Optimal Decision-Making of Green Supply Chain with Complementary Products

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Abstract. Green supply chain management has received increased attention in recent years as a result of government regulation and increased consumer awareness of environmental protection, and firms invest in green products to meet the new competitive market conditions. In this paper, a supply chain model is developed for two types of green products, development-intensive green product and marginal cost-intensive green product, to explore the effects of differences in cost structure and complementary relationships between products on supply chain equilibrium results. Unlike most green supply chain management studies, two supply chains provide complementary products to the market. This paper finds that there is significant variability in the effect of market potential on manufacturers' efforts to increase the greenness of their products. The marginal cost-intensive green product is more suitable for the manufacturer, irrespective of the size of the market potential. The main contribution of this paper is the inclusion of complementary product relationships in the field of green supply chain management and the exploration of the differences in the role of complementary relationships in the supply chains of different green product types.

Keywords: green product development · complementary products · pricing policy · green supply chain

1 Introduction

Weather extremes caused by global warming, air pollution and environmental damage have had a negative impact on human survival and economic development, and economic losses and supply chain disruptions caused by major meteorological disasters are becoming increasingly prominent. In response to climate chaos, the 27th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP27) stated that the world must work together to solve the climate problem, and China proposed carbon peaking and carbon neutrality goals at the 75th Session of the United Nations General Assembly. In the field of supply chain management, the concept of low-carbon and sustainable development is gradually gaining ground, making green supply chains a topic of great interest in recent research [1, 2]. Green products, which can also be regarded as sustainable products or eco-friendly products, can be developed

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and designed not only to circumvent government environmental controls and reduce damage to the environment, but also to open up new product markets and form new industrial formats. In green supply chain management, the pricing and green degree of green products are key issues in the decision-making process and the research in this paper is centered on this issue.

The development of green supply chain management is driven by many factors. At the government level, policies, such as subsidy on green supply chain technology investment [3], carbon taxes [4] are gradually being adopted to improve the sustainability of the economy. The national carbon emissions trading market is an institutional innovation that uses market mechanisms to control and reduce greenhouse gas emissions and promote green development. At the market level, increased consumer demand and preference for green products is another important factor in the promotion of green products for research and development [1]. In a dual-channel supply chain, (Tao et al., 2022) [5] showed that consumer green awareness drives manufacturers to increase the greenness of their products, regardless of the channel structure. Sharing green costs between manufacturers and retailers is the optimal solution. In this case, the dual-channel supply chain performs best in terms of improving product greenness and supply chain performance. At the technical level, technological advances and R&D collaboration between firms have provided support for the development of green products. Consumer recognition of green products and new market demand resulting from green technology innovations have made many firms willing to invest in green products [6].

The supply chain structure setting is a prerequisite for conducting research on green supply chain management. In this issue, in order to focus on the pricing and greenness level issues, (Hong and Guo, 2019; Song et al., 2023; Tao et al., 2022; Zhang et al., 2021) [1, 3, 5, 7] studied the green supply chain consisting of one manufacturer and one retailer, and thus analyzed the supply chain channel design. (Jafari et al., 2017) [8] investigated the scenario that multiple retailers compete with each other. In the study by (Mondal et al., 2020) [9], manufacturers collected used products from customers for remanufacturing through both online and offline channels. Different with (Pal and Sarkar, 2022) [2], this paper does not consider the issue of channel conflict and channel competition with the retailer resulting from direct sales by the manufacturer. In addition, the two retailers in this study provide complementary products to the market and the relationship between the two is more cooperative than competitive.

In the field of green supply chain management, market demand can be influenced by the combination of the price and the green degree of the product, and thus the implementation of pricing strategies and the choice of green level are central issues. (Das et al., 2022) [10] found that higher optimal pricing in the retail channel and lower levels of product greening in the decentralized scenario. The opposite result of double marginalization was found in (Li et al., 2016) [11], where the retail price was higher in centralized green supply chains than in decentralized ones. The same conclusion appears in the study by (Mondal et al., 2020) [9]. By examining the pricing strategies and coordination mechanisms between the members of the dual-channel supply chain, (Ranjan and Jha, 2019) [12] suggested that the cooperative model has a high level of green quality. From a channel selection perspective, (Pal and Sarkar, 2022) [2] found higher levels of green for the double dual-channel model than for the single double-channel model. (Jamali and Rasti-Barzoki, 2018) [13] explored the existence of the substitution relationships between green products and non-green products, and the findings suggested that the centralized scheme could achieve higher greenness than the decentralized scheme. The problem of the optimal strategy for product price and green level is central to this paper. Different with the above studies, two supply chains in this study offer complementary products to the market. The focus of this paper is to explore the determination of a firm's optimal price strategy and greenness when there is a complementary relationship between products. In addition, the issue of green product design is included in the scope of this paper.

