PRICING AND ENERGY EFFICIENCY DECISIONS BY MANUFACTURER UNDER CHANNEL COORDINATION

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Abstract. The profit level of the green supply chain under two decision modes is explored in cooperative and non-cooperative games, where the variable decision timing in direct channel and retail channel within the manufacturer management is studied based on the theory of observable delay game. This paper discusses how the total profit of the green supply chain can realize the profit of the inferior copy of the superior under the two decision-making modes. In the existing literature, it is usually assumed that the pricing decisions of the manufacturers and retailers are made simultaneously. In this study, our model takes into account not only the decision on the pricing, but also on the product innovation. Decision makers can choose the levels of the decision variables as well as the decision times. The observable delay game theory is applied to the study of the decision-making of price levels and energy efficiency levels in multi-channel supply chains. Early pricing decisions can be extended to the study of the product development process. This is more in line with the development of the market in reality. The results of our model show that: (a) an increase of the product efficiency innovation by the manufacturers will lead to

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an increase in the demand at the retail channel; (b) the enhancement of con-
sumers’ awareness of the environmental protection and the improvement of the
price sensitivity of the double-channel crossing have positive effect on the profit
level of the general channel; (c) the manufacturers are motivated to adopt a
marketing strategy that masks disadvantages with advantages. After the man-
ufacturer determines the energy efficiency level of the product, it is found that
the direct channel to increase the pricing decision time and the creation of
input from a high cost are more conducive to achieving higher revenue; (d)
after comparing the total profits of the two decision models, the manufacturer
can obtain all the surplus profit of the retailer by coordinating the fixed fee
of the two-part tariff contract. At the same time, the perfect replication of
decentralized decision-making and the total profit level of centralized decision-
making are realized. Through the coordination of the choice of variable pricing
time and tariff contract, not only the perfect Nash equilibrium of non cooper-
ative game is formed, but also the optimal variable decision-making scheme of
multi-channel green supply chain is provided for manufacturers to maximize
their profits.

1. Introduction. With the rapid development of the Internet industry, the impact
on business is mainly reflected in the increase of channels, that is, network direct
sales channels begin to appear in public life, and play an important role in people’s
daily life. It is precisely because of the impact of the Internet on life that it has
driven the development of China economy and brought many enterprises opportu-
nities to open up new markets. This new channel can help retailers develop new
customer segments and generate more demand. But it may erode existing chan-
nels, increase operating costs, and cause retailers to lose profits. Profit conflicts
between manufacturers and retailers are inevitable. Therefore, how to coordinate
the dual-channel supply chain has become an extensive research topic. In order
to better manage multi-channel sales, manufacturers will make corresponding solu-
tions to maximize profits according to market expectations and product research.
Relatively successful cases include: After receiving the order information on the of-
icial website, IBM directly passes the information to the dealer, trying to alleviate
some conflicts, while HP provides commissions to intermediaries based on online or-
der volumes [32]. In a supply chain structure, wholesale price contracts are almost
always inefficient, and more complex contracts can be used to eliminate this ineffi-
ciency and redistribute rents among all parties in the supply chain. The retailer
is worried about the quantity discount and interest conflict of the two tariff con-
tracts, and may like the manufacturer competition provided by these contracts [4].
There are also references that show in the multi-channel supply chain, it has be-
come a very common way to coordinate the supply chain by formulating a two-part
charging contract.

The progress of science and technology also promotes the improvement of peo-
ple’s quality of life. Green sustainable development will naturally become a topic of
continuous concern. It is the promotion of environmental awareness that promotes
the development of green market. At the same time, some businesses have begun
to attract customers with green products, energy-efficient products, environmen-
tal protection and energy-saving products as gimmicks. The market has gradually
emerged environmental protection products focusing on green technology innovation
of home appliances. China adheres to long-term green, sustainable and low-carbon
development and gradually permeates the concept of green and sustainable develop-
ment in all aspects. Compared with the past, the energy efficiency level and energy
utilization efficiency of the existing products in China have been greatly improved.
In order to achieve better energy conservation and emission reduction and improve
the efficiency of resource utilization, further improvement is needed. The overall improvement of energy efficiency of refrigeration products is realized through the elimination of inefficient products, and the optimization of the green product market. At the same time of improving the green technology, it also stimulates the benign competition among manufacturers, improves the product performance to the maximum extent, and meets the needs of people’s life keeping pace with the times. Compared with household appliances, the energy efficiency level represents the environmental protection level of the product, which is used to measure the energy consumption rate of household appliances. Energy-efficient products cause less pollution, so buying them is an important way to reduce carbon emissions. There are also literatures that show that according to the survey data, when people choose products, consumers’ awareness of environmental protection will make them more willing to buy green products [11]. With the increasing demand for green products, many large companies have begun to ask their manufacturers to take green measures, but the cost burden has fallen on the suppliers, making it difficult for them to do so. An effective way in the research and development of green supply chain is to identify ways to help manufacturers set appropriate energy efficiency levels and control the cost of green innovation.

For the two-channel green supply chain, two kinds of decisions are required to be considered: Centralized decision and decentralized decision. The centralized decision is to maximize the overall supply chain profit, for which manufacturers and retailers make their respective decisions at the same time maximizing the supply chain profit. In this case, to avoid the profit conflict caused by the pricing conflict, the sales prices of the two channels are kept the same in general. In the decentralized decision-making, the wholesale price and the direct price are usually determined by the manufacturer, while the retail price is set by the retailer. Policymakers make decisions to maximize their own interests. The relationship between technological innovation level and cooperation agreement mode is studied in [12]. In order to balance the retailer’s environmental innovation efforts in cooperative and non-cooperative situations, it forms the basis for the distribution of cost and revenue under the contract of sharing the cost and revenue, and provides the possibility for negotiation between the retailers and the suppliers [34].

In the electronic industry, the presence of delay is unavoidable in the supply chain. In a distributed newsboy model with multiple demands, the effect of price and order delay is analyzed [16]. Dell has adopted a “centralized management” strategy, which requires all suppliers to establish inventory in the warehouse near the company. This enables faster and more accurate sharing of order information so that suppliers can better respond to the order information. Delayed manufacturing reduces the company’s inventory costs and speeds up the turnover of the capital chain. These conditions indicate that under the premise of observable delay theory, it is very important to determine the optimal decision-making time of variables in the discrete decision-making stage, and it is the best case to determine the production after obtaining the most accurate order information. In this way, the risk of inventory cost of the company can be minimized and the service level can be improved. Especially when a company wants to develop a new green product and sell it through multiple channels, it can also make the best choice by deliberately adjusting the time sequence. At present, most references have not applied the observable time-delay game theory to the decision-making of different prices and energy efficiency levels in multi-channel supply chains. Therefore, we discuss the
decision time of variables. Compared with the existing literature, the application of observable delay in multi-channel supply chain pricing is also a multi angle management decision problem. Therefore, we choose the optimal equilibrium profit under the decentralized decision in the time series combination, and calculate whether it can achieve the optimal profit under the centralized decision. If not, can we copy the profits of the whole supply chain under the centralized decision-making by describing the “fixed” effect of each variable coefficient in the two costs. Therefore, this paper aims to study:

1. How to set the main pricing and green energy efficiency levels in a centralized and decentralized environment?

2. Can the coordinated replication of channels by the manufacturer be realized by coordinating the “fixed” fee $k$ in the two-charging contract?

