A Three-Player Game Model for the Green Supply Chain in the Home Appliance Industry

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Abstract: Green supply chain management is an effective management approach for the home appliance industry to pursue the strategy of sustainable development and improve product international competitiveness. In this paper, a three-player game model is proposed to study the relationship and game status among governments, enterprises and consumers in the green supply chain of the home appliance industry. The equilibrium analysis shows that the subsidy and penalty from the governments play an important role in encouraging enterprises to deploy green strategy and motivating consumers to buy green home appliance. Moreover some countermeasures are put forward from the perspective of supervision by government.
Key words: Green supply chain; Home appliance industry; Three-player game; Static games of complete information

1 Introduction

Since the beginning of the 21st century, the topic of protecting ecological environment and realizing sustainable development has been receiving increasing scrutiny from both researchers and practitioners. Many countries in the world have issued many strict environmental protection laws and regulations to strengthen the environmental protection and management, especially in the recent years.

WEEE directive 2002/96/EC (Waste Electrical and Electronic Equipment, as amended by 2003/108/EC) and RoHS directive 2002/95/EC (Restriction of Hazardous Substances) are two important regulations relating to household electrical and electronic equipment used by consumers. The objective of the WEEE directive is to improve the level of environmental protection within the European Union through the reduction of waste from household electrical and electronic equipments. Equipment producers are responsible for the management of takeback and disposal of waste starting from 13 August 2005. The RoHS directive aims at the harmonization of the legislation in the EU Member States on the restriction of the use of hazardous substances in household electrical and electronic equipment. The general rule is that equipment containing a certain level of lead, mercury, cadmium, hexavalent chromium, PBB's and PBDE's may not be placed onto the market after 1 July 2006. As a main country of manufacturing and exporting home appliances, China will be seriously affected by these regulations. Therefore, there is no time to delay for Chinese home appliance industry to establish green supply chain, which could be of great significance to improve our product competitiveness in international markets, protect the environment and implement the strategy of sustainable development. However the green supply chain of the home appliance industry is more complex than the traditional one due to its diversifying components and operational objectives, therefore, the coordination and management could be much more difficult [1]. The mutual relationships between the main stakeholders will certainly influence the effective implementation of the green supply chain in the home appliances. Therefore, it is necessary to analyze the relationships among governments, enterprises and consumers in the green supply chain of the home appliance industry in order to promote its further development.

2 Research Status on the Game Analysis of Green Supply Chain

It has not been a long time since the concept of Green Supply Chain was proposed. That was in 1996, the National Scientific Funds (NSF) in USA provided $400,000 financial aid to the Manufacture Research Consortium (MRC) in Michigan State University to conduct a research project named “Environmental Responsible Manufacture” and then the definition of Green Supply Chain was proposed firstly [2]. From then on, more and more scholars began to research the green supply chain from different perspectives. The so-called green supply chain is a kind of modern management mode which takes the environmental impact and resource efficiency into a comprehensive consideration within the entire

supply chain. Taking green manufacturing theory and supply chain management technology as the foundation, it involves suppliers, manufacturers, distributors and users, with the purpose to make the environmental impact (negative effect) minimum and resource efficiency maximum during the whole process from material acquisition, processing, packaging, storage, transportation, usage to scrapping [3]. The basic objective of green supply chain management is to protect environment and make use of resources effectively.

As for game theory, in mathematics, it models strategic situations, or games, in which an individual's success in making choices depends on the choices of others [4]. Game theory has been wildly used in many subject areas, including the field of supply chain management. Many researchers have studied supply chain coordination with contracts and proposed many game models.