The issue of green products type, which is distinguished by the nature of costs, was first introduced by (Zhu and He, 2017) [14]. Relying on (Qian, 2011) [15]'s classification criteria based on the driving force of the product quality level, (Zhu and He, 2017) [14] classified green products into development-intensive green product (DIGP) and margin cost-intensive green product (MIGP) based on the main cost drivers of greenness. Subsequently, (Dey et al., 2019) [16] explored the impact of firm gaming patterns and strategic inventories on the development of green product types under different purchasing strategies. In the context of green product development, (Gao et al., 2020) [17] found that higher green standards can consistently improve the environmental benefits of DIGP. However, setting increasingly high green standards for MIGP is not always desirable. The market size or market potential of a green product directly affects the firm's profitability. (Fadavi et al., 2022) [18] found that when the market size is larger than expected, the best choice for making green product is DIGP; conversely, if the market potential is low, MIPG is the best choice. This paper follows the above research model to analyze the game relationship between firms in the case of two green product types and to compare the effects of market parameter variables on the greenness of both.

This paper is the first to examine complementary products in the context of green supply chains. Unlike substitutes, complementary products, such as badminton and badminton rackets, desks and chairs, lenses and frames for glasses, and so on, support each other in terms of function and role, and consumers need one product when they buy the other in order to perform the function of the product and get all the benefits of products. In terms of business relationships, firms that offer complementary products benefit from increased market demand from other firms, and thus the two are more cooperative than competitive. Therefore, in green supply chains, price strategies and greenness choices also differ when firms work together to provide complementary goods to the market. In addition, the type of green product, i.e. the cost structure of green products, also has an impact on the firm's decision. In summary, this paper focuses on the following issues:

- In a model consisting of two green supply chains, how do firms play and compete with each other to form the market equilibrium?
- How do the types of green products affect firms' price and greenness decisions, and how do market parameter variables differ in their impact on firms' decisions across product types?
- How does the complementary relationship between green products affect manufacturers' and retailers' decisions?

The main contributions of this paper to green supply chain management are: firstly, this paper extends the design of supply chain structures to two models of supply chains that deliver products to the market. In the field of green supply chain management research, much of the focus has been on the design of contractual mechanisms to improve supply chain performance and product greenness, neglecting the relationships between products, and this paper will extend on this area. Secondly, this paper explores the role of green product types in green supply chain. Although the production choices of intensive green products and marginal cost-intensive green products are explored in (Gao et al., 2020; Zhu and He, 2017) [14, 17], there is still a gap in the exploration of the factors affecting the choice between DIGP and MIGP. The research in this paper helps to enrich this area. Finally, the paper examines the role of the indicators of market potential and product substitutability.

2 Model Description

We consider two green supply chains offering complementary products to the market, which can be seen as an extension of (Swami and Shah, 2013; Tao et al., 2022) [5, 19] in terms of supply chain structure design. Figure 1 depicts the structure of the supply chain model to be explored in this paper.

In terms of upstream and downstream supply chain relationships, it is assumed that the upstream manufacturer acts as the Stackelberg leader relative to its downstream retailer (Das et al., 2022; Hong and Guo, 2019; Jamali and Rasti-Barzoki, 2018) [7, 10, 13]. There are two stages to the manufacturer-retailer game. In the first stage, manufacturers are responsible for the design, manufacture and production of green products. The research of (Swami and Shah, 2013) [19] assumed that both the manufacturer and the retailer can work on the green level of the product, while the manufacturer is responsible for the greenness of the product in (Li et al., 2016; Ranjan and Jha, 2019) [11, 12]. Given the reality of the situation and the subject of this paper, the latter approach is followed in this study, where the manufacturer invests in improving the greenness of the product and sets the wholesale price of the product according to the retailer's order requirements. As this study does not address the issue of changes in production costs caused by firms through technological innovation or scale effects, production costs are assumed to be zero without considering green inputs to simplify the model building process. In the second stage, the retailer receives the product and sets the selling price to maximize profits based on the market demand for the product. In this paper, the product demand faced by retailers is consistent with (Gao et al., 2020; Pal and Sarkar, 2022) [2, 17] and

