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RESEARCH ARTICLE

The impact of cross-shareholding under different power structures considering green investment and green marketing

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Abstract
Cross-shareholding has played an important role in strengthening strategic synergy among enterprises, but its impact on the green development of enterprises is unclear. In this paper, we construct an analytical framework that includes a manufacturer and a retailer to explore the impact of cross-shareholdings under different leaderships on green supply chain operational decisions and profits, in which the manufacturer invests in green technologies and the retailer conducts green marketing. By constructing and solving the game model of manufacturer-led and retailer-led before and after cross-shareholding, it is found that after cross-shareholding, the product's green level and the retailers' marketing level are improved. For supply chain leaders, cross-shareholdings always increase their profits. Only when the follower holds the leader's shares no more than a certain value, cross-shareholding will increase the total profit of the supply chain. In addition, we obtain the optimal decisions and profits of the supply chain in the integrated situation and design two-part pricing contracts to achieve cross-shareholding supply chain coordination. The results of this paper can provide theoretical guidance and decision support for enterprises interested in using cross-shareholding to improve supply chain performance.

Keywords Green supply chain · Cross-shareholding · Green investment · Green marketing · Coordination

Introduction

Issues such as global warming and environmental pollution are hot topics because they are closely related to human production and life. People are becoming more aware of environmental issues, which influence their purchasing decisions. According to Accenture's survey, more than 80% of respondents consider the environmental attributes of products when making purchasing decisions (Agrawal et al. 2011). In recent years, "green product" has become a popular term (Fan et al. 2022; Mu et al. 2022; Rizzi et al. 2022). Green products refer to products that can effectively use resources in the whole process of research and development, production and manufacturing, sales and use, and elimination of scrapping, which are conducive to ecological balance and do not cause pollution and harm to the environment and consumers. Green investing is considered one of the most important strategic decisions for businesses and has proven to be profitable (Wei and Huang 2022, Zhu et al. 2022). Driven by this economic benefit, many manufacturers have invested a lot of energy in the development of green products. For example, after 10 years of research and development, Gree Electric appliances launched a "zero carbon source" air conditioning technology, which breaks through the energy efficiency limits of existing air conditioners and can reduce the carbon emissions of air conditioners by 85.7%. The metal frame used around the sides of the iPhone SE comes from a new process developed by Apple's $4.7 billion green bond project, which invests in various renewable energy initiatives.

Green marketing is seen as an effective tool to inform consumers about the green performance of products and further stimulate demand (Rahbar and Wahid 2011, Zeng et al. 2022). Green marketing provides information about green

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products and inspires consumers to be socially responsible. For example, Suning.com advocates the concept of green and sustainable consumption and works together with partners to increase the main promotion of green energy-saving products, upgrade the old-for-new service to promote the upgrade of home appliance consumption, and inject new impetus into green development. Red Star Macalline, the largest furniture platform operator in China, invests heavily in advertising, such as billboards, trade shows, and other promotions, recommending green products, which has a great impact on market competition. Retailers' green marketing will inevitably have an impact on manufacturers' green investments, but the interaction between manufacturers' green investments and retailers' green marketing is unclear.

With the development of globalization and the increasingly fierce competition in the product market, the vicious competition among enterprises has intensified, and the operating risks have increased. To solve the above problems, both upstream and downstream enterprises in the supply chain want to seek deeper strategic cooperation, and the cross-shareholding strategy is increasingly used (Cerqueti et al. 2020; Sun et al. 2022). Cross-shareholding refers to two or more enterprises holding a certain percentage of each other's shares to enhance their strategic synergy. For example, COSCO, Wuhan Iron and Steel Group, and China State Shipbuilding Corporation all seek collaboration through cross-shareholding. At the end of 2015, COSCO Group transferred 250 million shares to Wuhan Iron and Steel Group and 200 million shares to China State Shipbuilding Corporation to strengthen the strategic cooperation between upstream and downstream enterprises. In response, China State Shipbuilding Corporation and Wuhan Iron and Steel Group transferred 43.92 million and 500 million shares to COSCO Group, respectively. Cross-shareholding has changed the original co-competition relationship between enterprises, but it is not yet clear the impact of this change on green supply chain management. In addition, the power structure has an important impact on supply chain operation decisions, because different power structures imply different decision sequences among enterprises. Therefore, it is necessary to explore the impact of cross-shareholding under different power structures.

Motivated by the aforementioned discussion, this paper mainly explores the impact of cross-shareholding on the operational decisions and profits of green supply chains under different power structures. Specifically, we focus on exploring the following questions:

(1) What is the impact of cross-shareholding under different power structures on the optimal pricing, green investment, and green marketing of supply chain members?
(2) Can cross-shareholding under different power structures improve the profits of supply chain members?
(3) How to achieve the coordination of a cross-shareholding supply chain?

To solve the above questions, we construct an analytics framework that includes a manufacturer and a retailer. Among them, the manufacturer makes green investment, while the retailer carries out green marketing. When the manufacturer dominates and the retailer dominates the supply chain, the game model before and after cross-shareholding is constructed. Through the comparative analysis of the equilibrium results under different models, we reveal the impact of cross-shareholding on the optimal decision-making and profits of enterprises. Finally, we propose two-part pricing contracts to achieve the coordination of cross-shareholding supply chains.

To the best of our knowledge, this paper is the first study to explore the impact of cross-shareholding on operational decision-making and profits in green supply chains under different power structures. We reveal the impact of cross-shareholding on manufacturers' green investment, retailers' green marketing, product pricing decisions, and supply chain members' profits, and further, explore the differences in this impact across different power structures. In addition, we design a coordination contract to improve the performance of the cross-shareholding supply chain. The obtained conclusions can provide theoretical guidance for enterprises that want to adopt the cross-shareholding strategy and carry out green development.

The rest of this paper is organized as follows. "Literature review" section is a review of the relevant literature. "Model" section contains model building and model solving. The equilibrium results under different models are analyzed and discussed in "Analysis and discussion" section. "Coordination of cross-shareholding supply chain" section presents the coordination contract. "Conclusion" section is a summary of this paper. All proofs are presented in the Appendix.

Literature review

There are three categories of literature related to this paper. The first is green product decision-making, the second is green marketing, and the third is cross-shareholding. This section reviews the existing literature and identifies how this paper differs from the existing literature.

Green product decision-making

At present, the decision-making issue of green products has attracted the attention of many scholars. One category of literature focuses on exploring whether enterprises should produce green products. For example, Dong et al. (2019) establish a two-stage sales model in which both manufacturers and retailers can make green investment in the second stage, mainly exploring the green investment strategies of supply chain members. Shen et al. (2020) investigate the best product line design strategies for green and non-green products based on quality differences. Hussain et al. (2020) examine the pricing behavior of a monopoly market with the implementation of green technology decisions under the emission reduction subsidy policy. Zhang et al. (2020) examine the green investment decisions of two enterprises that compete for quality. In addition, they further explore the government's incentives for subsidies for green investment and optimal subsidy schemes. Another category of literature focuses on how green products are manufactured and sold. Guo et al. (2020) construct a fashion supply chain consisting of one manufacturer and two competing retailers, investigating how retail competition and consumer returns affect the development of green products for fashion apparel. Xiao and Choi (2019) investigate manufacturers' quality and green decisions and product line selection and explore the impact of product line length on environmental performance. Li et al. (2020) examine green product design issues in a supply chain consisting of one manufacturer and two retailers, one of which has fairness considerations. They consider two different green products: marginal-intensive green products and development-intensive green products. Liu et al. (2020) examine which contracts under different power structures can more effectively incentivize enterprises to improve the greenness of their products and benefit them. Li et al. (2021a) study the optimal decision-making, profit, and social welfare in a green supply chain when a manufacturer or retailer conducts green product development. Qiao et al. (2021) analyze the sustainability and profitability performance of green product supply chains under centralized and decentralized scenarios and apply quantity discounts and cost-sharing contracts to improve supply chain performance. Considering two cooperation strategies (investment sharing and innovation sharing), Hafezi et al. (2022) explore the impact of different cooperation strategies on green product pricing, quality, and corporate profits. Similar to the above literature, this paper also considers manufacturers for green product development. However, unlike the above literature, we also consider retailers' green marketing and focus on exploring the impact of cross-shareholding on corporate operational decisions and profits.