Generally speaking, the two-level supply chain structure composed of a manufacturer and a retailer is often studied in management science. However, in the study of decentralized decision making, this paper takes into account the decision motivation of observable delay game model. On the premise of reducing channel conflicts, manufacturers should reasonably choose wholesale prices under the distribution mode, take the initiative to bear the research and development costs brought by improving energy efficiency, and encourage retailers to continue to cooperate. In the initial stage of cooperation, the retailer should also provide the manufacturer with a fixed fee similar to the “alliance fee” to achieve revenue sharing and protect the interests of the manufacturer. We take the MTO production mode as the main supply chain operation mode, and add time series combination in the decision-making process model. Then, the changes of the decision variables of the manufacturer and the retailer under different decision modes and time series combinations in dual-channel supply chain are compared to select the best decision. It is of great research value to add “decision time of variable selection” into the decision process of decision variables. Through the choice of pricing opportunity, the variable decision-making of other members of the supply chain is affected, and the corresponding strategic response is generated. Although the market has raised concerns about innovative technologies for energy efficiency, theoretical research on the issue is scarce. Our research aims to fill this gap. We provide a theoretical analysis framework to capture as much information as possible about the characteristics of multi-channel supply chain, and allow us to assess the potential profitability, and make sound and optimal strategic decisions for manufacturers. Therefore, our research is closer to the variable decision-making in the green supply chain in real life, rather than just the price decision-making. With the increase of people’s demand for green products, more attention has been paid to the market countermeasures in the investment decision of green products. In particular, it has a certain reference value to solve the problem of how to accurately implement the variable decision-making strategy to maximize the profits of the supply chain.

Our model shows that:

The level of green energy efficiency, green innovation input and overall supply chain profit under centralized decision making are higher than the equilibrium achieved under decentralized decision making. In the case of decentralized decision making, manufacturers and retailers show different profit levels when making pricing and energy efficiency decisions in different time frames. In other words, the time for the selection of decision variables affects the profit level. Moreover, the earlier the manufacturer decides on the direct channel pricing, the greater the positive impact
it has on its profit. Intuitively speaking, the earlier the product price positioning is generated online, the better the potential customers will be able to generate the expected purchase price expectation, achieve the effect of product promotion, and eliminate the shopping experience under the influence of the store distance, time arrangement and external factors. The existence of the competition between online and offline cannot be avoided. When the online sales price is announced, the offline price is bound to be restricted by the price setting. Manufacturers who first set direct channel prices have advantages. Manufacturers create a high cost phenomenon, more conducive to its higher earnings. By adopting the strategy of disguising advantages and disadvantages, manufacturers can raise the overall price level to maximize consumer surplus. For these reasons, customers’ demand will increase, which will affect their profits. In addition, we can conduct channel coordination through the two-part tariffs contract signed by the manufacturer and the retailer to achieve the perfect acquisition of the retailer’s surplus by the manufacturer. We also find that manufacturers’ green investment is positively correlated with their profits. With the improvement of energy efficiency, the demand for green commodities is also increasing, showing that the potential market demand for green commodities is large. People are also catering to the market demand for green innovate on technology and developing high-standard green investment. At the same time, it also brought about the growth of profits, the improvement of living standards and the progress of social civilization.

The rest of the paper is structured as follows. Section 2 expounds the research status research situation of green supply chain coordination from the perspective of game theory. Section 3 describes the cooperation and non-cooperation game models under centralized and decentralized decision-making. It also investigates when manufacturers should make retailers related decisions on pricing and energy efficiency, so as to determine the time and level of variables in the relevant equilibrium game. In Section 4, we compare the total profits under the two decision-making models, and analyze the influence of cross-price sensitivity and product green sensitivity on the indicators. Finally, the channel coordination of the fixed part \( k \) in the two-part tariff contract adopted in the model is carried out. By adjusting the parameters to replicate the advantage decision, the overall profit of the supply chain under the disadvantage decision is realized. The last part is the summary of the paper.

2. Related literature. Behavioral analysis of marketing channels has always been a core issue, and it is clear that different strategic interactions will have different impacts on individual and collective interests. The internet allows prices to change rapidly and encourages consumers to act strategically, which poses huge risks for dual-channel manufacturers [21]. The widespread use of the Internet has indicated that the increase of channels is inevitable. The increase of the second sales channel will not only lead to the diversification of sales methods, but also produce corresponding channel conflicts [33]. This new channel can help retailers find new customers and generate additional demand, but it may also hurt retailers by eating into existing channels and increasing operating costs [37]. The work [29] proposed a decision-making framework and model, and studied the strategic choice of appropriate channel structure under the distribution channel. The work [7] discussed the optimal decision of product greenness in the supply chain under different supply chain structures, green product types and competition types. The work [6] discussed the internal problems of channel coordination. The decisions of each channel member affect the profits of the other channel members, which affects their actions. Lack
of coordination of these decisions can lead to undesirable consequences. Manufacturers act as suppliers and competitors of retailers in the dual-channel supply chain, so there is a wide range of upstream and downstream dual marginalization contradiction and peer channel conflict between manufacturers and retailers. Therefore, how to reasonably solve the strategic problems of the corresponding channels has aroused everyone’s thinking and research.

In the coordination of the dual-channel supply chain, the manufacturer can adjust the decision time of each price variable to achieve the effect of coordinating the profit of the supply chain. In [30], several insights have been generated into manufacturers’ optimal pricing strategies. Competition is common in all links of the supply chain. How to gain advantage in the competition is the main consideration for each enterprise to gain more market shares. The long listing time of Japan’s top companies is an important factor in gaining competitive advantage: mainly from shortening product development cycle, shortening factory process times and shortening inventory management time. In fact, time management cannot only effectively reduce operating costs, but also improve the technical level of products, so as to achieve higher product coverage. The work [8] showed how the timing of decision affects the risk sharing between the government and suppliers, and ultimately the cost of subsidy programs. Although manufacturers attached an importance to the timing of decision variables [25], there exists no timing in both product pricing and energy efficiency level decisions. To date, China attaches great importance to the strategy of green sustainable development. Therefore, people in China have begun to pay more attention to green sustainable development. The promotion of environmental awareness has greatly promoted the development of green market. In recent years, people’s overall understanding of environmental management and corporate strategy has changed significantly, requiring enterprises to consider more and more stakeholders [10]. The work [9] showed that government subsidies are often introduced at the early stage of green technology adoption to help them become more economically viable. Several important aspects of using environmental taxes to spur innovation and “green” emissions-reduction technology options were investigated in [19]. In [35], it was indicated that marketing green products is conducive to improving the supply chain environment. Higher product performance (or quality) usually leads to more consumers willing to pay, but this is also associated with higher design and production costs [23]. Based on this, the inclusion of green investment in the model is more in line with the actual needs of the real society, taking into account the sustainable innovative production of future products. The level of energy efficiency is used to reflect the increased demand for green investment and products after the upgrading of innovative technologies, thus driving economic development and realizing efficient operation of the supply chain. This is also the basic point that distinguishes this paper from those in the existing literature. It is more meaningful to study from the perspective of practical needs. The work [15] studied the trade-offs faced by channel partners when they have the opportunity to invest in cost reduction or quality improvement, i.e., demand enhancement. The effects of consumer environmental awareness (CEA) on order volume and channel coordination in the supply chain of a manufacturer and a retailer were investigated. The results show that the return contract can help both parties realize the expected profits under the centralized mode, and the order quantity of environmental products increases with the increase of CEA [36].
In recent years, it has become common to coordinate dual-channel green supply chain through contract. The work [20] showed that two tariffs can be used to prevent destructive downstream price competition. Compared with traditional wholesale price contracts, revenue sharing contracts are more extensive in commercial use and coordination between supply chain and retailers [5]. Many scholars have begun to study whether the supply chain can be coordinated by making a two-part charging contract, which was effectively verified. In [18], Jeuland and Shugan found that manufacturers can coordinate the supply chain through two wholesale price contracts. A fixed portion of $k$ in the contract plays the role of profit-sharing and distributes the profits of the manufacturer and the retailer. This is also the benchmark for the two-part pricing contract considered in this article. When the channel structure is characterized by strong retailers (such as Wal-Mart and home depot), better positioning and pricing of new products will determine the success of new products [24]. In [22], it was found that the intensification of traditional double marginalization will lead to greater loss of channel efficiency. The revenue sharing contract can coordinate the dynamic supply chain. The work [13] compared the coordination effect of the profit sharing rules, RPM and the tariffs of the two parts. The work [31] also discussed similar issues concerning the two-part tariffs. In [28], a channel model was developed in the presence of major retailers to examine how manufacturers best coordinate such a channel, where manufacturers were required to coordinate channels through volume discounts or tariffs in both parts of the menu. Manufacturers must choose their channel coordination mechanisms wisely. Therefore, in this paper, our concern is on whether we can design an effective two-part charging contract to coordinate the green supply chain, so as to maximize the replication of the advantage strategic profit and green energy efficiency level of the inferior strategy under the two decision-making modes.

