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Study on cooperative operation strategy of low carbon supply chain

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Abstract. In this paper, the feasibility and motivation of the low carbon supply chain are analyzed. On this basis, the cooperative strategy of low carbon supply chain process to reduce the carbon footprint of the product is discussed. Through the game analysis, the synergistic stability of the low carbon supply chain has been demonstrated.

Key words. low carbon supply chain, carbon footprint, collaborative operation, game analysis
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1. Introduction

Customer's individuality and diversification of product requirements and the ever-shortening of the product's life cycle, the cost advantages and low-carbon benefits of mass production and economies of scale are facing unprecedented challenges. To avoid secondary logistics and decentralized manufacturing Resulting in excessive carbon emissions, and to maximize the needs of customers to customize, low-carbon quality preferences and global social low-carbon economic development requirements, also to reduce the intermediate links of mass customization products focus on manufacturing a variety of low-carbon supply chain structure optimization model which is being gradually explored and practiced [1].

Figure 1 is the product supply chain structure model which is not subjected to national carbon emission reduction mandatory constraints in the entire life cycle. Because both the cost of services and the cumbersome market wholesale may affect the market monopoly position of large raw material suppliers operating efficiency

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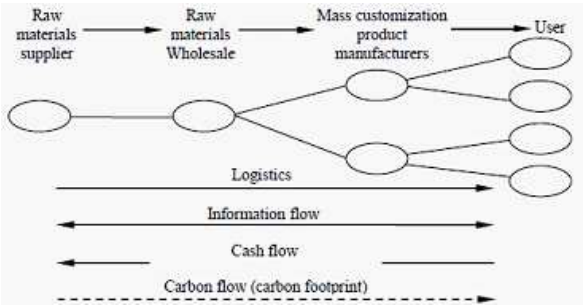

Fig. 1. Product supply chain structure model with no low carbon synergy

and performance, these raw material suppliers prefer to wholesale raw materials to large quantities of orders wholesalers. They may not be willing to directly face the needs of orders and more small quantities of small and medium-sized manufacturers or retailers, however, many small and medium-sized manufacturers, which are directed to the market, hold the majority of users of the real needs [2]. Based on long-term market profits and maintenance of user relationships and the availability of raw materials from raw material wholesalers, small and medium-sized manufacturers may prefer to maintain this supply chain structure, so small and medium-sized manufacturers produce raw materials needed for customization From the supplier to the wholesalers and then to the manufacturer, there have been the use of energy efficiency halved and energy consumption doubled the phenomenon caused by secondary logistics. So that the unit product in the entire life cycle of carbon emissions increased exponentially, carbon costs are also an excessive increase due to the product cost naturally increased [3]. If the product manufacturer is lack of information collaboration with wholesaler, the supplier can only provide standard models and standard size specifications of the raw materials according to the raw material industry standards for wholesalers, due to the raw materials logistics and manufacturing loss rate, the purchase of raw materials must be much larger than the number of customized products themselves, too much raw materials will be an additional increase in the processing of carbon costs and carbon consumption in their own formation, logistics and finished products manufacturing.

Taking into account the product carbon footprint comes from the supply chain suppliers in the processing of raw materials supply, manufacturers design, manufacturing product, logistics, finished product sales logistics, service, waste recycling and other aspects of the product, manufacturers which is a core enterprise with optimized design of low-carbon supply chain structure, the implementation of lean production, agile manufacturing and on-time production model will directly affect the structure of low-carbon supply chain and the carbon emissions of unit products throughout the life cycle [4]. Combined with a low carbon product supply chain in the practical application of the low-carbon emission reduction, the low-carbon cooperation as shown in Figure 2, which is a product supply chain structure optimization model.

In Figure 2, forecast information cooperation, information cooperation, inven-

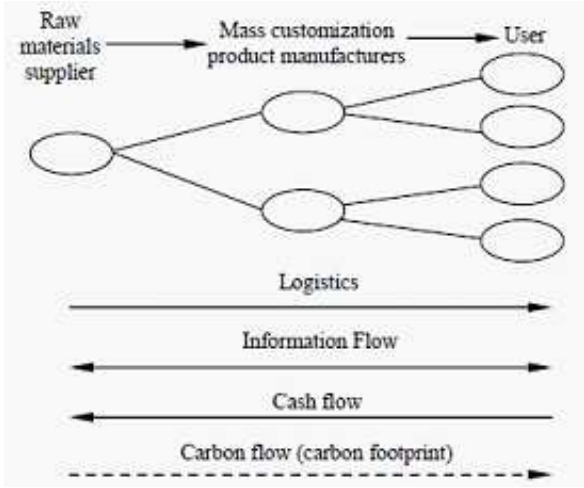

Fig. 2. Optimization model of supply chain structure for a product with low carbon synergy

