Game Analysis of Enterprise, Government and Consumer in Green Supply System

Jia Liu, Nan Liu, and Yao Li

Abstract—**Green supply chain is a hot topic in current logistics management, but so far there is no precise definition. Scholars basically only consider the upstream and downstream enterprises in the green supply chain analysis, sometimes introducing government as an external factor. We suggest the enterprise, the government and the consumer are all endogenous variables in the green supply system. Using game theory, we analyze their behavior of joining the green supply system respectively, and find solutions under different conditions. A new management system is put forward, which has some realistic meanings.**

Index Terms—**evolutionary game, green supply system, Nash equilibrium, static game, supply chain management**

I. Introduction

Environmental problems always attract the attention of governments and business organizations. However, it is difficult for enterprises to achieve a balance between business benefits and environmental protection when they try to maximum the profit. An increasing number of scholars realize that only by integrating environmental protection into enterprises' strategies can release the conflict between business benefits and environmental protection. This paper quoted the idea of Jeremy Hall (2000) that green supply system aims to optimize the utility of environmental management, from the perspective of sustainable development, by ecological design of purchase, production and consumption in the supply chain, in which upstream and downstream enterprises have close contact with each other.

However, green supply chain which only focuses on enterprises cannot achieve the objective of green logistics. Governmental macro control, green consumptions, and enterprises, are gradually becoming three foundations of green logistics, which is green supply system in this article. First, if the country promotes green culture, the country will set up a positive image, which is definitely a strongly competitive factor, since green trade barrier severely affected developing countries. Second, consumers are the initiator of green supply chain. In many terms, consumers can force enterprises improve environmental management to increase profits, while most enterprises cannot notice the benefits brought by environment by themselves. The inner motivation of enterprises for profits, the macro control of governments, and the green preference of consumers constitute the inner drive for enterprises to change the production method. If there are effective outer inducements, the market will evolve towards "Green Market". We set the enterprise, the government and the consumer respective roles in the game model to build a green supply system, which is different from previous research of relationship between upstream and downstream enterprises only.

Through our research, this article build models separately towards three points and analyze the evolutionary stable strategy of enterprises, the evolution of governments under green trade barriers, and the consumer behavior of different green preferences in the diversified product market. Then a green supply system is generated and the balance point has been resolved.

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II. Current Research Analysis

Current researches on green logistics mainly fall into two categories, the game between upstream and downstream entrepreneurs in the supply chain, or the game between government and enterprises.

Some researches set the upstream entrepreneurs and downstream entrepreneurs as bilateral sides of the game, whereas government is only an extrinsic factor. They analyze factors influencing the coordination between supply chain members, including cooperation and trust, their relationship, and pricing strategies.

Some literatures research into the game between enterprises and government, which is the mainstream of current green supply chain game research. In this realm, researchers in our country have made great contribution Their researches include game between government's power abuses and corporate bribery, game between government's misconducts and enterprise's pollution control. The responsibility mechanism for loss and government's action of asymmetric information are also considered.

Nonetheless, two respects of current researches should be paid attention to. Firstly, these researches mainly take consumer behavior as the external environmental factor, whereas the reality is that the consumer serves as the initiator of green supply chain, and the preference of consumers for green products is the internal motivation and one determinant for enterprises to step further in green production. Therefore, the consumer should be taken as a crucial variable in analysis instead of an external environmental factor. Secondly, whereas most scholars are researching about the upstream and downstream enterprises, almost none delves into

exploring the green supply system consisting of these trilateral sides, government, enterprises, as well as consumers.

III. Models on Game Theory

A. Analysis of enterprises entering the green supply system based on game theory

1) Assumptions

a) Only two enterprises, A and B, exist in the market and they are all rational economic men, aiming to maximize their profits.

b) There are two kinds of strategy that enterprises can choose from: a green mode, the manufacturing of green products, or a non-green mode, the manufacturing of non-green products with the same function.

c) The price, the unit cost and the incremental cost of the product are the same at two enterprises whereas choosing the same mode.

d) Since green market is still in early development, people have relatively low awareness of green products, thereby resulting in lower consumption and demand of green products than that of non-green products.

e) Each of the two enterprises has an accurate understanding of characteristics and utility but not the action of the other enterprise before making decisions. So the game between the two is one-stage static game of complete information.