However, game analysis between the participating subjects in the green supply chain is very limited. Most of the existing research results are about the game analysis between governments and enterprises. Pantumsinchai (1992) [5] pointed out that government's support increased enterprise's economic and environmental performance, and then the enterprise further integrated and make the whole supply chain 'green'. In order to investigate the game between governments and core-enterprises in green supply chains, Zhu and Dou (2007) [6] analyzed their respective costs and benefits, and studied the game status by evolutionary game theory. Li and Liu et al (2007) [7], from the government supervision's angle, built up dynamic game models of reverse logistics by using the game theory. Xu and Zheng (2008) [8] studied the relationship between governments and corporations in green supply chain under the condition of impeaching. Cao and Wen (2011) [9] set up a game model between governments and enterprises in green supply chain and analyzed their behavior and equilibrium strategies. There are also a few scholars having tried to conduct preliminary analysis of the multilateral game relationship between governments, enterprises and consumers in the green supply chain, e.g., Wang (2004) [10], Yu and Liu (2011) [11].

Some researchers analyzed the relationship between the enterprises within green supply chain, e.g., Wang and Yan (2009) [12] analyzed the respective costs and benefits of suppliers and core-enterprise in green supply chain, and established an evolutionary game model between governments and enterprises based on evolutionary game theory. Hou and Wang (2010) [13] studied the relationship between enterprises of green supply chain and those of traditional one.

Some scholars conducted some analysis of the game relationship in the green supply chain connected with specific industries, e.g., Zhou and Zhang (2007) [14] analyzed the relationship between government, coal and electricity, Feng and Wang (2010) [15] analyzed the different intention and game action between client and general contactor in the progress of constructing green supply chain in construction industry. The authors of this paper have ever analyzed the relationship between enterprises and consumers in the green supply chain of the home appliance industry [16].

It can be found that the research results about the game analysis between the main stakeholders is so limited and there is no research result found about the game relationship analysis connected with the background of home appliance industry except the authors' previous study. Concerning of the pressure from the more strict environmental rules such as WEEE and RoHS, it will be essential to study the game relationship between the main stakeholders in the green supply chain of the home appliance industry, which will be helpful to promote the construction and development of the green supply chain.

3 A Three-Player Game Model among Governments, Enterprises and Consumers

3.1 Basic assumptions and definitions

The construction of the green supply chain in the home appliance industry requires involvement of governments, enterprises, consumers and other relevant society members. In order to facilitate the analysis, here we assume that there are only three stakeholders, i.e. governments, home appliance enterprises (simply as "enterprises") and consumers. In other words, the game is a three-player game. Governments refer to local governments and also include some relevant organizations or committees who focus on the environment protection and are entitled to issue some environmental regulations or rules. Enterprises refer to those who are engaged in home appliances manufacturing or sales and consumers get home appliances from enterprises. Meanwhile, we assume that governments, enterprises and consumers are all rational economic men, who take the benefit maximization as their goal. All players of the game know the strategies and payoffs of others. In short-term equilibrium, the game problem can be regarded as a kind of static games of complete information and seek Nash equilibrium.

In the current market conditions with green home appliances and traditional home appliances coexist, the enterprises have two strategies: one is to offer green home appliances, e.g., home appliance

manufacturers actively develop ecological design and introduce some available technologies to manufacture green home appliances, or retailers actively promote and sell the green home appliances; the other one is to offer traditional home appliances by using traditional methods to design, manufacture and sell home appliances, and in this circumstance enterprises will be punished by governments and pay for penalty due to not meeting the requirements of environmental protection. Consumers also have two strategies to adopt: i.e., acceptance or rejection. Here we assume that consumers should return the waste home appliances when they decide to accept green home appliances, and they can get an amount of compensation from governments correspondingly, which just reflects the current policy of "trading in old appliances for a new one" in China. As for governments, they can adopt the strategy of nonsupervision, which means they will supervise whether the enterprises has deployed green supply chain management. If they find the enterprises are offering green home appliances, they give them a sum of money as subsidy. Conversely they will punish the enterprises. Governments can choose the strategy of Nonsupervision too, which means they will do nothing, so there is no subsidy and no penalty in this case.