tory purchasing plan, information collaborative product design information synergy, the execution of the purchase order information coordination is a basic guarantee to optimize the structure of the product supply chain, business process reengineering and optimization is the low carbon supply chain play a key and core of agile, flexible manufacturing [5]. The users' personalized and diversified demand information accurately transmitted to the manufacturer, which will develop a sophisticated procurement plan manufacturers focus on the real demand of multiple users, and require suppliers of raw materials to provide raw materials for its low carbonation from the performance, size, quantity, specifications and other aspects. The purchasing of low carbon raw materials lays the foundation for low carbon transportation, low carbon storage, low carbon circulation processing and waste disposal.

Transportation is the main source of carbon emissions in the whole logistics process, the mass customization product manufacturers, which is alternative raw materials wholesalers, becomes the downstream node of raw materials suppliers, changes two times as a one logistics, shorts the logistics and supply chain, so that accounted for the low carbon supply chain dominated by mass customization products manufacturers can improve the transportation conditions, transportation routes and streamline links through the planning reasonable layout and system of transport routes, which is playing an advantage for various modes of transport (such as multi-model transportation), the use of clean fuels and low pollution vehicles and other means can also achieve low carbon transport [6]. Manufacturers of mass customized products also reduce the carbon footprint of their products through low carbon production and low carbon distribution of low-carbon products required by users.

The mass customization product manufacturers, from the angle of the optimization of supply chain structure and reducing intermediate links in the supply chain explore the carbon footprint reduction problem throughout the life cycle of the prod-

uct, which is on the perspective of the supply chain to reduce intermediate process, and to ensure the stable coordination between the manufacturers and suppliers, but also the low carbon supply chain coordination key to reduce the carbon footprint of products [7].

2. GAME ANALYSIS OF COOPERATIVE STABILITY

2.1. Problem Description

The provisions of the state mandatory policies on low carbon emissions and low carbon product quality of user preference from forced supply chain production and logistics competitive products must be a low carbonization and cost advantages of the products. Based on the three level structure of the supply chain system of a single product cycle(Fig. 1) and the two level structure of the supply chain system(Fig. 2), which is the paper research object, by comparing the structure of three level supply chain of a product with two level supply chain structure analysis, this paper draws conclusions that reducing the supply chain structure optimization of intermediate links is an effective way to realize low carbon supply chain, and focuses on the two level supply chain structure system(as shown in Fig. 2) of low-carbon collaborative stability game analysis..

The structure of the two kinds of supply chain can only provide for single low-carbon products users, in the three level supply chain structure (Fig. 2), the carbon footprint of products mainly come from small and medium manufacturers customized products and manufacturing sectors, the rest of the carbon footprint comes from the raw material supplier's manufacturing process, suppliers, wholesalers and small manufacturers logistics process. In the two level supply chain coordination(Fig. 2), the carbon footprint of products mainly come from manufacturers customized product manufacturing process, the rest of the carbon footprint comes from suppliers of raw materials of low carbon manufacturing, suppliers and manufacturers logistics process.

In two stage supply chain, mass customization product manufacturer is the leader of low carbon supply chain collaboration, which is responsible for manufacturing and logistics low-carbon products, followed by a low carbon supply chain collaboration supplier, which is responsible for low carbon raw materials manufacturing and low-carbon logistics.

Three level supply chain will evolve to two level supply chain which will achieve benefits of low carbon emissions, suppliers of raw materials will evolve to low carbon raw material suppliers, small and medium-sized manufacturers will evolve to mass customization product manufacturers or be replaced by them, therefore, suppliers and manufacturers' income from the two level supply chain is completely rational, the existence of customized product cost, price and manufacturing and logistics process of high carbon consumption information is completely rational, and also there will be no mistakes. As a result, the carbon footprint generated in each process will be less than the carbon footprint generated in the three level supply chain, and the desired profit will not be lower than the income obtained through

the three level supply chain. In order to strengthen the stability of low carbon coordination between members of the supply chain, the manufacturers, as a low carbon supply chain collaboration leader, must take the initiative to conduct carbon emission reduction and share a certain proportion of the cost of carbon emission reduction suppliers, vendors themselves also need to bear the remaining part of the cost of carbon emission reduction.

