frac{C_g}{E_d+E_b+E_p+E_r+C}$, $F(y) \equiv 0$, no matter y takes any value, the game is in a state of equilibrium.

When $x \neq \frac{C_g}{E_d+E_b+E_p+E_r+C}$, let $F(y) = 0$ then $y_1 = 0, y_2 = 1$ are the two equilibrium points.

Take the derivative of $F(y)$

$$\frac{dF(y)}{dy} = (1-2y)\left[x\left(E_d + E_b + E_p + E_r + C\right) - C_g\right]. \quad (10)$$

Evolutionary stable strategy (ESS) requires $\frac{dF(y)}{dy} < 0$.

When $x > \frac{C_g}{E_d+E_b+E_p+E_r+C}$, $x\left(E_d + E_b + E_p + E_r + C\right) - C_g > 0$, so $\frac{dF(y)}{dy}|_{y=0} > 0, \frac{dF(y)}{dy}|_{y=1} < 0$, therefore $y = 1$ is the equilibrium point, the government authorities tend to choose to regulate.

When $x < \frac{C_g}{E_d+E_b+E_p+E_r+C}$, $x\left(E_d + E_b + E_p + E_r + C\right) - C_g < 0$,so $\frac{dF(y)}{dy}|_{y=0} < 0, \frac{dF(y)}{dy}|_{y=1} > 0$, therefore $y = 0$ is the equilibrium point, the government authorities tend to choose not to regulate.

Dynamic trend and stability of the government authorities' strategic choices under the condition of three kinds of different X values is shown in Fig.2.

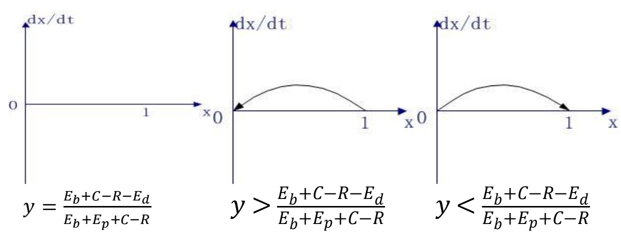

Fig.1. Replicator dynamics phase diagram of the producers and auditors

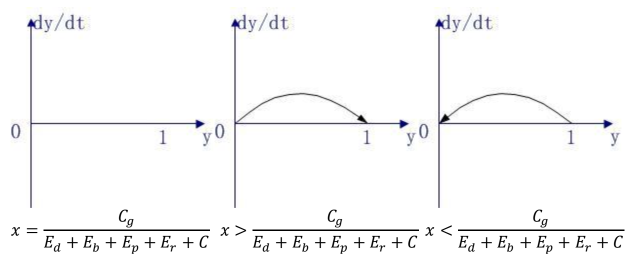

Fig.2. Replicator dynamics phase diagram of the government authorities

C. Tripartite Evolutionary Game Stability Analysis

1. Tripartite Evolutionary Game Equilibrium Solution

Place the tripartite replicator dynamic trends in the coordinate plane, as is shown in Fig. 3. Four kinds of equilibrium can be obtained:

TABLE III
JACOBI MATRIX'S VALUE AND TRACE OF EACH EQUILIBRIUM POINT

Equilibrium points	detJ	trJ
(0, 0)	$(E_d + R - E_b - C)C_g$	$E_d + R + C_g - (E_b + C)$
(0, 1)	$(E_d + E_p)C_g$	$C_g + E_d + E_p$
(1, 0)	$(E_d + R - E_b - C)(E_d + E_b + E_p + E_r + C - C_g)$	$2E_b + E_p + E_r + R - C_g$
(1, 1)	$(E_d + E_p)\,[C_g - (E_d + E_b + E_p + E_r + C)]$	$C_g - (E_b + E_r + C)$

