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SUPPLY CHAIN'S GREEN INVESTMENT STRATEGY TO COPE WITH AN ENTRANT THREAT CONSIDERING DIFFERENTIATED COMPETITIVENESS

Chunyu Li[1], Peng Xing[1,*] and Yanting Li[2]

Abstract. Facing the strengthening of consumer environmental awareness, we investigate the green investment and green subsidy problem of an incumbent supply chain (ISC) taking into account whether the external manufacturer (EM) encroach. Green investment strategies are explored under three scenarios: no-green investment, ex-ante and ex-post green subsidies by the incumbent manufacturer (IM), and green investment by the supplier. The results show that market size does not influence supplier channel selection and investment decisions. The green investment strategy is significantly affected by investment cost efficiency. Meanwhile, contrary to expectation, the more the investment is, the more willing the incumbent supply chain is to invest. Moreover, under a single-channel format, the incumbent supply chain can't always achieve Pareto equilibrium. However, in the presence of the supplier green investment, although each green investment scenario can improve the profit, it cannot realize Pareto equilibrium. In addition, when the dual-channel format is adopted, the local areas can achieve Pareto equilibrium under different scenarios. The supplier plays an important role as it holds a monopoly upstream in the supply chain. As a result, the supplier's green investment generates excellent profit and consumer surplus; however, there will be fluctuations in the optimal strategy of the incumbent manufacturer.

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1. Introduction

As urbanization and industrialization have increased, green manufacturing has attracted more and more attention in recent years due to concerning environmental friendliness, low emissions, and recyclability in the manufacturing process [14,25]. Green manufacturing has been limited owing to the conflict between environmental and economic goals. Therefore, to improve environmental quality, in addition to the environmental policies of the government, enhancing green investment motivation is also needed. Through the pressure of environmentally conscious consumers on firms, firms that develop a closed-loop supply chain, produce green products and invest in green technology to reduce the damage to the environment, the supply chain has become more competitive [3]. Thus, the green development of enterprisers is crucial to the stability of the entire chain [6]. As a result,

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[1] Business School, Faculty of Economics, Liaoning University, Shenyang 110136, P.R. China.
[2] School of Business Administration, Northeastern University, Shenyang 110169, P.R. China.
*Corresponding author: pxing@lnu.edu.cn; chzhangneu@163.com

green investment has become a core measure to promote green manufacturing within the supply chain, and it is increasingly important to channel operations [45].

Due to the raising consumer environmental awareness (CEA), consumers are changing their lifestyles to reduce the impact on the environment and will pay more for green products of higher quality [13]. According to the BBMG Consumer Awareness Report, 67% of US citizens support the idea of buying green products, while 51% are willing to pay more for those products. Environmentally friendly "green products" have become more and more popular. The Ali Research Institute found that 65 million online users, about 16% of Taobao.com's active users, meet the characteristics of green consumers [15,24]. With the advent of the Green Era, consumers are starting to keep an eye on product safety and sustainability through green production, green R&D and green manufacturing. In order to improve the willingness-to-pay (WTP) of green consumers, suppliers introduce green technology in production processes to achieve green manufacturing [12]. For example, Lenovo developed an innovative "low-temperature solder paste process" which can reduce about 6000 tons of carbon dioxide emissions per year. Gree adopted a new generation of refrigeration technology in air-conditioning production, reducing carbon emissions by 9064.4 tons per year. However, since green investment is a significant expense for companies, it is important to make appropriate investment decisions in the green supply chain [27].

Because downstream firms can benefit from the increased demand due to suppliers' green investments. Therefore, they have the incentive to subsidize suppliers to make a green investment [6,45]. For instance, H&M invested in a manufacturing process to reduce emissions and improve green production, and Walmart directly funded upstream companies to promote green supply [32]. Huawei invests in green operations, and BYD, as an upstream supplier, cooperates with Huawei in green innovation of system operation. Foxconn, a supplier to Apple, Dell, and so on, is investing in green sourcing and sustainable development while Apple is investing in production. This shows that green subsidies can have a positive effect on green investment. The green subsidy not only affects a company's upstream partners but also its competitors. Suppliers furnish green products subsidized by downstream manufacturers to other potential manufacturers. Thus, it is worthwhile to explore which member should provide green subsidies and analyze their role in green investment.

It is common practice for suppliers to provide products to the market through manufacturers. In addition, there may also be other manufacturers to approve manufacturers in a supply chain, who encroach by producing and selling substitute products to the same market. Firm encroachment greatly changes the market structure, bringing new challenges to the incumbent companies and affecting their investment decisions [10,23]. However, the supplier has the right to choose the supply contract and directly determine the channel structure of downstream manufacturers. In practice, the supplier must choose between selling through one or many manufacturers [19]. When suppliers choose the dual-channel, potential competitors can enjoy the benefits of green investment by free-riding. As a result, the supplier may resist the entry of the external manufacturer. In business practice, channel selection decisions of the supplier can lead to strong investment conflicts and expensive legal battles. Therefore, it is very important to study the impact of the changes in the supply chain's channel structure on green investment.

Specifically, we put forward the following questions related to supplier channel selection and incumbent supply chain green investment/subsidy:

(a) How does the monopolistic supplier respond to external manufacturer encroachment, and under what conditions does the supplier permit it to encroach?
(b) Does the incumbent manufacturer always have the incentive to provide green subsidies to the supplier? Is the supplier willing to make green investments without a downstream green subsidy?
(c) What impact does the incumbent manufacturer's green subsidy decision sequence have on channel formats? Which decision sequence is better?
(d) What is the impact of channel structure changes on green investment strategies? Which investment strategy is easiest to implement, and which one achieves the highest profitability?

To address the above research questions, we proceed to the following work. First, the supplier considers whether to allow the external manufacturer to encroach on the supply chain. Second, within the existing supply

chain, the supplier or manufacturer decides whether to invest in/subsidize green technology. According to the different green investment strategies, the following scenarios are discussed: (i) the basic model without green investment (N scenario), (ii) Ex-ante investment subsidy (I scenario) and ex-post investment subsidy (P scenario) by the incumbent manufacturer, and (iii) green investment by the supplier (S scenario).

According to previous research, the supplier's total profit increases under external manufacturer encroachment. Regardless of whether the supplier allows the external manufacturer to encroach, consumer surplus is greatest in the I channel except under the N, I and S scenarios. Additionally, when green investment and investment subsidies all exist in the supply chain, there are some interesting results. Although each strategy can achieve improvement, it is difficult to achieve Pareto equilibrium under a single channel. However, the dual-channel can achieve partial equilibrium under the SE format.

The remainder of this paper is organized as follows. In Section 2, we briefly review the related literature. In Section 3, we present the model establishment. In Section 4, we set up the model without green investment as a benchmark. In Section 5, we further explore green subsidy strategies under different decision sequences. In Section 6, we explore supply chain decisions under the supplier's green investment. In Section 7, we analyze the players' attitudes toward green investment. In Section 8, we extend the research and the comparison with existing research. In Section 9, we summarize the results from the preceding sections and conclude the paper.

2. Literature review

This paper is closely related to the stream of literature on consumer environmental awareness (CEA), green investment/subsidy and channel selection. In the following section, we describe how our research is a connection with the literature in these areas and where it differs from prior work.

2.1. CEA in green supply chain

The impact of CEA on the green supply chain (GSC) has been widely discussed in academic circles. Numerous articles have explored the relationship between CEA and firm decisions, demonstrating the impact of the CEA on green operations [11, 21, 28]. Using empirical analysis, green factors affecting CEA have been analyzed to verify their effect on the operation. Yu *et al.* [42] primarily utilized empirical analysis and mathematical modeling to carry out the function of the CEA, and verified how manufacturers determine the green grade and production quantity of products. Akbar *et al.* [2] utilized regression analysis to examine the influence of green purchasing attitude, green perceived value, green trust and ecological knowledge on green purchasing intention. Ahmad and Zhang [1] discussed the antecedents of green online purchase intentions, which are characterized by green reputation, green trust, consumer social responsibility, green perception value and green participation. Qualitative analysis methods have also been used to discuss CEA's green investment. Bansal and Gangopadhyay [4] considered the policies and measures to improve environmental quality by analyzing the impact of the CEA on consumers' WTP. Zhang *et al.* [43] analyzed the impact of CEA on the number of orders, and discuss how to improve the market competitiveness of enterprises.

In summarizing the aforementioned literature, we find that the research mainly the CEA in many aspects through qualitative and quantitative research methods. However, the above studies are less concerned with green or environmental issues in dynamic supply chain structures and rarely consider differentiated green operations between competing supply chains. Based on these, our research is distinguished from previous research in that we explore the impact of differences in marketing power on CEA-based demand, and explore their sensitivity on supply chain investment strategy.

2.2. Green investment

Some literature investigates the investment decisions in GSC operation when considering CEA [43]. Based on the framework of a supplier and a manufacturer, green investment decisions and coordination mechanisms are explored in-depth. Taleizadeh *et al.* [35] developed a game model to analyze the impact of the CEA, cap and trade supervision on green supply chains in cooperative and non-cooperative supply chains. Jauhari *et al.*

[17] constructed a mathematical model of inventory in the system composed of manufacturer and multi-retailer, and discussed the optimal inventory level and green technology investment under carbon tax policy. Zhang *et al.* [44] examined the impact of the CEA and retailer fairness concerns on green investment and prices in the supply chain. Green investment under different channel structures and competition formats is also studied. Yan *et al.* [39] analyzed whether and when competing retailers should invest under competition pressure and upstream investment, and discussed the performance of equilibrium results. For green product design issues under competition, Du *et al.* [9] constructed the NMG, OMG and TMG models, and discussed the manufacturer's green design strategy. Under a competitive environment, Shi *et al.* [33] considered three investment options, *i.e.*, one manufacturer, two retailers and one retailer investment, and analytically derived the optimal solution, economic and environmental performance. Wang *et al.* [37] studied the interactive relationship between the online retailer's green investment and supplier's channel choice under supplier competition.

In both the case of single-channel and competitive channels, the existing literature on green investment only considers a fixed channel structure, and focuses on the impact of green investment on supply chain decision-making and operation. However, none of this literature studies the differences in green investment patterns based on dynamic channel structures. Our research considers the impact of channel structure changes on green investment from the perspective of the supplier.

2.3. Investment subsidy

Since upstream green investment can result in downstream indirect profits, the study of this investment fits into the expanding literature on GSC subsidy strategies [40, 42]. From the perspective of supply chain external, some scholars study the impact of government green subsidy mechanisms on the green operation of supply chain. Considering the government's subsidy strategy, Cohen *et al.* [8] quantified the demand uncertainty, and analyzed the impact of green subsidies on different participants (government, firms and consumers). Song and Wang [34] constructed a model of a leading manufacturer and a successor retailer, and explored the mechanism of government subsidies on the supply chain under different decision-making scenarios. Further, from the internal perspective of the supply chain, the green subsidy mechanisms of different members are studied. In the context of consumers' attention to environmental issues, Bian *et al.* [5] focused on the incentive of environmental subsidy on green technology investment. Huang *et al.* [16] discussed three modes, *i.e.*, green credit, production subsidies and sales subsidies for green manufacturers with limited funds, and tried to find a win–win subsidy mode among participants. Zhang *et al.* [45] investigated whether upstream competing manufacturers, which sell products through the same retailer would invest in green solutions, explored when downstream retailers would subsidize and encourage manufacturers to invest, and analyze the environmental benefits of different investment strategies. ... The prior literature mainly focuses on the influence of fixed-cost green subsidies on strategic operations in different aspects. However, from the perspective of differentiated green subsidy format, how to make the optimal green subsidy decision is not discussed. Compared with the aforementioned analysis, our study concentrates on the incumbent manufacturer's subsidy strategies, and discusses the influence of downstream green subsidy strategies at different time points on the decision-making of the green supply chain.

2.4. Channel selection

With the development of the digital economy, channel patterns have gradually diversified [5]. Under two competing retailers, Nie *et al.* [30] considered the two-period game model of channel encroachment and analyze the cross-channel effect on the retailer/manufacturer. Chen *et al.* [7] considered that contract manufacturers (CM) built their own brand products to compete with original equipment manufacturers (OEM) in the three-level outsourcing supply chain composed of CM, OEM and retailer, and explained the effect of the CM's varying channel encroachment formats (direct sales, encroachment into internal retailers or external retailers) on the participant benefits. Li *et al.* [22] investigated the suppliers' encroachment in two competing supply chains, extended the analysis of multiple identical supply chains, and identified the encroachment efficiency on suppliers, retailers and the entire system.

TABLE 1. A summary of the main literature.

Reference	Green investment	Green subsidy (Type)	Investment timeline	Encroachment (Type)
Bian *et al.* [5]	✓(Consumer fixed cost subsidy)			
Cohen *et al.* [8]	✓(Government fixed cost subsidy)			
Du *et al.* [9]	✓(Supplier)			
Huang *et al.* [16]	✓(Supplier)	✓(Government/bank subsidy)		
Wang *et al.* [38]	✓(Supplier and retailer)			
Yan *et al.* [39]	✓(Supplier and retailer)			
Mori [29]			✓	
Li *et al.* [26]	✓(Retailer)		✓	
Zhang *et al.* [45]	✓(Manufacturer)	✓(Retailer)	✓	
Yoon [41]	✓(Supplier)			✓(Supplier)
Wang *et al.* [36]				✓(Potential retailer)
Our work	✓	✓	✓	✓(Potential manufacturer)

In each of the above research on supplier encroachment, retailer encroachment and supply chain encroachment are all considered from the perspective of the encroacher, but exists a gap in the research of the supply chain encroachment in the context of the encroachment of external competitors. Given the background of the current supply crises along with a lack of related research on this topic, we consider the issue of the suppliers' selection regarding allowing external manufacturer encroachment.