2) Game model

Based on the following assumptions, we build a game model to see whether enterprises will choose a green mode and enter the green supply system. We develop a general formula to calculate the profit π during an operation period, given q as the selling volume, p as the price, c as the unit cost, F as the fixed cost and ΔC as the incremental cost. Here ΔC is crucial in determining the differences in costs between a green mode and a non-green mode. Since a green mode requires enterprises to improve processes and to curb pollution, ΔC is larger when enterprises choosing a green mode rather than a non-green mode. Define ΔC as:

$$\Delta C = \begin{cases} \Delta C_g & \text{when enterprises choose a green mode} \\ 0 & \text{when enterprises choose a non-green mode} \end{cases}, \quad (1)$$

which gives the profit formula:

$$\pi = (p - c)q - F - \Delta C. \quad (2)$$

Note we represent the green mode and non-green mode of corresponding variables with subscript g, n.

Assumption C gives

$$\begin{cases} \Delta C_A = \Delta C_B = \Delta C \\ F_{An} = F_{Ag} = F_{Bn} = F_{Bg} = F \\ p_{Ag} = p_{Bg} = p_g \\ p_{An} = p_{Bn} = p_n \end{cases}. \quad (3)$$

Due to an increase in cost and the long term interests, such as environmental protection and sustainability, the price of green products is higher than that of non-green products:

$$p_g > p_n. \quad (4)$$

According to assumption A, the demand of the market is equal to the supply:

$$\begin{cases} q_{Ag} + q_{Bg} = q_g \\ q_{An} + q_{Bn} = q_n \end{cases}. \quad (5)$$

Because green market is still in its early development, assumption D, the demand of green products is lower than that of non-green products:

$$q_g < q_n. \quad (6)$$

Similarly, when the two enterprises choose the same mode:

$$\begin{cases} q_{Ag} < q_{An} \\ q_{Bg} < q_{Bn} \end{cases}. \quad (7)$$

Profit-maximizing, the ultimate goal for rational economic men, is the main basis and basic principles for decision-making of the two enterprises. Thereby the game pay-off matrix of the two enterprises A, B is shown in the table below.

TABLE I. GAME PAY-OFF MATRIX OF THE TWO ENTERPRISES

A \ B	Implementing a Green Mode	Implementing a Non-green Mode
Implementing a Green Mode	$\pi_{Ag\|Bg}, \pi_{Bg\|Ag}$	$\pi_{Ag\|Bn}, \pi_{Bn\|Ag}$
Implementing a Non-green Mode	$\pi_{An\|Bg}, \pi_{Bg\|An}$	$\pi_{An\|Bn}, \pi_{Bn\|An}$

3) Further discussions of the game model

Now we take a closer look at the game pay-off matrix and discuss the possible outcomes under different circumstances.

When $\pi_g > \pi_n$, which gives

$$\begin{cases} \pi_{Ag|Bg} > \pi_{An|Bg} \\ \pi_{Ag|Bn} > \pi_{An|Bn} \\ \pi_{Bg|Ag} > \pi_{Bn|Ag} \\ \pi_{Bg|An} > \pi_{Bn|An} \end{cases}, \quad (8)$$

And

$$(p_g - c)q_g - \Delta C > (p_n - c)q_n. \quad (9)$$

Under this circumstance, the increase in profits brought by an increase in price p_g exceeds the resulting decrease brought by a reduction in sales q_g and an increase in cost ΔC. Hence, whether enterprise A chooses a green mode or a non-green mode, enterprise B will always choose to implement a green mode. Similarly, enterprise A will implement a green mode. Therefore, a "Nash Equilibrium" is reached. Both enterprises will implement green mode, maximizing their profits as well as increasing social utility. So this outcome is stable, also contributed to Pareto improvement.

Similarly, other outcomes under different conditions can be reached using the same analysis. The following Table II presents the different equilibrium solutions under respective conditions.

Clearly, the equilibrium solutions under different conditions in one stage game are not always (implementing green mode, implementing green mode), which is the Pareto optimal. But in multi-stage game, particularly evolutionary game, the two enterprises will find green mode profitable by study and research, thereby adjusting their strategies and eventually choosing to implement green mode. Therefore, with changes in situation, non-optimal solutions will gradually approach Pareto optimal solution.