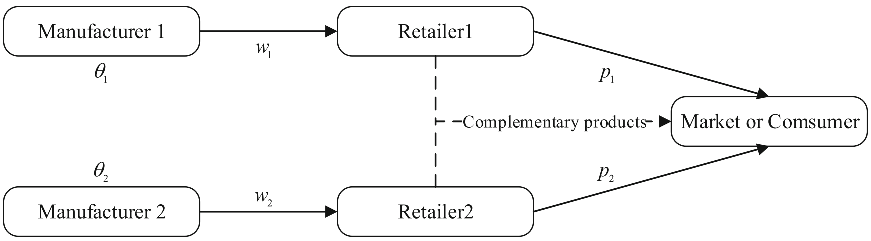

Fig. 1. Green supply chain model for the provision of complementary products

is a linear function of product price and product greenness. The market demand function is as follows,

$$D_i = a_i - \beta p_i - \gamma p_j + \lambda_i \theta_i,\ i = 1, 2,\ j = 3 - i \quad (1)$$

where a_i, i.e. market potential for retailer i, is positive and large enough to make manufacturers willing to invest in the production of green products, β and γ represent own-price elasticity of demand and cross-price elasticity of demand respectively. $\beta > \gamma > 0$ to ensure that complementary relationships exist between products and self-price elasticity of demand is more than cross-price elasticity of demand. θ_i is the green index of product i, representing the degree of greenness or green level, and $\lambda_i > 0$ measures the marginal increase in demand due to increased greenness and can be regarded as consumer preference coefficient for green products or greening effectiveness parameter.

This paper assumes that information is symmetrical in the supply chain and the decisions of all participants are observable. In addition, the research is carried out in the deterministic market environment. Therefore, market clearing is included in the implicit assumption. In the following study, we use the superscripts d and m to represent the equilibrium results for the case where the manufacturer produces development-intensive green product and margin cost-intensive green product, respectively. Also, we use the subscripts ri and mi to represent the i-th retailer and manufacturer.

3 Equilibrium Results Under Two Type of Products

3.1 Model Solution with Development-Intensive Green Product

The concept of development-intensive product was first introduced by (Krishnan and Zhu, 2006) [20] in analysis of a firm's cost function in improving product quality, which assumed a large investment in the product development phase and small to negligible marginal cost in the production process, e.g. software and pharmaceutical development. The development of green supply chains has led to the gradual application of this cost structure to the analysis of green product R&D. The concept of development-intensive product was proposed earlier by (Zhu and He, 2017) [14], and its similar cost structure for green products has been widely used early in (Li et al., 2016; Ranjan and Jha, 2019; Swami and Shah, 2013; Yang et al., 2022) [6, 11, 12, 19]. In the current green practice process, for example, the main inputs of new energy enterprises, energy-efficient lamps and energy-efficient air conditioning products are concentrated in the product development stage. Based on this, the scenario in which manufacturers produce development-intensive green product is considered in this section.

According to the sequential order of the Stackelberg game in the supply chain and following the backward induction, this paper first discusses the retailer's price decision. The profit function of the retailer *i* is:

$$\pi_{ri}(p_i) = (p_i - w_i)D_i \quad (2)$$

The retailer's profit function takes the first-order derivative function of the product price, and it can subsequently be calculated to give a response function of the price with respect to the wholesale price and the green level as:

$$p_i(w_i, w_j, \theta_i, \theta_j) = \frac{2\beta(a_i + \beta w_i + \lambda_i\theta_i) - \beta\gamma w_j - \gamma(a_j + \lambda_j\theta_j)}{4\beta^2 - \gamma^2} \tag{3}$$