A comparison of this study with the main research from the above literature review presents the limitations of previous research and illustrates the improvements of this work on previous research issues such as green investment, green subsidies and channel allocation. Based on the above literature review, we find that it is of great significance to study the interaction between green investment and channel configuration under differentiated marketing power. Firstly, we contribute to the literature on green operations in the competitive supply chain through the research of both green investment and green subsidy strategies. Second, we fill the gap of dynamic subsidy strategy under the different green subsidy formats and subsidy timelines. Third, we contribute to dynamic supply chain encroachment by exploring the impact of entrant encroachment on the decision-making and operation of incumbent supply chain members. We believe that these research results can provide valuable insights into the firm practical and theoretical development of green supply chain investment under dynamic structures (Tab. 1).

3. PROBLEM DESCRIPTION

We consider an incumbent supply chain (ISC) consisting of an incumbent manufacturer and a monopolistic supplier (N format). The supplier decides whether to provide products to an external manufacturer (EM). If the supplier chooses to sell through multiple channels (E format), the incumbent manufacturer (IM) and external manufacturer (EM) have a difference in marketing power. Facing the competitive entrant threat, the supplier or incumbent manufacturer determines a green investment/subsidy strategy, including green procurement, green production, green emissions and other green operations. The different channel formats in the market are depicted in Figure 1.

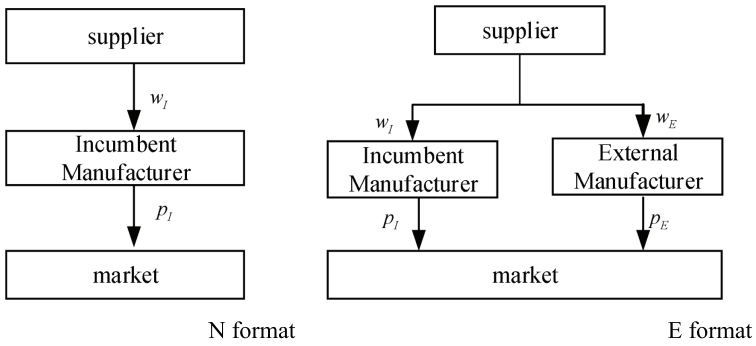


FIGURE 1. Supply chain structure.

TABLE 2. Notation descriptions.

Symbols	Description
$V = \{\mathrm{N}, \mathrm{I}, \mathrm{P}, \mathrm{S}\}$	Investment strategies: no investment (N), IM ex-ante subsidy (I) or ex-post subsidy (P), supplier investment (S)
$G = \{G_1, G_2\}$	Supplier provides product to EM (G_1) or not (G_2) in different investment scenarios. where $G_1 = \{\mathrm{NN}, \mathrm{IN}, \mathrm{PN}, \mathrm{SN}\}$ and $G_2 = \{\mathrm{NE}, \mathrm{IE}, \mathrm{PE}, \mathrm{SE}\}$.
$m, n \in \{\mathrm{I}, \mathrm{E}\}$	IM Channel (I) or EM channel with encroachment (E) ($m \neq n$)
$T = \{\mathrm{I}, \mathrm{E}, \mathrm{S}\}$	I denotes IM, E denotes EM, S denotes supplier
θ	Green investment level
m_m	Manufacturer's margin profit in m channel (CNY/unit)
w_m	The wholesale price in m channel (CNY/unit)
D_m^G	Demand of the m channel under the G format (units)
Π_T^G	Profit of T member under the G format (CNY)
CS_m^G	Customer surplus of the m channel under the G format
a	The market size (units)
k	Green investment cost factor
κ	The investment cost efficiency ($\kappa = k/\tau^2$)
ϕ_m	Marketing power in m channel ($(0 < \phi_{\mathrm{E}} < \phi_{\mathrm{I}} = 1)$)
ϕ	Marketing power difference between the IM and EM ($\phi = \phi_{\mathrm{E}}/\phi_{\mathrm{I}}$)

(1) Demand specification

Basic demand is $D_m^G = a - p_m^G + \phi_m p_n^G$ ($m, n =$ I or E, and I $\neq$ E), and respectively represents the channel of the IM and EM. In fact, incumbent firms tend to have competitive advantages in terms of customer loyalty and brand reputation against competitors, which comes from a first-mover advantage. Therefore, an incumbent manufacturer has an advantage with respect to any new entrants, which is derived from the experience obtained working in production, marketing, and so on [18,20]. Channel I as the leader has greater marketing power, so $\phi_{\mathrm{I}} > \phi_{\mathrm{E}} > 0$. To simplify the model, $\phi = \phi_{\mathrm{E}}/\phi_{\mathrm{I}}$ $(0 < \phi < 1)$ denotes the marketing power difference, with a larger, representing marketing power. We normalize $\phi_{\mathrm{I}} = 1$ and $\phi_{\mathrm{E}} = \phi$ [38]. When the supplier provides product for the IE and EM, the demands are $D_{\mathrm{I}}^{G_2} = a - p_{\mathrm{I}}^{G_2} + p_{\mathrm{E}}^{G_2}$ and $D_{\mathrm{E}}^{G_2} = a - p_{\mathrm{E}}^{G_2} + \phi p_{\mathrm{I}}^{G_2}$. When the supplier only provides products for the IM, the demand is $D_{\mathrm{I}}^{G_1} = 2a - (1-\phi)p_{\mathrm{I}}^{G_1}$.

(2) Green investment
Green investment strategies of the ISC include the following situations: basic model without green investment (N scenario), green subsidy by the IM, which can be divided into ex-ante green subsidy (I scenario) or ex-post green subsidy (P scenario), green investment by the supplier (S scenario). Because the green investment in this paper mainly focuses on the investment of product materials and production technology, so as to improve the green performance of the product. As the upstream monopoly supplier of the supply chain, it has greater channel powers. Therefore, and the supplier provides the same products for different downstream enterprises in the basic model. At the same time, we consider the situation that suppliers push to provide differentiated products to downstream enterprises in the extended mode (*i.e.*, Sect. 8.1), and make a comparative analysis with the basic model. Therefore, under EM encroachment, the demands are $D_{\mathrm{I}}^{G_2} = a - p_{\mathrm{I}}^{G_2} + p_{\mathrm{E}}^{G_2} + \tau\theta^{G_2}$ and $D_{\mathrm{E}}^{G_2} = a - p_{\mathrm{E}}^{G_2} + \phi p_{\mathrm{I}}^{G_2} + \tau\theta^{G_2}$, otherwise, it is $D_{\mathrm{I}}^{G_1} = 2a - (1-\phi)p_{\mathrm{I}}^{G_1} + \tau\theta^{G_1}$. Green investment as a one-off investment is handled during the production process, and the green investment cost is $k(\theta_m^G)^2/2$ [21, 43]. All notations in the paper are destined in Table 2.

4. Basic model analysis

We first study the basic model where the ISC does not make any green investments. We establish the NN and NE subgame models based on whether EM encroaches, which serves as a benchmark to compare with subsequent scenarios.

4.1. NN format

Under the NN format, the supplier does not provide a product to the EM without green investment. The demand function is $D_{\mathrm{N}}^{\mathrm{NN}} = 2a - (1-\phi)p_{\mathrm{N}}^{\mathrm{NN}}$. The profit functions of the supplier and IM are as follows: $\Pi_{\mathrm{I}}^{\mathrm{NN}} = D_{\mathrm{N}}^{\mathrm{NN}} m_{\mathrm{N}}^{\mathrm{NN}}$ and $\Pi_{\mathrm{S}}^{\mathrm{NN}} = D_{\mathrm{N}}^{\mathrm{NN}} w_{\mathrm{I}}$.

Lemma 1. *The optimal decisions are* $m_{\mathrm{I}}^{\mathrm{NN}} = \frac{2a}{3-3\phi}$, $w_{\mathrm{I}}^{\mathrm{NN}} = \frac{2a}{3-3\phi}$, $p_{\mathrm{I}}^{\mathrm{NN}} = \frac{2a}{3-3\phi}$; *the equilibrium profits are* $\Pi_{\mathrm{I}}^{\mathrm{NN}} = \frac{4a^2}{9-9\phi}$, $\Pi_{\mathrm{S}}^{\mathrm{NN}} = \frac{4a^2}{9-9\phi}$; *and the consumer surplus is* $\mathrm{CS}_{\mathrm{I}}^{\mathrm{NN}} = \frac{2a^2}{9}$.

4.2. NE format

Under the NE format, the supplier provides products to the EM without green investment. The supply chain system contains three players, namely the supplier, IM, and EM. The demand functions are $D_{\mathrm{I}}^{\mathrm{NE}} = a - p_{\mathrm{I}}^{\mathrm{NE}} + p_{\mathrm{E}}^{\mathrm{NE}}$ and $D_{\mathrm{E}}^{\mathrm{NE}} = a - p_{\mathrm{E}}^{\mathrm{NE}} + \phi p_{\mathrm{I}}^{\mathrm{NE}}$. The profit functions of the supplier, IM and EM are: $\Pi_{\mathrm{I}}^{\mathrm{NE}} = D_{\mathrm{I}}^{\mathrm{NE}} m_{\mathrm{I}}^{\mathrm{NE}}$, $\Pi_{\mathrm{E}}^{\mathrm{NE}} = D_{\mathrm{E}}^{\mathrm{NE}} m_{\mathrm{E}}^{\mathrm{NE}}$ and $\Pi_{\mathrm{S}}^{\mathrm{NE}} = D_{\mathrm{I}}^{\mathrm{NE}} w_{\mathrm{I}}^{\mathrm{NE}} + D_{\mathrm{E}}^{\mathrm{NE}} w_{\mathrm{E}}^{\mathrm{NE}} - \Upsilon$.

Lemma 2. *The optimal decisions are* $m_{\mathrm{I}}^{\mathrm{NE}} = \frac{3aZ}{B}$, $m_{\mathrm{E}}^{\mathrm{NE}} = \frac{9a(1+\phi)}{2B}$, $w_{\mathrm{I}}^{\mathrm{NE}} = \frac{a(51-17\phi+2\phi^2)}{2B(1-\phi)}$, $w_{\mathrm{E}}^{\mathrm{NE}} = \frac{a(60-17\phi-7\phi^2)}{78-116\phi+34\phi^2+4\phi^3}$; *the equilibrium profits are* $\Pi_{\mathrm{I}}^{\mathrm{NE}} = \frac{3a^2C}{B^2}$, $\Pi_{\mathrm{E}}^{\mathrm{NE}} = \frac{81a^2(1+\phi)^2}{4B^2}$, $\Pi_{\mathrm{S}}^{\mathrm{NE}} = \frac{Aa^2}{4B^2(1-\phi)}$; *and the consumer surplus are* $\mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}} = \frac{a^2(2\phi^2+13\phi-24)^2}{2B^2}$ *and* $\mathrm{CS}_{\mathrm{E}}^{\mathrm{NE}} = \frac{81a^2(\phi+1)^2}{8B^2}$. *Where* $A = (8\phi^4 + 47\phi^3 - 118\phi^2 + 1755\phi - 2988)$, $B = 39 - 19\phi - 2\phi^2$, $C = (\phi+8)^2(3-2\phi)$, $Z = \phi + 8$.

Proposition 1. $m_{\mathrm{I}}^{\mathrm{NE}} < m_{\mathrm{I}}^{\mathrm{NN}}$, $w_{\mathrm{I}}^{\mathrm{NE}} \le w_{\mathrm{I}}^{\mathrm{NN}}$ *if* $0 \le \phi \le \phi_{\mathrm{N1}}$; *otherwise,* $w_{\mathrm{I}}^{\mathrm{NE}} > w_{\mathrm{I}}^{\mathrm{NN}}$. $\Pi_{\mathrm{I}}^{\mathrm{NE}} < \Pi_{\mathrm{I}}^{\mathrm{NN}}$, $\Pi_{\mathrm{S}}^{\mathrm{NE}} \ge \Pi_{\mathrm{S}}^{\mathrm{NN}}$. *Where* $\phi_{\mathrm{N1}} = \frac{1}{28}(\sqrt{793} - 25)$.

Proposition 1 shows that channel competition leads to a lower selling price and profit margin for the IM. When channel competition is lower, the IM has a stronger channel advantage and the wholesale price of the product is less than that of the EM, and *vice versa*, as shown in Figure 2a. The supplier has a technology monopoly in the upstream of the supply chain. With the encroachment of the EM, the dual-channel operation of the supplier can improve sales, resulting in an increase of profit. But the encroachment always leads to a loss of IE profit due to lower marginal revenue and lower demand. Therefore, the incumbent supply chain can't implement Pareto improvement in dual-channel operation, as shown in Figure 2b.

