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Modeling and Simulation of Low Carbon Supply Chain Based on the Product Attributes

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Abstract. The influence of product attributes on low carbon supply chain is studied in this paper. In the background of global emphasis on green and low carbon economy, there are low carbon and quality attributes for the product. In order to meet the requirements of the consumer demand, the enterprise needs to coordinate the relationship between quality and low carbon products at the same time. So the enterprise should adjust of low carbon action to achieve product quality attributes and product attributes to the low carbon balance. Based on the two variable utility theory, through the construction of the supply chain demand structure model, the influence of the product attributes in the supply chain is simulated and analyzed by numerical calculation of low-carbon supply chain process.

1. Introduction
The product is the consumption target provided by the upstream and downstream enterprises of the supply chain, and is the intermediary between the consumers and the supply chain enterprises [1]. The impact of product effect and can not be simply equated with consumer awareness of low carbon, as can be observed, for most consumers, despite the catastrophic consequences of climate change to contemporary people with profound shock, but because it is not clear the date of the disaster and its possible tolerance level, so consumers generally do not at the same time strengthen low carbon consciousness weakening the basic characteristics of products such as preference, in the automobile products, carbon emissions is significantly higher than the average family car, but from the perspective of products, their sales with certain rationality [2]. It has its advantages in bad traffic conditions, and it can also meet the security requirements in the city (obviously it can be better protected in a traffic accident than a small car). In other words, for consumers, meet the quality by using the utility is the basic value. In the background of low carbon economy [3], low carbon consciousness of consumers while the increase of products to meet the requirement of low carbon low carbon utility, resulting in low carbon value of the product, the product has the double the quality and properties of low carbon [4].

Through the review of the literature, it could be found that the existing literature mainly focused on the realization of low-carbon products, including design, production, packaging, pricing and so on. And some studies pay more attention to the cost and supply chain profit pressure from the low carbon products, but there is no further discussion on product attributes bring to the low carbon supply chain problems. This paper has mainly studied the relationship between products attributes and low carbonization in supply chain.

2. Construction of Low Carbon Supply Chain and Some Assumptions
The dual attributes of the product makes it necessary for the supply chain to consider the relationship between quality and low carbon, and to coordinate the relationship between the two attributes [5]. There is contradiction between quality usually products and low carbon consumption, because more often means higher quality, such as the car will consume more than ordinary cars, steel and have more displacement; notebook computer production of Apple Corp in the United States [6], because the rice with the whole block pin cutting method to produce the result a large number of strokes is waste material, but also guarantees the sheer amount of the industry's highest level of heat dissipation efficiency and the advantages of traditional food and beverage; China soup is very exquisite, continuous cooking candle, candle will shorten the cooking time if to reduce carbon emissions, but also reduce the consumer of food quality evaluation etc..

2.1. Construction of Low Carbon Supply Chain
Firstly, choose reasonable partners. In the process of building an enterprise supply chain, one of the important factors is to choose the right partner, and it is also the main part of the whole supply chain. Therefore, enterprises must follow the premise of enterprise strategy, select the right partner. If both partners are not able to long-term development, then once the partners were changed, the supply chain will need more or less reconstruction work, which is not only a waste of time and energy of the enterprise, but also caused a serious economic loss to the enterprise. Secondly, achieve low carbonization of the process. Under the guidance of the new society low-carbon model, in the process of building the supply chain of enterprises, it is necessary to re organize the entire supply chain work-flow. In the low carbon mode of the supply chain, many important factors such as the core enterprises, manufacturers, distributors, suppliers and so on are to be re to low-carbon vision for the effective optimization, so as to enable enterprises to maximize production efficiency. Establish a process re-engineering platform is a good method, on this platform, can the enterprise information sharing in supply chain is established in the process of various factors, thus, logistics service flow and the flow of funds of the enterprises to make good guarantee, to make it more adapt to changes in current society market. In the construction process of supply chain, to make low-carbon protection for each link in the planning stage, to make the whole planning in as soon as possible after the whole operation process to achieve synchronization and integration, and in the purchase stage, you can purchase mode widely used to make appropriate optimization to find goods sectors, thus reducing procurement of manpower and resources, thereby reducing the production cost of enterprises.
Finally, build low carbon evaluation system. The construction of low carbon evaluation system can be evaluated by the actual low carbonization degree of the enterprise. Thus, it provides a benchmark and comparability for the low carbonization process of each enterprise. And then effectively improve the low carbon progress of enterprises.