TABLE II. DIFFERENT EQUILIBRIUM SOLUTIONS UNDER RESPECTIVE CONDITIONS

Condition	Equilibrium Solution
$\begin{cases}\pi_{Ag\|Bg} > \pi_{An\|Bg}\\ \pi_{Ag\|Bn} > \pi_{An\|Bn}\\ \pi_{Bg\|Ag} > \pi_{Bn\|Ag}\\ \pi_{Bg\|An} > \pi_{Bn\|An}\end{cases}$	(implementing green mode, implementing green mode)
$\begin{cases}\pi_{Ag\|Bg} < \pi_{An\|Bg}\\ \pi_{Ag\|Bn} < \pi_{An\|Bn}\\ \pi_{Bg\|Ag} < \pi_{Bn\|Ag}\\ \pi_{Bg\|An} < \pi_{Bn\|An}\end{cases}$	(implementing non-green mode, implementing non-green mode)
$\begin{cases}\pi_{Ag\|Bg} > \pi_{An\|Bg}\\ \pi_{Ag\|Bn} < \pi_{An\|Bn}\\ \pi_{Bg\|Ag} > \pi_{Bn\|Ag}\\ \pi_{Bg\|An} < \pi_{Bn\|An}\end{cases}$	(implementing non-green mode, implementing non-green mode) or (implementing green mode, implementing green mode)
$\begin{cases}\pi_{Ag\|Bg} > \pi_{An\|Bg}\\ \pi_{Ag\|Bn} < \pi_{An\|Bn}\\ \pi_{Bg\|Ag} < \pi_{Bn\|Ag}\\ \pi_{Bg\|An} > \pi_{Bn\|An}\end{cases}$	Does not exist.
$\begin{cases}\pi_{Ag\|Bg} > \pi_{An\|Bg}\\ \pi_{Ag\|Bn} > \pi_{An\|Bn}\\ \pi_{Bg\|Ag} < \pi_{Bn\|Ag}\\ \pi_{Bg\|An} > \pi_{Bn\|An}\end{cases}$	(implementing green mode, implementing non-green mode)

4) Implications and Conclusions

No matter how much social utility will be improved by green mode, in short term, enterprises as rational economic men will always make decisions on the basis of profit-maximizing. The first two conditions in Table. II indicate that when the increase in revenue exceeds the resulting increase in costs, enterprises will implement green mode, vice versa.

a) Implications:

1) As a result of enterprises focusing on short term interests, the game between enterprises may not reach optimal solution. Hence, government should influence the outcome of game through macroeconomic regulations. e.g. government can increase ΔC when enterprises choose to implement non-green mode or become an agent in the game. (We will discuss this point in latter research.)
2) Consumers are another crucial factor in this game. If consumers prefer green products, the demand of green products q_g will increase and the demand of their alternative, non-green products, q_n will decrease, resulting in a higher probability for enterprises to implement green mode.
3) Technology improvement, such as reduction in ΔCg, will also have a positive effect.
4) In multi-stage games, the role of study is significantly important. Publicizing green products and enterprises which produce them will encourage non-green enterprises to learn and to do the same. Gradually non-green enterprises will "evolve" into green enterprises.

b) Conclusions:

1) Uncertainty will result when solely relying on market mechanisms to promote the formation of the green market.
2) There are three possible approaches which will encourage enterprises to implement green mode: reducing the costs to produce green product by external incentives or by technology improvement and increasing consumers' preference for green products.

5) The Operation Mechanism of Green Supply Chain

Nowadays green market does not include only one enterprise but the whole supply chain. Therefore the above game model is actually extended and the term enterprise now means the whole supply chain as shown in Fig. 1 below. Upstream and downstream enterprises have effect on each other in the chain, which our analysis above can be extended to. In practice, non-green supply chain will gradually "evolve" into green supply chain under certain conditions when enterprises implement green mode.