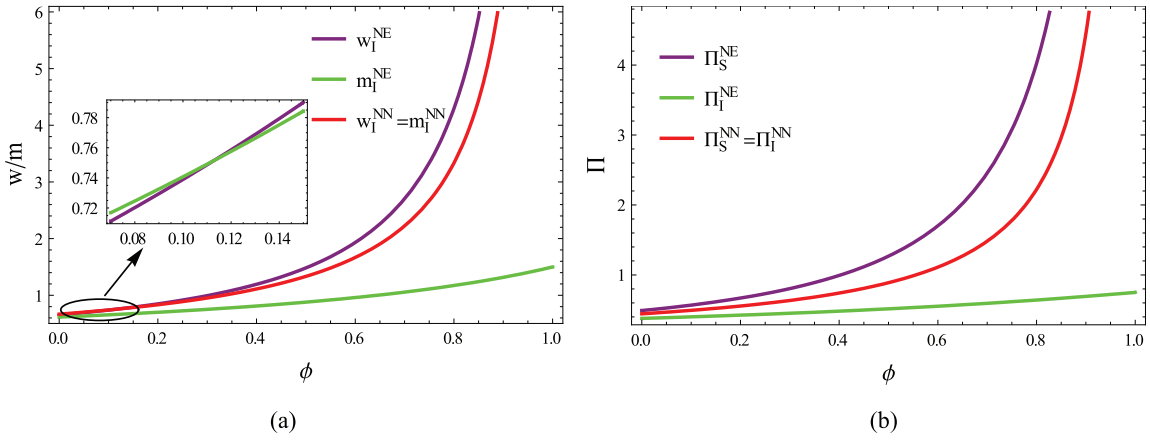


FIGURE 2. The impact of EM encroachment on equilibrium results under N scenario. (a) The impact of EM encroachment on decisions. (b) The impact of EM encroachment on profits.

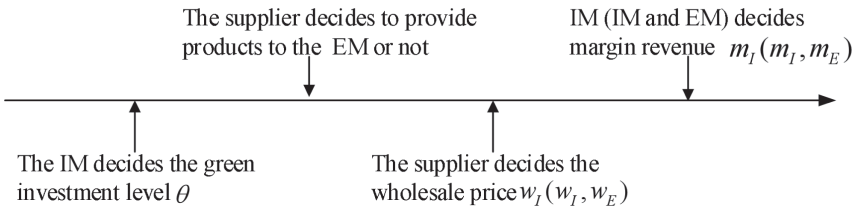


FIGURE 3. The timeline of the I scenario.

5. Model analysis of IM's green subsidy

Manufacturers are close to the market and thus can react first when there is a shift in consumer purchasing toward green. We study the situations where the IM subsidizes the supplier's green investment. According to the supplier's channel selection and the IM's subsidy strategies, we establish models for I and P scenarios.

5.1. I scenario

The ex-ante IM's green subsidy, namely I scenario, means that the IM makes the subsidy decision before the supplier decision, as shown in Figure 3. Considering the supplier's decision of whether to furnish products for the EM, we establish the IN and IE subgame models.

5.1.1. IN format

Under the IN format, the IM subsidizes the supplier to invest in green technology, but the EM does not enter the market. The profit functions of the supplier and IM are $\Pi_I^{IN} = D_I^{IN} m_I^{IN} - k(\theta_I^{IN})^2/2$ and $\Pi_S^{IN} = D_I^{IN} w_I^{IN}$.

Lemma 3. *The optimal decisions are* $\theta_I^{IN} = \frac{2a\tau}{9k+4\tau^2-9k\phi}$, $m_I^{IN} = \frac{2a(1-3\kappa(\phi-1))}{(\phi-1)(9\kappa(\phi-1)-4)}$ *and* $w_I^{IN} = \frac{a(4-6\kappa(\phi-1))}{(\phi-1)(9\kappa(\phi-1)-4)}$; *the equilibrium profits are* $\Pi_I^{IN} = \frac{4a^2(2-3\kappa(\phi-1))^2}{(1-\phi)(4-9\kappa(\phi-1))^2}$ *and* $\Pi_S^{IN} = \frac{2a^2(18\kappa^2(\phi-1)^2+11k(1-\phi)+2)}{(1-\phi)(4+9\kappa(1-\phi))^2}$; *and the consumer surplus is* $CS_I^{IN} = \frac{2a^2(2+3\kappa(1-\phi))^2}{(4+9\kappa(1-\phi))^2}$.

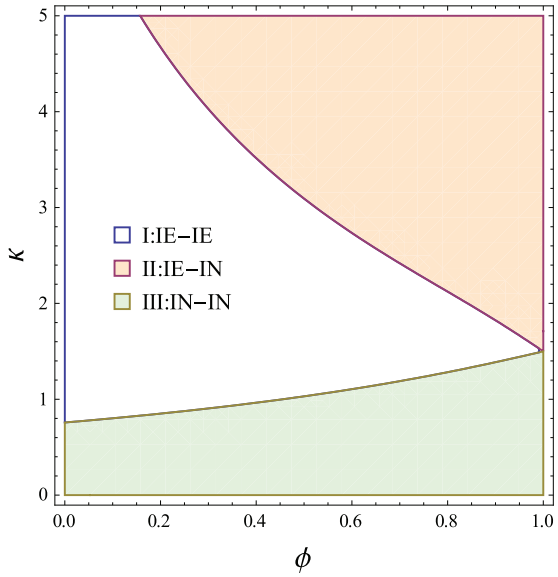


FIGURE 4. Supplier-IM channel preference under E scenario.

5.1.2. IE format

Under the IE format, the EM encroaches on the market and the IM provides a green subsidy to the supplier. When the supplier provides a product to the EM, channel competition arises between the two manufacturers. The profit functions of the supplier, IM and EM are as follows: $\Pi_{\mathrm{I}}^{\mathrm{IE}} = D_{\mathrm{I}}^{\mathrm{IE}} m_{\mathrm{I}}^{\mathrm{IE}} - k(\theta_{\mathrm{I}}^{\mathrm{IE}})^2/2$, $\Pi_{\mathrm{E}}^{\mathrm{IE}} = D_{\mathrm{E}}^{\mathrm{IE}} m_{\mathrm{E}}^{\mathrm{IE}}$ and $\Pi_{\mathrm{S}}^{\mathrm{IE}} = D_{\mathrm{I}}^{\mathrm{IE}} w_{\mathrm{E}}^{\mathrm{IE}} + D_{\mathrm{E}}^{\mathrm{IE}} w_{\mathrm{I}}^{\mathrm{IE}}$.

Lemma 4. *For* $\kappa \geq \kappa_{\mathrm{I}}^1$, *the optimal decisions are* $w_{\mathrm{I}}^{\mathrm{IE}} = \frac{a\kappa A(2\phi^2-17\phi+51)}{2(1-\phi)(\kappa A^2-6C)}$, $w_{\mathrm{E}}^{\mathrm{IE}} = \frac{a\kappa(70\phi^2+1803\phi-2340-14\phi^4-167\phi^3)}{2(\phi-1)(\kappa B^2-6C)}$ *and* $\theta_{\mathrm{I}}^{\mathrm{IE}} = \frac{6a\tau C}{kB^2-6\tau^2 C}$; *the equilibrium profits are* $\Pi_{\mathrm{I}}^{\mathrm{IE}} = \frac{3a^2\kappa C}{\kappa B^2-6C}$, $\Pi_{\mathrm{E}}^{\mathrm{IE}} = \frac{81a^2\kappa^2F^2}{4(\kappa B^2-6C)^2}$ *and* $\Pi_{\mathrm{S}}^{\mathrm{IE}} = \frac{a^2\kappa^2B^2A}{4(1-\phi)(\kappa B^2-6C)^2}$; *and the consumer surplus are* $\mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}} = \frac{a^2\kappa^2(4\phi^4+64\phi^3+121\phi^2-963\phi+936)^2}{2(\kappa B^2-6C)^2}$ *and* $\mathrm{CS}_{\mathrm{E}}^{\mathrm{IE}} = \frac{81a^2\kappa^2(2\phi^3+19\phi^2+B)^2}{2(2\kappa B^2-12C)^2}$, *where* $\kappa_{\mathrm{I}}^1 = \frac{6(\phi+8)^2(3-2\phi)}{(2\phi^2+19\phi-39)^2}$, $F = 39 - 2\phi^3 - 21\phi^2 + 20\phi$.

Proposition 2. *Under I scenario, the channel strategies and green subsidy strategies of the supply chain system:*

(a) *The supplier adopts a single-channel format if* $0 < \kappa < \kappa_{\mathrm{I}}^1$. *The EM always prefers to encroach if* $\kappa \geq \kappa_{\mathrm{I}}^1$, *and the supplier always permits the EM to encroach and takes the dual-channel format. However, IM prefers EM encroachment when* $\kappa_{\mathrm{I}}^1 < \kappa < \kappa_{\mathrm{I}}^2$, *and IM prefers monopoly operation when* $\kappa \geq \kappa_{\mathrm{I}}^2$.

(b) *If* $0 < \kappa < \kappa_{\mathrm{I}}^1$, *there will be no green subsidy; if* $\kappa \geq \kappa_{\mathrm{I}}^1$, *ex-ante green subsidy is carried out. Meanwhile, Any time the supplier always prefers the IM to green sudsize its product.*

Proposition 2(a) shows that the positive impact of green investment cannot offset the channel competition loss if κ is in the lower. The dual-channel format would lead to serious channel conflict. Because of the vicious price competition generated between the two channels, the dual-channel would be unable to obtain a profit. Hence, the supplier only provides products for the IM. If κ is higher, the green investment could bring great benefits. Thus, the supplier is willing to establish a new distribution channel to furnish products to the EM, which profits by expanding market demand. However, the IM has different preferences. The positive impact of investment is small in dual-channel when $\kappa_{\mathrm{I}}^1 < \kappa < \kappa_{\mathrm{I}}^2$, and the benefits of the investment do not cover the marginalization losses due to channel competition, so the IM doesn't prefer the EM encroachment. Conversely, the IM prefers a dual-channel structure when $\kappa > \kappa_{\mathrm{I}}^2$, as shown in Figure 4.

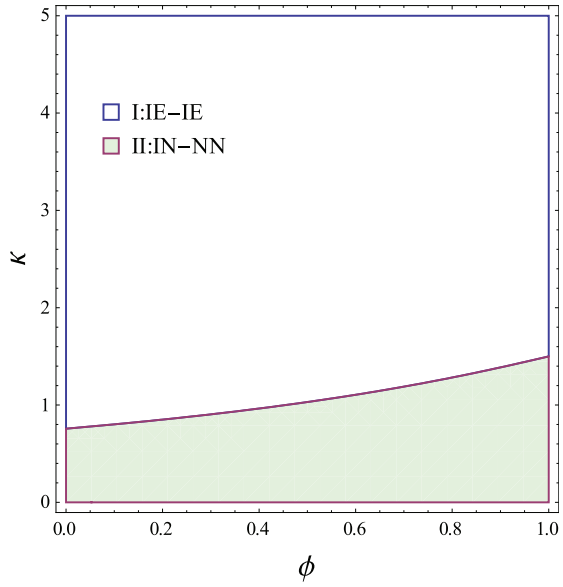


FIGURE 5. Supplier-IM green subsidy preference under E scenario.

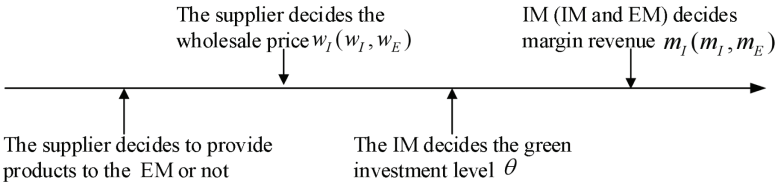


FIGURE 6. The timeline of the P scenario.

Proposition 2(b) shows the green subsidy preference for the IM and supplier. Regardless of whether the supply chain has a single-channel or dual-channel structure, suppliers can always benefit from additional demand riders for green investment and therefore always prefer IM for green subsidies. The positive impact of investment is small in single-channel when $0 < \kappa < \kappa_{\mathrm{I}}^{1}$, therefore IM will not subsidize it; the benefits of green investment increase when $\kappa \geq \kappa_{\mathrm{I}}^{\mathrm{I}}$ and the IM can mitigate the adverse effects of competition through investment and thus will subsidize green, as shown in Figure 5.

5.2. P scenario

The manufacturer's ex-ante green subsidy may lead to the supplier's wholesale price premium situation by investment-free riding, which is not conducive to the manufacturer's operation. Therefore, we study the situations where the IM adopts ex-post green subsidy, namely the P scenario. The IM decides to make a green investment after the supplier sets the wholesale price, as shown in Figure 6. According to whether to supply products for the EM, we establish the PN and PE subgame models.

5.2.1. PN format

Under the PN format, the EM does not enter the market and the IM provides an ex-post subsidy to facilitate the green investment of the supplier. The profit functions of the supplier and IM are $\Pi_{\mathrm{I}}^{\mathrm{PN}} = D_{\mathrm{I}}^{\mathrm{PN}} m_{\mathrm{I}}^{\mathrm{PN}} - k(\theta_{\mathrm{I}}^{\mathrm{PN}})^2/2$ and $\Pi_{\mathrm{S}}^{\mathrm{PN}} = D_{\mathrm{I}}^{\mathrm{PN}} w_{\mathrm{I}}^{\mathrm{PN}}$.

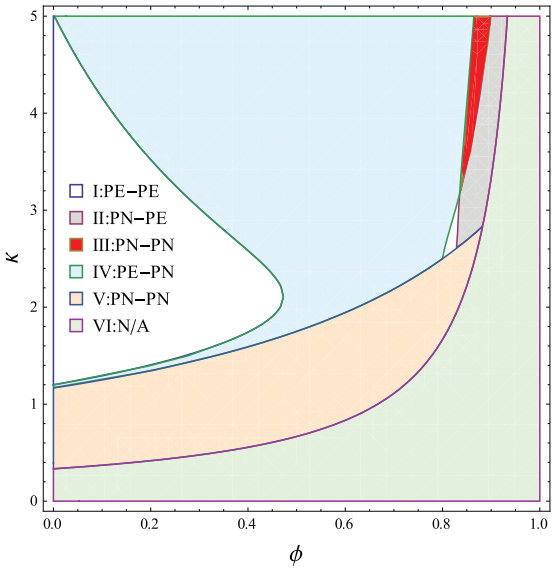


FIGURE 7. Supplier-IM channel preference under P scenario.