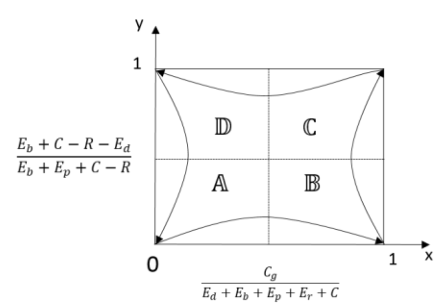

Fig.3. Tripartite evolutionary game track schematic

When the initial state falls in $\mathbb{A}$ region, the game converges to the equilibrium point $(x = 1,\ y = 0)$, namely, (Collusion, Non Regulation) is the necessary choice of all participants in the triple game which include the producers, auditors and government authorities.

When the initial state falls in $\mathbb{B}$region, the game converges to the equilibrium point $(x = 1,\ y = 1)$, namely, (Collusion, Regulation) is the necessary choice of all participants in this triple game.

When the initial state falls in $\mathbb{C}$ region, the game converges to the equilibrium point $(x = 0,\ y = 1)$, namely, (Non Collusion, Regulation) is the necessary choice of all participants in this triple game.

When the initial state falls in $\mathbb{D}$egion, the game converges to the equilibrium point $(x = 0,\ y = 0)$, namely, (Non Collusion, Non Regulation) is the necessary choice of all participants in this triple game.

According to the method proposed by Friedman [14], the group dynamics described by a differential equations system, the stability of equilibrium point can obtained by analysis of local stability of Jacobi matrix, i.e., if the determinant value of the matrix is positive and the trace is negative, the partial equilibrium point is the evolutionarily stable strategy (ESS); if the determinant value of the matrix and the trace are both positive, then the partial equilibrium point is not a stable point; if the determinant value of the matrix is positive and the trace is 0, then the partial equilibrium point is the saddle point. The game's Jacobi matrix is as follows:

$$
\mathrm{J} = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix}
= \begin{bmatrix} (2x-1)[y(E_b+E_p+C-R)+(E_d-E_b-C+R)] & x(x-1)(E_b+E_p+C-R) \\ y(1-y)(E_d+E_b+E_p+E_r+C) & (1-2y)[x(E_d+E_b+E_p+E_r+C)-C_g] \end{bmatrix}
$$

Stability analysis of the four equilibrium points is shown in Table III.

2. Parameter Analysis

(a) According to the above mentioned basic assumptions (b), $E_d + R - E_b - C < 0$, know $\det\mathrm{J} < 0$, the value of $\mathrm{tr}\mathrm{J}$ is uncertain, (0,0) is the saddle point.

(b) In any case, (0, 1) point is the unstable point.

(c) When $E_b + C - R > E_d$ and $E_d + E_b + E_p + E_r + C < C_g$, if $2E_b + E_p + E_r + R < C_g$, namely $C_g > max(2E_b + E_p + E_r + R, E_d + E_b + E_p + E_r + C)$, then (1,0) point is the stable point, the producers and auditors collude, the government authorities do not regulate; if $2E_b + E_p + E_r = C_g$, then (1,0) point is the saddle point; if $2E_b + E_p + E_r > C_g$, then(1,0) point is the unstable point.

(d) When $E_d + E_b + E_p + E_r + C < C_g$, $C_g > E_b + E_r + C$ is always true, then (1,1) is always the unstable point.

IV. CONCLUSIONS

By above game analysis, we draw the following conclusions:

First, through parameter analysis (c), we found that if the government authorities' regulation cost C_g is greater than the maximum of all fine plus costs of the producers to implement EPR, the government authorities will choose not to regulate, and then the producers and auditors will select to collude, that means the government authorities should control the regulation cost within scope of $C_g < max(2E_b + E_p + E_r + R, E_d + E_b + E_p + E_r + C)$, otherwise it is not conducive to resolve collusive behavior problem. To improve this situation, the government authorities need to reduce regulation cost by improving existing regulation mechanism and introducing advanced management method.