According to existing literatures, we make some assumptions and definitions about the benefits and the costs for governments, enterprises and consumers in order to determine the payoff for each player with every possible combination of actions. When enterprises choose to offer traditional home appliances, R_B and C_B respectively represent the total revenues and the total costs, and F_B represents the payable penalty to governments due to not meeting the requirement of implementing green supply chain. When enterprises choose to offer green appliances, R_B' and C_B' respectively represent the total revenues and the total costs in this case, and S_B represents the subsidy that they can obtain from governments. As for consumers, according to western theory of cost-benefit analysis, the benefits include indirect benefits and direct benefits. Indirect benefits can be expressed by the difference between the price consumer willing to pay psychologically and the actual one, and R_C and R_C' respectively represent the indirect benefits from traditional home appliances and green ones. Here direct benefit mainly refers to the subsidy S_C from governments if the consumers return the waste home appliances at the same time of choosing green home appliances. As for governments, except the subsidy S_B and S_C, C_E represents the costs of supervision and L_E shows the loss of the social welfare due to the environmental disruption from the traditional home appliances. It should be pointed out that the revenue may be increased if enterprises choose to offer green home appliances, but the cost could be increased correspondingly. Normally there could be such relation as $R_B'-C_B' < R_B-C_B$, because if not, enterprises will inevitably choose to offer green appliances, because they can not only obtain an extra subsidy, but also not to be punished by governments. Meanwhile $R_C'+S_C >0$, because our intention is to motivate consumers to accept green home appliances, therefore, the benefits to consumers including the subsidy should be at lease greater than zero.

3.2 Payoff matrix of governments, enterprises and consumers

Based on the above assumptions and definitions, we can construct a three-player game model among governments, enterprises and consumers, which is represented by a payoff matrix shown in Table 1. Each player has two strategies, which are specified following the name of players. The payoffs are provided in the interior. The first number is the payoff received by enterprises; the second is the payoff for the consumers; and the third is the payoff for governments.

Table 1 Payoff Matrix of Governments, Enterprises and Consumers

		Consumers Acceptance (C_1)	**Consumers** Rejection (C_2)
Governments Supervision (E_1)	**Enterprises** Offer Green Home Appliances (B_1)	$R_B'-C_B'+S_B$, $R_C'+S_C$, $-C_E-S_B-S_C$	$-C_B'+S_B$, 0, $-C_E-S_B$
	Enterprises Offer Traditional Home Appliances (B_2)	$R_B-C_B-F_B$, R_C, $-C_E-L_E+F_B$	$-C_B-F_B$, 0, $-C_E-L_E+F_B$
Government Nonsupervision (E_2)	**Enterprises** Offer Green Home Appliances (B_1)	$R_B'-C_B'$, R_C', 0	$-C_B'$, 0, 0
	Enterprises Offer Traditional Home Appliances (B_2)	R_B-C_B, R_C, $-L_E$	$-C_B$, 0, $-L_E$

4 Equilibrium Analysis of the Three-Player Game Model

4.1 Nash equilibriums

Through a basic analysis of the above-proposed three-player game model, it could be found that six strategies combinations will probably be pure strategy Nash equilibriums under particular conditions, i.e., (Offer Green Home Appliances, Acceptance, Nonsupervision), (Offer Green Home Appliances, Rejection, Nonsupervision) (Offer Traditional Home Appliances, Supervision), (Offer Traditional Home Appliances, Rejection, Supervision), (Offer Traditional Home Appliances, Acceptance, Nonsupervision) and (Offer Traditional Home Appliances, Rejection, Nonsupervision). Among them, the strategies combination (Offer Green Home Appliances, Acceptance, Nonsupervision) is an ideal equilibrium, which could exists when $R_B'-C_B'>R_B-C_B$ and $R_C'>0$. This indicates that the enterprises' payoff of offering green appliances surpasses the amount of offering traditional appliances, therefore, enterprises will be certainly choose to offer green home appliances. At the same time, the consumers' benefit of accepting green home appliances is more than the one when they choose traditional appliances. Hence governments do not need to supervise. As for the strategies combination (Offer Green Home Appliances, Rejection, Nonsupervision), it is obviously an unreasonable state, which will occurs when $C_B'<C_B$ and $R_C'<0$. In this circumstance, there must be some problem of the pricing for the green home appliances. If changing the pricing policy, the equilibrium state will move to the ideal one. It should be noted that the condition $R_B'-C_B' >R_B-C_B$ is hard to achieve in reality, because normally the costs increase will be more than revenue increase in the green supply chain.