Lemma 5. *For* $\kappa \geq \kappa_p^0(\kappa_p^0 = \frac{1}{3(1-\phi)})$, *the optimal decisions are* $m_{\mathrm{I}}^{\mathrm{PN}} = \frac{2a\kappa}{3\kappa(1-\phi)-1}$, $\theta_{\mathrm{I}}^{\mathrm{PN}} = \frac{2a\tau}{3k-3k\phi-\tau^2}$ *and* $w_{\mathrm{I}}^{\mathrm{PN}} = \frac{2a\kappa}{3\kappa(1-\phi)-1}$; *the equilibrium profits are* $\Pi_{\mathrm{I}}^{\mathrm{PN}} = \frac{2a^2\kappa(2\kappa(1-\phi)-1)}{(3\kappa(\phi-1)+1)^2}$ *and* $\Pi_{\mathrm{S}}^{\mathrm{PN}} = \frac{4a^2\kappa^2(1-\phi)}{(3\kappa(\phi-1)+1)^2}$; *and the consumer surplus is* $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PN}} = \frac{2a^2\kappa^2(\phi-1)^2}{(1+3\kappa(\phi-1))^2}$.

5.2.2. PE format

Under the PE format, the IM provides the supplier with an ex-post investment subsidy. When the supplier provides products for the EM, the profit functions of the supplier, IM and EM are: $\Pi_{\mathrm{I}}^{\mathrm{PE}} = D_{\mathrm{I}}^{\mathrm{PE}} m_{\mathrm{I}}^{\mathrm{PE}} - k(\theta_{\mathrm{I}}^{\mathrm{PN}})^2/2$, $\Pi_{\mathrm{S}}^{\mathrm{PE}} = D_{\mathrm{I}}^{\mathrm{PE}} w_{\mathrm{E}}^{\mathrm{PE}} + D_{\mathrm{E}}^{\mathrm{PE}} w_{\mathrm{I}}^{\mathrm{PE}}$ and $\Pi_{\mathrm{E}}^{\mathrm{PE}} = D_{\mathrm{E}}^{\mathrm{PE}} m_{\mathrm{E}}^{\mathrm{PE}}$.

Lemma 6. *For* $\kappa \geq \kappa_{\mathrm{P}}^1$, *the optimal decisions* $w_{\mathrm{I}}^{\mathrm{PE}} = \frac{a(\kappa(2\phi^2-17\phi+51)-4Z)}{2(1-\phi)(\kappa B-5Z)}$, $w_{\mathrm{E}}^{\mathrm{PE}} = -\frac{a(\kappa(7\phi^2+17\phi-60)+4Z)}{2(1-\phi)(\kappa B-5Z)}$ *and* $\theta_{\mathrm{I}}^{\mathrm{PE}} = \frac{3a\tau Z}{kB-5\tau^2 Z}$; *the equilibrium profits* $\Pi_{\mathrm{I}}^{\mathrm{PE}} = \frac{3a^2\kappa Z^2(7-\kappa(4\phi-6))}{2(\kappa B+5Z)^2}$ *and* $\Pi_{\mathrm{E}}^{\mathrm{PE}} = \frac{81a^2\kappa^2(\phi+1)^2}{4(\kappa B-5Z)^2}$, $\Pi_{\mathrm{S}}^{\mathrm{PE}} = \frac{a^2(\kappa^2 A-16Z^2-H_3)}{4(1-\phi)(\kappa B-5Z)^2}$; *and the consumer surplus are* $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PE}} = \frac{a^2(\kappa H_1+4Z)^2}{8(\phi-1)^2(\kappa B-5Z)^2}$ *and* $\mathrm{CS}_{\mathrm{E}}^{\mathrm{PE}} = \frac{a^2(\kappa H_1+4Z)(\kappa H_2+4Z)}{8(\phi-1)^2(\kappa B-5Z)^2}$. *Where* $\kappa_{\mathrm{P}}^1 = \frac{7}{6-4\phi}$, $H_1 = 4\phi^2 + 59\phi - 99$, $H_2 = 16\phi^2 + 17\phi - 69$, $H_3 = 8\kappa(\phi^3 + 25\phi^2 + 82\phi - 432)$.

Proposition 3. *Under P scenario, the channel strategies and green subsidy strategies of the supply chain system:*

(a) *If* $0 < \kappa \leq \kappa_p^0$, *no channel exists in the supply chain system. If* $\kappa_{\mathrm{I}}^0 < \kappa < \kappa_{\mathrm{P}}^1$, *the EM doesn't encroach in the market, and supplier adopts single-channel format. If* $\max\{\kappa_{\mathrm{P}}^0, \kappa_{\mathrm{P}}^1\} \leq \kappa \leq \kappa_{\mathrm{P}}^2$, *the EM prefers to encroach in the market, but the supplier are reluctant to provide products for EM. If* $\kappa > \max\{\kappa_{\mathrm{P}}^0, \kappa_{\mathrm{P}}^1, \kappa_{\mathrm{P}}^2\}$, *the supplier always are always willing to provide products for IM and EM.*

(b) *No green subsidy is provided in single-channel structure if* $0 < \kappa < \kappa_{\mathrm{P}}^0$; *green subsidy is adopted in single-channel structure if* $\kappa_{\mathrm{P}}^0 \leqslant \kappa \leqslant \kappa_{\mathrm{P}}^1$; *no green subsidy is provided in dual-channel structure if* $\kappa_{\mathrm{P}}^1 \leqslant \kappa \leqslant \kappa_{\mathrm{P}}^5$; *green subsidy is adopted in dual-channel structure if* $\kappa > \kappa_{\mathrm{P}}^5$.

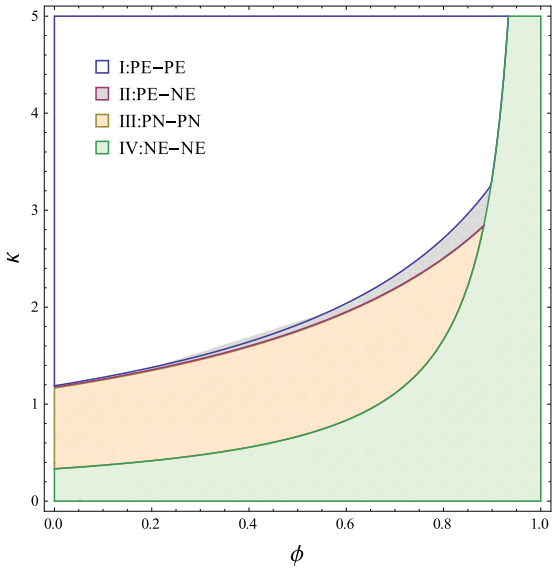


FIGURE 8. Supplier-IM green subsidy preference under P scenario.

The results for Proposition 3(a) are similar to those under the I scenario. Under the investment scenario, the operation would bring negative utility to supply chain members, so no channel exists in the supply chain system when κ is lower. Suppliers begin to sell products through single channels with the increase of κ, due to the improvement of the operating profit. When κ increases to a certain value, EM tries to encroach on the market. However, the horizontal marginalization effect brought through channel competition leads to the reluctance of suppliers to supply products to EM. Therefore, suppliers only prefer the dual-channel structure when $\kappa > \max\{\kappa_{\mathrm{P}}^0, \kappa_{\mathrm{P}}^1, \kappa_{\mathrm{P}}^2\}$. However, IM has different preferences. IM prefers a dual-channel structure only when only one of κ and ϕ is small with EM encroachment, namely, $\max\{\kappa_{\mathrm{P}}^0, \kappa_{\mathrm{P}}^1\} \leqslant \kappa_{\mathrm{P}}^3$ or $\kappa \geqslant \kappa_{\mathrm{P}}^4$, otherwise, channel competition will reduce IM's profit. As shown in Figure 7. The supplier and IM can achieve channel preference equilibrium in Regions I, III and V.

The results for Proposition 3(b) are similar to those under the I scenario. When κ is lower, the positive impact of investment cannot cover the investment cost, so the IM does not invest in green technology. The supplier will always accept the green subsidy with the increase of κ. If the investment cost efficiency is in the middle range, the investment can provide a positive impact but cannot recover the loss caused by channel competition. Hence, the supplier only furnishes products for the IM under green subsidy, but IM is unwilling to carry out green subsidies. If investment cost efficiency is larger, the return on investment improves such that the supplier and IM can achieve a profit by establishing a new distribution channel. Therefore, the supplier chooses to furnish products for the EM, as shown in Figure 8.

Corollary 1. *Scenarios N, I, and P are compared to obtain the IM's strategy and supplier's strategy as shown in Figures 9 and 10. It shows that the supplier will only provide products for the IM and sell products in the single-channel format when the investment cost efficiency is low; otherwise, the supplier chooses the dual-channel format. The positive utility of investment cannot make up for the cost loss when* $0 < \kappa < \kappa_{\mathrm{I}}^0$*, so ISC players are unwilling to invest in green technology. As the investment cost efficiency increases, the influence of green investment also gradually rises. The IM will carry out green investment subsidies when* $\kappa > \kappa_{\mathrm{I}}^0$*. When the investment cost efficiency is larger, the supplier provides products for two manufacturers. Operating cost does not affect the formulation of the strategy, but only affects thresholds of the transformation between different strategies. When the P and I scenarios exist simultaneously, the supplier and IM have different choices.*

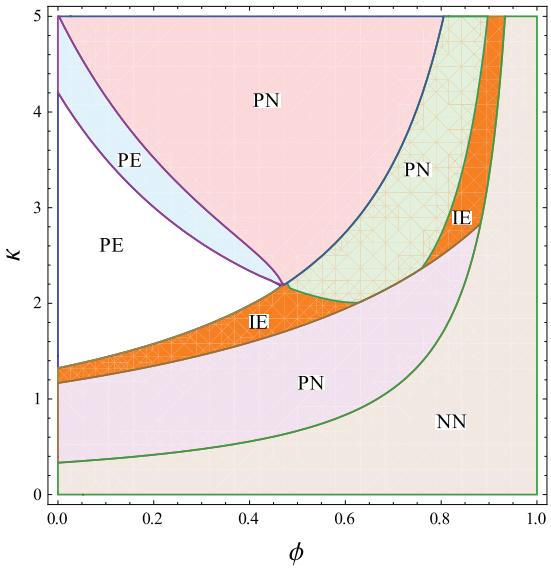


FIGURE 9. IM mode preference under I scenario.

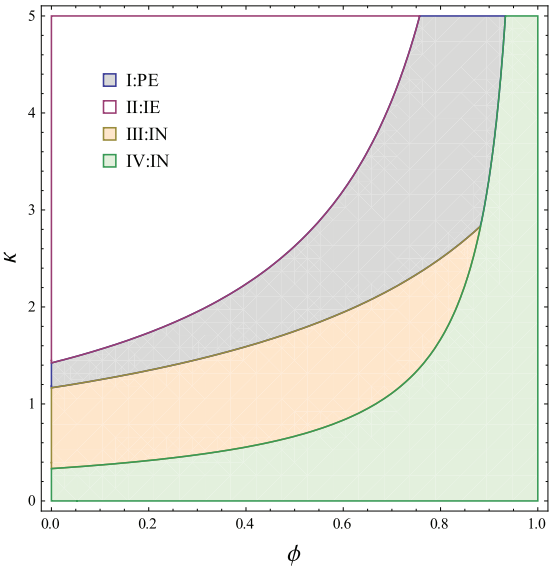


FIGURE 10. Supplier mode preference under I scenario.

Corollary 2. *Under the IM's green subsidy, the Pareto equilibrium of the ISC is realized under PE format, as shown in the Figure 11. According to Figure 11, as investment cost efficiency increases, the IM prefers investment modes transition from the NN format to the PN format as shown in Figure 9 in single-channel, but the supplier always prefers the IN format as shown in Figure 10. Therefore, the ISC can't achieve equilibrium in a single-channel. When a dual-channel operation is adopted, only local areas can achieve equilibrium under the PE format. We illustrate the ISC's equilibrium strategy as shown in Figure 11. Compared with the P scenario,*

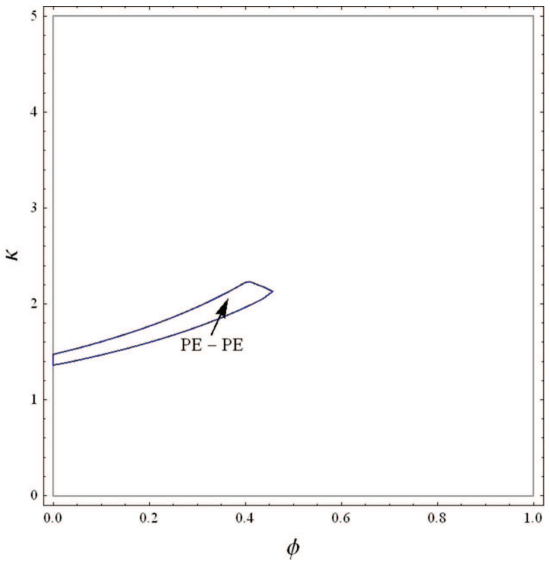


FIGURE 11. Equilibrium regions of the supply chain among N, I and P scenarios.