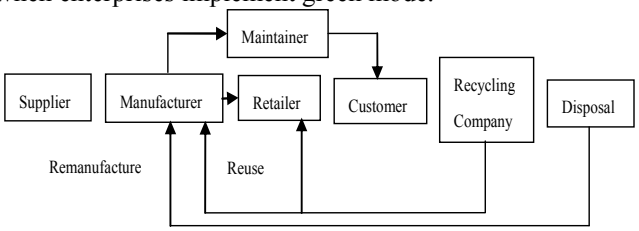

Figure 1. Green supply chain

B. Analysis of the Government joining green supply system

1) Assumptions

a) Government has an accurate understanding of policies implemented by any other governments.

b) Assume that any government will balance the effectiveness from all aspects of interests in the system, using P represented.

c) Set G for the will of a government to join the green supply system and the degree of implementation. The value of G is between 0 and 1 and is influenced by the change of the internal and external environment.

d) The revenue and expenditure, denoted as P, of a government in the green supply system mainly come from four aspects: social revenue E, government image F, regulatory cost S, environmental cost R, that is $P(G) = E + F - S - R$.

e) If a government does not join the green supply system, it will be under the green trade barriers of other countries, assume this effect as H, then the equation is $P(G) = E + F - S - R - H$.

f) The regulatory cost of any government is the same, and the environmental cost changes when a government joins the green supply system.

g) If the regulatory cost of any government is the same, the environmental cost changes whether a government joins the green supply system or not.

2) Game model

Based on the above assumptions, the stronger willingness a government has to join the green supply system, the greater degree of implementation and the fewer the environmental costs are, thus,

$$\frac{dR}{dG} < 0 . \qquad (10)$$

And for the social revenue E and the government image F,

the stronger willingness to join the green supply system and the greater degree of implementation a government has, the better social revenue and the government images are.

Therefore, for any government not joining the green supply system, we have the following game matrix:

TABLE III. THE GAME MATRIX OF GOVERNMENT JOINGINH THE GREEN SUPPLY SYSTEM

Tactics		Not joining the Green Supply System	
		Join	*Not Join*
Joining the Green Supply System	***Continue***	$(E_1+F_1-S_1-R_1,\ E_2+F_2-S_2-R_{2)}$	$(E_1+F_1-S_1-R_1,\ E_2^{'}+F_2^{'}-S_2-R_2^{'}-H_{2)}$
	Quit	$(E_1^{'}+F_1^{'}-S_1-R_1^{'}-H_1,\ E_2+F_2-S_2-R_2)$	$(E_1^{'}+F_1^{'}-S_1-R_1^{'},\ E_2^{'}+F_2^{'}-S_2-R_{2)}^{'}$

3) Results

Joining the green supply system will affect social revenue and image of the government:

$$\begin{cases} E_1 > E_1^{'} \\ F_1 > F_1^{'} \\ S_1 < S_1^{'} \\ R_1 < R_1^{'} \\ H_1, H_2 > 0 \end{cases} . \tag{11}$$

For the government who does not join the green supply system, because

$$\begin{cases} E_1+F_1-S_1-R_1 > E_1^{'}+F_1^{'}-S_1^{'}-R_1^{'}-H_1 \\ E_1+F_1-S_1-R_1 > E_1^{'}+F_1^{'}-S_1^{'}-R_1^{'} \end{cases}, \tag{12}$$

In consideration of its benefits, it will continue to maintain the status;

For other government who has not joined the green supply system, because

$$\begin{cases} E_2+F_2-S_2-R_2 > E_2^{'}+F_2^{'}-S_2^{'}-R_2^{'}-H_2 \\ E_2+F_2-S_2-R_2 > E_2^{'}+F_2^{'}-S_2^{'}-R_2^{'} \end{cases}, \tag{13}$$

and taking social revenue, the government image and green trade barriers into account, it will eventually join the green supply system.

4) Conclusions

In summary, the decision to join the green supply system of a government follows the international trends and benefits the whole country. However, the process of joining the green supply systems varies from country to country due to different economic conditions and other factors.