Under the setting of the same pricing decision time problem, we added the selection time of energy efficiency level to explore the influence of controlling the product energy efficiency level and green technology cost input on the commodity pricing and profit level, so that the model is more in line with the development process of market operation. People began to pay more attention to environmental protection and green consumption, which also brought about the rapid renewal of goods. In other words, enterprises began to improve their products and produce more energy-efficient products to meet the needs of the public. In [3], it was suggested that moving from environmental awareness to market-driven pressure can stimulate green production. High energy efficiency products have better performance, and bring better product benefit. Therefore, the purchase of energy efficient products has become an important means to reduce emissions and improve healthy competition in the market. With the continuous updating of high energy efficient products in the market, it will gradually eliminate high energy consumption and low energy efficiency products, and promote the improvement of energy efficiency of energy-saving products. In this paper, a decision-making method with two-channel variables is proposed, which is not only a price variable, but also an energy efficiency level variable of green cost input. That is to say, the combination of time series is added to the dual-channel pricing process, and the optimal balance decision is made by comparing the price, energy efficiency level and profit under different time series combinations.
3. Proposed model.

Table 1. Notations

| Symbol | Description                                      |
|--------|--------------------------------------------------|
| $p_M$  | Direct price                                     |
| $p_R$  | Retail price                                     |
| $c$    | Marginal cost                                    |
| $c_1$  | Wholesale price                                  |
| $x$    | Level of energy efficiency                       |
| $g$    | Sensitivity of energy efficiency levels to demand|
| $\theta$ | Cross-price sensitivity between the channels  |
| $a_M$  | Intercept of the demand function for the direct  |
| $a_R$  | Intercept of the demand function for the retail   |
| $b_M$  | Sensitivity of demand in the direct channel to the direct channel price |
| $b_R$  | Sensitivity of demand in the retail channel to the retail channel price |
| $q_M$  | The demand at the direct end                     |
| $q_R$  | The demand at the retail end                     |
| $t_{c,1}$ | Period when the manufacturer chooses the wholesale price |
| $t_{p_M}$ | Period when the manufacturer chooses the direct channel price |
| $t_{p_R}$ | Period when the retailer chooses the retail channel price |
| $t_x$  | Period when the manufacturer chooses the level of energy efficiency |
| $E$    | Manufacturer precede retailer in setting direct price |
| $S$    | Manufacturer and retailer setting the order of direct price at the same time |
| $L$    | Manufacturer setting the order of direct price later than retailer |
| $\pi_M$ | Profit for the manufacture under decentralized decision-making |
| $\pi_R$ | Profit for the retailer under decentralized decision-making |
| $\pi_V$ | Profit of the whole supply chain under centralized decision-making |

Figure 1. Channels describe.

3.1. Assumptions. Firstly, we provide the model setup to support this article. The use of the variables are listed in Table 1 in the model. The manufacturer’s variable cost per unit of production is $c$ and sells the product directly or through retailers to consumers. As shown in Figure 1, we define direct channels as the channels through which manufacturers sell products directly to consumers, and
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Retail channels as the channels through which manufacturers sign product wholesale contracts with retailers and retailers sell products directly to consumers. In the retail channel, the manufacturer first sets the energy efficiency level $x$, then sets the unit wholesale price to $c_1$, and sells the product to the retailer at the set price. We use the blue dotted lines to indicate the use of two pricing contracts between the manufacturer and the retailer. Manufacturers delegate retail price decision to retailers, who resell the products.

As shown in Figure 1, we assume that the processing of customer orders is in the supply chain, where both the direct channel and the retail channel use the make-to (MTO) system, and our model does not take into account the shortage cost and inventory issues. We assume that customers send their order information directly to the manufacturer of the direct channel or to the retailer of the retail channel. In the direct channel, the manufacturer begins production after receiving the customer’s order information, and then delivers the product to that customer. On the other hand, when the retailer receives the customer’s order, it resends the order information to the manufacturer, who receives the product order information, starts production, and finally sends it to the customer. Therefore, retailers act as agents or intermediaries in the process of selling products.

3.2. Equilibrium strategy analysis. We discuss the centralized decision-making situation, in which manufacturers and retailers jointly determine product prices and green investments to maximize supply chain profits. Then, we analyze and discuss the equilibrium under decentralized decision making. That is, the manufacturer decides on the energy efficiency level, the wholesale price in the two charging contracts and the direct price in the direct channel, while the retail price in the retail channel is determined by the retailer.

Model analysis in the case of centralized decision making.

In the case of centralized decision making, when direct sales channels are introduced, manufacturers and retailers are bound to have disputes over the profit imbalance caused by inconsistent pricing. Therefore, price consistency strategy is generally chosen to reduce the pricing strategy contradiction between the two channels. In the case of the same price, we assume that the demand functions of the two channels are respectively:

$$q_M = a_M - bp + gx,$$
$$q_R = a_R - bp + gx.$$  (1)

The improvement of environmental awareness leads to the positive correlation between energy efficiency level and demand function, that is, with the improvement of energy efficiency level, the demand increases gradually. Here $p$ and $q$ are, respectively, represent price and quantity, and the subscripts $M$ and $R$ of $q$ signify the direct and retail channels. For example, $q_M$ means the demand at the direct end, $q_R$ means the demand at the retail end. The basic parameters $a_M$ and $a_R$ are determined by the market potential of the direct and retail channels, respectively. Respectively, $b$ and $g$, the demand sensitivity to the price of the two channels and the demand sensitivity to the energy efficiency levels of the two channels. We assume that the parameters are such that the following inequalities are satisfied:

$$b > g, \quad \frac{a_M}{c} > b, \quad \frac{a_R}{c} > b.$$  (2)

The first inequality shows that the price is more sensitive to demand than the level of energy efficiency. The last two inequalities are derived from the inverse
demand function, where it is common to assume that the demand function is a linear function in the green supply chain.

In the field of operation management, the investment cost is usually assumed as a quadratic function, which is written as $\frac{x^2}{2}$ to represent the green investment cost. The convex investment cost function reflects the diminishing marginal return of the investment cost [2]. It shows that with the improvement of green investment level, manufacturers also bear more and more investment costs. Thus, the resulting profit function is:

$$\pi_V = (p - c)(a_M + a_R - 2bp + 2gx) - \frac{x^2}{2}. \tag{3}$$

The research scheme of centralized decision making is considered as the first step. By maximizing the above objective function, the optimal pricing and energy efficiency level can be obtained as given in Proposition 1 below.

**Proposition 1.** Under the centralized decision, $\pi$ can be maximized with $p = \frac{a_M + a_R + (2b - 4g^2)c}{4(b - g^2)}$, $x = \frac{(a_M + a_R - 2bc)g}{2(b - g^2)}$.

**Proof.** See appendix. \qed

From the above model, we see that, in a certain range, the positive correlation between the overall supply chain profit and energy efficiency level is relatively obvious in the case when the price of centralized decision-making is consistent. With the increase of the phase sensitivity coefficient $g$ of the energy efficiency, the energy efficiency of products is improved, indicating an increase in the innovation investment. So the cost of production goes up. To ensure that products remain profitable, when the innovation cost increases, the price will also increase. We also see an upward trend in overall profit. That is to say, when the whole society opts for green living, increasing the cost of the green innovation and the technology upgrade will bring about positive benefit to the profit of the supply chain.