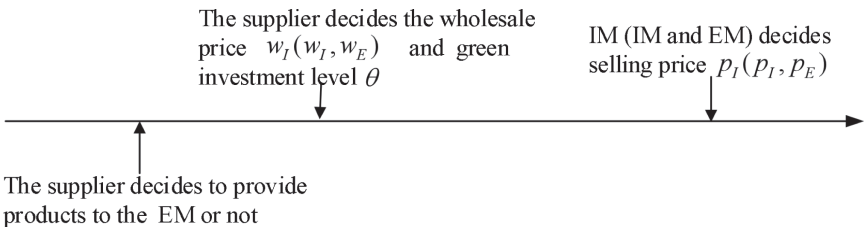


FIGURE 12. The timeline of the P scenario.

the I scenario is from the perspective of the ISC to consider green subsidy strategy, thus when the IM is dominant, the equilibrium can be achieved in the presence of the P scenario.

6. Model analysis of supplier's green investment

Under the S scenario, the supplier adopts green investment, and the decision timeline of the P scenario is shown in Figure 12. When the IM provides a green subsidy, the profits of both the supplier and the EM will be adversely affected. A win–win between the supplier and IM can only be achieved locally. Thus, when the IM is not required to make a green subsidy, would the supplier (who already knows the market preference) be willing to make a green investment? To solve this problem, the SN and SE subgame models are established.

6.1. SN format

Under the SN format, the supplier invests in green technology, but the EM is not allowed in the market. The profit functions of the supplier and the IM are $\Pi_{\mathrm{I}}^{\mathrm{SN}} = D_{\mathrm{I}}^{\mathrm{SN}} m_{\mathrm{I}}^{\mathrm{SN}}$ and $\Pi_{\mathrm{S}}^{\mathrm{SN}} = D_{\mathrm{I}}^{\mathrm{SN}} w_{\mathrm{I}} - k\left(\theta_{\mathrm{S}}^{\mathrm{SN}}\right)^2/2$.

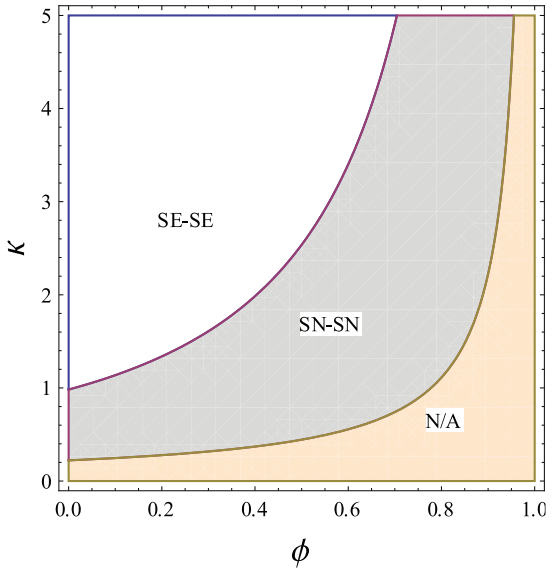


FIGURE 13. Supplier-IM's channel preference under S scenario.

Lemma 7. *Under the SN format, for* $k \geqslant k_{\mathrm{I}}^{0}$, *the optimal decisions are* $m_{\mathrm{I}}^{\mathrm{SN}} = \frac{6ak}{9\kappa(1-\phi)-2}$, $w_{\mathrm{I}}^{\mathrm{SN}} = \frac{6a\kappa}{9\kappa(1-\phi)-2}$ *and* $\theta_{\mathrm{S}}^{\mathrm{SN}} = \frac{4a\tau}{9k-k\phi-2\tau^2}$; *the equilibrium profits are* $\Pi_{\mathrm{I}}^{\mathrm{SN}} = \frac{36a^2\kappa^2(1-\phi)}{(9\kappa(\phi-1)+2)^2}$ *and* $\Pi_{\mathrm{S}}^{\mathrm{SN}} = \frac{4a^2\kappa}{9\kappa(1-\phi)-2}$; *and the consumer surplus is* $\mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} = \frac{18a^2\kappa^2(\phi-1)^2}{(9\kappa(\phi-1)+2)^2}$. *Where* $\kappa_{\mathrm{S}}^{0} = \frac{2}{9(1-\phi)}$.

6.2. SE format

Under the SE format, the supplier invests in green technology and the EM enters the market. The profit functions of the supplier, IM and EM are as follows: $\Pi_{\mathrm{I}}^{\mathrm{SE}} = D_{\mathrm{I}}^{\mathrm{SE}} m_{\mathrm{I}}^{\mathrm{SE}}$, $\Pi_{\mathrm{E}}^{\mathrm{SE}} = D_{\mathrm{E}}^{\mathrm{SE}} m_{\mathrm{E}}^{\mathrm{SE}}$ and $\Pi_{\mathrm{S}}^{\mathrm{SE}} = D_{\mathrm{I}}^{\mathrm{SE}} w_{\mathrm{I}}^{\mathrm{SE}} + D_{\mathrm{E}}^{\mathrm{SE}} w_{\mathrm{I}}^{\mathrm{SE}} - k\left(\theta_{\mathrm{S}}^{\mathrm{SN}}\right)^2/2$.

Lemma 8. *For* $\kappa \geqslant \kappa_{\mathrm{S}}^{1}$, *the optimal decisions are* $m_{\mathrm{I}}^{\mathrm{SE}} = \frac{6a\kappa B\left(8-\phi^2-7\phi\right)}{2\kappa(1-\phi)B^2-A}$, $m_{\mathrm{E}}^{\mathrm{SE}} = \frac{9a\kappa\left(B-\phi^2B-8\phi^4\right)}{2\kappa(1-\phi)B^2+A}$, $w_{\mathrm{I}}^{\mathrm{SE}} = \frac{a\kappa B\left(2\phi^2-17\phi+51\right)}{2\kappa(1-\phi)B^2-A}$, $w_{\mathrm{E}}^{\mathrm{SE}} = \frac{a\kappa\left(2340-1803\phi-70\phi^2+167\phi^3+14\phi^4\right)}{2\kappa(1-\phi)B^2-A}$ *and* $\theta_{\mathrm{S}}^{\mathrm{SE}} = \frac{a\tau A}{2k(\phi-1)B^2+\tau^2A}$; *the equilibrium profits are* $\Pi_{\mathrm{I}}^{\mathrm{SE}} = \frac{12a^2\kappa^2(3-2\phi)\left(7\phi+\phi^2-8\right)^2B^2}{(2\kappa(\phi-1)B^2-A)^2}$, $\Pi_{\mathrm{E}}^{\mathrm{SE}} = \frac{81a^2\kappa^2\left(4\phi^4-B\phi^2+B\right)^2}{(2\kappa(\phi-1)B^2-A)^2}$ *and* $\Pi_{\mathrm{S}}^{\mathrm{SE}} = \frac{a^2\left(8\kappa\left(\phi^3+25\phi^2+82\phi-432\right)-\kappa^2A+16(\phi+8)^2\right)}{4(1-\phi)(\kappa B-5(\phi+8))^2}$; *and the consumer surplus are* $\mathrm{CS}_{\mathrm{I}}^{\mathrm{SE}} = \frac{a^2\kappa^2B^2\left(4\phi^2+59\phi-99\right)^2}{2\left(2\kappa(\phi-1)(2\phi^2+19\phi-39)^2-A\right)^2}$ *and* $\mathrm{CS}_{\mathrm{E}}^{\mathrm{SE}} = \frac{a^2\kappa^2\left(2691-1974\phi-439\phi^2+338\phi^3+32\phi^4\right)^2}{2(2\kappa(\phi-1)B^2-A)^2}$.

Proposition 4. *Under S scenario, the channel strategies and green investment strategies of supply chain system:*

(a) *If* $0 < \kappa < \kappa_{\mathrm{S}}^{0}$, *the supplier does not invest; if* $\kappa_{\mathrm{S}}^{0} < \kappa$, *the supplier chooses green investment.*
(b) *If* $0 < \kappa < \kappa_{\mathrm{S}}^{0}$, *no channels are able to operate. If* $\kappa_{\mathrm{S}}^{0} \leqslant \kappa \leqslant \kappa_{\mathrm{S}}^{1}$, *the supplier only furnishes product for the IM; if, the supplier provides product for both the IM and the EM.*

Proposition 4 presents the green investment and channel format under the S scenario, which are mainly affected by the investment cost efficiency, competitive intensity and operating cost. The EM always prefers encroachment, and the EM's encroachment causes channel conflicts, leading to double marginalization. When

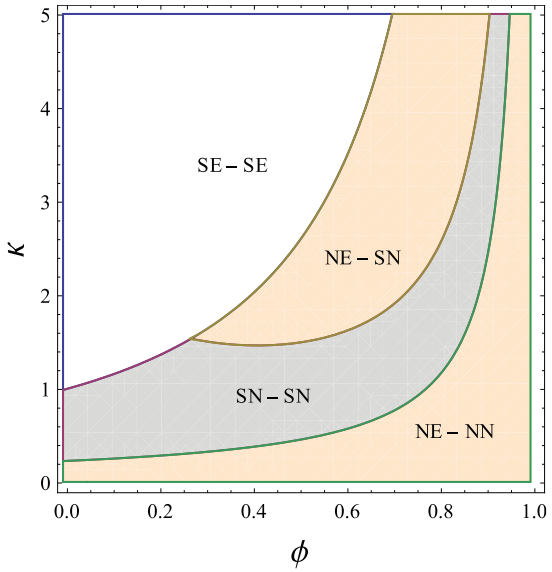


FIGURE 14. Supplier-IM's investment preference under S scenario.

the channel conflicts are intense or the cost efficiency is low, the supplier will choose single-channel sales; otherwise, the supplier will choose multi-channel sales as shown in the Figure 13. However, if the supplier conducts normal sales, green investment isn't always beneficial to all members of the supply chain as shown in the Figure 14, supplier and IM have the same investment format preference in the dual-channel when the investment cost efficiency is larger; however, it can achieve investment equilibrium only partially areas in the single-channel.

7. Strategy analysis of supply chain

In the preceding section, we derived the supplier and manufacturers' optimal decisions and profits under different scenarios. In this section, we compare the decisions and profits under different situations (N, I, P and S scenarios), and obtain the optimal green investment strategy and channel configuration format.

7.1. Green investment strategy

Proposition 5. *The thresholds for green investment under different formats:*
(a) $\kappa_{\mathrm{S}}^0 < \kappa_{\mathrm{P}}^0$. (b) *If* $0 < \phi < \phi_T^1$, $\kappa_{\mathrm{I}}^1 < \kappa_{\mathrm{S}}^1 < \kappa_{\mathrm{P}}^1$; *if* $\phi_T^1 \leqslant \phi < 1$, $\kappa_{\mathrm{I}}^1 < \kappa_{\mathrm{P}}^1 \leqslant \kappa_{\mathrm{S}}^1$.

Proposition 5 shows that when the supplier operates under a single-channel format, the investment thresholds of the SN formats are lower than those of the dual-channel formats when the difference in marketing power is large. Green investment thresholds are related to the difference in marketing power. When the difference in marketing power is weak, the investment threshold under the PE format is higher and when the difference in marketing power is strong, the investment threshold under the SE format is larger. Regardless of whether the format is single-channel or dual-channel, the I scenario has the lowest green investment threshold. This finding is depicted in Figure 15.

Proposition 6. *Under different scenarios, the green investment levels:*

(a) *If* $\kappa > \kappa_{\mathrm{P}}^0$, $\theta_{\mathrm{PN}} > \theta_{\mathrm{SN}} > \theta_{\mathrm{IN}}$; *if* $\kappa_{\mathrm{S}}^0 \leqslant \kappa \leqslant \kappa_{\mathrm{P}}^0$, $\theta_{\mathrm{SN}} > \theta_{\mathrm{IN}} > \theta_{\mathrm{PN}} = 0$; *if* $0 \leqslant \kappa \leqslant \kappa_{\mathrm{S}}^0$, $\theta_{\mathrm{IN}} > \theta_{\mathrm{SN}} = \theta_{\mathrm{PN}} = 0$.
(b) *If* $\max\{\kappa_{\mathrm{P}}^1, \kappa_{\mathrm{S}}^1\} \leqslant \kappa \leqslant \kappa_\theta^0$, $\theta_{\mathrm{SE}} \geqslant \theta_{\mathrm{IE}} \geqslant \theta_{\mathrm{PE}}$; *if* $\kappa > \kappa_\theta^0$, $\theta_{\mathrm{SE}} > \theta_{\mathrm{PE}} > \theta_{\mathrm{IE}}$.

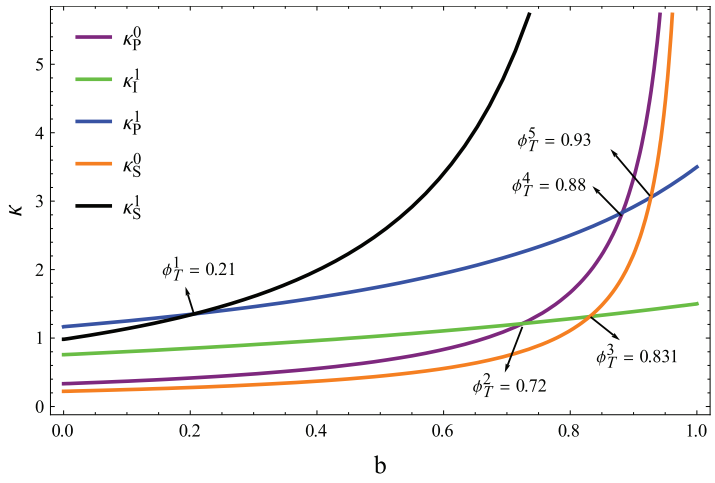


FIGURE 15. Green investment threshold under different green investment strategies.