2.2. Model Assumptions

Hypothesis 1: product carbon footprint comes from raw material manufacturing and logistics, raw materials whole salers logistics, manufacturers' product manufacturing and logistics process. The unit product carbon footprint is determinated, optimization of raw material suppliers and manufacturers manufacturing product manufacturing sectors can effectively reduce carbon emissions, and low carbon raw materials suppliers from raw materials saving and improving product manufacturing efficiency can help manufacturers to effectively reduce carbon emissions and carbon cost of customized product manufacturing.

Hypothesis 2: the initial carbon footprint of the unit, raw material and unit product logistics are all the same.

Hypothesis 3: In the two level supply chain and the three echelon supply chain, the initial carbon footprint of the raw material manufacturing unit is all the same.

Hypothesis 4: The initial carbon footprint of the mass customization product chain in the two echelon supply chain is less than the initial carbon footprint of the three stage supply chain.

Hypothesis 5: Carbon emission reduction costs are positively related to carbon emission reduction cost factor and carbon emission reduction level.

Hypothesis 6: Product supplier, demand information and user preference demand are information sharing, so the product market demand can not appear bullwhip effect, but the user demand preference of low carbon product will be more willing to accept the lower carbon footprint products, and also there is a mark of the low carbon footprint of products, namely carbon the footprint is lower, the product demand is more stable.

Hypothesis 7: In the three level supply chain, the price of supplier's unit raw material is the same as the unit raw materials in the two level supply chain.

Hypothesis 8: Raw material suppliers have the same carbon reduction costs as low carbon raw material suppliers.

2.3. Parameter Description

D is the number of low-carbon products produced by the manufacturer, but also the user's demand;

$D \cdot n_1$ is the number of raw materials required by the supplier in the three supply chain through the wholesaler to the manufacturer to produce the number of low carbon products;

$D \cdot n_2$ is the number of low-carbon raw materials required by the supplier in the

secondary supply chain to provide the manufacturer with the production of low-carbon products D. It is more advantageous for the manufacturer's product less manufacturing carbon consumption and the emission quantity in terms of quantity, size, type, size and processing convenience;

As the suppliers in the secondary supply chain can be optimized from the aspects of performance, specifications, model, size and other aspects of large-scale customization products manufacturers to provide low-carbon raw materials, and the utilization of raw materials of mass customization of product manufacturers is higher, and also can use the same amount of raw materials to produce more low-carbon products, so that is $n_1 > n_2 > 1$;

P_s is the price at which a supplier sells a unit (low carbon) raw material;

P_c is the trading price of carbon emissions on the market;

π is the revenue function.

In the three-tier supply chain model operation:

CCF_{s1} is the initial carbon footprint of the supplier's raw material manufacturing chain;

η_{s1} is the supplier's carbon cost reduction coefficient;

e_{s1} is the supplier's carbon reduction level;

$C(e_{s1})$ is the cost of carbon reduction for suppliers' raw materials manufacturing, and then:

$$C(e_{s1}) = \frac{1}{2}\eta_{s1}e_{s1}^2 \tag{1}$$

P_w is the price of the wholesalers to sell a unit of raw materials;

P_{m1} is the price of small and medium manufacturers to sell a unit of low carbon products ;

ccf_{s1} is the initial carbon footprint of the supplier's raw material in logistics process;

ccf_w is initial carbon footprint of the wholesaler unit of raw materials in logistics process;

CCF_{m1} is the initial carbon footprint of the manufacturer's product manufacturing chain;

ccf_{m1} is the initial carbon footprint of the manufacturer's product in logistics process;

η_{m1} is the manufacturer's carbon cost reduction coefficient;

e_{m1} is the manufacturer's carbon emission reduction level;

$C(e_{m1})$ is the cost of carbon reduction for the manufacturer's manufacturing chain, and then:

$$C(e_{m1}) = \frac{1}{2}\eta_{m1}e_{m1}^2 \tag{2}$$

In the secondary supply chain model operation:

η_{s2} is the carbon cost reduction coefficient of the supplier;

e_{s2} is the supplier's carbon reduction level;

