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The Construction of the Green Supply System based on Game Theory

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***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.**

Keywords-supply chain management; static game; evolutionary game; the green supply system; Nash equilibrium

I. 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, while 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, including 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.

These researches mainly take consumer behavior as the external environmental factor, while 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. While most researches are 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.

II. 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 while 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. 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:

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

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 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. The following table presents the different equilibrium solutions under respective conditions.

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)

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.

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 indicate that when the increase in revenue exceeds the resulting increase in costs, enterprises will implement green mode, vice versa.

a) Implications:

- 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.)
- 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.
- Technology improvement, such as reduction in ΔC_g, will also have a positive effect.
- 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:

- Uncertainty will result when solely relying on market mechanisms to promote the formation of the green market.
- 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. In practice, non-green supply chain will gradually "evolve" into green supply chain.

Figure 1. Green supply chain.

B. Analysis of the Government joining green supply system

1) Assumptions

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

b) 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.

c) 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 $P(G) = E + F - S - R$.

d) 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 $P(G) = E + F - S - R - H$.

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

2) Game model

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,

$$\frac{dR}{dG} < 0 . \tag{10}$$

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.

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:

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

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

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

it will continue to maintain the status;

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

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

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

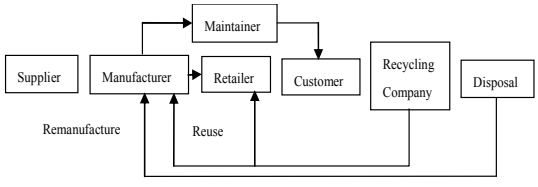
4) Conclusions

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. 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:

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

b) Assumptions

- All products have the same function and the utilities.
- Different products have different green degree and they are not fully substitute for each other.
- If there are N consumers with different preference, each consumer can buy at most one unit product.
- 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

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

2) Solutions:

a) Solution to the boundary conditions of three consumer categories

- 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:

$$\theta_0 * s_0 - p(s_0) + f = 0 . \quad (15)$$

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

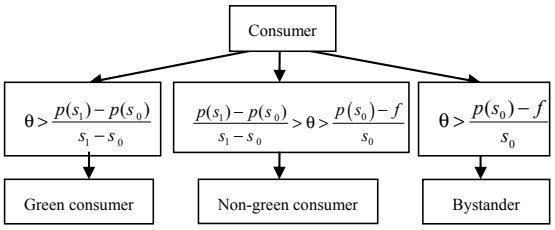
$$\theta_0 = \frac{p(s_0) - f}{s_0} . \quad (16)$$

- 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:

$$\theta_1 * s_1 - p(s_1) + f = \theta_1 * s_0 - p(s_0) + f . \quad (17)$$

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



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

- Additional assumption:

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

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, while green products and non-green products can translate to each other directly.

b) Solutions to the qualifications of three categories of consumers

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

3) Conclusion

Two factors determine consumer decision-making are:

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, and vice versa. For consumers, product price is an extrinsic determinant.

b) Green preference

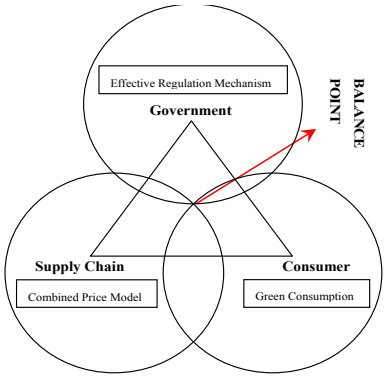
Green preference determines the ability to enter green supply system. Under the same threshold for entry, the stronger the green preference is, the larger number of non-green consumers will turn into green consumers and vice versa. Green preference serves as an intrinsic determinant.

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.

III. THE CONSTRUCTION OF GREEN SUPPLY SYSTEM

A. The structure of the system

Based on the above game analysis of the three roles, it is easy to see that the enterprise, the government and the consumer has interacted with each other in the green supply system.



B. System Operation Mechanism

Figure 3 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.

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 links.

C. Balance 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.

Figure 3. Construction of green supply system.

IV. LIMITATIONS AND FUTURE RESEARCH

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 the most valuable research topic in the future.

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