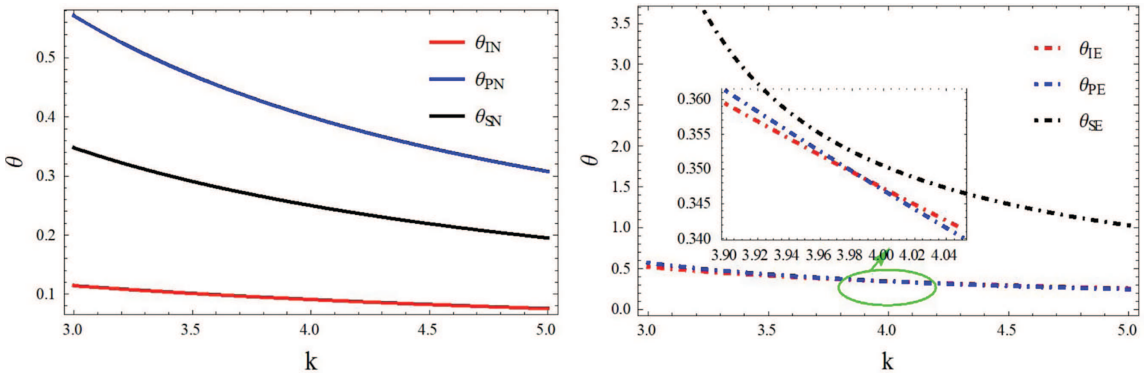


FIGURE 16. Green investment level under different formats. (a) The single-channel structure. (b) The dual-channel structure.

Proposition 6 demonstrates investment levels in different formats. It can be seen that the IN and SN formats can obtain a higher investment level with a lower investment cost efficiency. However, when the investment cost efficiency is greater, the investment level under the PN format outperforms that under all other three scenarios. But the supplier has greater investment motivation under the SE format when the supply chain operates in the dual-channel. When the cost efficiency is small, the IE format is relatively good; otherwise, the SE format is better, as shown in Figure 16.

7.2. Incumbent supply chain's green format preference

Proposition 7. *In the single-channel format, comparing the profits of the supplier and the IM:*

(a) $\kappa_P^0 \leqslant \kappa < \kappa_N^1$, $\Pi_S^{PN} > \Pi_S^{SN} > \Pi_S^{IN} > \Pi_S^{NN}$; *if* $\kappa_N^1 \leqslant \kappa$, $\Pi_S^{PN} > \Pi_S^{IN} > \Pi_S^{SN} > \Pi_S^{NN}$.
(b) *If* $\kappa_P^0 \leqslant \kappa < \kappa_N^2$,$\Pi_I^{SN} > \Pi_I^{IN} > \Pi_I^{PN} > \Pi_I^{NN}$; *if* $\kappa_N^2 \leqslant \kappa$, $\Pi_I^{SN} > \Pi_I^{PN} \geqslant \Pi_I^{IN} > \Pi_I^{NN}$.
Where $\kappa_N^1 = \frac{\sqrt{37}\sqrt{\phi^2-2\phi+1}-\phi+1}{9(\phi^2-2\phi+1)}$, $\kappa_N^2 = \frac{\sqrt{193}\sqrt{\phi^2-2\phi+1}-7\phi+7}{36(\phi^2-2\phi+1)}$.

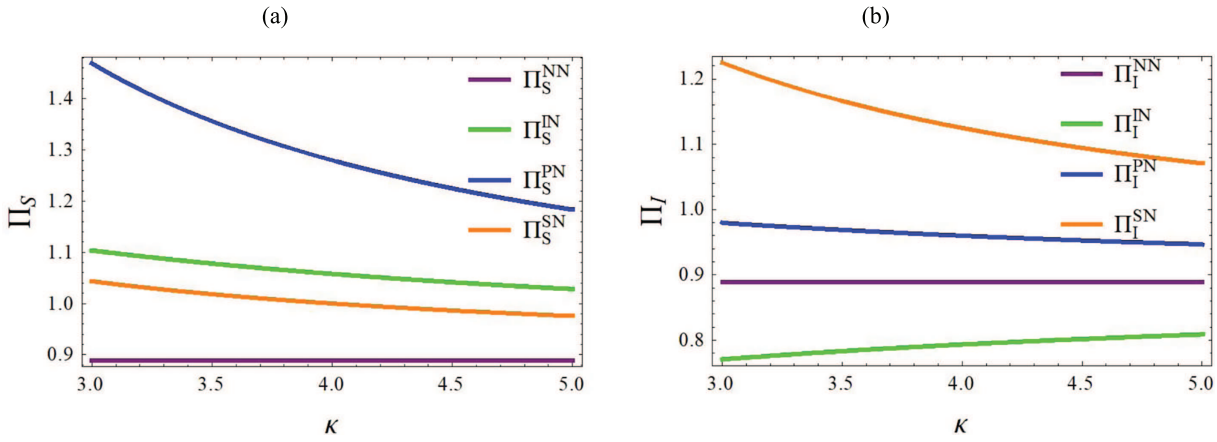


FIGURE 17. Profits of the supplier and the IM in a single-channel format. (a) The supplier's profits. (b) The IM's profits.

Proposition 7 demonstrates the green investment format preference in a single-channel. Because the thresholds and sensitivities of green subsidies are different under different formats, the optimal strategies of supply chain members are constantly changing. If $\kappa_P^0 \leqslant \kappa < \kappa_I^1$, the supplier does not permit the EM to irrupt the existing market under the green investment strategy, as illustrated in Proposition 7 and Figure 17. When the investment cost efficiency is low, the green investment is more profitable, but the supplier and IM's decisions diverge. For the supplier, PN format is more beneficial, while SN format is better for the incumbent manufacturers. However, even if the investment benefits both parties, the investment strategy cannot be implemented. This is because when there are multiple investment scenarios, both the supplier and the IM expect the other to underwrite the investment cost, so the two parties do not reach an agreement.

Corollary 3. *In the uncertain-channel format, the investment strategies:*

(a) *If* $\kappa_P^1 \leqslant \kappa < \kappa_{PI}^S$, $\Pi_S^{PE} > \Pi_S^{IE} > \Pi_S^{NE} > \Pi_S^{SN}$; *if* $\kappa_{PI}^S \leqslant \kappa < \kappa_S^1$, $\Pi_S^{IE} \geqslant \Pi_S^{PE} > \Pi_S^{NE} > \Pi_S^{SN}$; *if* $\kappa_I^1 \leqslant \kappa < \kappa_P^1$, $\Pi_S^{IE} > \Pi_S^{NE} > \Pi_S^{PN} > \Pi_S^{SN}$; *if* $\kappa_P^0 \leqslant \kappa < \kappa_I^1$, $\Pi_S^{NE} > \Pi_s^{PN} > \Pi_S^{IN} > \Pi_S^{SN}$.
(b) *if* $\kappa_{PI}^I \leqslant \kappa < \kappa_S^1$,$\Pi_I^{PE} \geqslant \Pi_I^{IE} > \Pi_I^{NE} > \Pi_I^{SN}$; *If* $\kappa_p^1 \leqslant \kappa < \kappa_{PI}^I$, $\Pi_I^{IE} > \Pi_I^{PE} > \Pi_I^{NE} > \Pi_I^{SN}$; *if* $\kappa_I^1 \leqslant \kappa < \kappa_P^1$, $\Pi_I^{IE} > \Pi_I^{NE} > \Pi_I^{SN} > \Pi_I^{PN}$; *if* $\kappa_P^0 \leqslant \kappa < \kappa_I^1$, $\Pi_I^{NE} > \Pi_I^{SN} > \Pi_I^{IN} > \Pi_I^{PN}$.

According to Corollary 3, the supplier chooses either singe-channel or dual-channel format considering a green investment in $\kappa_I^1 \leqslant \kappa < \kappa_P^1$. With the change of κ and ϕ, the optimal investment strategy of both the supplier and manufacturers is to choose diversity, with dual-channel formats always better than a single-channel format. When the investment cost efficiency is high, the IE format is more beneficial to the supplier, while the PE format is better for the IM. The opposite is true when the investment cost efficiency is in the middle range.

Corollary 4. *Considering the encroachment of the EM, the supplier and the IM choose different investment strategies:*

(a) *If* $\kappa_S^1 \leqslant \kappa < \kappa_{PI}^S$, $\Pi_S^{SE} > \max\{\Pi_S^{PE}, \Pi_S^{IE}\} > \Pi_S^{NE}$; *if* $\kappa_S^1 \leqslant \kappa < \kappa_{SI}^S$ *and* $\kappa_{PI}^S \leqslant \kappa < \kappa_{SI}^S$, $\Pi_S^{PE} > \max\{\Pi_S^{SE}, \Pi_S^{PE}\} > \Pi_S^{NE}$; *if* $\kappa_{SI}^S \leqslant \kappa$ *and* $\kappa_{SP}^S \leqslant \kappa < \kappa_{SI}^S$, $\Pi_S^{SE} > \Pi_S^{IE} > \Pi_S^{SE} > \Pi_S^{NE}$.
(b) $\Pi_I^{SE} > \Pi_I^{PE} > \Pi_I^{IE} > \Pi_I^{NE}$.

Corollary 4 shows that the supplier implements a dual-channel format considering the green investment in $\kappa \geqslant \kappa_P^1$. As the difference in marketing power increases, mitigated channel conflict motivate a member of the ISC green investment. When the IM has an advantage in marketing power, it always performs optimally under

SE format. However, supplier channel selection is affected by investment cost efficiency. As the investment cost efficiency increases, the optimal investment strategy changes from SE to PE format. Thus, when cost efficiency is large, *i.e.*, $\kappa > \left\{\kappa_{SP}^{\mathrm{S}}, \kappa_{\mathrm{S}}^{1}\right\}$, the ISC can achieve partial Pareto improvement under SE format.

7.3. Consumer surplus

In this section, we compare the consumer surplus under different situations (N, I, P and S scenarios), discuss the impact of channel structure change on consumer surplus, and provide management insights for the firm's market development and ongoing operations.

7.3.1. The impact of encroachment on consumer surplus

Proposition 8. $\mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{NE}}$ *and* $\mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}} < \mathrm{CS}_{\mathrm{I}}^{\mathrm{NN}}$.

Proposition 8 states that channel encroachment can bring better market prospects. Although channel conflict causes wholesale prices to decrease when channel competition is lower, manufacturers can decrease the selling prices of their channels to maintain profits, thus decreasing consumer surplus. The IM possesses greater marketing power, therefore consumers who purchase from I channel can receive greater satisfaction.

Proposition 9. *Under IM's green subsidies, comparing the consumer surplus in different channels:*

(a) $\mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{IE}}$. *If* $\kappa \geqslant \kappa_{\mathrm{CS}}^{\mathrm{I}}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{IN}} \geqslant \mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}}$; *if* $\kappa_{\mathrm{I}}^{1} < \kappa < \kappa_{\mathrm{CS}}^{\mathrm{I}}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{IN}} \geqslant \mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}}$; *if* $\kappa_{\mathrm{I}}^{0} \leqslant \kappa \leqslant \kappa_{\mathrm{I}}^{1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{IN}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{IE}} = \mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}}$.

(b) *If* $\kappa > \kappa_{\mathrm{CS}}^{\mathrm{P}_1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{PE}}$; *if* $\kappa_{\mathrm{P}}^{1} < \kappa < \kappa_{\mathrm{CS}}^{\mathrm{P}_1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PE}} < \mathrm{CS}_{\mathrm{E}}^{\mathrm{PE}}$. *If* $\kappa > \kappa_{\mathrm{CS}}^{\mathrm{P}_2}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{PN}}$; *if* $\kappa_{\mathrm{CS}}^{\mathrm{P}_2} \leqslant \kappa \leqslant \kappa_{\mathrm{CS}}^{\mathrm{P}_3}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PE}} \leqslant \mathrm{CS}_{\mathrm{I}}^{\mathrm{PN}}$; *if* $\kappa_{\mathrm{P}}^{0} \leqslant \kappa \leqslant \kappa_{\mathrm{P}}^{1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PN}} \geqslant \mathrm{CS}_{\mathrm{E}}^{\mathrm{PE}} = \mathrm{CS}_{\mathrm{I}}^{\mathrm{PE}}$.

Where $\kappa_{\mathrm{CS}}^{\mathrm{I}} = \frac{2(6\phi^4+77\phi^3+125\phi^2-643\phi+381+\Upsilon_1)}{4\phi^5+36\phi^4-87\phi^3+122\phi^2-309\phi+234}$; $\kappa_{\mathrm{CS}}^{\mathrm{P}_2} = \frac{2\phi^2+15\phi-8-\sqrt{448-12\phi^4-60\phi^3+217\phi^2-512\phi}}{2(2\phi^3-\phi^2+5\phi-6)}$;
$\Upsilon_1 = \sqrt{20\phi^8 + 548\phi^7 + 5049\phi^6 + 11868\phi^5 - 56921\phi^4 - 138018\phi^3 + 591415\phi^2 - 646062\phi + 235017}$;
$\kappa_{\mathrm{CS}}^{\mathrm{P}_1} = \frac{4(\phi+8)}{39-4\phi^2-35\phi}$.

Proposition 9 implies that, under the I scenario, the IM's sequence of green subsidies does not affect consumers' purchasing strategy; regardless of whether the supplier allows IE encroachment, the consumers surplus is always optimal under the I channel. However, under the P scenario, the consumer surplus changes as the channel format changes. The consumer surplus in the E channel increases with the difference in marketing power, while under I channel the opposite is true. When the cost efficiency is high, consumer surplus in the I channel is better, while when the cost efficiency is low, it is superior in the E channel. Additionally, consumer surplus in the I channel is not always better in the absence of encroachment. Therefore, most of the time, the purchasing decision in the dual-channel can result in greater consumer surplus when the cost efficiency is high.