If the guidance of governments comes into play, e.g., governments set up suitable S_B, S_C and F_B, there will be mixed strategies equilibrium, where a pure strategy is chosen at random, subject to some fixed probability, and the green supply chain will come true too. Here we assign enterprises the probability p_1 of playing B_1 (Offer Green Home Appliances) and $(1-p_1)$ of playing B_2 (Offer Traditional Home Appliances), assign consumers the probability p_2 of playing C_1 (Acceptance) and $(1-p_2)$ of playing C_2 (Rejection), and assign governments the probability p_3 of playing E_1 (Supervision) and $(1-p_3)$ of playing E_2 (Nonsupervision), where $0\le p_1\le 1$, $0\le p_2\le 1$ and $0\le p_3\le 1$, then the expected revenue of different strategies for governments, enterprises and consumers can be determined by the following equations.

$$\begin{aligned} E_{E_1}(p_1,p_2,p_3) &= p_1[p_2(-C_E-S_B-S_C)+(1-p_2)(-C_E-S_B)] \\ &\quad +(1-p_1)[p_2(-C_E-L_E+F_B)+(1-p_2)(-C_E-L_E+F_B)] \\ &= -p_1p_2S_C+p_1(-S_B-F_B+L_E)+(-C_E+F_B-L_E) \end{aligned} \tag{1}$$

$$E_{E_2}(p_1,p_2,p_3) = p_1[0p_2+0(1-p_2)]+(1-p_1)[p_2(-L_E)+(1-p_2)(-L_E)] = (1-p_1)(-L_E) \tag{2}$$

$$\begin{aligned} E_{B_1}(p_1,p_2,p_3) &= p_3[p_2(R_B'-C_B'+S_B)+(1-p_2)(-C_B'+S_B)]+(1-p_3)[p_2(R_B'-C_B')+(1-p_2)(-C_B')] \\ &= p_3S_B+p_2R_B'-C_B' \end{aligned} \tag{3}$$

$$\begin{aligned} E_{B_2}(p_1,p_2,p_3) &= p_3[p_2(R_B-C_B-F_B)+(1-p_2)(-C_B-F_B)]+(1-p_3)[p_2(R_B-C_B)+(1-p_2)(-C_B)] \\ &= p_2R_B-p_3F_B-C_B \end{aligned} \tag{4}$$

$$E_{C_1}(p_1,p_2,p_3) = p_3[p_1(R_C'+S_C)+(1-p_1)R_C]+(1-p_3)[p_1R_C'+(1-p_1)R_C] = p_1p_3S_C+p_1R_C'+(1-p_1)R_C \tag{5}$$

$$E_{C_2}(p_1,p_2,p_3) = 0 \tag{6}$$

For governments, enterprises or consumers, when the expected revenue of their two strategies is equal, the game will reach to an equilibrium state and then we can determine the probability p_1, p_2, and p_3 correspondingly.

$$MakeE_{E_1}=E_{E_2},\qquad then\qquad p_1=\frac{F_B-C_E}{S_B+F_B+p_2S_c} \tag{7}$$

$$MakeE_{B_1}=E_{B_2},\qquad then\qquad p_2=\frac{p_3(S_B+F_B)+(C_B-C_B')}{R_B-R_B'} \tag{8}$$

$$MakeE_{C_1}=E_{C_2},\qquad then\qquad p_3=\frac{p_1(R_C-R_C')-R_C}{p_1S_C} \tag{9}$$

4.2 The analysis of influencing factors

It should be taken into consideration that governments should play a leading role in the construction of the green supply chain in the home appliance industry. Therefore, they should not make decisions only from the view of economic benefit and need to adopt some policies to motivate enterprises and consumers to participate the green supply chain, although these policies could add costs to them. Here we focus on the analysis of the factors influencing the probability p_1 and p_2.