2.2. Some Assumptions
The contradiction between weak quality and low carbon properties of the products also exist, such as power service, power plant using coal, natural gas, hydro, wind, solar and nuclear energy to generate electricity for power products consumers need, there is no difference in quality, but in the low carbon level is very different. This characteristic of power services can be called "image quality" and "low carbon decoupling", but that does not mean that all services are quality decoupled from low carbon. For example, consulting services, can be considered to meet the quality and low carbon decoupling, in face-to-face consultation, transportation to the front of the customer, or by the video system with remote client conversation, and will not affect the effect of consultation, but can serve the effects of carbon emissions significantly; but for the mobile communication service, is not this is the case, taking into account the requirements including the quality of mobile communication service in the coverage, connection rate, the number of wireless base station indoor distribution system in a mobile communication network must continue to grow, and keep the hours of uninterrupted, and even prove intelligent carrier has a remarkable energy-saving effect off technology, also will be abandoned
because ensure the connection rate requirements for mobile communication services, the contradiction between quality and carbon emissions is very prominent.

Different types of product supply chain, in the process of low-carbon, is bound to be affected by the dual attributes of the product, the upstream and downstream enterprises in the supply chain must balance between the two attributes, looking for a reasonable balance point.

This is the main research contents in influencing the quality of product attributes and properties of low carbon, supply chain upstream and downstream enterprises to carry out incentive and obstacle of carbon reduction action, the quality of carbon emission intensity of products related to supply chain emissions reduction effect.

In order to simplify the analysis process, without considering the impact of carbon disclosure and the initial low carbon level of the supply chain before the emission reduction decision, it is assumed that both the low carbon level decision of the supply chain enterprises is also the carbon reduction decision. The supply chain is composed of an upstream enterprise (manufacturer) and a downstream enterprise (retailer). The upstream enterprise is established as the core enterprise, and the upstream enterprise can make a decision on the wholesale price of the intermediate variable. Low carbon parameter, expressed as $e_x = e_e - e_o$, is the difference between carbon emission and low carbon standard.

The parameters description of upstream enterprises in supply chain is shown as the $p_e$ represents the ex-factory price/wholesale price of the upstream enterprise products, the $c$ represents the unit cost of the product, the $\pi_u$ represents upstream corporate profits.

The parameters description of downstream enterprises in supply chain is shown as the $p$ represents the retail prices of downstream products, sets downstream enterprises only purchase cost $p_e$, the $\pi_d$ represents downstream corporate profits.

So the profit maximization of the upstream enterprises in the supply chain is achieved after the carbon disclosure:

$$\text{Max } \pi_u(p_e) = \text{Max}(A + t \cdot e_x - B \cdot p) \cdot (p_e - c)$$

(1)

The profit maximization of the enterprises in the supply chain after carbon disclosure is as follows:

$$\text{Max } \pi_e(p) = \text{Max}(A + t \cdot e_x - B \cdot p) \cdot (p - p_e)$$

(2)

where $A > 0, B > 0$ are coefficient of the demand function.

In order to obtain the demand function of the supply chain product by the consumer utility function, the following assumptions are made:

1. Different consumers have different willingness to pay for quality and low carbon, so Assume that $\theta$ and $\beta$ respectively represent the random variable subject to uniform distribution in $(\theta_{\max} - \theta_{\min})$ and $(\beta_{\max} - \beta_{\min})$;

2. $\theta$ and $\beta$ are independent of each other;

3. Assume that the total number of consumers on the market is 1, Consumers who are in demand for the product are the consumers who meet the condition $U_c(\theta, \beta) \geq 0$.

3. Demand Function of Low Carbon Supply Chain

The purpose of consumer spending is to obtain utility consumer surplus. For the products supplied by the supply chain, the following assumptions can be made on consumer behavior:

$$U = \begin{cases} \theta \times S - p \geq 0, \text{buy} \\ \theta \times S - p < 0, \text{else} \end{cases}$$

(3)
where \( U \) is the utility/consumer surplus; \( S \) is the quality parameter of products, on behalf of the quality of the product; \( p \) is product price; \( \theta \) is consumer preference of quality parameters, is the willingness of consumers on the quality of the payment. Generally, \( \theta > 0 \), and the value is different for different consumers.

In the context of low carbon economy, low carbon products will increase the consumer preferences, consumer demands on the use of the content, and the optimization of the environment, so that the products provided by the utility should not only satisfy the consumer demand for the use of performance, but also to meet the consumer demand for the performance of low carbon, low carbon performance reflect the requirements of the low carbon consumer awareness. Taking into account the low carbon conscious consumers will have a certain willingness to pay for the low carbon value, the product structure of the low-carbon economy will have a two variable utility value structure.

Changes in consumer behaviors may be made in the context of a low carbon economy:

\[
U_e = \begin{cases} 
\theta \times S + \beta \times e_d - p \geq 0, & \text{buy, else} \\
< 0, & \text{esle} 
\end{cases}
\]  

(4)

where: \( U_e \) is the utility/consumer surplus; \( e_d \) is the low carbon parameter of the product, which represents the low carbon level of the product; \( \beta \) is the low carbon preference parameter of consumption which represents the consumer's willingness to pay for low carbon, and generally there is \( \beta > 0 \).