In the case that manufacturers produce DIGP, the profit of manufacturer i is

$$\pi_{mi}(w_i, \theta_i) = w_i D_i - f\theta_i^2 \tag{4}$$

where f represents the fixed green cost coefficient in DIGP model. Substitute Eq. (1) and (3) into (4), and the manufacturer's optimal decision regarding the wholesale price and greenness of the product can be calculated as

$$\begin{cases} w_i^d = \dfrac{f(4\beta^2-\gamma^2)(f(a_i\beta(8\beta^2-3\gamma^2)-2a_j\gamma(3\beta^2-\gamma^2))-a_i\beta^2\lambda_j^2)}{f^2(4\beta^2-\gamma^2)((4\beta^2-2\gamma^2)^2-\beta^2\gamma^2)-f\beta^3(\lambda_1^2+\lambda_2^2)(8\beta^2-3\gamma^2)+\beta^4\lambda_1^2\lambda_2^2} \\ \theta_i^d = \dfrac{\beta^2\lambda_i(f(a_i\beta(8\beta^2-3\gamma^2)-2a_j\gamma(3\beta^2-\gamma^2))-a_i\beta^2\lambda_j^2)}{f^2(4\beta^2-\gamma^2)((4\beta^2-2\gamma^2)^2-\beta^2\gamma^2)-f\beta^3(\lambda_1^2+\lambda_2^2)(8\beta^2-3\gamma^2)+\beta^4\lambda_1^2\lambda_2^2} \end{cases} \tag{5}$$

Proposition 1. For the development-intensive green product, the profit of manufacturer i is jointly concave in w_i^d and θ_i^d when.

$$\frac{f}{\lambda_i^2} > \frac{\beta^3}{(4\beta^2-\gamma^2)(2\beta^2-\gamma^2)}$$

Proof of Proposition 1. Second order partial derivatives of the manufacturer's profit function with respect to wholesale price and the degree of greenness respectively

$$\begin{aligned} \frac{\partial^2\pi_{mi}^d}{\partial(w_i^d)^2} &= -\frac{2\beta(2\beta^2-\gamma^2)}{4\beta^2-\gamma^2} \\ \frac{\partial^2\pi_{mi}^d}{\partial w_i^d\partial\theta_i^d} &= \frac{\partial^2\pi_{mi}^d}{\partial\theta_i^d\partial w_i^d} = \frac{2\beta^2\lambda}{4\beta^2-\gamma^2} \\ \frac{\partial^2\pi_{mi}^d}{\partial(\theta_i^d)^2} &= -2f \end{aligned} \tag{6}$$

Substituting the second derivative into the Hessian matrix,

$$\begin{aligned} H &= \begin{bmatrix} \frac{\partial^2\pi_{mi}^d}{\partial(w_i^d)^2} & \frac{\partial^2\pi_{mi}^d}{\partial w_i^d\partial\theta_i^d} \\ \frac{\partial^2\pi_{mi}^d}{\partial\theta_i^d\partial w_i^d} & \frac{\partial^2\pi_{mi}^d}{\partial(\theta_i^d)^2} \end{bmatrix} = \begin{bmatrix} -\frac{2\beta(2\beta^2-\gamma^2)}{4\beta^2-\gamma^2} & \frac{2\beta^2\lambda}{4\beta^2-\gamma^2} \\ \frac{2\beta^2\lambda}{4\beta^2-\gamma^2} & -2f \end{bmatrix} \\ &= -\frac{4\beta(f(4\beta^2-\gamma^2)(2\beta^2-\gamma^2)-\beta^3\lambda_i^2)}{(4\beta^2-\gamma^2)^2} \end{aligned} \tag{7}$$

Let $H < 0$, and the conclusion in Proposition 1 can be get.

Substituting the manufacturer's optimal decision into the retailer's price response function yields the product price set by the retailer as

$$p_i^d = \frac{2f(3\beta^2-\gamma^2)(f(a_i\beta(8\beta^2-3\gamma^2)-2a_j\gamma(3\beta^2-\gamma^2))-a_i\beta^2\lambda_j^2)}{f^2(4\beta^2-\gamma^2)((4\beta^2-2\gamma^2)^2-\beta^2\gamma^2)-f\beta^3(\lambda_1^2+\lambda_2^2)(8\beta^2-3\gamma^2)+\beta^4\lambda_1^2\lambda_2^2} \tag{8}$$

The profits of supply chain participants can be obtained based on the product greenness and price decisions of manufacturers and retailers.