Green marketing

Consumers' green buying behavior is related to their knowledge of products' environmental performance (Hong and Guo 2019). Therefore, green marketing is necessary to stimulate the demand for products with green attributes. Several studies have shown that the environmental properties of a product can be a compelling selling point (Atkinson and Rosenthal 2014). Green marketing is a way for businesses to position their products as green in the minds of consumers and plays an important role in marketing (Erdogmus et al. 2016). Green marketing reveals information about the green performance of products, educates consumers, and enhances consumers' environmental responsibility. Green marketing has received the attention of scholars in the field of operation management. For example, considering online channels selling green products and offline channels selling non-green products, Wang and Song (2020) explore pricing, green investment, and marketing effort decisions in the context of demand uncertainty. Similarly, considering the green quality level of products and green marketing, Ranjan and Jha (2019) examine pricing and coordination strategies for dual-channel supply chains. Li et al. (2021b) explore the impact of different contract types on green investment and marketing efforts, and further analyze firms' contact preferences. Li et al. (2021c) investigate the effects of government subsidies on green technology investment and green marketing coordination of the supply chain under the cap-and-trade mechanism. Heydari et al. (2022) propose revenue-sharing and buyback contracts that coordinate conflicts of interest and green marketing efforts in the green sales channel. Kou et al. (2022) investigate the value of green marketing in cooperative emissions reduction under different power structures. Shi et al. (2022) examine who is more suitable for implementing green product development and green marketing. This paper also considers manufacturers investing in green products and retailers doing green marketing. However, different from them, this paper focuses on exploring the impact of cross-shareholding on corporate green investment and green marketing decisions as well as profits.

Cross-shareholding

The role of cross-shareholding in finance has been extensively studied. Some scholars have studied the effect of cross-shareholding on financial performance (Brooks et al. 2018), corporate innovation (Gao et al. 2019), and corporate externalities governance (He et al. 2019) from an empirical perspective. In recent years, some scholars have explored the impact of cross-shareholding on supply chain operational decisions. For example, Chen et al. (2017) find that whether it is a "push" supply chain or a "pull" supply chain, supply chain members can achieve win–win through cross-shareholding. Zhang and Meng (2021) explore the impact of cross-shareholding on value co-creation in the closed-loop supply chain. Xia et al. (2021) study the impact of cross-shareholding on the emission reduction level and firms' profits in supply chains dominated by manufacturers and retailers, respectively. Ren et al. (2021) explore the operating mechanism behind three shareholding strategies (forward, backward, and cross-shareholding) in a supplier-led green supply chain and examine companies' shareholding preferences. Different from the above studies, this paper focuses on the impact of cross-shareholding on product pricing and green levels, retailers' green marketing, and corporate earnings, and designs corresponding contracts to achieve cross-shareholding supply chain coordination.

Literature summary

This literature review shows that some scholars have explored manufacturers' investment decisions about green products but have not considered retailers for green marketing; some scholars have considered a green investment by manufacturers and green marketing by retailers but have not considered cross-shareholding strategies between them. To the best of our knowledge, no scholar has explored the impact of cross-shareholding on green supply chain pricing, green investment, green marketing, and profits. Therefore, we are unable to provide theoretical guidance on the optimization of corporate decision-making in the context of cross-shareholding. This paper aims to study this issue to fill gaps in existing research.

Table 1 shows the similarities and differences between our work and the most relevant literature, which clarifies the outstanding contributions of this paper.

Model

Model building

We consider a supply chain consisting of a manufacturer and a retailer, where the manufacturer produces a product and sells it through the retailer. The introduction of the national environmental protection policy and the improvement of consumers' awareness of environmental protection has inspired manufacturers to improve the green level of their products and retailers to improve the level of green marketing. Manufacturers improve production activities by designing green products or innovating green production processes, while retailers improve sales activities by selling green products in the market and making marketing efforts. These green initiatives all require investment from both manufacturers and retailers, i.e., manufacturers make green investments and retailers make marketing investments.

Following prior literature (Li et al. 2021b; Shi 2019), we assume that the product demand function is as follows:

$$D = a - p + e + kv$$

where a represents the market size, p represents the retail price, e represents the green level of the product, and v represents the retailer's green marketing level. The parameter k measures the impact of green marketing on demand, i.e., the marketing effect.

Table 1 Differences between this paper and most relevant studies

Paper	Green investment	Green marketing	Coordination	Cross-shareholding
Qiao et al. (2021)	√		√	
Kou et al. (2022)	√	√		
Shi et al. (2022)	√	√		
Xia et al. (2021)			√	√
Li et al. (2021b)	√	√	√	
Li et al. (2021c)	√	√	√	
Our paper	√	√	√	√

To ensure that there is an optimal solution for the model, it is assumed $0 < k < \sqrt{3}$ here. Usually, the marketing effect has a certain limit, which is in line with the actual situation.

It is assumed that the green investment cost of manufacturers is expressed as a quadratic function of the green level, i.e., e^2 (Chen 2001; Guo et al. 2020; Li et al. 2021b). In addition, we assume that the green marketing cost is a quadratic function of the marketing level, i.e., v^2 (Guo et al. 2020; Li et al. 2021b; Ma et al. 2017; Taylor 2002).

The notations used in this paper are shown in Table 2.

We use ML and RL to denote that the manufacturers and retailers dominate the supply chain, respectively. The decision sequence of the model is shown in Fig. 1. First of all, the supply chain members choose whether to adopt the cross-shareholding strategy, and secondly consider the ML or the RL. In ML, the manufacturer first decides w and e, then the retailer decides p and v. In RL, the retailer firstly decides p and v, then the manufacturer decides w and e.

In the following, we denote non-cross-shareholding and cross-shareholding situations with superscripts Di and Ci, respectively, where $i \in \{M, R\}$. For example, DM refers to a manufacturer-led non-cross-shareholding supply chain, and CM refers to a manufacturer-led cross-shareholding supply chain.

To study the impact of cross-shareholding on green supply chain operation strategies under different dominance, we construct decision-making models before and after cross-shareholding.