Second, the assumption (b) shows that if $E_d > E_b + C - R$, namely, if the collusion cost between the producers and auditors is too high, collusion does not occur, therefore we can try to create more collusion obstacles of the producers and auditors through the means of improving the regulation mechanism so that to prevent "free rider" phenomenon.

Third, each party's initial selection proportion in the evolutionary game makes disparate equilibrium status in final result, therefore the government authorities should strengthen the publicity and education of EPR institution, so that the producers and auditors can fully understand the significance of EPR implementation, think about their own behavior from the perspective of sustainable development, and regard EPR system as a measure to keep their own long-term interests, so that they obey the law voluntarily.

Fourth, for all producers, if$-C + R > 0$, namely, the producers can benefit from the EPR implementation, "free riders" can be completely eliminated. Therefore, through incentives, the government authorities can actively guide the producers to develop "recycling technology," and take advantage of waste products efficiently, so that the ideal EPR effects can be realized.

REFERENCES

[1] Zhao YP, Zhu QH, Fu ZQ, "Development and Implication of Product-oriented Environmental Management Institutions ", *Science& Technology Progress and Policy*, 2008, 08:122-125.

[2] Nnorom I C, Osibanjo O, "Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries", *Resources, conservation and recycling*, 2008, 52(6): 843-858. http://dx.doi.org/10.1016/j.resconrec.2008.01.004

[3] Lifset R, Atasu A, Tojo N. "Extended Producer Responsibility ". *Journal of Industrial Ecology*, 2013, 17(2): 162-166 http://dx.doi.org/10.1111/jiec.12022

[4] Lindhqvist T. "Extended producer responsibility in cleaner production: Policy principle to promote environmental improvements of product systems", Doctor Dissertation, Lund University, Sweden, 2000.

[5] Sander K, Tojo N, Vernon J. The Producer Responsibility Principle of the WEEE Directive. DG ENV. Study Contract N° 07010401/2006/449269/MAR/G4, Aug., 2007.

[6] Akenji L, Hotta Y, Bengtsson M, et al. "EPR policies for electronics in developing Asia: an adapted phase-in approach". *Waste Management & Research*, 2011: 0734242X11414458.

[7] Manomaivibool P, Vassanadumrongdee S. "Extended producer responsibility in Thailand". *Journal of Industrial Ecology*, 2011, 15(2): 185-205 http://dx.doi.org/10.1111/j.1530-9290.2011.00330.x

[8] Dwivedy M, Suchde P, Mittal R K. "Modeling and assessment of e-waste take-back strategies in Indian". *Resources, Conservation and Recycling*, 2015, 96: 11-18. http://dx.doi.org/10.1016/j.resconrec.2015.01.003

[9] Zhao YP, Zhu QH, Wu CY. "Strategies for Choice of EPR-Oriented Government and Production Enterprises' Behaviors Using Game Analysis", *Chinese Journal of Management,* 2007, 06:737-742.

[10] Fu XY, Zhu QH, Dou YJ. "Evolutionary Game Analysis of Governments and Electronic Manufacturers Based on the Implementation of WEEE

Regulations”. *Management Review*, 2011, 10:171-176.
[11] Zheng YH, Tian HF, “Government and Producer’s Game Analysis and System Based on EPR”. *Operations Research and Management Science*, 2012, 06:217-224
[12] Wang ZH, Yin JH. “Factors and Characteristics of E-waste recycling for Chinese Household Electrical Appliance enterprises (in Chinese)”, *Management World*, 2008, 04:175-176.
[13] Zhong YG, Qian Y, Yin FF, Zhou XD.“ Stimulating residents to recycle waste electrical and electronic equipments: A system dynamics model”, *Systems Engineering-Theory& Practice*, 2010, 04:709-722.
[14] Friedman D. “Evolutionary games in economics” *Econometrica: Journal of the Econometric Society*, 1991: 637-666.
http://dx.doi.org/10.2307/2938222