3.2 Model Solution with Margin Cost-Intensive Green Product

In contrast to development-intensive green product, the marginal cost-intensive green product the product where product development costs are negligible compared to marginal manufacturing costs. These products mainly consist of adding new module or the use of new materials in the production process to reduce the environmental impact, and this type of product is investigated in the research of (J. Gao et al., 2018; Zhu and He, 2017) [14, 21]. For such products, the greenness of the product mainly affects the variable costs of the production process.

In the case of MIGP, the response function for retailer prices remains the same as in Eq. (3). The intrinsic difference in MIGP case is that the manufacturer's greening costs receive both the production volume and the green coefficient, at which point the manufacturer's profit function is

$$\pi_{mi} = (w_i - v\theta_i^2)D_i \tag{9}$$

where v is the variable green cost coefficient in MIGP model. By substituting the market demand and the response function of product price into the manufacturer's profit function and taking the partial derivative of the whole price and green level, the manufacturer's optimal decision is obtained algebraically.

$$\begin{cases} w_i^m = \dfrac{v(2\beta^2-\gamma^2)(a_i\beta(8\beta^2-3\gamma^2)-2a_j\gamma(3\beta^2-\gamma^2))}{v(16\beta^4-17\beta^2\gamma^2+4\gamma^4)(2\beta^2-\gamma^2)} \\ +\dfrac{\beta(\beta\lambda_i^2(12\beta^2-5\gamma^2)-\gamma\lambda_j^2(7\beta^2-2\gamma^2))}{v(16\beta^4-17\beta^2\gamma^2+4\gamma^4)(2\beta^2-\gamma^2)} \\ \theta_i^m = \dfrac{\beta\lambda_i}{v(2\beta^2-\gamma^2)} \end{cases} \tag{10}$$

Proposition 2. For the margin cost-intensive green product, the profit of manufacturer i is jointly concave in w_i^m and θ_i^m, when.

$v > \frac{-\beta(\beta\lambda_i^2(8\beta^4-5\beta^2\gamma^2+\gamma^4)-\gamma\lambda_j^2(14\beta^4-11\beta^2\gamma^2+2\gamma^4))}{(2\beta^2-\gamma^2)^2(8a_i\beta^3-3a_i\beta\gamma^2-6a_j\beta^2\gamma+2a_j\gamma^3)}$ and $\frac{a_i}{a_j} > \frac{2\gamma(3\beta^2-\gamma^2)}{\beta(8\beta^2-3\gamma^2)}$ or when.

$v < \frac{-\beta(\beta\lambda_i^2(8\beta^4-5\beta^2\gamma^2+\gamma^4)-\gamma\lambda_j^2(14\beta^4-11\beta^2\gamma^2+2\gamma^4))}{(2\beta^2-\gamma^2)^2(8a_i\beta^3-3a_i\beta\gamma^2-6a_j\beta^2\gamma+2a_j\gamma^3)}$ and $\frac{a_i}{a_j} < \frac{2\gamma(3\beta^2-\gamma^2)}{\beta(8\beta^2-3\gamma^2)}$

The proof Proposition 2 is similar to Proposition 1, this paper does not go into too much detail.

Based on the response function of the retailer's price and the manufacturer's optimal decision, the price set by the retailer can be obtained as

$$p_i^m = \frac{2v(2\beta^2-\gamma^2)(3\beta^2-\gamma^2)(a_i\beta(8\beta^2-3\gamma^2)-2a_j\gamma(3\beta^2-\gamma^2))}{v(16\beta^4-17\beta^2\gamma^2+4\gamma^4)(2\beta^2-\gamma^2)(4\beta^2-\gamma^2)} + \frac{\beta(7\beta^2-2\gamma^2)(\beta\lambda_i^2(8\beta^2-3\gamma^2)-2\gamma\lambda_j^2(3\beta^2-\gamma^2))}{v(16\beta^4-17\beta^2\gamma^2+4\gamma^4)(2\beta^2-\gamma^2)(4\beta^2-\gamma^2)} \tag{11}$$

The profitability of the participating firms in the green supply chain can be obtained by substituting the optimal decision into the profit function.

4 Discussion of Equilibrium Results

4.1 The Effect of Market Potential

The size of the market potential undoubtedly affects firms' motivation and incentive to develop green products, and the market conditions applicable to different green product types have been explored in studies by (Fadavi et al., 2022) [18]. In conjunction with supply chain equilibrium results, this section focusses on the effect of market potential on the decisions of manufacturers and retailers.