Considering the channel conflict and the complexity of the market, we discuss the inconsistencies of the centralized decision price here. Now, for the case of price inconsistency, the demand functions of these two channels are assumed to take the forms as given below:

$$q_M = a_M - b_M p_M + \theta p_R + gx,$$
$$q_R = a_R - b_R p_R + \theta p_M + gx. \tag{4}$$

The increasing awareness of environmental protection has a positive impact on people’s spiritual and material needs. The garbage classification that is now being popularized in many countries is one such example. The impact of environmental protection on market demand is reflected in the model by the level of energy efficiency. That is, the energy efficiency level is positively correlated with the demand function. The subscripts $M$ and $R$ represent, respectively, the two sales channels - one for the manufacturers and one for the retailers. For example, $q_M$ represents the number of manufacturers in the direct sales channel, and $q_R$ represents the number of retailers in the retail channel. The intercepts $a_M$ and $a_R$ are determined by the market potential of direct and retail channels, respectively. The parameters $b_M$ and $b_R$ are the price sensitivity coefficients of the two channels with reference to the demand. The parameter $\theta$ is the cross-price sensitivity coefficient of the two channels, and $g$ is the contribution coefficient of the energy efficiency level. We assume that
the above parameters are such that the following inequalities are satisfied:

\[ b_M > \theta, \quad b_R > \theta, \quad b_M > g, \quad b_R > g, \quad \frac{a_M}{c} > b_M - \theta, \quad \frac{a_R}{c} > b_R - \theta. \]  

(5)

The latter two inequalities indicate that when the selling price in the demand function is the lowest production cost and the energy efficiency level (i.e., energy efficiency level is 0) is not considered, the demand is greater than 0. The green cost is usually assumed to be a quadratic function, which is used to represent the green investment cost. The cost of green is usually taken as a quadratic function, where \( \frac{x^2}{g} \) is used to represent the cost of energy efficiency innovation. The resulting profit function is

\[ \pi_V = (p_R - c)(a_M - b_Rp_R + \theta p_M + gx) + (p_M - c)(a_M - b_Mp_M + \theta p_R + gx) - \frac{x^2}{2}. \]  

(6)

According to the formula of the profit function, the profit of the overall supply chain under the centralized decision is a concave function of direct selling price, the retail price and the energy efficiency level. Their optimal solutions are given in Proposition 2 given below.

\textbf{Proposition 2.} Under the centralized decision-making of price inconsistency, the optimal pricing of the direct channel and the retail channel given, respectively, by

\[ p_M = \frac{[a_M + (b_M - \theta)c][2b_M - g^2] + [a_R + (b_R - \theta)c][2\theta + g^2] - 4(b_R + \theta)cg^2}{2[2(b_Mb_R - \theta^2) - (b_M + b_R + 2\theta)g^2]}, \]

\[ p_R = \frac{[a_R + (b_R - \theta)c][2b_M - g^2] + [a_M + (b_M - \theta)c][2\theta + g^2] - 4(b_M + \theta)cg^2}{2[2(b_Mb_R - \theta^2) - (b_M + b_R + 2\theta)g^2]}. \]

the optimal energy efficiency level is

\[ x = \frac{[a_M + (b_M - \theta)c][b_R + \theta] + [a_R + (b_R - \theta)c][b_M + \theta] - 4(b_Mb_R - \theta^2)c}{2(b_Mb_R - \theta^2) - (b_M + b_R + 2\theta)g^2}. \]

\textit{Proof.} See appendix.

Model analysis under decentralized decision making.

First of all, on the basis of the above setup, we take into account the problem of two-channel price competition. Price competition is a common phenomenon in a multi-channel supply chain, as decision-makers all hope to maximize their own interests through coming out beneficial strategies for their own channels. Price diversity in the decentralized decision-making is used to stimulate manufacturers and retailers to take advantage of price competition. Therefore, we analyze the non-consistent price situation of the two channels, assuming that the demand functions of the two channels are:

\[ q_M = a_M - b_Mp_M + \theta p_M + gx, \]

\[ q_R = a_R - b_Rp_R + \theta p_M + gx. \]  

(7)

In the case of price inconsistency, the price change in the channel itself is more sensitive to the demand function than that in the other channel. That is, \( b_M > \theta, \quad b_R > \theta \). When the green investment is not taken into account, i.e., the energy efficiency level coefficient \( g \) is 0, the demand function is greater than 0, and hence, \( \frac{a_M}{c} > b_M - \theta, \quad \frac{a_R}{c} > b_R - \theta \). In addition, demand is more sensitive to the price
of its own channel than to the level of energy efficiency, that is \( b_M > g \), \( b_R > g \). We analyze on the premise that the manufacturer and retailer have signed two charging contracts, and the green investment here is expressed as \( \frac{x^2}{2} \) under the same centralized decision. The resulting profit function is:

\[
\pi_M = (c_1 - c)q_R + (p_M - c)q_M + k - \frac{x^2}{2},
\]

\[
\pi_R = (p_R - c_1)q_R - k.
\]  

(8)

Here, the manufacturer sells the products to the retailer at the wholesale price of \( c_1 \) in the two-fee contracts, and the retailer pays the manufacturer a fixed fee \( k \). We only take into account the manufacturers’ green cost investment. The improved performance of the products will correspondingly drive the sales volume of the retailers, thus increasing their profits. At the same time, due to the increase in the investment cost of the manufacturer, some adjustments in the pricing or designated fixed fees are inevitable so as to balance the profits of both parties. Fixed fee \( k \) also plays a role of profit sharing between manufacturers and retailers.

On the basis of the above, we consider the observable delay model proposed in [17], which is mainly divided into two stages. First, the decision variables, which are the wholesale price and the direct price, are determined by the manufacturer, the energy efficiency level of the product, and the retail price determined by the retailer. In the first stage, the manufacturer chooses to determine the energy efficiency level of the product the first time, then the manufacturer and retailer simultaneously announce the time when they will choose the price, and make a commitment to implement this choice before actually taking action. In the second stage, the manufacturer and the retailer choose their prices after the announcement, knowing that competitors will make corresponding decisions on time and price according to their own choices. Since there are four control variables \( x, t_{c_1}, t_{p_M}, t_{p_R} \), they are determined in four stages. We adopt the four-period discrete time setting for the second stage hypothesis. The manufacturer determines the energy efficiency level, wholesale price, and direct channel price, and the retailer determines the retail prices and chooses between these four stages. The next step is to determine the timing of the pricing. Let \( t_x, t_{c_1}, t_{p_M}, t_{p_R} \) represent the times of setting the energy efficiency level, the wholesale price, the direct channel price and the retail channel price, respectively. Because the manufacturer and the retailer choose four stages to determine each variable, the time interval for these four variables can be 1, 2, 3 or 4. That is, in the first phase, we assume that the model considers what would happen if the manufacturer proposed the level of efficiency that they wanted to achieve \( t_x = 1 \). The manufacturer then selects \( t_{c_1}, t_{p_M} \) from \{2,3,4\} and the retailer selects \( t_{p_R} \) from \{2,3,4\}. As assumed in other supply chain literature (e.g. [26], [1]), these time variables usually satisfy \( t_{c_1} < t_{p_R} \). In other word, the retailer chooses to determine the retail price after the manufacturer determines the wholesale price.