$C(e_{s2})$ is the supplier of carbon production costs for low carbon raw materials, and then:

$$C(e_{s2}) = \frac{1}{2}\eta_{s2}e_{s2}^2 \tag{3}$$

CCF_{s2} is the initial carbon footprint for suppliers of low carbon raw materials manufacturing;

ccf_{s2} is the supplier initial carbon footprint of low carbon raw materials in logistics process ;

P_{m2} is the price of the mass customization of product manufacturers to sell a unit of low carbon products;

η_{m2} is the carbon cost reduction coefficient for mass customization product manufacturers;

e_{m2} is the level of carbon reduction for mass customization product manufacturers;

$C(e_{m2})$ is the cost of carbon reduction for mass product customization, and then:

$$C(e_{m2}) = \frac{1}{2}\eta_{m2}e_{m2}^2 \tag{4}$$

φ is the proportion factor of the mass customization product manufacturer sharing the carbon cost of the supplier, $0 < \varphi < 1$;

CCF_{m2} is the initial carbon footprint of mass product customization of the low carbon products manufacturing sector;

ccf_{m2} is the initial carbon footprint of mass product customization of the low carbon products logistics sector.

3. MODEL CONSTRUCTION AND SOLUTION

3.1. The Construction of the Model

In the three level supply chain, the raw material supplier's revenue function is:

$$\pi_{s1} = P_s D \cdot n_1 - \frac{1}{2}\eta_{s1}e_{s1}^2 - P_c D \cdot n_1(CCF_{s1} + ccf_{s1}) \tag{5}$$

Raw material wholesaler's revenue function:

$$\pi_w = (P_w - P_s)D \cdot n_1 - P_c D \cdot n_1 \cdot ccf_w \tag{6}$$

Product manufacturer's revenue function:

$$\pi_{m1} = P_{m1}D - P_w D \cdot n_1 - \frac{1}{2}\eta_{m1}e_{m1}^2 - P_c D(n_1 \cdot CCF_{m1} + ccf_{m1}) \tag{7}$$

Supply chain revenue function:

$$\begin{aligned}\pi_{sc1} = {} & P_{m1} \cdot D - \tfrac{1}{2}\eta_{s1}e_{s1}^2 - \tfrac{1}{2}\eta_{m1}e_{m1}^2 - P_c D \cdot n_1(CCF_{s1} + ccf_{s1} + ccf_w) \\ & -P_c D(n_1 \cdot CCF_{m1} + ccf_{m1})\end{aligned} \tag{8}$$

In the secondary supply chain, the low-carbon raw material supplier's revenue

function:

$$\pi_{s2} = P_s D \cdot n_2 - \frac{1}{2}(1-\varphi)\eta_{s2} e_{s2}^2 - P_c D \cdot n_2 (CCF_{s2} + ccf_{s2}) \tag{9}$$

The revenue function of mass customization product manufacturers:

$$\pi_{m2} = P_{m2} D - P_s D \cdot n_2 - \frac{1}{2}\eta_{m2} e_{m2}^2 - \frac{1}{2}\varphi\eta_{s2} e_{s2}^2 - P_c D(n_2 \cdot CCF_{m2} + ccf_{m2}) \tag{10}$$

Supply chain revenue function:

$$\begin{aligned} \pi_{sc2} = {} & P_{m2} \cdot D - \tfrac{1}{2}\eta_{s2} e_{s2}^2 - \tfrac{1}{2}\eta_{m2} e_{m2}^2 - P_c D(n_2 \cdot CCF_{s2} + ccf_{s2}) \\ & - P_c D(n_2 \cdot CCF_{m2} + ccf_{m2}) \end{aligned} \tag{11}$$

3.2. The Solution of the Model

The same product from the two supply chain income comparison, by (11) minus (8)available:

$$\begin{aligned} \Delta\pi_{sc} = \pi_{sc2} - \pi_{sc1} = {} & (P_{m2} - P_{m1})D + \tfrac{1}{2}\eta_{s1} e_{s1}^2 + \tfrac{1}{2}\eta_{m1} e_{m1}^2 - \tfrac{1}{2}\eta_{s2} e_{s2}^2 - \tfrac{1}{2}\eta_{m2} e_{m2}^2 \\ & + P_c D \cdot n_1 (CCF_{s1} + ccf_{s1} + ccf_w) + P_c D(n_1 \cdot CCF_{m1} + ccf_{m1}) \\ & - P_c D \cdot n_2 (CCF_{s2} + ccf_{s2}) - P_c D(n_2 \cdot CCF_{m2} + ccf_{m2}) \end{aligned} \tag{12}$$