Proposition 3. Regardless of the type of green product, the wholesale and retail prices of the product increase with market potential. In the DIGP model, market potential has a positive effect on greenness, whereas product greenness is not influenced by market potential in the MIGP model.

Proof of Proposition 3. The first-order derivative functions of the decision variables in supply chain equilibrium results with respect to market potential are obtained separately:

$$\begin{cases} \dfrac{\partial w_i^d}{\partial a_i} = \dfrac{f(4\beta^2-\gamma^2)(8\beta^3 f-\beta^2\lambda_j^2-3f\beta\gamma^2)}{f^2(4\beta^2-\gamma^2)((4\beta^2-2\gamma^2)^2-\beta^2\gamma^2)-f\beta^3(\lambda_1^2+\lambda_2^2)(8\beta^2-3\gamma^2)+\beta^4\lambda_1^2\lambda_2^2} \\ \dfrac{\partial p_i^d}{\partial a_i} = \dfrac{2f\beta(3\beta^2-\gamma^2)(8f\beta^2-\beta\lambda_j^2-3f\gamma^2)}{f^2(4\beta^2-\gamma^2)((4\beta^2-2\gamma^2)^2-\beta^2\gamma^2)-f\beta^3(\lambda_1^2+\lambda_2^2)(8\beta^2-3\gamma^2)+\beta^4\lambda_1^2\lambda_2^2} \\ \dfrac{\partial \theta_i^d}{\partial a_i} = \dfrac{\beta^2\lambda_i(8f\beta^2-\beta\lambda_j^2-3f\gamma^2)}{f^2(4\beta^2-\gamma^2)((4\beta^2-2\gamma^2)^2-\beta^2\gamma^2)-f\beta^3(\lambda_1^2+\lambda_2^2)(8\beta^2-3\gamma^2)+\beta^4\lambda_1^2\lambda_2^2} \end{cases}$$

$$\begin{cases} \dfrac{\partial w_i^m}{\partial a_i} = \dfrac{\beta^2(8\beta^2-3\gamma^2)}{16\beta^4-17\beta^2\gamma^2+4\gamma^4} \\ \dfrac{\partial p_i^m}{\partial a_i} = \dfrac{2\beta(24\beta^4-17\beta^2\gamma^2+3\gamma^4)}{(4\beta^2-\gamma^2)(16\beta^4-17\beta^2\gamma^2+4\gamma^4)} \\ \dfrac{\partial \theta_i^m}{\partial a_i} = 0 \end{cases}$$

In the DIGP model, it is easy to obtain $\partial w_i^d/\partial a_i > 0$, $\partial p_i^d/\partial a_i > 0$ and $\partial \theta_i^d/\partial a_i > 0$, subject to the constraint condition that the manufacturer's profit function is jointly concave. In the MIGP model, it is easy to obtain $\partial w_i^m/\partial a_i > 0$, $\partial p_i^m/\partial a_i > 0$, based on the relationship between β and γ. Proposition 3 can be proved.

An increase in market potential can lead firms to raise prices in order to achieve higher profits, as is evident in many studies. But this paper finds significant differences in the impact of market potential on green level when there are differences in the costs of greenness. The implication for management is that the approach of promoting firms to increase the greenness of their products by increasing market demand is only valid for DIGP.

4.2 The Effect of Product Substitutability

Due to the complexity of equilibrium results, this section uses numerical analysis in analyzing the effect of product complementarities. We set equal market potential $a_1 = a_2 = 100$, given that the two product types need to be combined to meet market demand. In order to capture the differences in market demand for the two product categories, consumer preference coefficients for green products are assumed that $\lambda_1 = 2$, $\lambda_2 = 1.6$. In addition, we set $\beta = 1.1, f = 7, v = 1$. It is verified that the manufacturers profit functions jointly concave in the range $\gamma \in (0.2, 1)$. Considering the correlation between wholesale and retail prices, we do not show the variation in prices in the numerical analysis. The variation of the wholesale price and greenness with product complementarity is shown in Fig. 2.