4. Analysis.

4.1. Solution of the model.

\[
\pi_M = (c_1 - c)(a_R - b_R p_R + \theta p_M + gx) + (p_M - c)(a_M - b_M p_M + \theta p_R + gx) +
\]

\[
k - \frac{x^2}{2},
\]

\[
\pi_R = (p_R - c_1)(a_R - b_R p_R + \theta p_M + gx) - k.
\]
Using equation (4), we state the profit expression for the manufacturer and retailer, because the second stage has four variables \( t_x, t_{c_1}, t_{pM}, t_{pR} \) and four cycles. We only consider the case that the energy efficiency level \( t_x = 1 \) is determined the first time, and there are \( 3^3 = 27 \) time series combinations for profit calculation. The constraint \( t_{c_1} < t_{pR} \) shows that we only need to study 9 combinations. In addition, through calculation, we find that there are three income equilibrium situations under the 9 possible time series combinations. We use the sequence \( E, S \) and \( L \) to represent the direct channel price set by the manufacturer before and after the retailer sets the retail price, respectively. Let the \( E \) sequence be expressed as \((t_x, t_{c_1}, t_{pM}, t_{pR}) = (1, 2, 3, 3), (1, 2, 2, 4), (1, 2, 3, 4), (1, 3, 2, 4), (1, 3, 3, 4)\) because \( t_{pM} < t_{pR} \) is true for all of these combinations. The \( S \) sequence is denoted as \((t_x, t_{c_1}, t_{pM}, t_{pR}) = (1, 2, 3, 3), (1, 2, 4, 4), (1, 3, 4, 4)\) because \( t_{pM} = t_{pR} \) is true for all of these combinations. At last, the \( L \) sequence is denoted as \((t_x, t_{c_1}, t_{pM}, t_{pR}) = (1, 2, 4, 3)\) because \( t_{pM} > t_{pR} \) is true for all of these combinations. After that, we add superscripts \( E, S \) and \( L \) to each variable and payoff to represent the results under different sequences.

The equilibrium results are:

**Case (1):** Sequence \( E \)

\[
x^E = \frac{2 \left( Y_M - B_0 c \right) \left( b_R + \theta \right) g + L_R B_0 g}{4 b_R B_0 - 2 \left( b_R + \theta \right) g^2 - g^2 B_0},
\]

\[
e_1^E = \frac{1}{2} \left( \frac{Y_R}{B_0} + c \right) + \frac{\left( b_M + \theta \right) g x^E}{2 B_0},
\]

\[
p_M^E = \frac{1}{2} \left( \frac{Y_M}{B_0} + c \right) + \frac{\left( b_R + \theta \right) g x^E}{2 B_0},
\]

\[
p_R^E = \frac{1}{2} \left( \frac{Y_R}{B_0} + c \right) + \frac{L_R}{4 b_R} + \frac{1}{4} \frac{b_M + \theta}{2 B_0} \right) g x^E,
\]

\[
\pi_R^E = \frac{\left( L_R + g x^E \right)^2}{16 b_R} - k,
\]

\[
\pi_M^E = \left( \frac{Y_M - B_0 c + \left( b_R + \theta \right) g x^E}{4 b_R B_0} \right)^2 + \left( \frac{L_R + g x^E}{8 b_R} \right)^2
\]

\[
+ k - \left( \frac{x^E}{2} \right)^2.
\]
Case.(2): Sequence $S$

$$x^S = \frac{(Y_M - B_0c) \left(b_R + \theta\right) gB_1 + 4b_M b_R g L_R B_0}{2b_R B_0^2 B_1 - \left(b_R + \theta\right)^2 g^2 B_4 - 4b_M b_R g^2 B_0},$$

$$c_1^S = \frac{1}{2} \left(\frac{Y_R}{B_0} + c\right) + \frac{(b_M + \theta) g x^S}{2B_0} - \frac{\theta^2 \left(L_R + g x^S\right)}{2b_R B_4},$$

$$p_M^S = \frac{1}{2} \left(\frac{Y_M}{B_0} + c\right) + \frac{(b_M + \theta) g x^S}{2B_0} + \frac{\theta L_R}{B_4} + \frac{3 \left(b_R + \theta\right) b_M b_R g x^S}{2 \left(4b_M b_R - \theta^2\right) B_0}$$

$$- \frac{3\theta^3 g x^S}{2B_4 \left(4b_M b_R - \theta^2\right)},$$

$$p_R^S = \frac{1}{2} \left(\frac{Y_R}{B_0} + c\right) + \frac{\left(b_M + \theta\right) g x^S}{2B_0} + \frac{\left(4b_M b_R + \theta^2\right) \left(L_R + g x^S\right)}{2b_R B_4},$$

$$\pi_R^S = \frac{\left(2b_M b_R + \theta^2\right)^2 \left[a_R - \left(b_R - \theta\right) c + g x^S\right]^2}{b_R B_4^2} - k,$$

$$\pi_M^S = \frac{\left[Y_M - B_0c + \left(b_R + \theta\right) g x^S\right]^2}{4b_R B_0^2} + \frac{b_M \left(L_R + g x^S\right)^2}{B_4} + k - \frac{\left(x^S\right)^2}{2}.$$

Case.(3): Sequence $L$

$$x^L = \frac{(Y_M - B_0c) \left(b_R + \theta\right) gB_5 + \left(2b_M b_R - \theta^2\right)^2 g L_R B_0}{2b_R B_0^2 B_5 - 2 \left(b_R + \theta\right)^2 g^2 B_5 - \left(2b_M b_R - \theta^2\right)^2 g^2 B_0},$$

$$c_1^L = \frac{1}{2} \left(\frac{Y_R}{B_0} + c\right) + \frac{(b_M + \theta) g x^L}{2B_0} - \frac{b_M \theta^2 \left(L_R + g x^L\right)}{2B_5},$$
commodity sales volume and the profit. That is, the larger the
reflects the impact of green technology cost on the commodity pricing strategy, the
sions. As can be seen from the above model, the level of the energy efficiency partly
accelerated the pace of market science and technology research and development,
saving products is increasing. The emergence of new energy-saving products has
constantly improving, so that the market demand for energy-efficient green energy-
speaking, people’s consumption level of products and environmental awareness are
be achieved, which will bring the maximum profit to the manufacturer. Generally
the overall optimal development, the optimal product energy efficiency level can
the balance of interests of both sides. Therefore, under the premise of controlling
from infringement, the manufacturer will coordinate on other pricings to maintain
investment cost is borne by the manufacturer, in order to protect its own interests
stimulate the purchase volume of the retailer. However, since the green innovation
increase sales, the manufacturer adopts the strategy of reducing wholesale price to
increase of \( x \) means that the manufacturer’s production cost increases. In order to
means that the manufacturer's production cost increases. In order to
profit to the manufacturer. Generally
speaking, people’s consumption level of products and environmental awareness are
constantly improving, so that the market demand for energy-efficient green energy-
saving products is increasing. The emergence of new energy-saving products has
accelerated the pace of market science and technology research and development,

\[
\begin{align*}
 p^L_M &= \frac{1}{2} \left( \frac{Y_M}{B_0} + c \right) + \frac{(b_R + \theta) g x^L}{2 B_0} + \frac{(2 b_M b_R - \theta^2) \theta L_R}{2 B_0} \\
 &\quad + \frac{(2 b_M b_R - \theta^2) \theta^2 + b_M \theta B_0}{4 b_M B_0 (2 b_M b_R - \theta^2)} g x^L - \frac{\theta^3 (3 b_M b_R - \theta^2) g x^L}{4 (2 b_M b_R - \theta^2) B_0}, \\
 p^L_R &= \frac{1}{2} \left( \frac{Y_R}{B_0} + c \right) + \frac{(b_M + \theta) g x^L}{2 B_0} + \frac{(4 b_M b_R - \theta^2) b_M L_R}{2 B_0} \\
 &\quad + \frac{b_M g x^L}{2 \left(2 b_M b_R - \theta^2\right)} - \frac{b^2_M b_R \theta^2 g x^L}{2 \left(2 b_M b_R - \theta^2\right) B_0}, \\
 \pi^L_R &= \frac{2 b^3 M b_R \left(L_R + g x^L\right)^2}{2 B_0 (2 b_M b_R - \theta^2)} - k, \\
 \pi^L_M &= \frac{\left(Y_M - B_0 c + (b_R + \theta) g x^L\right)^2}{4 b_R B_0} + \frac{(L_R + g x^L)^2}{4 b_R B_0}, \\
 &\quad + k - \frac{(x^L)^2}{2}.
\end{align*}
\]

The symbols contained in these equations are defined by:
\( Y_M = a_M + a_R \theta \), \( Y_R = a_R b_M + a_M \theta \), \( L_M = a_M - (b_M - \theta) c \), \( L_R = a_R - (b_R - \theta) c \), \( B_0 = b_M b_R - \theta^2 \), \( B_4 = 8 b_M b_R + \theta^2 \), \( B_5 = 8 b^2_M b^2_R - 5 b_M b_R \theta^2 + \theta^4 \).