4.1.1 Influencing factors of the probability p_1

From equation (8), we can easily draw the following conclusions.

(1) P_2 is an increasing function of S_B, F_B, C_B-C_B' and p_3.When S_B or F_B increases, enterprises would be more willing to offer green home appliances in order to obtain subsidy from the governments to compensate the costs or to avoid to be punished. As for C_B-C_B', since $C_B<C_B'$, so $C_B-C_B'<0$. Then when C_B-C_B' increases, the cost difference between offering green appliances and traditional ones decreases, which shows there will be not too much cost increase for offering green appliances. Taking further considering of the governments penalty, enterprises would have more motive power to offer green home appliances. When the probability p_3 increases, i.e., governments will have more probability to adopt the strategy of supervision, enterprises will prefer to offer green home appliances. Then whenever in which circumstance of the above, the probability of consumers to accept green home appliances may increase correspondingly along with the increase supply of green home appliances onto the market.

(2) P_2 is a decreasing function of R_B-R_B'. Since $R_B-R_B'>0$, then when R_B-R_B' decreases, which means offing green home appliances would not decrease the revenue too much. Therefore, enterprises would choose to offer green appliances and the probability of consumers to accept green home appliances will increase similarity.

4.1.2 Influencing factors of the probability p_2

Here we change equation (9) to the following form, so that we can easily find the influencing factors.

$$p_1 = \frac{1}{1-\frac{R_C' + p_3 S_C}{R_C}} \tag{10}$$

(1) p_1 is an increasing function of R_C', S_C and p_3. More R_C' means more benefits to consumers and the probability of accepting green home appliances will be increasing. When S_C increases, consumers would be more willing to accept green home appliances because they can obtain a subsidy from governments. When the probability p_3 increases, i.e., governments will have more probability to adopt the strategy of supervision, consumers will prefer to accept green home appliances. Affected by the increasing demand of green home appliances, enterprises would be willing to offer more green home appliances to the market. Therefore, p_2 will increase.

(2) p_1 is a decreasing function of R_C .When R_C increases, consumers will have more tendency to accept traditional home appliances and enterprises would be driven to choose offering traditional home appliances.

When governments decide to choose the strategy of supervision all the time, i.e., p_3 equals 1, equation (8) and (10) are the same as the results stated in literature [16].

5 Conclusions

In general, in the static game of complete information between governments, enterprises and consumers in the green supply chain of the home appliance industry, there probably are six pure strategy Nash equilibriums. Except the ideal strategies combination (Offer Green Home Appliances, Acceptance, Nonsupervision), the others are not what we desire. Mixed strategy equilibrium also exists. From the perspective of governments, appropriate S_B, F_B and S_C will be helpful to increase the probability of enterprises and consumers to participate the green supply chain. This indicates that governments should carry out more preferential policies to ensure consumers to gain a certain amount of subsidy S_C in order to encourage them to accept green home appliances and ensure the enterprises to gain subsidy S_B simultaneously so as to compensate their increased cost when choosing to offer green products. At the same time, the penalty F_B should be big enough so that the punishment for those enterprises choosing to offer traditional home appliances should be effective. Governments' guidance will be very helpful in the initiate stage of the construction of the green supply chain in the home appliance industry.

In the long run, the governments should play a very import role in the construction of the green

supply chain in the home appliance industry. The governments should begin with improving laws and regulations about environmental protection, cultivating green price system and green market in order to create favorable external conditions to improve the construction of the green supply chain in the home appliance industry. Meanwhile the role of market in the aspect of resource allocation should effectively come into play and lead the enterprises to consciously pursue scientific management approaches and techniques of green supply chain. Only by doing so, can the home appliance industry realize sustainable development.

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