The decision-making model for non-cross-shareholding is as follows:w

$$\begin{cases} max\pi_m^{Di}(w, e) = (w - c)D - e^2 \\ max\pi_r^{Di}(p, v) = (p - w)D - v^2 \end{cases}$$

In the case of cross-shareholding, the manufacturer owns a percentage l_m of the retailer's shares and the retailer owns a percentage l_r of the manufacturer's shares. To ensure that enterprises can make relevant decisions independently, we assume that

Table 2 Notations

Notations	Definitions
a	Market size
p	Retail price
w	Wholesale price
c	Production cost
e	Green level of product
v	Green marketing level
k	Marketing effect
l_m	The proportion of the retailer's shares held by the manufacturer
l_r	The proportion of the manufacturer's shares held by the retailer
π_m	Manufacturer's profit
π_r	Retailer's profit
π_{sc}	Total profit of supply chain

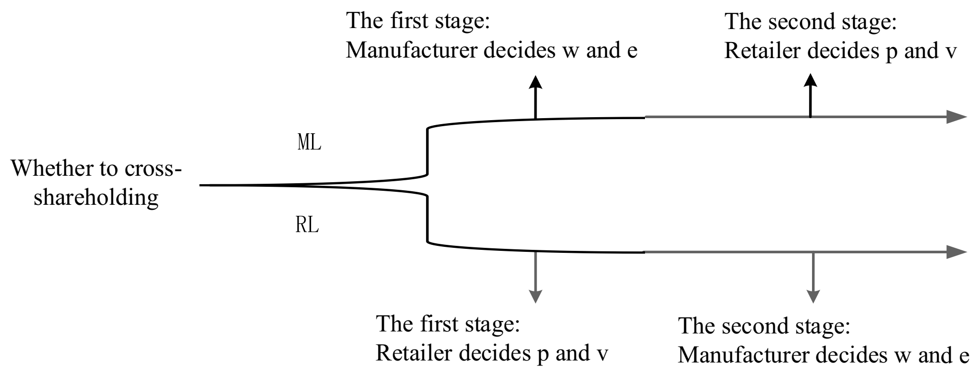


Fig. 1 The decision sequence

$0 \leq l_m, l_r \leq 50\%$. The sequence of event decisions in non-cross-shareholding supply chains still applies to cross-shareholding supply chains. As the cross-shareholding ratio between supply chain members changes, the synergy between upstream and downstream members will change, and the decisions that follow will also change.

The decision-making model for cross-shareholding is as follows:

$$\begin{cases} max\pi_m^{Ci}(w,e) = (1-l_r)[(w-c)D-e^2] + l_m[(p-w)D-v^2] \\ max\pi_r^{Ci}(p,v) = (1-l_m)[(p-w)D-v^2] + l_r[(w-c)D-e^2] \end{cases}$$

Model solving

In this section, the equilibrium result of the non-cross-shareholding supply chain under different dominances will be given first, and then the equilibrium result of the cross-shareholding supply chain under different dominations will be given.

Non-cross-shareholding

Lemma 1. In model DM, the equilibrium results are as follows:

$$p^{DM} = \frac{6a+c-ak^2-ck^2}{7-2k^2}, w^{DM} = \frac{4a+3c-ak^2-ck^2}{7-2k^2}, v^{DM} = \frac{k(a-c)}{7-2k^2}$$
$$e^{DM} = \frac{a-c}{7-2k^2}, \pi_m^{DM} = \frac{(a-c)^2}{7-2k^2}, \pi_r^{DM} = \frac{(4-k^2)(a-c)^2}{(2k^2-7)^2},$$

Lemma 2. In model DR, the equilibrium results are as follows:

$$p^{DR} = \frac{-ck^2+5a+c}{6-k^2}, w^{DR} = \frac{-ck^2+2a+4c}{6-k^2}, v^{DR} = \frac{k(a-c)}{6-k^2}, e^{DR} = \frac{a-c}{6-k^2}$$
$$\pi_m^{DR} = \frac{3(a-c)^2}{(k^2-6)^2}, \pi_r^{DR} = \frac{(a-c)^2}{6-k^2}$$

Corollary 1. $\frac{\partial e^{Di}}{\partial k} > 0, \frac{\partial v^{Di}}{\partial k} > 0, i = \{M, R\}$

Corollary 1 points out that as the marketing effect increases, both the green level and the marketing level will increase. This is because when retailers find that green marketing is more effective, they will improve their marketing to a greater extent. For manufacturers, when demand becomes more sensitive to retailers' marketing efforts, manufacturers have a greater incentive to increase the greenness of their products. The management implication of Corollary 1 is that if the green marketing effect is better, manufacturers can increase green investment, and retailers can further improve their marketing efforts.

Cross-shareholding

Lemma 3. In model CM, the equilibrium results are as follows:

$$p^{CM} = -\frac{6a+c-4al_m-6al_r-2cl_r-ak^2-ck^2+4al_ml_r+ak^2l_m+ak^2l_r+ck^2l_r-ak^2l_ml_r}{4l_m+8l_r-4l_ml_r-k^2l_m-2k^2l_r+2k^2+k^2l_ml_r-7}$$

$$w^{CM} = \frac{\begin{pmatrix} 4a+3c-8al_m-4al_r-3cl_m-11cl_r-ak^2+4al_m{}^2-ck^2+8cl_r{}^2-ak^2l_m{}^2-2ck^2l_r{}^2+8al_ml_r+8cl_ml_r \\ +2ak^2l_m+ak^2l_r-4al_m{}^2l_r+ck^2l_m+3ck^2l_r-4cl_ml_r{}^2-2ak^2l_ml_r-2ck^2l_ml_r+ak^2l_m{}^2l_r+ck^2l_ml_r^2 \end{pmatrix}}{(l_m+l_r-1)(4l_m+8l_r-4l_ml_r-k^2l_m-2k^2l_r+2k^2+k^2l_ml_r-7)}$$

$$v^{CM} = \frac{k(a-c)(l_r-1)}{4l_m+8l_r-4l_ml_r-k^2l_m-2k^2l_r+2k^2+k^2l_ml_r-7}$$

$$e^{CM} = -\frac{a-c}{4l_m+8l_r-4l_ml_r-k^2l_m-2k^2l_r+2k^2+k^2l_ml_r-7}$$

$$\pi_m^{CM} = \frac{(a-c)^2\left(l_r-1\right)}{4l_m+8l_r-4l_ml_r-k^2l_m-2k^2l_r+2k^2+k^2l_ml_r-7}$$

$$\pi_r^{CM} = \frac{(\alpha-c)^2+(4l_m+9l_r-8l_ml_r-k^2l_m-2k^2l_r+4l_ml_r^2+k^2-4l_r^2+k^2l_r^2+2k^2l_ml_r-k^2l_ml_r^2-4)}{(4l_m+8l_r-4l_ml_r-k^2l_m-2k^2l_r+2k^2+k^2l_ml_r+7)^2}$$

Lemma 4. In model CR, the equilibrium results are as follows:

$$p^{CR} = \frac{-5a+c\left(-1+k^2\right)+3al_r+l_m\left(5a+c-3al_r\right)}{-6+k^2-3l_m\left(-2+l_r\right)+3l_r}$$

$$w^{CR} = \frac{\begin{pmatrix} 2a+4c-7al_m-2al_r-5cl_m-7cl_r+5al_m{}^2-ck^2+cl_m^2 \\ +3cl_r{}^2+5al_ml_r+7cl_ml_r-3al_m{}^2l_r+ck^2l_m+ck^2l_r-3cl_ml_r^2 \end{pmatrix}}{(l_m+l_r-1)(k^2+6l_m+3l_r-3l_ml_r-6)}$$

$$v^{CR} = -\frac{k(a-c)}{k^2+6l_m+3l_r-3l_ml_r-6}, e^{CR} = \frac{(a-c)\left(l_m-1\right)}{k^2+6l_m+3l_r-3l_ml_r-6}$$

$$\pi_m^{CR} = \frac{(a-c)^2\left(l_m-1\right)}{k^2+6l_m+3l_r-3l_ml_r-6}$$

$$\pi_m^{CR} = -\frac{(a-c)^2\left(6l_m+3l_r-6l_ml_r+k^2l_m+3l_m^2l_r-3l_m^2-3\right)}{\left(k^2+6l_m+3l_r-3l_ml_r-6\right)^2}$$

Corollary 2. $\frac{\partial e^{Ci}}{\partial l_m} > 0, \frac{\partial e^{Ci}}{\partial l_r} > 0, \frac{\partial v^{Ci}}{\partial l_m} > 0, \frac{\partial v^{Ci}}{\partial l_r} > 0$, $i = \{M, R\}$.