Since the cost of carbon reduction is a one-time investment, it can be assumed that the cost of carbon reduction in the two supply chains is the same, namely:

$$(\frac{1}{2}\eta_{s1} e_{s1}^2 + \frac{1}{2}\eta_{m1} e_{m1}^2) - (\frac{1}{2}\eta_{s2} e_{s2}^2 + \frac{1}{2}\eta_{m2} e_{m2}^2) = 0 \tag{13}$$

From hypothesis two and three can be seen that $ccf_{s1} = ccf_w = ccf_{m1} = ccf_{s2} = ccf_{m2}$,that is, the initial carbon footprint of the unit raw material and the unit product logistics is the same; From the hypothesis four we can see that $CCF_{m1} > CCF_{m2}$, that is, the initial carbon footprint of the small and medium-sized manufacturer's product manufacturing process is greater than the initial carbon footprint of the low-carbon product manufacturing segment of the mass customization product manufacturer, that is $CCF_{s1} = CCF_{s2}$, namely, the initial carbon footprint of the manufacturer's raw material manufacturing chain is the same, that is $n_1 > n_2 > 1$, and then:

$$P_c D(n_1 \cdot CCF_{m1} - n_2 \cdot CCF_{m2}) > 0 \tag{14}$$

$$P_c D \cdot n_1 (CCF_{s1} + ccf_{s1} + ccf_w) - P_c D \cdot n_2 (CCF_{s2} + ccf_{s2}) > 0 \tag{15}$$

Practice shows that mass customization products have a more cost advantage, the two supply chain unit product price relationship can be expressed as $0 < P_{m1} \leq P_{m2}$, and then:

$$(P_{m2} - P_{m1}) \cdot D \geq 0 \tag{16}$$

Put (13,14,15,16) into the formula (12), it is available that:

$$\Delta\pi_{sc} = \pi_{sc2} - \pi_{sc1} = (P_{m2} - P_{m1})D + P_cD \cdot n_1(CCF_{s1} + ccf_{s1} + ccf_w) - P_cD \cdot n_2(CCF_{s2} + ccf_{s2}) + P_cD(n_1 \cdot CCF_{m1} - n_2 \cdot CCF_{m2}) > 0 \quad (17)$$

By comparison of carbon footprint per unit of product through the three-tier supply chain and secondary supply chain, we can seen that:

$$CCF_{s1} + ccf_{s1} + ccf_w + CCF_{m1} + ccf_{m1}) > CCF_{s2} + ccf_{s2} + CCF_{m2} + ccf_{m2} \quad (18)$$

The above equation (17, 18) shows that reducing the supply chain of a product in the intermediate chain can both increase the economic benefits of the entire supply chain and reduce the carbon footprint of the product throughout the supply chain. The reduction in the carbon footprint of the product is mainly due to the increase in the carbon production capacity of the mass customization product manufacturer and the reduction in the supply of the low-carbon raw materials and the ineffective flow of the packaging, transportation, handling and other activities. It is the results of manufacturer's low carbon synergy.

4. GAME ANALYSIS OF NASH EQUILIBRIUM INCOME

The carbon footprint of different products has different upper limit requirements, the government mandatory provisions generally do not allow more than the upper limit, therefore, even if the supply chain members do not engage in low-carbon emissions reduction cooperation between each member companies, their own have to bear the obligations and responsibilities of low-carbon emission reduction. Supply chain members of the enterprise through the supply chain strategic alliance to form a competitive advantage in the market, and ultimately to ensure that their earnings expectations are not lower than a certain goal, based on the minimum expected value to maximize the benefits of business and supply chain development which is the common Vision. However, the reduction of carbon footprint will inevitably cost the cost of enterprises, but also affect the overall benefits of member companies and supply chains, but the government and the state of the enterprise carbon emission reductions are mandatory, at the same time, more and more users' strong demands for low-carbon quality products will force supply chain member companies through the synergy to achieve low-carbon emission reduction and income balance.

Mass customization products manufacturers in the process of low-carbon supply chain to reduce emissions act as a leader in ensuring low-carbon emissions based on profitability, while manufacturers by sharing a certain percentage of suppliers of carbon reduction costs to ensure that suppliers provide low-carbon raw materials, which is the key to low-carbon supply chain coordination and stability. In order to achieve the rationalization of corporate earnings and supply chain products to minimize carbon footprint, low carbon supply chain acts as a leader in low-carbon emission reductions, manufacturers and low-carbon raw material suppliers will achieve Nash equilibrium income through low-carbon emission reduction cooperative game.