C. Consumer Behavior Model

1) Product Difference Model

Consumer is the original initiator of green supply chain, thus, the preference of consumers for green products is the intrinsic motivations for entrepreneurs to step further in green production. The hypothesis is that different products have different green degrees, according to which products can be divided into two sub categories: green products and non-green products. In the meanwhile, different consumers have different green preferences, according to which consumers can be divided into three sub categories: green consumers who purchase green products, non-green consumers who purchase non-green products and bystanders who purchase nothing. This article develops a product differentiation model to explore what intrinsic and extrinsic factors influence the choices of consumer, which is the initiator of green supply system.

a) Symbols:

1) f denotes the utility of products function.
2) S denotes green degree. When $s=s_1$, the product is green, and when $s=s_0$, the product is non-green.
3) θ denotes the green preference. θ subjects to an equitable distribution ranging on [0,1]. The number of consumers with the preference parameter θ (θ≤x) is xN. The green utility of consumers with the preference parameter θ is θs.
4) P(s) is the product price determined by s.

b) Assumptions

1) All products have the same function and the utilities consumers get from the function are all f.
2) Different products have different green degree and they are not fully substitute for each other.
3) If there are N consumers with different preference, each consumer can buy at most one unit product.
4) Different consumers have different preference for green products; we classify them to three categories: green consumer who only purchase green products, non-green consumer who never buy green products, bystander who buy neither of them.
5) Without considering the influence of green degree on price, the utility that all consumers obtain from the green degree is non-negative.

The utility that consumers can get can be denoted

$$\begin{cases} \theta s - p(s) + f & \text{purchasing product with green preference } s \\ 0 & \text{purchasing nothing} \end{cases} \tag{14}$$

2) Solutions:

a) Solution to the boundary conditions of three consumer categories

1) Between the non-green consumers and bystanders:

θ_0 denotes the preference parameter when there is no differentiation between consuming non-green product and nothing:

$$\theta_0 * s_0 - p(s_0) + f = 0 . \tag{15}$$

Then we can deduce that the boundary condition between non-green consumers and bystanders is:

$$\theta_0 = \frac{p(s_0) - f}{s_0} . \tag{16}$$

2) Between the green consumers and non-green consumers:

θ_1 denotes the preference parameter when there is no differentiation between consuming green product and non-green products:

$$\theta_1 * s_1 - p(s_1) + f = \theta_1 * s_0 - p(s_0) + f . \tag{17}$$

Similarly, the boundary condition between green consumers and non-green consumers is

$$\theta_1 = \frac{p(s_1) - p(s_0)}{s_1 - s_0} . \tag{18}$$

3) Additional assumption:

$$\frac{s_1}{s_0} < \frac{p(s_1)-f}{p(s_0)-f}, \tag{19}$$

then we get $0<\theta_0<\theta_1<1$, and this restricts that bystanders and green consumers can not directly translate to each other without getting across non-green product, whereas green products and non-green products can translate to each other directly.

b) Solutions to the qualifications of three categories of consumers

1) Green consumer

$$\theta > \theta_1 = \frac{p(s_1)-p(s_0)}{s_1-s_0}. \tag{20}$$

When the green preferences of consumers meet the above conditions, consumers will choose to purchase green products to maximize their utility.

2) Non-green consumer

$$\theta_0 = \frac{p(s_0)-f}{s_0} < \theta < \frac{p(s_1)-p(s_0)}{s_1-s_0} = \theta_1. \tag{21}$$

When the green preferences of consumers meet the above conditions, consumers will choose to purchase non-green products to maximize their utility.

3) Bystander

$$\theta > \frac{p(s_0)-f}{s_0} = \theta_0. \tag{22}$$

When the green preferences of consumers meet the above conditions, consumers will choose to purchase nothing. To stimulate the potential purchasing power of this group, their green preference should be raised.

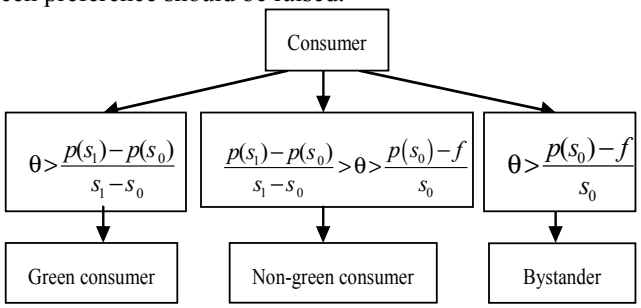

Figure 2. Solutions to the qualifications of three comsumer categories.