By comparing the variables of Proposition 3, we arrive at the following conclusions. As can be seen from the above model, the level of the energy efficiency partly
reflects the impact of green technology cost on the commodity pricing strategy, the
commodity sales volume and the profit. That is, the larger the \( x \) is, the more the manufacturer will invest in green technology in the product. The more advanced the product is, the more attractive it will be to customers, and the demand of potential customers will increase accordingly. In the model, the demand for \( q_M \) and \( q_R \) of the
two channels also increases as \( x \) increases. The green innovation cost for improving
the product performance is borne by the manufacturer alone. Therefore, the
increase of \( x \) means that the manufacturer’s production cost increases. In order to
increase sales, the manufacturer adopts the strategy of reducing wholesale price to
stimulate the purchase volume of the retailer. However, since the green innovation
investment cost is borne by the manufacturer, in order to protect its own interests
from infringement, the manufacturer will coordinate on other pricings to maintain
the balance of interests of both sides. Therefore, under the premise of controlling
the overall optimal development, the optimal product energy efficiency level can
be achieved, which will bring the maximum profit to the manufacturer. Generally
speaking, people’s consumption level of products and environmental awareness are
constantly improving, so that the market demand for energy-efficient green energy-
saving products is increasing. The emergence of new energy-saving products has
accelerated the pace of market science and technology research and development,
promoted the development and progress of social civilization, and also brought about a greater space for future development of green market and achieved a higher product profitability.

Based on the equilibrium variables in Proposition 3, the following proposition follows readily.

**Proposition 3.** From the equilibrium results and variables, the following relations are valid.

\[
\pi^E_M > \pi^S_M > \pi^L_M \quad \text{and} \quad \pi^E < \pi^S \\
x^E > x^S > x^L \quad \text{and} \quad c^E_1 > c^S_1 > c^L_1
\]

**Proof.** See appendix.

The following corollary is derived from Proposition 3.

**Corollary 1.** In Figure 2, the crossover line is due to the premise and the assumption \( t_{c_1} < t_{pR} \), and the conflict between the timing sequence profit combination the assumption. In all the time series combinations, the combination in which the profits in parentheses are circled constitutes the Nash equilibrium solution of the interests of the manufacturer and the retailer \([27]\). In other words, the manufacturer and the retailer observe each other’s strategic decision timing so as to make the choice of their decision timings to obtain the optimal strategy to maximize their own interests.

**Proposition 4.** \((t_x,t_{c_1},t_{pM},t_{pR})=(1,2,2,3),(1,2,2,4),(1,3,2,4),(1,3,3,4)\). The combinations that make up the perfect Nash equilibrium of the subgame are \((t_x,t_{c_1},t_{pM},t_{pR})\).
$t_{PR}=(1,2,2),(1,2,2,4),(1,3,2,4),(1,3,3,4)$, and these are all attributed to the sequence $E$. This suggests that the manufacturer’s choice of the direct channel price should best be made before or at the same time as his choice of the wholesale price, and before the retailer’s decision of retail price, in order to reach an equilibrium state, given the choice of energy efficiency level in the first place.

Proof. See appendix.

4.2. Rationale. In this section, we will introduce the basic principles of our model. The first is that a centralized decision is made based on the strategy of global optimization, so the final overall profit is optimal. Compared with the equilibrium decision under decentralized decision making, the decision makers are independent of each other, and they can make the final decision from the perspective of maximizing their respective interests. This decision will inevitably lead to double marginal effects, resulting in the final overall supply chain profit being less than the optimal profit level under the centralized decision. For the above reasons, the manufacturer coordinate channels in order to maximize the profit.

Secondly, we analyze the three main decision timescales under decentralized decision making. The first step is to have an understanding of the observable delay theory. The theory of delayed game was first proposed in [14], which was expressed as follows: In a non-cooperative game, different decision-making orders of game players will have different effects on the final result, thus producing different outcomes. Therefore, whether the player needs to make decision in advance, simultaneously or later in the game will have a great impact on the final result of the game. In a non-cooperative game, it is assumed that there are only two players. The player who makes the first decision is bound to gain an advantage over the player who makes the next decision. This is because the goals of both sides of the game are the same, and high-yielding player has an advantage in decision time. In this game, decision-makers have the incentive to speed up the decision-making time to improve their own inferior status. Different from the traditional game, the “first time” here is not the “first time” in the whole game process, but the first decision strategy in the sub-game. The decentralized supply chain model in this paper is based on the observable delay model.

Different profit and variables are analyzed under three sequences in the decentralized decision making. According to Proposition 3, under the sequence of $E$, the manufacturer’s maximum profit can be achieved, and the retailer’s pricing time is later than that of the manufacturer, so there is a certain degree of loss of customer flow. As a result, retailer generates lower profit level. The energy efficiency level $x$ reaches the maximum under the $E$ sequence, that is, the energy efficiency level is determined for the first time in the combination of all variable decision sequences, so that the cost investment in green technology can reach the maximum and the benefit to the manufacturer is also the largest. All price variables are also closely related to the energy efficiency. The wholesale price $c_1$ reaches its maximum at Series $E$, that is, the manufacturer can increase the wholesale price and sales the price by disguising the high cost, so as to obtain the consumer surplus. In addition, $p_R$ does not affect the strategy made by $p_M$ because the manufacturer substitutes $p_R$ into the profit function in an earlier period and maximizes it, which is represented by the other three variables of the manufacturer’s decision. That is, the manufacturer can predict all the possible pricing strategies of the retailer early to develop the corresponding optimal countermeasures. Because the direct channels
do not have double margins, this pre-optimization allows manufacturer to obtain the highest profit from the direct channels compared to the retail channel. The profit of the manufacturer of $S$ sequence is less than that of the manufacturer of $E$ sequence. In order to achieve a better profit state, the manufacturer will reduce the cost and the price to earn more profits from the retail channel. Reducing the green input cost will reduce the energy efficiency level of the product $x^S < x^E$. The energy efficiency level will also affect the wholesale price. The wholesale price will fall, that is, $c^S_1 < c^E_1$. Finally, we consider the L sequence, where the manufacturer first determines the energy efficiency cost input and sets the direct channel price with reference to the established retail channel price. To minimize the drop in sales, the manufacturer has again had to reduce the technology cost by reducing the energy efficiency. Lower the energy efficiency level also affects the wholesale price reduction strategies, and hence encouraging the retailer to increase trading volumes. Since the manufacturer sets the direct channel price at the final stage, the decision makers will adjust the prices for their own benefits. The double marginal effect is enhanced, resulting in the manufacturer getting the lowest profit in this sequence.

5. **Numerical examples.** In the existing literature, the decision-makers in the decentralized supply chain are independent of each other, and they all make their own decisions aiming to maximize their respective interests, and hence the double marginal effect is obvious. We compare the influence of various factors on the channel strategy factors through example analysis under two supply chain structures.