Corollary 2 shows that the green level and the marketing level are positively related to the cross-shareholding ratio. With the increase of the cross-shareholding ratio, the supply chain members will further improve the green level and marketing level. The underlying reason is that cross-shareholding enhances the synergy between companies, prompting them to make larger green investment and promotion decisions. The management implication of Corollary 2 is that the cross-shareholding mechanism can motivate enterprises to pay more attention to environmental issues, thereby reducing the cost of social and environmental governance. Through empirical analysis of the annual data samples of Chinese A-share listed firms from 2014 to 2019, Tian et al. (2021) find that firms' participation in cross-shareholding will have a positive impact on corporate environmental protection investment. That is to say, the higher the cross-shareholding scale, the greater the firms invest in environmental protection.

Analysis and discussion

Based on the equilibrium results of the four models, this section further explores the impact of cross-shareholding on green supply chain operational decisions and profits. The values of l_{m1}, l_{m2}, l_{m3} and l_{r1}, l_{r2} are presented in Appendix.

The impact of cross-shareholding on firms' decision-making

This subsection explores how cross-shareholding affects pricing, products' green levels, and retailers' marketing levels.

First, the effect of cross-shareholding on wholesale and retail prices is examined, and Proposition 1 is proposed.

Proposition 1.

(1) In ML, if $l_{r1} < l_r \leq 50\%$, then $w^{CM} > w^{DM}$; otherwise, $w^{CM} \leq w^{DM}$.
(2) In RL, if $\max[\min(l_{m1}, l_{m2}), 0] < l_m \leq \min[\max(l_{m1}, l_{m2}), 50\%]$, then $w^{CR} > w^{DR}$; otherwise, $w^{CR} \leq w^{DR}$.
(3) In RL, if $\max[\min(l_{m1}, l_{m2}), 0] < l_m \leq \min[\max(l_{m1}, l_{m2}), 50\%]$, then $w^{CR} > w^{DR}$; otherwise, $w^{CR} \leq w^{DR}$.
In ML, when $k^2 \geq 1$, then $p^{CM} > p^{DM}$; when $k^2 < 1$: if $\frac{l_m(k^4-6k^2+8)}{12-2(1+l_m)k^2+8l_m} < \frac{1}{2}$ and $\frac{4l_m(4-k^2)(1-k^2)}{(6-k^2)+4l_m(4-k^2)(1-k^2)} < l_r \leq \frac{1}{2}$, then $p^{CM} > p^{DM}$ and $p^{CM} \leq p^{DM}$ otherwise.
(4) In RL, when $k^2 \geq 1$, then $p^{CR} > p^{DR}$; when $k^2 < 1$: if $\frac{3l_r}{5-3l_r} < k^2$ and $\frac{3l_r\left(1-k^2\right)}{5k^2+3l_r\left(1-k^2\right)} < l_m \leq \frac{1}{2}$, then $p^{CR} > p^{DR}$ and $p^{CR} \leq p^{DR}$ otherwise.

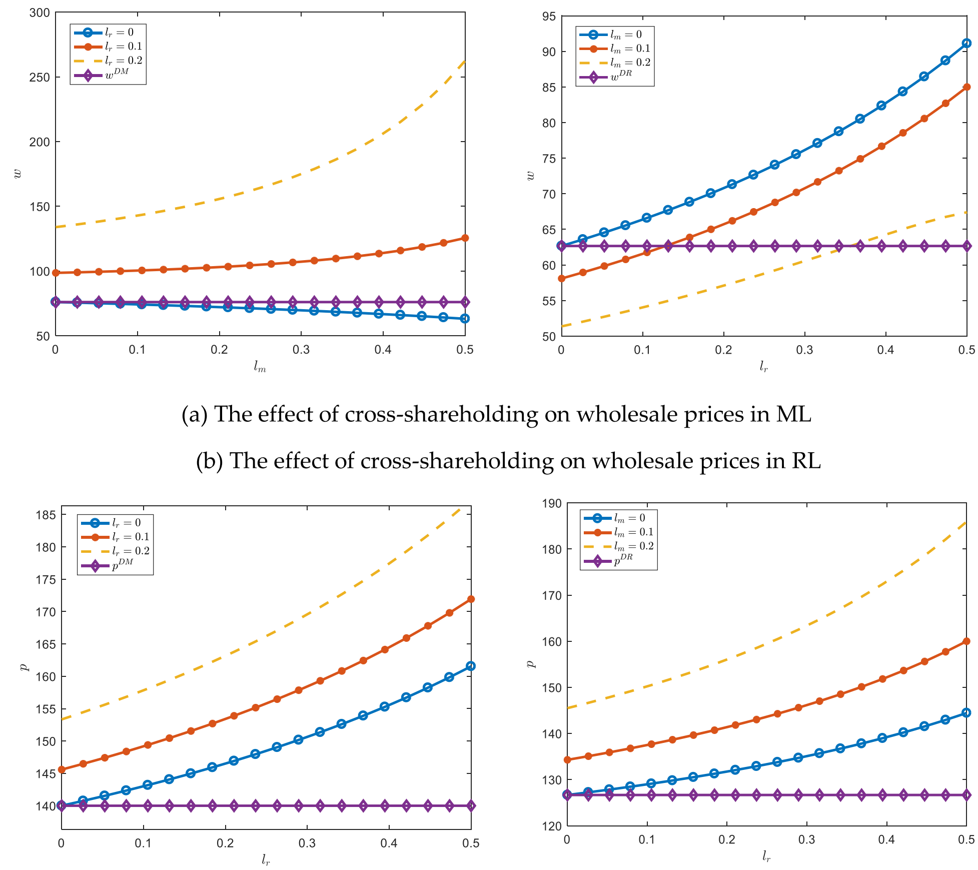
Proposition 1 shows that cross-shareholding affects wholesale and retail prices. A high cross-holding ratio of supply chain followers will result in higher wholesale and retail prices than those in non-cross-shareholding supply chains. In ML, when l_r is above a certain threshold, manufacturers will charge higher wholesale prices than non-cross-shareholding (see Fig. 2a). Accordingly, retailers must increase retail prices to protect their profit margins (see Fig. 2c). In RL, when l_m is below a certain threshold ($0 \leq l_m \leq max\left[min\left(l_{m1}, l_{m2}\right), 0\right]$), although the wholesale price charged by the manufacturer is lower than that in the non-cross-shareholding supply chain (see Fig. 2b), the retail price is higher than that in the non-cross-shareholding supply chains (see Fig. 2d). This is because cross-shareholding reduces competition among supply chain members and increases the degree of monopoly, leading to higher retail prices. This means that cross-shareholding increases the burden on consumers.

Next, we analyze the impact of cross-shareholding on the green level and the marketing level and propose Proposition 2.

Proposition 2. There are $e^{Ci} > e^{Di}, v^{Ci} > v^{Di}$ for any l_m and l_r, where $i = \{M, R\}$.