Proposition 10. *Under supplier's green investment, comparing the consumer surplus in different channels:*
$\mathrm{CS}_{\mathrm{I}}^{\mathrm{SE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{SE}}$. *If* $\kappa \geqslant \max(\kappa_{\mathrm{CS}}^{\mathrm{S}_1}, \kappa_{\mathrm{S}}^{1})$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{SE}} \leqslant \mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}}$; *if* $\kappa_{\mathrm{S}}^{1} < \kappa < \kappa_{\mathrm{CS}}^{\mathrm{S}_1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{SE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}}$; *if* $\kappa_{\mathrm{S}}^{0} \leqslant \kappa \leqslant \kappa_{\mathrm{S}}^{1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} \geqslant \mathrm{CS}_{\mathrm{E}}^{\mathrm{SE}} = \mathrm{CS}_{\mathrm{I}}^{\mathrm{SE}}$.

Proposition 10 shows that consumer surplus generated in different formats is affected by the combination of cost efficiency and channel competition intensity. Fierce competition and low-cost efficiency values cause the supplier to sell products through a single-channel. As channel conflicts relax, the supplier permits the EM to encroach into the market. The ensuing competition stimulates consumers' desire and increases their willingness to buy, thus increasing consumer surplus.

7.3.2. Consumer surplus under different channel structures

Proposition 11. *In the single channel format, comparing the consumer surplus:*
If $\kappa > \kappa_{\mathrm{P}}^{0}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{IN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{NN}}$; *if* $\kappa_{\mathrm{S}}^{0} \leqslant \kappa \leqslant \kappa_{\mathrm{P}}^{0}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{IN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{NN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{PN}}$; *if* $0 < \kappa < \kappa_{\mathrm{S}}^{0}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{IN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{NN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} = \mathrm{CS}_{\mathrm{I}}^{\mathrm{PN}}$.

Proposition 11 shows that consumer surplus is only related to cost efficiency and marketing power difference under the single-channel format. When all investment scenarios can operate normally, *i.e.*, high cost efficiency, PN format is better for consumers. PN format is not adopted with lower cost efficiency, and consumers prefer either IN or SN format.

Corollary 5. *In the uncertain-channel format, comparing the consumer surplus:*

(a) *If* $\kappa_{\mathrm{P}}^{1} < \kappa_{\mathrm{CS}}^{\mathrm{E}_1} \leqslant \kappa < \kappa_{\mathrm{S}}^{1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{PE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}}$*; if* $\kappa_{\mathrm{CS}}^{\mathrm{E}_1} \leqslant \kappa < \kappa_{\mathrm{CS}}^{\mathrm{E}_2} < \kappa_{\mathrm{S}}^{1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{PE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}}$*; if* $\kappa_{\mathrm{CS}}^{\mathrm{E}_2} < \kappa < \kappa_{\mathrm{S}}^{1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}}$*. If* $\kappa_{\mathrm{I}}^{1} < \kappa_{\mathrm{CS}}^{\mathrm{E}_3} \leqslant \kappa < \kappa_{\mathrm{P}}^{1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}}$*; if* $\kappa_{\mathrm{CS}}^{\mathrm{E}_3} \leqslant \kappa < \kappa_{\mathrm{CS}}^{\mathrm{E}_4} < \kappa_{\mathrm{P}}^{1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}}$*; if* $\kappa_{\mathrm{CS}}^{\mathrm{E}_4} < \kappa < \kappa_{\mathrm{P}}^{1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{PN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}}$*; if* $\kappa_{\mathrm{P}}^{0} \leqslant \kappa < \kappa_{\mathrm{I}}^{1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{SN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{IN}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}}$.

(b) *If* $\kappa_{\mathrm{P}}^{1} \leqslant \kappa < \kappa_{\mathrm{S}}^{1}$, $\mathrm{CS}_{\mathrm{E}}^{\mathrm{PE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{NE}}$*; if* $\kappa_{\mathrm{I}}^{1} \leqslant \kappa < \kappa_{\mathrm{P}}^{1}$, $\mathrm{CS}_{\mathrm{E}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{NE}}$*; if* $\kappa_{\mathrm{P}}^{0} \leqslant \kappa < \kappa_{\mathrm{I}}^{1}$, $\mathrm{CS}_{\mathrm{E}}^{\mathrm{NE}} > 0$.

Corollary 5 shows that the consumer surplus in the I channel and E channel is similar at different cost efficiency levels. Greater consumer surplus can be obtained in the dual-channel when cost efficiency is lower, otherwise, Greater consumer surplus can be obtained in the single-channel. Consumer surplus is sensitive to investment cost efficiency. As investment cost efficiency improves, consumer satisfaction under the PE format exceeds that under both the IE and NE formats.

Corollary 6. *In the dual-channel format, comparing the consumer surplus:*

(a) *If* $\kappa > \kappa_{\mathrm{S}}^{1}$, $\mathrm{CS}_{\mathrm{I}}^{\mathrm{PE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{SE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}}$.

(b) *If* $\kappa > \kappa_{SP}^{\mathrm{E}} > \kappa_{\mathrm{S}}^{1}$, $\mathrm{CS}_{\mathrm{E}}^{\mathrm{PE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{SE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{NE}}$*; if* $\kappa_{\mathrm{S}}^{1} < \kappa \leqslant \kappa_{SP}^{\mathrm{E}}$, $\mathrm{CS}_{\mathrm{E}}^{\mathrm{SE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{PE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{IE}} > \mathrm{CS}_{\mathrm{E}}^{\mathrm{NE}}$.

Corollary 6 shows the consumer surplus under dual-channel formats. The selling price and consumer surplus both decrease with cost efficiency but increase with marketing power difference. With mild cost efficiency, for consumers who buy products from the IM or EM, the SE format is always the best. However, when the investment cost efficiency improves, consumer surplus in the E channel under the PE format is higher than that under the SE format, and green investment always brings greater satisfaction to consumers.

8. Discussion

In this section, we mainly discuss the research results from two aspects. First, we extend the designed model by considering the green investment under differentiated products. Secondly, this paper makes a detailed comparison with other existing models in green investment.

8.1. Extension

In reality, the supplier may provide differentiated products for different manufacturers when the incumbent manufacturer subsidizes the green investment. In this section, we design that supply provides the green products for IM, and provide the generic product for EM respectively, namely R scenario. Therefore, the demands in different channels can be specified as: $D_{\mathrm{I}}^{X} = a - p_{\mathrm{I}}^{X} + p_{\mathrm{E}}^{X} + \tau\theta^{X}$ and $D_{\mathrm{E}}^{X} = a - p_{\mathrm{E}}^{X} + \phi p_{\mathrm{I}}^{X} (X \in \{\widehat{\mathrm{IE}}, \widehat{\mathrm{PE}}\})$. The profit functions of the supplier, IM and EM are as follows: $\Pi_{\mathrm{I}}^{X} = D_{\mathrm{I}}^{X} m_{\mathrm{I}}^{X} - k(\theta_{\mathrm{I}}^{X})^2/2$, $\Pi_{\mathrm{E}}^{X} = D_{\mathrm{E}}^{X} m_{\mathrm{E}}^{X}$ and $\Pi_{\mathrm{S}}^{X} = D_{\mathrm{I}}^{X} w_{\mathrm{E}}^{X} + D_{\mathrm{E}}^{X} w_{\mathrm{I}}^{X}$.

(1) $\widehat{\mathrm{IE}}$ format

Lemma 9. *For* $\kappa \geqslant \max\left\{\kappa_{\widehat{\mathrm{IE}}}^{1}, 0\right\}\left(\kappa_{\widehat{\mathrm{IE}}}^{1} = \frac{3\left(24\phi^5-52\phi^4-22\phi^3+377\phi^2-660\phi+297\right)}{2(2\phi^3+17\phi^2-58\phi+39)^2}\right)$, *the optimal decisions are* $\theta_{\mathrm{I}}^{\widehat{\mathrm{IE}}} = \frac{a\tau\left(40\phi^5-76\phi^4-178\phi^3+1879\phi^2-3330\phi+1449\right)}{\Upsilon_2}$*; the equilibrium profits are* $\Pi_{\mathrm{I}}^{\widehat{\mathrm{IE}}} = -\frac{a^2(2\phi-3)\Upsilon_3}{2{\Upsilon_2}^2}$ *and* $\Pi_{\mathrm{S}}^{\widehat{\mathrm{IE}}} = \frac{a^2\Upsilon_4}{(2\kappa\Upsilon_2)^2}$.

Where $\Upsilon_2 = \left(2\kappa\left(2\phi^3+17\phi^2-58\phi+39\right)^2 - 66\phi^3 - 3\left(24\phi^5-52\phi^4+377\phi^2-660\phi+297\right)\right)$;

$\Upsilon_3 = \left(24\kappa^2\left(2\phi^3+35\phi^2+113\phi-312\right)^2(\phi-1)^4 + 6\left(4\phi^3-16\phi^4+28\phi^2+5\phi-3\right)^2\kappa\Upsilon_5\right)$;

$$\Upsilon_4 = \begin{pmatrix} \kappa^2 B^2\left(8\phi^4 + 47\phi^3 - 118\phi^2 + 1755\phi - 2988\right)(\phi-1)^3 + 2\kappa\Upsilon_6(\phi-1)^2 \\ -3(3-2\phi)^2\left(64\phi^7 - 180\phi^6 - 184\phi^5 + 1175\phi^4 + 1791\phi^3 - 9086\phi^2 + 9795\phi - 3483\right) \end{pmatrix};$$

$$\Upsilon_5 = \begin{pmatrix} 2293076\phi^3 - 19952\phi^7 + 296744\phi^6 - 440342\phi^5 - 677403 \\ -382003\phi^4 + 32\phi^9 - 3762954\phi^2 + 2659698\phi - 13552\phi^8 \end{pmatrix};$$

$$\Upsilon_6 = \begin{pmatrix} 32\phi^8 + 776\phi^7 - 1788\phi^6 - 50414\phi^5 + 229405\phi^4 \\ -261207\phi^3 - 266319\phi^2 + 768609\phi - 444366 \end{pmatrix}.$$

(2) $\mathrm{P}\widehat{\mathrm{E}}$ format

Lemma 10. *For* $\kappa \geqslant \kappa^1_{\mathrm{P}\widehat{\mathrm{E}}}\left(\kappa^1_{\mathrm{P}\widehat{\mathrm{E}}} = \frac{5}{2(3-2\phi)}\right)$, *the optimal decisions are* $\theta_{\mathrm{I}}^{\mathrm{P}\widehat{\mathrm{E}}} = \frac{3a(\phi+8)}{\tau(39\kappa-2\kappa\phi^2-19\kappa\phi-7\phi-29)}$; *the equilibrium profits are* $\Pi_{\mathrm{I}}^{\mathrm{P}\widehat{\mathrm{E}}} = \frac{9a(3-\kappa\phi-\kappa)}{2(7\phi+29)-2\kappa}$ *and* $\Pi_{\mathrm{S}}^{\mathrm{P}\widehat{\mathrm{E}}} = \frac{a^2\Upsilon_7}{4(\phi-1)(7\phi-\kappa B+29)^2}$.

Where $\Upsilon_7 = \begin{pmatrix} \kappa^2\left(8\phi^4 + 47\phi^3 - 118\phi^2 + 1755\phi - 2988\right) - 1804 \\ +2\kappa\left(2052 - 38\phi^3 - 437\phi^2 + 43\phi\right) - 40\phi^2 - 181\phi \end{pmatrix}.$

(3) Extension analysis

Proposition 12. (a) $\kappa^1_{\mathrm{I}\widehat{\mathrm{E}}} < \kappa^1_{\mathrm{IE}}$; $\kappa^1_{\mathrm{P}\widehat{\mathrm{E}}} < \kappa^1_{\mathrm{PE}}$. (b) $\theta_{\mathrm{I}}^{\mathrm{I}\widehat{\mathrm{E}}} < \theta_{\mathrm{I}}^{\mathrm{IE}}$; $\theta_{\mathrm{I}}^{\mathrm{P}\widehat{\mathrm{E}}} < \theta_{\mathrm{I}}^{\mathrm{PE}}$.

Proposition 12 shows the impact of differentiated product strategies on the equilibrium threshold and investment level as shown in Figure 18. Differentiated product strategy can lower the threshold of channel encroachment because it can slow down the competition between channels. Meanwhile, the green investment level will sink due to the decrease in the comprehensive consumer WTP.