The influence of single factor $g$ on the total profit of two kinds of decisions: We adopt $\pi^D$ to represent the difference between the total profit under the centralized decision-making and the total profit under the decentralized decision-making, $\pi^c$ to represent the total profit under the centralized decision-making and $\pi^d$ to represent the total profit under the decentralized decision-making. The comparison between the total channel profit under the decentralized decision-making and the total channel profit under the centralized decision-making is carried out through an example analysis. Assumes that $a_M = a_R = 100$, $b_M = b_R = 1$, $c = 10$, $\theta = 0.3$, $\theta = 0.4$, $\theta = 0.5$, and $g$ from 0.1 to 0.65. Taking the channel profit under decentralized decision-making as an example, this paper compares the total channel profit under centralized decision-making by using sensitivity analysis, consumer’s sensitivity to green product preference and dual channel cross sensitivity to different prices.

As it can be seen from the above charts, the total channel profit always increases with the improvement of consumers’ sensitivity to green, no matter in the case of the centralized decision or the decentralized decision. The energy efficiency of the products is also improved, and the greenness of the products is improved, which also means that manufacturer’s innovation cost and production cost are increased. In real life, the energy-efficient products are also more popular and slightly more expensive than the less energy-efficient ones. The total profit curve of the centralized decision is located above the total profit curve of the decentralized decision. Both curves show an upward trend with the improvement of the demand sensitivity of the energy efficiency. Therefore, from the perspective of the manufacturer management marketing, the final profitability level can be guaranteed by increasing the input of the green innovation cost of the products.

We now investigate the influence of the multiple factors $g$ and $\theta$ on the steady state of the supply chain under two kinds of decisions. We will compare the steady-state changes of $g$ and $\theta$ acting on the different supply chain structures simultaneously. We shall analyze their impacts on the profitability and the demand of the
dual-channel supply chain. We assume that the values of parameter range remains the same as above. We now adjust the parameter $\theta$ so that $g$ increases at a rate of 0.01 within $0.1 \sim 0.65$.

In the horizontal comparison, as the sensitivity of the energy efficiency to the demand increases, the channel demand increases, and the overall profit of both the channels increases. In the longitudinal comparison, it can be seen that with the increase of the cross-channel price sensitivity, the overall profit level also increases. When the cross-channel price sensitivity is unchanged, with the improvement of the sensitivity of the energy efficiency level to the demand, the green energy efficiency level of the products is improved to a certain extent, accompanied by the increase of the product technology cost input. In response to the call for green living, and sustainable green living, the manufacturer is also experimenting with the energy efficiency innovation to make their products more popular with consumers. On the one hand, the input of green innovation cost causes increase in the production cost of the products, so the product pricing is affected. On the other hand, it also lead to an increase in the market demand. From the model calculation, it can be seen that the product benefit brought by the demand is higher than the profit level before the product technology upgrade. In general, improving the sensitivity of the energy efficiency level to the demand will lead to an increase in the market demand and the product benefit level.
Figure 4. Effect of $g$ on $q_M$ and $q_R$.

It can be intuitively seen from the figure above that the difference between the profit of the centralized decision channel and the profit of the decentralized decision channel is always positive. According to the horizontal observation, with the increasing sensitivity of the energy efficiency innovation technology to the demand, the total profit under the centralized decision-making shows an upward trend. Longitudinally, keeping other parameters unchanged, with the increase of the cross-channel price sensitivity, the total profit under the centralized decision is higher than that under the decentralized decision, and the trend becomes more and more obvious. The gap between the two decision-making methods is also more prominent. Increased cross-price sensitivity means that the price change of any channel in the dual-channel green supply chain (consumers’ uncertainty in channel selection will increase due to price change) will have a positive impact on the demand of both the channels. In general, the more obvious the customer’s channel preference and product green preference are, the clearer the balance of the total profit of the supply chain under the two kinds of decisions will be. The difference between supply chain equilibrium is more significant between the two decision-making models with influence and single-factor sensitivity.

The increased sensitivity of the energy efficiency level to the demand means that the manufacturer needs to invest more in green innovation to meet the market demand and also improves the greenness of their products. In the pursuit of green, sustainable development of life today, consumers prefer high-tech green innovative products. Under the social background of continuous product upgrade, how to
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Figure 5. Effects of $g$ and $\theta$ on $\pi^d$.

Figure 6. Effects of $g$ and $\theta$ on $\pi^c$.

Figure 7. Effects of $g$ and $\theta$ on $q_M$ and $q_R$.

Figure 8. Effects of $g$ and $\theta$ on $\pi^D$.

achieve the coordination of channel protection and to achieve the optimal profit of the supply chain and the manufacturer? The purpose of this paper is to study the technological innovation and pricing decision of green product development process, and to meet the optimal profit of the manufacturer and the supply chain.
From the above analysis, we can intuitively see that when considering product energy efficiency, the sensitivity of the energy efficiency level to the demand and the sensitivity of the cross-channel price are positively correlated with the total profit of the two decision models. Moreover, under the influence of dual factors, higher profit level of the supply chain can be achieved. It is more conducive to achieve a win-win situation, thereby increasing the flexibility of the manufacturer channel coordination.

6. Channel coordination replication. The manufacturer achieve channel coordination by adopting two fee contracts that are widely used in green supply chain coordination. Similarly, profit sharing and quantity discount contract are considered in the literature for channel coordination. Now we only consider two-channel two-part charging contract \( \{c_1, k\} \), and choose \( x = x^* \) for the green energy efficiency level. The situation faced by the retailer at this time is: \( \max \pi_R = (p_R - c_1)(a_R - b_Rp_R + \theta p_M + gx) - k \). The retailer responds to \(c_1, x, p_M\) provided by the manufacturer’s contract as follows (subscript \(c\) is used to represent the variables in this coordination mode):

\[
p^*_R = \frac{a_R + \theta p_M + gx - b_Rc_1}{2b_R}. \tag{9}
\]

Based on the retailer’s response, the manufacturer optimizes its response by solving the following problems:

\[
\max_{x,c_1,p_M,k} \pi_{M,c}\{x,c_1,p_M,k\} = (p_R - c_1)(a_M - b_Mp_M + \theta p_R + gx) + (c_1 - c)(a_R - b_Rp_R + \theta p_M + gx) + k - \frac{x^2}{2}, \tag{10}
\]

s.t.

\[
(p^*_R - c^*_1)((a^*_R - b^*_R)p^*_R + \theta^* p^*_M + g^* x^*_c) - k \geq (p^*_R - c^*_1) (a^*_R - \theta p^*_M + g^* E - e^*_1) + g^*_E x^*_E). \tag{11}
\]

where \( p^*_R \) is given in (9) – (11) is an incentive constraint to ensure the retailer accepts the coordination contract offered by the manufacturer. The precondition for the retailer to accept the coordination mechanism is to ensure that his interest is greater than or equal to the income level in the pre-coordination equilibrium state. After coordination, the level of the green energy efficiency has been improved compared with that in the decentralized decision-making. Moreover, since the cost of the green innovation is entirely provided by the manufacturer, the manufacturer will have a large say in the coordination contract. The manufacturer’s optimal decision is given below as Proposition 5.

**Proposition 5.** The manufacturer coordinates the green supply chain by selecting the green energy efficiency level \( x^*_c = x^* \) and provides the retailer with the following two fee contract contents:

\[
\{c^*_1, p^*_M, k^*_c\} = \{c, p^*_R, p^*_M, (a^*_R - b^*_R)p^*_R + \theta^* p^*_M + g^* x^*_c) - (p^*_R - c^*_1)(a^*_R - b^*_R) + \theta p^*_M + g^*_E x^*_E)\}
\]

In this proposition, the supply chain can reach a complete coordination state and serve as a supply chain position for the centralized decision-making. When \( x^*_c = x^*, p^*_M = p^*_M, p^*_R = p^*_R\), all the incremental profit is taken by the manufacturer,
because his investment in the green innovation gives him the highest bargaining power, and the retailer’s profit is equal to the profit level of the decentralized decision.