Proposition 2 shows that cross-shareholding always encourages manufacturers to improve green levels and retailers to increase green marketing efforts. Proposition 2 is closely related to Corollary 2 and Proposition 1. From Corollary 2, it can be seen that the cross-shareholding ratio has a positive impact on the green level and the marketing level. From Proposition 1, the introduction of the cross-shareholding mechanism may increase the retail price, but reduce the demand of the product. For supply chain members, an effective way to keep demand down but keep profits up is to further increase the level of greenness or marketing. Figure 3 shows the relationship between the level of product greenness or the level of retailer marketing and the proportion of cross-shareholding. It is found that regardless of the

Fig. 2 The effect of cross-shareholding on wholesale and retail prices ($a = 100, c = 2, k = 1.5$)



(a) The effect of cross-shareholding on wholesale prices in ML

(b) The effect of cross-shareholding on wholesale prices in RL

(c) The effect of cross-shareholding on retail prices in ML

(d) The effect of cross-shareholding on retail prices in RL

cross-shareholding ratio, the product green level and the retailer's marketing level increase with the cross-shareholding ratio both in ML and RL, which validates Corollary 2.

The impact of cross-shareholding on firms' profits

Proposition 3. In ML, if $0 < l_r < l_{r1}$, then $\pi_{sc}^{CM} > \pi_{sc}^{DM}$. In RL, if $0 < l_m < l_{m3}$, then $\pi_{sc}^{CR} > \pi_{sc}^{DR}$.

Proposition 3 shows that cross-shareholding can alleviate the competition intensity among supply chain members under certain conditions, thereby improving the performance of the entire supply chain. However, this influence disappears when followers hold too much stake in the leader of the supply chain, because the follower holding too many shares in the leader threatens the leader's position, and the leader's power advantage may lead to the reduction of followers' profits, which in turn drags down the profits of the entire supply chain.

From Fig. 4, if $l_r < l_{r1}$, the total profit of the cross-shareholding supply chain in ML increases with l_m. Meanwhile, if $l_m < l_{m3}$, the total profit of the cross-shareholding supply chain in RL increases with l_r. However, when l_m is relatively large, the total profit of the cross-shareholding supply chain has a quadratic function relationship with l_r, that is, with the increase in l_r, the total profit shows a trend of first increasing and then decreasing until it is less than that of the non-cross-shareholding.

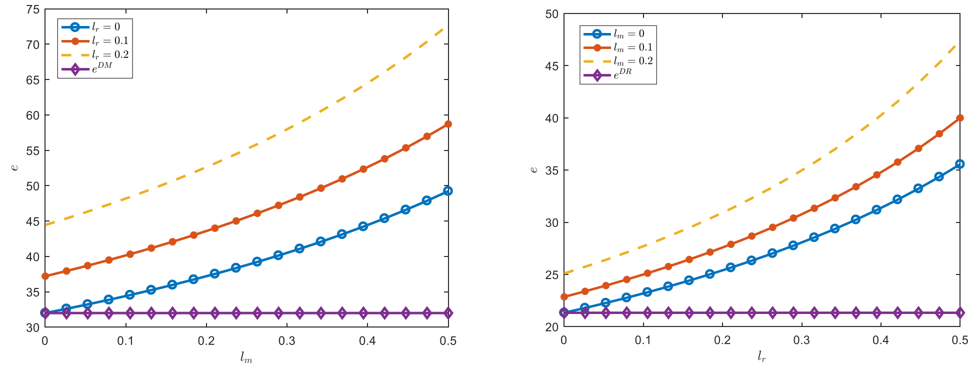
Proposition 4. In ML, there is $\pi_m^{CM} > \pi_m^{DM}$ for any l_{m} and l_{r}.

Proposition 4 shows that in ML, cross-shareholding makes the manufacturer more profitable. It can be seen from Fig. 5a that with the increase in the cross-shareholding ratio, the manufacturer's profit gradually increases. This shows that cross-shareholding is beneficial to manufacturers. With the increase in the shareholding ratio, that is, the deepening of cooperation, the manufacturer's income will be further improved.

Proposition 5. In RL, there is $\pi_r^{CR} > \pi_r^{DR}$ for any l_m and l_r.

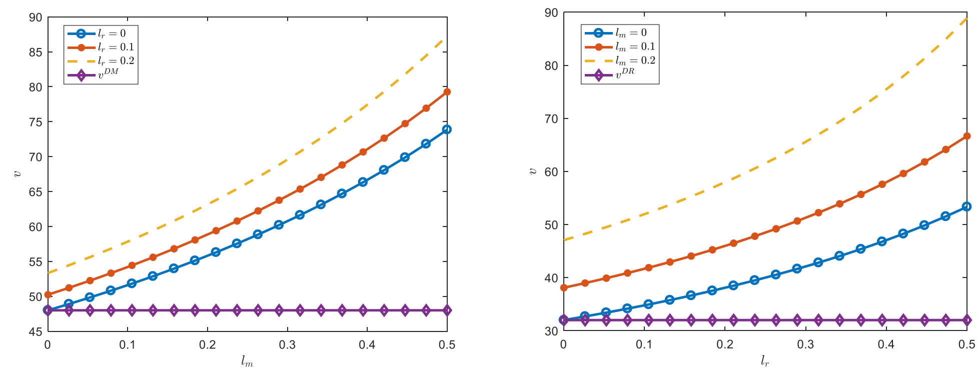
Proposition 5 shows that in RL, cross-shareholding increases the retailer's profit. It can be seen from Fig. 5b that with the increase in the shareholding ratio, the retailer's profit also gradually increases. Combined with Proposition 4, we know that cross-shareholding is always beneficial to the dominant player in the supply chain. This suggests that leaders in

Fig. 3 The effect of cross-shareholding on the green level and marketing level ($a = 100, c = 2, k = 1.5$)



(a) The effect of cross-shareholding on the green level in ML.

(b) The effect of cross-shareholding on the green level in RL.



(a) The effect of cross-shareholding on the marketing level in ML.

(b) The effect of cross-shareholding on the marketing level in RL.

the supply chain are more motivated to adopt a cross-shareholding strategy, which explains why Volkswagen, Porsche, and other auto companies have increased their earnings by cross-shareholding with their respective parts suppliers.

Coordination of cross-shareholding supply chain

In this section, we will design a coordination contract to further improve the performance of the cross-shareholding supply chain.

First, we solve the optimal decision in the integration situation. We use superscript C to denote the integration scenario. In the integrated scenario, the manufacturer and retailer as a whole maximize the total profit of the supply chain. In this case, the decision-making model is as follows:

$$\max \pi_{sc}^C = (p - c)D - v^2 - e^2$$

Lemma 5. In the integrated scenario, the equilibrium results are as follows: $p_{sc}^C = c + \frac{2(a-c)}{3-k^2}, e_{sc}^C = \frac{a-c}{3-k^2}, v_{sc}^C = \frac{k(a-c)}{3-k^2}, \pi_{sc}^C = \frac{(a-c)^2}{3-k^2}$.

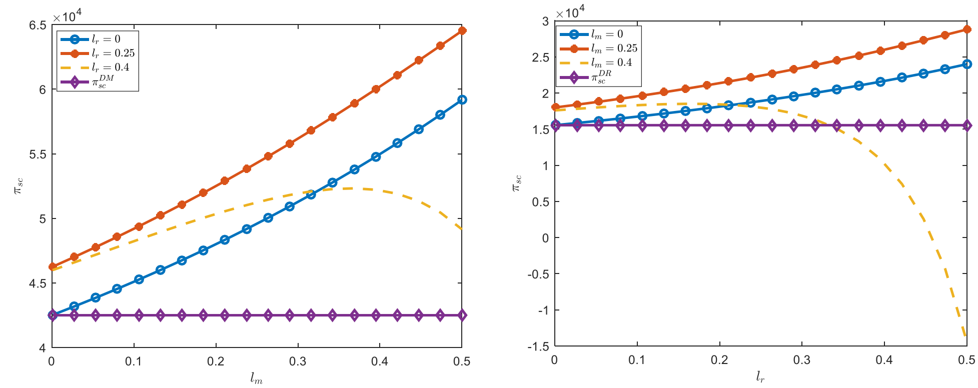
Proposition 6. (1) $\frac{\partial e_{sc}^C}{\partial k} > 0$, $\frac{\partial v_{sc}^C}{\partial k} > 0$. (2) $e_{sc}^C > e^{CM}$, $e_{sc}^C > e^{CR}$, $v_{sc}^C > v^{CM}$, $v_{sc}^C > v^{CR}$.