It should be noted that the results in the DIGP and MIGP models are not directly comparable due to the differences in the greening cost coefficients of the two green products. However, comparing the trends in the decision parameters as influenced by product substitutability leads to some conclusions and managerial insights. Combined with Fig. 2, we can see that a higher greening effectiveness parameter λ_1 leads the manufacturer to set a higher wholesale price and at the same time set a higher level of product greenness. The trend of the wholesale price with increasing product complementarity differs between the two types of green products. Figure 2(a) shows that the wholesale price for DIGP tends to decrease and then slowly increase in product substitutability,

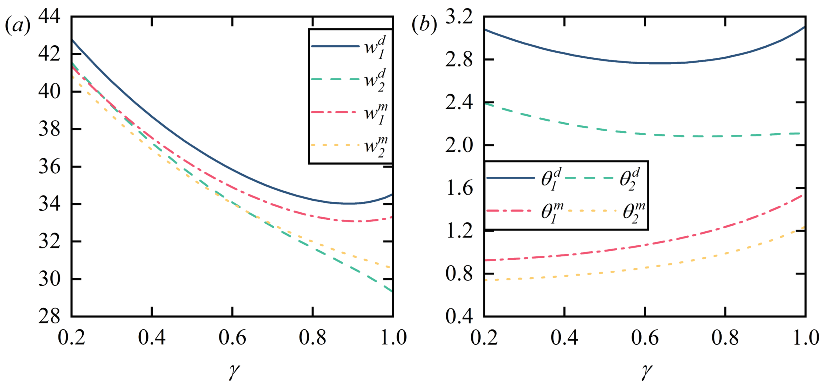

Fig. 2. Effects of product complementarity on wholesale prices and greenness

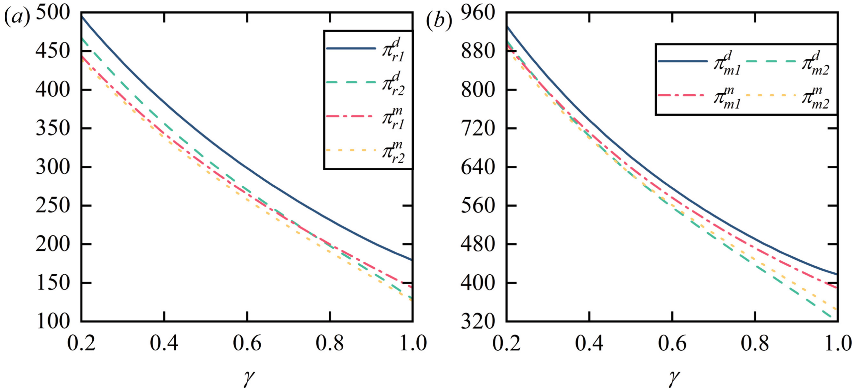

Fig. 3. Effects of product complementarity on profits of firms

while the wholesale price for MIGP continues to decrease with product complementarity. In terms of the choice of greenness for the two green products, Fig. 2(b) shows that product complementarity positively affects the increase in greenness for MIGP, while greenness for DIGP tends to decrease and then increase as product complementarity increases.

Changes in product substitutability ultimately affect the market profitability of the firms involved in the supply chain. And Fig. 3 illustrates how the profits of manufacturers and retailers change as product substitutability increases.

For both DIGP and MIGP, the impact of changes in product complementarity is nearly uniform for all firms in the supply chain, i.e. increased product complementarity has a negative impact on firms' profits.

5 Conclusion

This paper constructs a model of two supply chains supplying complementary goods to the market, and derives different equilibrium results under two types of green product (development-intensive green product and margin cost-intensive green product). By comparing supply chain equilibrium results of the two scenarios, the paper finds that there is a significant difference in the impact of market potential on manufacturers' willingness to develop green products, and the promotion of green products by increasing market potential is only applicable for DIGP. In addition, the main innovation of this research is to examine the role of product complementarity in green supply chain management. For MIGP, increased product complementarity has the exact opposite effect on the wholesale price and green level of products, while wholesale price and the degree of greenness for DIGP are affected by product complementarity in a somewhat similar way. The managerial significance of this paper lies mainly in the fact that in promoting the development of green supply chains and enhancing the greenness of products, it is important to consider not only the relationship between products, but also to focus on the type and cost structure of green products; otherwise, it may lead to completely opposite results.

Based on the research in this paper, there are the following directions that can be expanded in the future. At a time of rapid E-commerce development, considering manufacturers to open up online or direct sales channels would make the study go further. In addition, the cross-price elasticity of demand is considered, and the cross-effect of the greenness of complementary products, which was ignored in this study, could be analyzed from this perspective in future research.

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