There are four strategies for suppliers and manufacturers to cooperate in low-carbon reduction: strategy combination 1 (the supplier does not provide low-carbon raw materials, the manufacturer does not share the cost of carbon reduction by the supplier); strategy combination 2 (supplier does not provide Low-carbon raw materials, manufacturers share a certain percentage of suppliers of carbon reduction costs); strategic combination 3 (suppliers provide low-carbon raw materials, manufacturers do not share the cost of carbon reduction of suppliers); strategy combination 4 (suppliers provide low-carbon raw materials, manufacturers share a certain percentage of suppliers of carbon reduction costs). In the case of different combinations of strategies, the benefits of suppliers and manufacturers are not the same. Based on the limited rationality of the economists, suppliers and manufacturers will determine an optimal combination of strategies based on their expected returns. So the low carbon supply chain synergistic emission reduction and coordination stability can be achieved.

4.1. Analysis of the benefits of suppliers and manufacturers in the case of strategy combination 1

In the case where the supplier does not provide low-carbon raw materials and the manufacturer does not share the supplier's carbon reduction costs, the respective gains are shown in Table 1.

Table 1. Benefits of suppliers and manufacturers in the case of strategy combination 1

Supplier Revenue	$PD \cdot n_1 - \frac{1}{2}\eta_s e_s^2 - P_c D \cdot n_1 (CCF_s + ccf_s)$
Manufacturer Revenue	$P_{m1} D - P_w D \cdot n_1 - \frac{1}{2}\eta_{m1} e_{m1}^2 - P_c D(n_1 \cdot CCF_{m1} + ccf_{m1})$

Although raw material suppliers respond to the development of national low-carbon economic policies and implement low-carbon emission reductions, they do not provide customized raw materials from the perspective of information collaboration. From the perspective of suppliers, wholesalers and manufacturers, the raw material is not a low-carbon raw material, is not conducive to suppliers, wholesalers and manufacturers to improve the carbon productivity of unit products. The reason is that non-low-carbon raw materials lead to the production of customized products required for the increase in the number of raw materials, suppliers of raw materials manufacturing and logistics process, wholesalers logistics process, manufacturers' product manufacturing process and logistics process which will cause carbon costs and carbon footprint increased largely, and raw materials appear secondary logistics, so that the logistics costs and logistics carbon footprint increase. Manufacturers can not purchase directly from the supplier procurement, but only from the wholesalers at the procurement, manufacturers are not directly associated with the supplier, manufacture do not share the cost of carbon emissions from suppliers, wholesalers do share the entire supply chain part of the proceeds, these will result in the supply chain member companies are less than their earnings benefits. The strategy combination

is not the optimal strategy combination pursued by suppliers and manufacturers.

4.2. Analysis of the benefits of suppliers and manufacturers in the case of strategy combination 2

In the case where the supplier does not provide low-carbon raw materials and the manufacturer does share the supplier's carbon reduction costs, the respective gains are shown in Table 2.

Table 2. Benefits of suppliers and manufacturers in the case of strategy combination 2

Supplier Revenue	$PD \cdot n_1 - \frac{1}{2}(1-\varphi)\eta_s e_s^2 - P_c D \cdot n_1(CCF_s + ccf_s)$
Manufacturer Revenue	$P_{m1}D - P_w D \cdot n_1 - \frac{1}{2}\eta_{m1}e_{m1}^2 - \frac{1}{2}\varphi\eta_s e_s^2 - P_c D(n_1 \cdot CCF_{m1} + ccf_{m1})$

Raw material suppliers do not provide customized raw materials for manufacturers through information collaboration, in the process of suppliers' raw materials manufacturing and logistics , the carbon footprint of the manufacturer's manufacturing and logistics process, Carbon footprint's level of carbon productivity of member companies remain in their original state, revenue has not increased. The manufacturer's sharing of the supplier's part of the cost of carbon reduction is to encourage suppliers to reduce the carbon footprint and reduce the carbon footprint of the manufacturer's product and the logistics process. The manufacturer takes the initiative to share the part of the supplier's carbon reduction costs not only failed to achieve its objectives , but also to reduce their own income, manufacturers lack to share some of the suppliers of carbon emissions costs external power. The strategy combination 2 is not the optimal strategy combination pursued by suppliers and manufacturers.