Proposition 6 shows that the relationship between green level, marketing level, and marketing effect is similar to the relationship that exists in non-cross-shareholding supply chains. In addition, in the integrated scenario, both the green level and the marketing level are improved.

Although cross-shareholding can improve the performance of a green supply chain, the performance of integrated supply chains is still better than that of cross-shareholding. To further coordinate and improve the performance of the cross-shareholding supply chain, two-part pricing contracts are proposed.

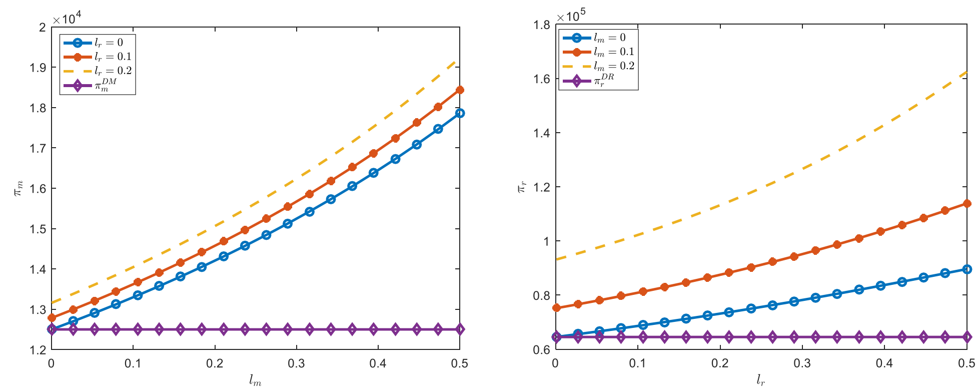
We use the superscript TC to denote coordinated decisions under two-part pricing contracts.

In ML, the decision model is as follows:



(a) ML (b)RL

Fig. 4 The impact of cross-shareholding on total supply chain profits ($a = 100, c = 2, k = 1.5$)



(a) ML (b) RL

Fig. 5 The impact of cross-shareholding on the profits of supply chain members ($a = 100, c = 2, k = 1.5$)

$$\begin{cases} \pi_m^{TC} = (1-l_r)[(w-c)D-e^2] + l_m[(p-w)D-v^2] + S \\ \pi_r^{TC} = (1-l_m)[(p-w)D-v^2] + l_r[(w-c)D-e^2] - S \\ \pi_m^{TC} \geq \pi_m^{CM} \\ \pi_r^{TC} \geq \pi_r^{CM} \end{cases}$$

That is, the manufacturer wholesales the product to the retailer at a lower price, and the transfer payment from the retailer to the manufacturer is S.

In RL, the decision model is as follows:

$$\begin{cases} \pi_m^{TC} = (1-l_r)[(w-c)D-e^2] + l_m[(p-w)D-v^2] - S \\ \pi_r^{TC} = (1-l_m)[(p-w)D-v^2] + l_r[(w-c)D-e^2] + S \\ \pi_m^{TC} \geq \pi_m^{CR} \\ \pi_r^{TC} \geq \pi_r^{CR} \end{cases}$$

That is, the manufacturer wholesales the product to the retailer at a higher price, and the transfer payment given to the retailer is S.

Proposition 7. (1) The cross-shareholding supply chain can be coordinated through the two-part pricing contract in ML, and the coordination parameters are satisfied with $w^{TC} = c$ and

$$S^{TC} = \frac{(a-c)^2 \left[\begin{array}{c} (4-k^2)^3(3-l_m^3+3l_m)(1-l_m)^2 - (4-k^2)^2[2+2(l_m-1)l_r^2-(1+2l_m)l_r] \\ +(4-k^2)[(l_m-1)l_r^2-2l_ml_r+l_m]+l_r \end{array} \right]}{2[(2-l_m)(1-l_r)(4-k^2)-1]^2(3-k^2)^2}.$$

(2) In RL, the coordination parameters are satisfied with $w^{TC} = \frac{-ck^2+2a+c}{3-k^2}$, $S^{TC} = (a-c)^2[\frac{3-k^2l_m-3l_r}{(-3+k^2)^2} + \frac{1-l_m}{-6+k^2-3l_m(-2+l_r)+3l_r}]$.

Proposition 7 shows that two-part pricing contracts can further coordinate the cross-shareholding supply chain and achieve Pareto improvement of the profits of supply chain members. In addition, the additional profits that supply chain leaders earn through two-part pricing contracts are strongly related to cross-shareholding ratios.

Conclusion

This paper constructs game models before and after cross-shareholding in the case of manufacturer-dominated and retailer-dominated supply chains. We use the backward induction method to solve the model and compare and analyze the optimal pricing strategy, green level, marketing level, and profits under different models. In addition, two pricing contracts are proposed to coordinate the cross-shareholding supply chain, so as to realize the reasonable distribution of the profits among the members of the supply chain under the cross-shareholding. The main conclusions and management implications are as follows.

First, unlike a retailer-led supply chain, when retailers hold more shares in manufacturers, manufacturers tend to set higher wholesale prices when they dominate the supply chain; but when retailers dominate the supply chain, wholesale prices will decrease as manufacturers hold more shares in retailers. For retail prices, as the cross-shareholding ratio increases, retailers always have an incentive to increase the price.

Second, under the two power structures, compared with non-cross-shareholding, cross-shareholding can always promote manufacturers to improve products' green levels and retailers to increase green marketing levels. Moreover, both the green level and the marketing level increase with the cross-shareholding ratio. Therefore, governments or supply chain managers can improve environmental performance by facilitating the use of cross-shareholding strategies.

Third, for a supply chain system dominated by a manufacturer or retailer, cross-shareholding has always been profitable. Cross-shareholding increases the total supply chain profit only if the follower does not hold more than a certain amount of the leader's stake. Therefore, the core enterprises in the supply chain can vigorously implement the cross-shareholding strategy and strengthen the coordination between upstream and downstream enterprises.

Finally, the two-part pricing contract can further improve the performance of the cross-shareholding supply chain, so that the total profit of the supply chain can reach the level of integrated decision-making, and the profit of supply chain members can be Pareto improved. Therefore, based on the cross-shareholding strategy, supply chain members can further adopt effective coordination contracts to further improve supply chain performance.

This paper also has the following research directions. First, to simplify the model, this paper adopts a linear demand function. In the future, nonlinear demand functions or probabilistic demand functions under different probability distributions can be considered to better fit the actual demand. Second, enterprises face the uncertainty of income when making green technology or marketing investment. The next step is to study the impact of cross-shareholding under different risk preferences of supply chain members. Finally, this paper explores the impact of cross-shareholding based on the profit maximization of supply chain members, and future research can further explore this issue from the perspectives of social and environmental benefits.