3) Conclusion

Based on the analysis above, we can reach the conclusion that product price and green preference are the two factors determining consumer decision-making.

a) Product Price

Product price determines the threshold for green supply system entry. The higher the price is, the higher the threshold will be for the consumers to enter green supply system. Contrarily, as the price gets lower, more green consumers will become non-green consumers. For consumers, product price is an extrinsic determinant.

b) Green preference

Green preference determines the ability to enter green supply system. Under the same threshold for entry, the stronger the green preference is, the larger number of non-green consumers will turn into green consumers. Contrarily, the weaker the green preference, the larger number of green consumers will turn non-green consumers. For consumers, green preference serves as an intrinsic determinant.

In sum, we conclude that in order to exert influence on consumer decision-making, the government and entrepreneurs can take measures to impact on the green preference of consumers and the product price.

IV. The Construction Of Green Supply System

A. The structure of the system

Based on the above game analysis of enterprises, government and consumer, it is easy to see that these three roles have interacted with each other in the green supply system, the relationship between them as shown in Fig. 3 below.

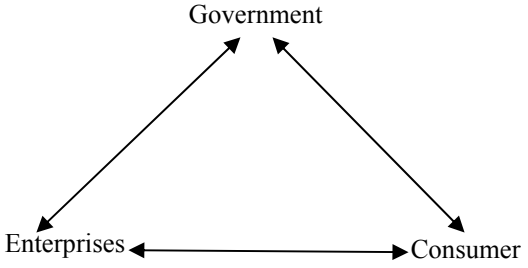

Figure 3. Simplified Diagram of Green Supply System.

B. System Operation Mechanism

As mentioned above, the existing green supply chain management has fully considered the coordination between upstream and downstream enterprise in the green supply chain, related to production, sales, recycling and other processes.

The operation mechanism of green supply chain has been explained in the first model, so we can see a more specific relationship between the three roles in Fig. 4 below when adding the supply chain to the system.

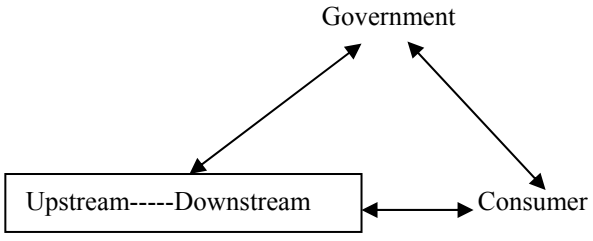

Figure 4. the Structure Diagram of Green Supply System

C. Balance System

Fig. 5 presents the green supply system diagram. Assume that each point-government, supply chain and consumer- is the center of a circle that represents the scope of each role's own behavior, simplifying the supply chain into one point.

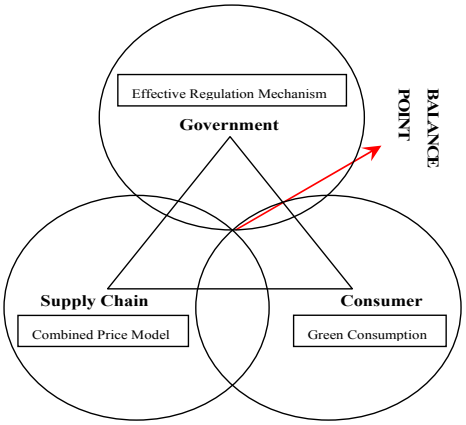

Figure 5. Construction of green supply system.

Through the game analysis of three lines in the triangle above, we can safely reach the conclusion that the three roles have their own balanced behavior respectively in the green supply system.

1) The supply chain has its combined price model, the profit of both upstream and downstream enterprises has been considered.

2) The government has its effective regulation mechanism, in which enterprise and consumer can turn themselves to "green" consciously.

3) Almost all the consumers prefer green products; they carry out green consumption in the system.

As the three roles influencing each other, causes the system in a dynamic state. The intersection of three circles in the diagram, the balance point, can be searched from Nash equilibrium in multi-game. In this situation, the system's balance state will continue under rational behavior.

V. Limitations And Future Research

In this article, we set the enterprise, the government and the consumer respective roles in the game model, analyzing the behavior of whether to join the green supply or not. According to the results we proved the existence of Nash equilibrium of the system. But we have not analyzed the interaction between any two roles in the system, which may be a highly valuable research topic in the future.

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