Proof. See appendix. □

7. Conclusion and discussion. This paper studied the pricing and energy efficiency decision of dual channel green supply chain under the centralized and the decentralized conditions. The manufacturer offers the retailer a two-part fee contract to maximize its expected profit through the channel contract coordination at a later stage. This paper paid more attention to the process and periodicity of product development and sales to reflect the sustainable development process. After the energy efficiency level is added as a decision variable reflecting the green cost, it is more in line with the actual response strategy formulated by the enterprise in response to the pace of continuous replacement in the real market. The starting point of the two decision-making models is different, so the profit obtained is also different. With the development of time, the level of technology is constantly updated. How to make the optimal decision in this process to obtain the maximum profit has become a continuous concern of most companies. We have shown that the order of variables still affects the interests of decision makers under the premise of considering the energy efficiency level of the product (i.e., green innovation cost). Moreover, the manufacturer can promotes green and energy-efficient products to improve the consumer’s sensitivity to the energy-efficient product and increases the sensitivity of the cross-channel price, so as to increase the demand and achieves a higher level of the supply chain profit.

Under the decentralized decision making, we applied the delay model theory to the green supply chain research. From the perspective of game theory, we show that if a manufacturer adopts a dual-channel supply chain, the timing of pricing for each channel constitutes a basic problem. As it can be seen from the model analysis, if the manufacturer of the green products wants to maximize profit, it should first determine the level of the green energy efficiency and then set the direct channel price before setting the wholesale price for the retailer. This can achieve the manufacturer’s optimal profit optimal. For the manufacturer and the retailer, makes more sense to find a balance between various possibilities. Unlike traditional pricing mechanisms, the manufacturer and the retailer have the motivation to speed up their pricing times to boost their profits. Put forward the optimal decision of “First-mover advantage”. Note that the “First-mover advantage” optimal decision here is not based on the overall game, but on each “sub-game” to occupy the first decision advantage. Manufacturers and retailers determine direct channel prices and retail channel prices respectively in each “sub-game”. In addition, the retailer sets the retail channel price after observing the manufacturer’s wholesale price. In other words, the manufacturer can make timely adjustment to the wholesale price by predicting the retailer’s response. In this process, the retailer also has the incentive to speed up the retail price decision to gain more profit. Here, we are more concern with finding out the performance of each variable under the decentralized decision to reach the equilibrium state. It can be seen from the calculation results of the model that a perfect Nash solution equilibrium can be achieved under the sequence E, and finally the optimal variable decision timing sequence under this sequence is selected. In other words, the energy efficiency level is determined first. Under the premise that the wholesale price is set earlier than the retail price, the decision of the direct channel price precedes the decision of the retail price. All the
optimal decision variables and the profit of the decision makers are obtained. We conclude that in the continuous process of the product development and upgrading, the direct channel pricing should be set earlier than the retail price. Compared with the traditional pricing model, this is more conducive to improve their own channel revenues.

At the later stage of the model, we realized the profit of the overall green supply chain under the centralized decision-making by coordinating contracts. The premise for the retailer to accept the coordination mechanism needs to be satisfied such that the channel income after coordination is not lower than the profit level before the coordination. Since the manufacturer bears all the cost of the green innovation, it has the highest bargaining power. The optimal decision for the manufacturer is to capture the profit surplus of the retailer, and the retailer obtains the same revenue as before the implementation of the coordination mechanism.

Appendix. Proof of Proposition 1.

We assume that \( \pi_V \) is a strictly concave and coercive function of \( p \) and \( x \). Thus, \( \pi_V \) has an optimal solution. Let \( \frac{\partial \pi_V}{\partial p} = 0, \frac{\partial \pi_V}{\partial p} = 0 \) to get the optimal price of the product and the optimal level of energy efficiency in the case of centralized decision-making with the same price. Therefore, the optimal supply chain profit under centralized decision is \( \pi_V = \frac{(a_M + a_R - 2bc)^2}{b(b-c)^2} \).

Proof of Proposition 2.

We assume that \( \pi_V \) is a strictly concave and coercive function of \( p_M, p_R \) and \( x \). Thus, \( \pi_V \) has the optimal solution. Let \( \frac{\partial \pi_V}{\partial p_M} = 0, \frac{\partial \pi_V}{\partial p_R} = 0, \frac{\partial \pi_V}{\partial x} = 0 \). Then, it follows that the optimal direct channel selling price, the retail channel selling price and the optimal energy efficiency level can be reached under the centralized decision of non-consistent prices.

The maximum profit: \( \pi_V = \frac{(B_1A_2 + B_2A_1 - 4B_3c)[B_1A_2 + B_2A_1 + 4B_3c - 4(A_1 + A_2)c]g^2}{2A^2} + \frac{(2B_1B_2A_3 + B_2^2A_4 - 4B_2A_1c^g + B_1^2A_4 - 4B_1A_1c^g)[2B_1 - (A_1 + A_2)g]}{2A^2} \)\[
\frac{(B_1A_3 + B_2A_3 - 4A_2c^g)[(B_1A_3 + B_2A_3 - 4A_1c^g)g - (a_M + a_R)(2B_1 + (A_1 + A_2)g)^2c]}{2A^2}.
\]

\( A_1 = b_M + \theta, A_2 = b_R + \theta, A_3 = 2b_R - g^2, A_4 = 2b_M - g^2, A_5 = 2\theta + g^2, A = 2(b_Mb_R - \theta^2) - (b_M + b_R + 2\theta)g^2, B_1 = a_M - (b_M - \theta)c, B_2 = a_R - (b_R - \theta)c, B_3 = b_Mb_R - \theta^2. \)

Proof of Proposition 3.

\( \pi^M - \pi^S > 0 \quad \pi^S - \pi^L > 0 \quad \pi^M - \pi^L > 0 \)
\( \pi^E - \pi^S < 0 \quad \pi^S - \pi^E < 0 \quad \pi^E - \pi^S < 0 \)
\( x^S - x^L > 0 \quad c^E - c^S > 0 \quad c^S - c^L > 0 \)

Proof of Proposition 4.

Proposition 4 indicates that when the energy efficiency level is determined first, the manufacturer needs to determine its direct channel price as early as possible to reach Nash equilibrium. If the manufacturer decides the direct channel price after setting the wholesale price, the Nash equilibrium will not be achieved. This is because the retailer has an opportunity to get a head start by accelerating the
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decision on the pricing. As shown in Figure 2, the sequence (1,2,3,4) did not reach Nash equilibrium. In this case, the manufacturer chooses the energy efficiency level, the wholesale price and the direct channel price according to the decision time in the order of (1,2,3). But then, the retailer can accelerate its retail pricing after the manufacturer’s decision on the wholesale price. In this way, he can realize the maximum benefit.

Proof of Proposition 5.

In view of the problem proposed by the manufacturer in (11) and (12), it follows from constraint (12) that the manufacturer can extract all the surplus of the retailer by choosing the appropriate fixed cost k, so as to reach the state of making a decision in the replication set.

So, set
\[ k^*_c = (p^*_R - c^*_c)(a^*_R - b^*_R p^*_M + \theta^* p^*_M + g^* x^*_c)^t - (p^*_E - c^*_c)(a^*_E - b^*_E p^*_E + \theta^* p^*_M + g^* x^*_E) \]

The manufacturer will face the following problems:
\[
\max_{x,c_1,M} \pi_M(x,c_1,M) = (p^*_R - c^*_c)(a^*_R - b^*_R p^*_M + \theta^* p^*_M + g^* x^*_c)^t + (p^*_E - c^*_c)(a^*_E - b^*_E p^*_E + \theta^* p^*_M + g^* x^*_E) - \frac{(x^*_c)^2}{2}
\]

According to the formula given by \( p_R \), the manufacturer’s optimal decision can be realized by the first-order conditions as follows:
\[ c^*_c = c, x^*_c = x^*, k^*_c = (p^*_R - c^*_c)(a^*_R - b^*_R p^*_M + \theta^* p^*_M + g^* x^*_c)^t - (p^*_E - c^*_c)(a^*_E - b^*_E p^*_E + \theta^* p^*_M + g^* x^*_E) \]

This completes the proof of the proposition.

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