Appendix

Proof of Lemma 1 We solve this model by backward induction and first consider the retailer's decision. The Hessian matrix of π_r^{DM} about p, v is $\begin{bmatrix} -2 & k \\ k & -2 \end{bmatrix}$. Since $0 < k < \sqrt{3}$, we can easily deduce that π_r^{DM} is joint concave in p, v. Let $\frac{\partial \pi_r^{DM}}{\partial p} = 0 \frac{\partial \pi_r^{DM}}{\partial v} = 0 \frac{\partial \pi_r^{DM}}{\partial v} = 0$, we have $p(w,e) = \frac{-wk^2+2a+2e+2w}{4-k^2}$, $v(w,e) = -\frac{ak+ek-kw}{4-k^2}$.

Substituting $p(w,e)$ and $v(w,e)$ into π_r^{DM}, the Hessian matrix of π_r^{DM} about w, e is $\begin{bmatrix} -\frac{4}{4-k^2} & \frac{2}{4-k^2} \\ \frac{2}{4-k^2} & -2 \end{bmatrix}$. Obviously, its sequential principal minors are $|H_1| = -\frac{4}{4-k^2} < 0$, $|H_2| = \frac{2(19-4k^2)}{(4-k^2)^2} > 0$, respectively. Hence, we know that π_r^{DM} is joint concave in w and e. Let $\frac{\partial \pi_m^{DM}}{\partial w} = 0 \frac{\partial \pi_m^{DM}}{\partial e} = 0$, we get $w^{DM} = \frac{4a+3c-ak^2-ck^2}{7-2k^2}$, $e^{MD} = \frac{a-c}{7-2k^2}$. From this, we can obtain p^{DM}, v^{DM}, π_m^{DM}, π_r^{DM}.

Proof of Lemma 2 We solve this model by backward induction and first consider the manufacturer's decision. Let $p = w + y$, we derive that the Hessian matrix of π_m^{DR} about w, e is $\begin{bmatrix} -2 & 1 \\ 1 & -2 \end{bmatrix}$. Obviously, π_m^{DR} is joint concave in w and e. Let $\frac{\partial \pi_m^{DR}}{\partial w} = 0 \frac{\partial \pi_m^{DR}}{\partial e} = 0$, we get $w(y,v) = \frac{2a}{3} + \frac{c}{3} - \frac{2y}{3} + \frac{2kv}{3}$, $e(y,v) = \frac{2a}{3} + \frac{c}{3} - \frac{2y}{3} + \frac{2kv}{3}$. Substituting $w(y,v)$ and $e(y,v)$ into π_r^{DR}, we get the Hessian matrix of π_r^{DR} with respect to y, v is $\begin{bmatrix} -\frac{4}{3} & \frac{2k}{3} \\ \frac{2k}{3} & -2 \end{bmatrix}$. Since $0 < k < \sqrt{3}$, we can easily induce that π_r^{DR} is joint concave in y, v. Let $\frac{\partial \pi_r^{DR}}{\partial y} = 0$, $\frac{\partial \pi_r^{DR}}{\partial v} = 0$, we obtain y^{DR}, v^{DR}. From this, we get $w^{DR}, e^{DR}, p^{DR}, \pi_m^{DR}, \pi_r^{DR}$

The proofs of Lemmas 3 and 4 are similar to Lemmas 1 and 2. Hence, we omit them.

Proof of Corollary 1 We can derive $\frac{\partial e^{DM}}{\partial k} = \frac{4k(a-c)}{(2k^2-7)^2} > 0$, $\frac{\partial e^{DR}}{\partial k} = \frac{2k(a-c)}{(k^2-6)^2} > 0$, $\frac{\partial v^{DM}}{\partial k} = \frac{(a-c)(2k^2+7)}{(2k^2-7)^2} > 0$, $\frac{\partial v^{DR}}{\partial k} = \frac{(k^2+6)(a-c)}{(k^2-6)^2} > 0$.

Proof of Corollary 2 (1) In ML, we can derive

$$\frac{\partial e^{CM}}{\partial l_m} = \frac{(4-k^2)(a-c)(1-l_r)}{(4l_m+8l_r-4l_ml_r-k^2l_m-2k^2l_r+2k^2+k^2l_ml_r-7)^2} > 0,$$
$$\frac{\partial e^{CM}}{\partial l_r} = \frac{(4-k^2)(a-c)(2-l_m)}{(4l_m+8l_r-4l_ml_r-k^2l_m-2k^2l_r+2k^2+k^2l_ml_r-7)^2} > 0,$$
$$\frac{\partial v^{CM}}{\partial l_m} = \frac{k(4-k^2)(a-c)(1-l_r)^2}{(4l_m+8l_r-4l_ml_r-k^2l_m-2k^2l_r+2k^2+k^2l_ml_r-7)^2} > 0,$$
$$\frac{\partial v^{CM}}{\partial l_r} = \frac{k(a-c)}{(4l_m+8l_r-4l_ml_r-k^2l_m-2k^2l_r+2k^2+k^2l_ml_r-7)^2} > 0$$

(2) In RL, we can derive $\frac{\partial e^{CR}}{\partial l_r} = \frac{(3-3l_m)(a-c)(1-l_m)}{(k^2+6l_m+3l_r-3l_ml_r-6)^2} > 0$, $\frac{\partial e^{CR}}{\partial l_m} = \frac{k^2(a-c)}{(k^2+6l_m+3l_r-3l_ml_r-6)^2} > 0$, $\frac{\partial v^{CR}}{\partial l_m} = \frac{k(6-3l_r)(a-c)}{(k^2+6l_m+3l_r-3l_ml_r-6)^2} > 0$, $\frac{\partial v^{CR}}{\partial l_r} = \frac{k(3-3l_m)(a-c)}{(k^2+6l_m+3l_r-3l_ml_r-6)^2} > 0$.

Proof Proposition 1 In ML, we can rewrite w^{CM} and w^{DM} as $w^{CM} = c + \frac{(a-c)(4-k^2)(1-l_m)^2(1-l_r)}{(1-l_m-l_r)[(4-k^2)(2-l_m)(1-l_r)-1]}$, $w^{DM} = c + \frac{(4-k^2)(a-c)}{7-2k^2}$. So, to compare w^{CM} and w^{DM}, we only need to compare their second part. Let $\theta_1 = \frac{\frac{(a-c)(4-k^2)(1-l_m)^2(1-l_r)}{(1-l_m-l_r)[(4-k^2)(2-l_m)(1-l_r)-1]}}{\frac{(4-k^2)(a-c)}{7-2k^2}}$ and $\delta = \frac{1}{4-k^2}$, we can get $\theta_1 = \frac{(2-\delta)(1-l_m)^2(1-l_r)}{(1-l_m-l_r)[(2-l_m)(1-l_r)-\delta]}$. If $l_{r1} = \frac{2+l_m^2\delta-l_m^2-2l_m\delta-\sqrt{l_m^2(2-l_m)^2(1-\delta)^2+4(1-l_m)^2}}{2(2-l_m)} < l_r < \frac{2+l_m^2\delta-l_m^2-2l_m\delta+\sqrt{l_m^2(2-l_m)^2(1-\delta)^2+4(1-l_m)^2}}{2(2-l_m)}$, we have $\theta_1 > 1$, that is, $w^{CM} > w^{DM}$. However, we can derive $\frac{2+l_m^2\delta-l_m^2-2l_m\delta+\sqrt{l_m^2(2-l_m)^2(1-\delta)^2+4(1-l_m)^2}}{2(2-l_m)} - \frac{1}{2} > \frac{2-(2-l_m)+l_m^2\delta-l_m^2-2l_m\delta+2(1-l_m)}{2(2-l_m)} > 0$. Therefore, if $l_{r1} < l_r \le 50\%$, then $w^{CM} > w^{DM}$ and $w^{CM} \le w^{DM}$ otherwise.