4.3. Analysis of the benefits of suppliers and manufacturers in the case of strategy combination 3

In the case where the supplier does provide low-carbon raw materials and the manufacturer does not share the supplier's carbon reduction costs, the respective gains are shown in Table 3.

Table 3. Benefits of suppliers and manufacturers in the case of strategy combination 3

Supplier Revenue	$PD \cdot n_2 - \frac{1}{2}\eta_s e_s^2 - P_c D \cdot n_2(CCF_s + ccf_s)$
Manufacturer Revenue	$P_{m2}D - P_s D \cdot n_2 - \frac{1}{2}\eta_{m2}e_{m2}^2 - P_c D(n_2 \cdot CCF_{m2} + ccf_{m2})$

Suppliers provide manufacturers with low-carbon raw materials directly. To avoid the wholesaler's second increase in sales of raw materials and secondary logistics costs, but also to avoid the secondary logistics process to increase the carbon footprint and improve the manufacturer's unit carbon production efficiency, the manu-

facturer and the entire supply chain are increased, manufacturers should share the increased benefits with suppliers to reduce the supplier's carbon emission reduction burden and encourage suppliers to provide long-term low for manufacturers providing carbonized raw materials, in order to achieve the supply chain of low-carbon benefits and economic benefits. As a leader in low-carbon emissions, manufacturers do not take the initiative to share the cost of carbon reduction of suppliers, suppliers lack economic incentives to produce low-carbon raw materials, so the strategy combination 3 is not the optimal strategy for suppliers and manufacturers to pursue.

4.4. Analysis of the benefits of suppliers and manufacturers in the case of strategy combination 4

In the case where the supplier does provide low-carbon raw materials and the manufacturer does share the supplier's carbon reduction costs, the respective gains are shown in Table 1.

Table 4. Benefits of suppliers and manufacturers in the case of strategy combination 4

Supplier Revenue	$PD \cdot n_2 - \frac{1}{2}(1-\varphi)\eta_s e_s^2 - P_c D \cdot n_2(CCF_s + ccf_s)$
Manufacturer Revenue	$P_{m2}D - P_s D \cdot n_2 - \frac{1}{2}\eta_{m2} e_{m2}^2 - \frac{1}{2}\varphi\eta_s e_s^2 - P_c D(n_2 \cdot CCF_{m2} + ccf_{m2})$

As the supplier can directly provide manufacturers with low-carbon raw materials, the manufacturer's incremental revenue is:

$$\Delta\pi_m = (P_w - P_s)D \cdot n_2 + P_c D \cdot n_2(CCF_{m1} - CCF_{m2}) > 0 \tag{19}$$

When $0 < \frac{1}{2}\varphi\eta_s e_s^2 < \Delta\pi_m$, namely, manufacturers take the initiative to share a certain percentage of suppliers of carbon emission reduction costs, suppliers and manufacturers achieve the benefits of Pareto improvement, the product is also greatly reduced in the entire supply chain carbon footprint. So the strategy combination 4 is the optimal strategy for suppliers and manufacturers to pursue. That is their respective income optimization, product carbon footprint minimization.

Conclusion 1: Reducing the intermediate process in the supply chain will help reduce the carbon footprint of the product throughout its life cycle and help improve the supply chain revenue.

Conclusion 2: Through the coordination of information and organizational processes, suppliers' low-carbon raw materials will help manufacturers to reduce carbon footprint of manufacturing and logistics process, is also conducive to improving the manufacturer's revenues.

Conclusion 3: To enhance the synergistic stability of the low-carbon supply chain, the manufacturer must share the revenue gain with the supplier for the reduction of the carbon footprint, with the aim of encouraging suppliers to actively implement low-carbon emissions and provide low-carbon Raw materials.

5. Summary

This article discusses the collaborative strategy of low-carbon supply chain processes that reduce product carbon footprints on the basis of ensuring that the benefits of supply chain members and the benefits of the entire supply chain are reduced. Firstly, the feasibility and motivation of the low carbon supply chain are analyzed, and then the cooperative strategy of the low carbon supply chain process to reduce the carbon footprint of the product is discussed. Lastly, the synergetic stability of the low carbon supply chain is demonstrated through game analysis. This paper does not consider the impact of government policy on the feasibility and motivation of low carbon supply chain, which is likely to be the direction of further research.

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