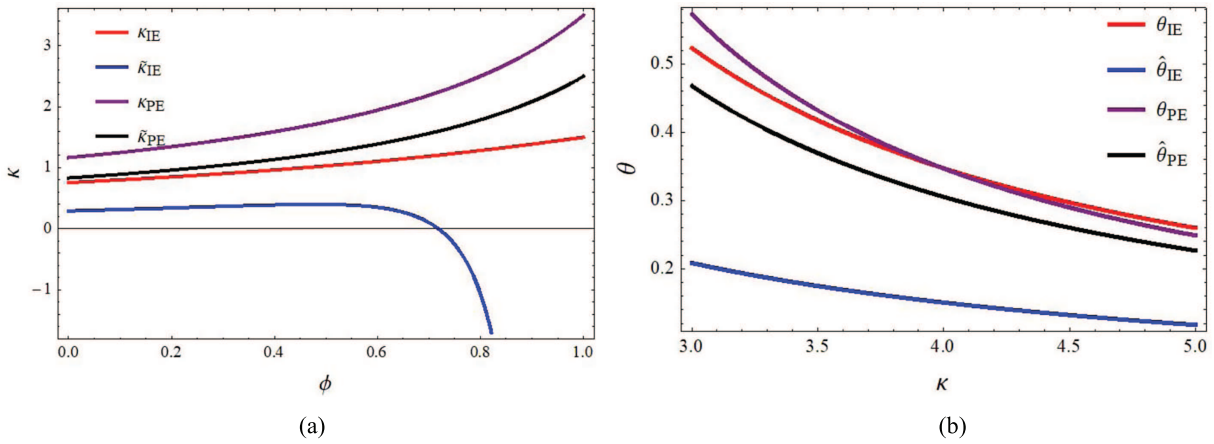
Proposition 13. (a) $\Pi_{\mathrm{I}}^{\mathrm{I}\widehat{\mathrm{E}}} < \Pi_{\mathrm{I}}^{\mathrm{IE}}$; $\Pi_{\mathrm{I}}^{\mathrm{P}\widehat{\mathrm{E}}} < \Pi_{\mathrm{I}}^{\mathrm{PE}}$. (b) $\Pi_{\mathrm{S}}^{\mathrm{I}\widehat{\mathrm{E}}} < \Pi_{\mathrm{S}}^{\mathrm{IE}}$; $\Pi_{\mathrm{S}}^{\mathrm{P}\widehat{\mathrm{E}}} < \Pi_{\mathrm{S}}^{\mathrm{PE}}$.

Proposition 13 shows the impact of differentiated product strategy on the equilibrium profits of the supplier and IM as shown in Figure 19. Differentiated product strategy can lower supplier profits due to the decrease of market demand. Meanwhile, the green investment level will sink because of the decrease of the comprehensive consumer WTP.

8.2. Comparison

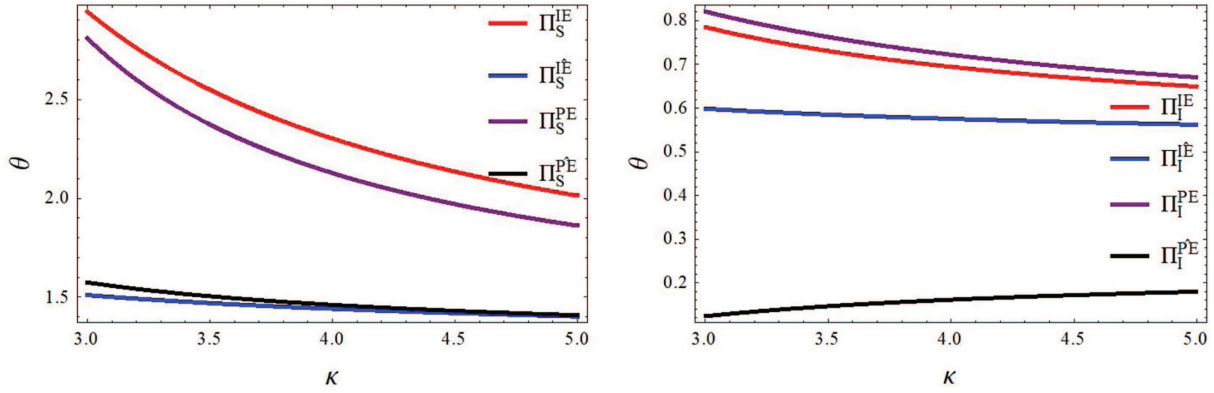
The practical results of green investment of incumbent supply chain and the channel configuration strategies of the supplier obtained in the paper are reformatory. Based on the dynamic operation of the supply chain system and the consumers environmentally conscious, the paper formulates different models to explore the green investment strategy from different perspectives, and acquires the matching results and management implications through strict theoretical derivation and numerical analysis. In addition, detailed comparisons between this paper and other existing green investment studies in reducing emissions are summarized from the research questions and main results to show the differences and necessity of this paper, as shown in Table 3.

Compared with the above research on the green supply chain that considers investment emission and green reduction, the research characteristics of this paper are as follows. On the one hand, based on the differences between investment enterprise subjects and investment timelines, a detailed study of the supply chain green investment strategies is conducted, and provides guidance and suggestions for enterprises to formulate optimal investment strategies. On the other hand, this paper is different from the existing studies from the perspective of environmental performance, and explores the green operation of supply chains from the perspective of WTP and consumer surplus, which makes up for the shortcomings of existing green studies.



(a) (b)

FIGURE 18. The impact of differentiated product strategies on equilibrium threshold and investment level. (a) Equilibrium threshold. (b) Green investment level.



(a) (b)

FIGURE 19. The impact of differentiated product strategies on equilibrium profits. (a) The supplier. (b) The IM.

9. CONCLUSION

Currently, many supply chain members are beginning to invest in green technology to capture the green market, and enhance corporate social responsibility. Stimulated by this green consumption, we investigate whether and when the ISC should invest in green technology in the face of an entrant threat, along with the impact of green investment strategy on the supply chain system. We identify the investment cost efficiency, and marketing power difference as pivotal drivers for the choice of green strategies, and describe how these factors affect the channel selection and green investment of supply chain members.

9.1. Summary findings

Compared with the existing research, we highlight several interesting findings and put forward some interesting management insights.

TABLE 3. Comparisons between the paper and the other existing studies.

Paper	Research questions	Main results
Jauhari *et al.* [17]	The paper focuses on the closed-loop supply chain (CLSC) system composed of manufacturers and retailers, and studies the impact of manufacturers' green technology investment on supply chain decision making, recovery and emission reduction.	Emissions and costs of the supply chain can be controlled by adjusting the production rate and setting an appropriate recovery rate. And green investment and recycling investment benefit reducing emissions.
Bansal and Gangopadhyay [4]	This paper studies policy measures to improve environmental quality based on consumer awareness of environmental protection.	A uniform subsidy policy improves average environmental quality, while a uniform tax policy worsens average environmental quality.
Hong *et al.* [14]	The paper studies the mechanisms of cooperation in green product supply chains and investigates the environmental performance under different mechanisms.	The collaboration may not always be beneficial to all partners; manufacturing became more profitable when manufacturers shared green costs with retailers, while retailers were worse off under cost-sharing contracts than under single-price contracts.
Yan *et al.* [36]	This paper studies whether and when competing retailers should invest and explores the results of supply chain equilibrium under a dynamic structure.	This study finds that retailers are more inclined to invest efficiently, which can lead to considerable improvement in demand at an acceptable cost level
Paul *et al.* [31]	The paper studies the impact of government intervention on carbon emissions in the production process in a three-tier supply chain consisting of a manufacturer and a retailer.	Under a cap-and-trade system, carbon credits and supply chain members in the market can help achieve greater economic benefits and emissions reductions.
This paper	The paper studies the green investment strategy of incumbent supply chian, when there is a potential threat of competitor encroachment and channel power difference	Optimal green operation strategies with different channel structures and investment conditions are given, taking into account differences in investment subjects and timelines, and SE format is suitable for suppliers with encroachment.

Firstly, increasing market size can improve the green investment level, expand market demand, and raise the members' profits, but does not affect the choice of the supplier channel format or the green investment strategy of the ISC. Furthermore, the optimal decisions of most supply chain members are negatively impacted by marketing power differences and the cost efficiency of green investment.

Secondly, under a monopolized market, there is no limit for channel encroachment in the absence of green investment, and dual-channel operations can always generate extra income, while under different channel formats investment thresholds are distinct. Since channel competition leads to supply chain losses, the investment threshold under a dual-channel format is higher than that under a single-channel format when the difference in channel powers is lower. Furthermore, as the supplier holds a monopoly, the SE format has the highest threshold under all situations and the optimal level of green investment can be obtained.

Thirdly, channel encroachment can promote green investment, thereby promoting the profit of all supply chain members. However, due to the impact of investment costs and channel conflicts, the supplier does not always empower the EM to encroach. The results show that green investment is always more profitable, regardless of who invests. Thus, when the dual-channel format is permitted, the ISC can achieve partial Pareto improvement under

the SE format. Nevertheless, it is noteworthy that under the single-channel format, although each investment strategy provides benefits, no one format will achieve Pareto equilibrium. This leads to a continuous change in investment strategies such that no members are willing to invest.

Fourthly, consumer surplus is robust except under the P scenarios. Simultaneously, based on the consumer's utility theory, consumer surplus in the I channel is better than that under the E channel except under the P scenarios. When the single-channel is adopted under each investment scenario, the PN format can obtain greater consumer surplus. In the presence of channel encroachment, consumer surplus in the I channel and E channel is similar. When channel encroachment always is permitted, the consumer surplus under the PE format clearly exceeds that under all other formats when the cost efficiency is high.

9.2. Managerial implications

The research results of this paper provide management implications for firms' green operations under a dynamic environment.

Firstly, manufacturer ER does not need to bear the production cost of products, so it always gains profits through margin price. Therefore, potential entrants can freely choose to encroach on and exit the market. Potential entrants can quit at any time when the market is unstable or fierce competition, which is also the reason for the flooding of all kinds of small shops in the market.

Secondly, the emergence of market competition will always nibble the market of manufacturer IR and bring a great threat to its operation. Green investment is a good means to alleviate the threat of competition. Meanwhile, manufacturers should adopt corresponding green investment strategies according to the actions of suppliers, which can prevent supplier premium and free riding.

Thirdly, suppliers always prefer to sell the same products through multiple channels. Selling through multiple channels can expand sales, and increase revenues, which is always preferable for suppliers. And differentiated product strategies do not provide positive benefits to firm operations. However, suppliers need to be careful when developing green investment strategies, and need to be constant in many ways, taking full account of green investment efficiency.

9.3. Future directions of research

In order to study channel encroachment and green investment, this study constructs hybrid GSC models consisting of a supplier and manufacturers. However, in practice, the supplier does not always hold a monopoly while two or more supply chains providing differentiated products can also be considered. In addition, due to the distance between the supplier and the market, uncertainty about market demand and consumer preferences may exist. It may also be interesting to consider green investment models constructed under incomplete information. Finally, green products are expanded to include multiple green levels in order to provide heterogeneous customers with appropriate products.

Appendix A.

Proof of Proposition 1. $w_{\mathrm{I}}^{\mathrm{NE}} - w_{\mathrm{I}}^{\mathrm{NN}} = \frac{a\left(14\phi^2+25\phi-3\right)}{6(\phi-1)(2\phi^2+19\phi-39)}$; we can obatin $w_{\mathrm{I}}^{\mathrm{NE}} \leqslant w_{\mathrm{I}}^{\mathrm{NN}}$ if $0 \leqslant \phi \leqslant \phi_{\mathrm{N1}}$; otherwise, $w_{\mathrm{I}}^{\mathrm{NE}} > w_{\mathrm{I}}^{\mathrm{NN}}$. Where $\phi_{\mathrm{N1}} = \frac{1}{28}\left(\sqrt{793}-25\right)$. $m_{\mathrm{I}}^{\mathrm{NE}} - m_{\mathrm{I}}^{\mathrm{NN}} = -\frac{5\phi^2+25\phi+6}{6\phi^3+51\phi^2-174\phi+117} < 0$; $\Pi_{\mathrm{I}}^{\mathrm{NE}} - \Pi_{\mathrm{I}}^{\mathrm{NN}} = \frac{a^2\left(38\phi^4+425\phi^3+557\phi^2-1416\phi-900\right)}{9(\phi-1)(2\phi^2+19\phi-39)^2} < 0$; $\Pi_{\mathrm{S}}^{\mathrm{NE}} - \Pi_{\mathrm{S}}^{\mathrm{NN}} = \frac{a^2\left(136\phi^4+1639\phi^3+2218\phi^2-7917\phi-2556\right)}{36(\phi-1)(2\phi^2+19\phi-39)^2} > 0$. □

Proof of Proposition 2. (a) $f_0(\kappa,\phi) = \Pi_{\mathrm{S}}^{\mathrm{IE}} - \Pi_{\mathrm{S}}^{\mathrm{IN}} > 0$, $f_1(\kappa,\phi) = \Pi_{\mathrm{I}}^{\mathrm{IE}} - \Pi_{\mathrm{I}}^{\mathrm{IN}}$, $f_2(\kappa,\phi)_{\kappa=\kappa_{\mathrm{I}}^2} = \Pi_{\mathrm{I}}^{\mathrm{IE}} - \Pi_{\mathrm{I}}^{\mathrm{IN}} = 0$. (b) $f_2(\kappa,\phi) = \Pi_{\mathrm{S}}^{\mathrm{IE}} - \Pi_{\mathrm{S}}^{\mathrm{NE}} > 0$, $f_3(\kappa,\phi) = \Pi_{\mathrm{S}}^{\mathrm{IN}} - \Pi_{\mathrm{S}}^{\mathrm{NN}} > 0$. □

Proof of Propositions 3–7 is similar to proof of Proposition 2, and thus omitted.

Proof of Proposition 8. $\mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}} - \mathrm{CS}_{\mathrm{E}}^{\mathrm{NE}} = \frac{a^2(2223-2658\phi+211\phi^2+208\phi^3+16\phi^4)}{8B^2} > 0$; $\mathrm{CS}_{\mathrm{I}}^{\mathrm{NE}} - \mathrm{CS}_{\mathrm{I}}^{\mathrm{NN}} = \frac{a^2(312\phi-900-163\phi^2+164\phi^3+20\phi^4)}{18B^2} < 0$. □

The proof of Propositions 9–13 are straightforward, and omit the others.

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