For the particular \( S, e_d, p \), the demand function of the supply chain is:

\[
q = \int_{\theta \max, \theta \min}^{\theta \max, \theta \min} \frac{1}{(\theta_{\max} - \theta_{\min}) \beta_{\max} - \beta_{\min}} d\beta d\theta 
\]

(5)

Taking into account the relationship between product quality and low carbon levels of the product, the following assumptions are made on the model:

\[
S = S_o - g \times e_d
\]

(6)

Which \( S_o \) represents the quality of products and low carbon independent parts, and there is \( g > 0 \).

Defining \( a = \frac{\theta_{\max}}{\theta_{\max} - \theta_{\min}}, b = \frac{1}{S_o(\theta_{\max} - \theta_{\min})}, t = \frac{\beta_{\max} + \beta_{\min}}{2S_o(\theta_{\max} - \theta_{\min})} \), the demand function of the supply chain is:

\[
q = a + (t-bg) e_d - bp 
\]

(7)

4. Supply Chain Demand Function with Product Attributes

Considering the upstream enterprises of supply chain as the core enterprises, the decision-making relationship between the upstream and downstream enterprises in supply chain can be analyzed according to Stackelberg game.

The reaction function of the downstream enterprise to the ex factory price is firstly obtained.

\[
\frac{\partial \pi_d(p)}{\partial p} = \frac{\partial}{\partial p} \left( (a+(t-bg)e_d-bp)(p-p_a) \right) 
\]

(8)

\[
p = \frac{a+(t-bg)e_d+bp_a}{2b} 
\]

(9)

Substitute the reaction function of the downstream enterprise into the maximization profit objective function of the upstream enterprise, and gets:
\[
\begin{align*}
\text{Max } \pi_u &= \max \left[ \frac{1}{2} \left( a + (t - bg) e_d - bp_u \right) \left( p_u - c + re_d \right) - he_d \right] \\
\end{align*}
\]  

(10)

The upstream enterprises need to make a decision on the ex factory price \( p_u \) and the low carbon level \( e_d \) of the unit product at the same time, and the first order of profit maximization is:

\[
\frac{\partial \pi_u(p_u, e_d)}{\partial p_u} = 0, \quad \frac{\partial \pi_u(p_u, e_d)}{\partial e_d} = 0
\]

(11)

By simultaneous equations, the ex-factory price \( p_u \) and the low carbon level \( e_d \) of the unit product which meet conditions are substituted into the retail price, manufacturing sales volume, upstream supply chain profit, and the profit of the downstream enterprises of the supply chain could be calculated as follow.

Ex-factory price:

\[
p_u^* = \frac{\left( b \cdot r + (t - bg) \right) \cdot (a - b \cdot c)}{8b \cdot h - \left( b \cdot r + (t - bg) \right)}
\]

(12)

Retail price:

\[
p^* = \frac{1}{2} \left( p_u^* + \frac{a + (t - bg) e_d^*}{b} \right)
\]

(13)

Sales volume:

\[
q^* = a + (t - bg) e_d^* - bp^*
\]

(14)

Low carbon level:

\[
e_d^* = \frac{4h(a + bc) - (br + (t - bg))(ra + (t - bg)e_d)}{8bh - (br + (t - bg))}
\]

(15)

Profits of upstream enterprises:

\[
\pi_u^* = \frac{1}{2} \left( a + (t - bg) e_d^* - bp^* \right) \left( p_u^* - c + re_d^* \right) - he_d^*
\]

(16)

Profits of downstream enterprises:

\[
\pi_d^* = (a + (t - bg) e_d^* - bp^* \right) (p^* - p_u^*)
\]

(17)

Taking into account the profit and low carbon levels of the upstream and downstream enterprises in the supply chain, the form of the decision value is rather complicated, so the analysis is carried out in the following example.

Figure 1. The influence of the correlation intensity.
5. Model Example and Analysis

For analyzing the constants and random variables in the low carbon analysis model of the supply chain considered as: $\theta$, $\beta$ are uniformly distributed over the interval $(0, 1)$; $S_0 = 10$; $c = 0.5$; $r = 0.001$; $h = 0.1$.

In the numerical example, the variation of the correlation intensity $(g, 0 \leq g \leq 1)$ of the product quality and carbon emission is considered only. The following calculation results can be obtained. If the upstream and downstream enterprises in the supply chain do not carry out carbon disclosure (and there is no further reduction action), then the profit of the enterprises in the supply chain will be as Figure 1.

By analyzing of the calculation results, in effect the dual attributes of products, not all of the supply chain have the conditions of low carbon; and this hinders the low-carbon supply chain conditions, awareness of low carbon low carbon concept does not depend on the strength of enterprises, the level of consumer or government on carbon emissions requirements in size, but by the in the supply chain enterprises and consumers jointly formed by choice.

6. Conclusion

The final product of low carbon level is the joint decision which is decided by the duality preference between the quality and low carbon enterprise to balance the dual attributes of products. The low carbon level change products, reasonable way still from the two aspects.

From the consumer side, you can change the consumer's duality preference, especially the quality preferences, to promote the improvement of low carbon products. But consumer pursuits of improving living standards are often intense and difficult to reverse.

7. References

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