(2) In RL, we can rewrite w^{CM} and w^{DR} as $w^{CR} = c + \frac{(a-c)(1-l_m)\{2[(2l_r-3)l_m-l_r+1]+l_m(1-l_r)\}}{(1-l_m-l_r)[3(1-l_m)(2-l_r)-k^2]}$, $w^{DR} = c + \frac{2(a-c)}{6-k^2}$. To compare w^{CR} and w^{DR}, we only need to compare their second part.

Let $\theta_2 = \frac{\frac{(a-c)(1-l_m)\{2[(2l_r-3)l_m-l_r+1]+l_m(1-l_r)\}}{(1-l_m-l_r)[3(1-l_m)(2-l_r)-k^2]}}{\frac{2(a-c)}{6-k^2}}$. By $\theta_2 = 1$, we have $l_{m1} = \frac{\frac{3}{2}l_m^2+[\frac{1}{2}+\frac{1}{2}(\frac{1}{2}k^2-6)-\frac{3}{2}k^2+4]l_r-\frac{1}{2}+(8-\frac{1}{2}k^2)\frac{1}{2}+\frac{3}{2}k^2-8-\sqrt{\Delta}}{\frac{3}{2}l_r(k^2-4)-1+(16-k^2)\frac{1}{2}+4(k^2-4)-k^2}$, $l_{m2} = \frac{\frac{3}{2}l_m^2+[\frac{1}{2}+\frac{1}{2}(\frac{1}{2}k^2-6)-\frac{3}{2}k^2+4]l_r-\frac{1}{2}+(8-\frac{1}{2}k^2)\frac{1}{2}+\frac{3}{2}k^2-8+\sqrt{\Delta}}{\frac{3}{2}l_r(k^2-4)-1+(16-k^2)\frac{1}{2}+4(k^2-4)-k^2}$, where $\Delta = (\frac{1}{2}-3)^2(1-l_r)^2\frac{1}{4}k^2 + \frac{3}{2}(1-l_m)(-\frac{1}{2}l_r^2 + \frac{15}{2}l_r - \frac{15}{2})k^2 + \frac{9}{4}(l_r^2 - 3l_r + 4)^2$. Therefore, if $\max(\min(l_{m1}, l_{m2}), 0) < l_m \le \min(\max(l_{m1}, l_{m2}), 50\%)$, then $w^{CR} > w^{DR}$ and $w^{CR} \le w^{DR}$ otherwise.

The proof of Proposition 1 (3) and (4) is similar to Proposition 1 (1) and (2), we omit it.

Proof Proposition 2 In ML, we have $e^{CM} - e^{DM} = \frac{(a-c)((4-k^2)[2-(2-l_m)(1-l_r)])}{(7-2k^2)[(4-k^2)(2-l_m)(1-l_r)-1]}$.

Since $(4-k^2)[2-(2-l_m)(1-l_r)] > 0$, we have $e^{CM} - e^{DM} > 0$. Similarly, it can be proved that $e^{CR} - e^{DR} > 0$.

In RL, we have $v^{CM} - v^{DM} = \frac{k(a-c)((4-k^2)(1-l_r)l_m+l_r)}{(7-2k^2)[(4-k^2)(2-l_m)(1-l_r)-1]}$.

Since $(4-k^2)(1-l_r)l_m + l_r > 0$, we have $v^{CM} - v^{DM} > 0$. Similarly, it can be proved that $v^{CR} - v^{DR} > 0$.

Proof Proposition 3 In ML, let $\delta = \frac{1}{4-k^2}$, by $\pi_{sc}^{CM} > \pi_{sc}^{DM}$, we have $0 < l_r < \frac{(1-l_m)\delta^2+(l_m^2+l_m-2)\delta-3l_m^2+4l_m+\sqrt{[(1-l_m)^2\delta-3l_m^2+4l_m](2-\delta)^2\delta}}{(3-2l_m)\delta^2+(l_m^2+4l_m-8)\delta-3l_m^2+4l_m} = l_{r2}$.

In RL, let $\gamma = \frac{k^2}{3}$, by $\pi_{sc}^{CR} > \pi_{sc}^{DR}$, we have $0 < l_m < \frac{(1-l_r)\gamma^2+(l_r^2+l_r-2)\gamma-3l_r^2+4l_r+\sqrt{[(1-l_r)^2\gamma-3l_r^2+4l_r](2-\gamma)^2\gamma}}{(3-2l_r)\gamma^2+(l_r^2+4l_r-8)\gamma-3l_r^2+4l_r} = l_{m3}$.

Proof of Proposition 4 We have $\pi_m^{CM} - \pi_m^{DM} = \frac{(a-c)^2((4-k^2)(1-l_r)l_m+l_r)}{(7-2k^2)[(4-k^2)(2-l_m)(1-l_r)-1]} > 0$, that is, $\pi_m^{CM} > \pi_m^{DM}$ for any l_m and l_r.

Proof Proposition 5 We have $\pi_r^{CR} - \pi_r^{DR} = \frac{12(a-c)(1-l_m)l_r+l_mk^2(a-c)^2}{4[3(1-l_m)(2-l_r)-k^2](6-k^2)} > 0$, that is, $\pi_r^{CR} > \pi_r^{DR}$ for any l_m and l_r.

Proof of Lemma 5 Let $\frac{\partial \pi_{sc}^C}{\partial p} = 0$, $\frac{\partial \pi_{sc}^C}{\partial v} = 0$, $\frac{\partial \pi_{sc}^C}{\partial e} = 0$, we have $p_{sc}^C = c + \frac{2(a-c)}{3-k^2}e_{sc}^C = \frac{a-c}{3-k^2}v_{sc}^C = \frac{k(a-c)}{3-k^2}$. From this, we get $\pi_{sc}^C = \frac{(a-c)^2}{3-k^2}$.

Proof Proposition 6 (1) We can derive $\frac{\partial e_{sc}^C}{\partial k} = \frac{2k(a-c)}{(3-k^2)^2} > 0$, $\frac{\partial v_{sc}^C}{\partial k} = \frac{(k^2+3)(a-c)}{(3-k^2)^2} > 0$.

(2) We can derive $v_{sc}^C - v^{CM} = \frac{k(a-c)((4-k^2)(1-l_m)(1-l_r)+l_r)}{(3-k^2)[(4-k^2)(2-l_m)(1-l_r)-1]} > 0$, $e_{sc}^C - e^{CM} = \frac{(a-c)((4-k^2)(2+l_m-2l_r-l_ml_r))}{(3-k^2)[(4-k^2)(2-l_m)(1-l_r)-1]} > 0$, that is, $v_{sc}^C > v^{CM}$ and $e_{sc}^C > e^{CM}$.

Similarly, it can be proved that $v_{sc}^C > v^{CM}$ and $e_{sc}^C > e^{CR}$.

Proof Proposition 7 (1) In ML, for the manufacturer is in the dominant position, we first consider the retailer's decisions. Let $\frac{\partial \pi_r^{TC}}{\partial p} = 0$ $\frac{\partial \pi_r^{TC}}{\partial v} = 0$, we have $p(w,e) = \frac{-(2(a+e)-(-2+k^2)w)(-1+l_\mathrm{m})+(-2+k^2)(-c+w)l_\mathrm{r}}{(-4+k^2)(-1+l_\mathrm{m})}$, $v(w,e) = \frac{-k(a+e-w)(-1+l_\mathrm{m})+k(-c+w)l_\mathrm{r}}{(-4+k^2)(-1+l_\mathrm{m})}$.

To reach the level of profit in the integration situation, there should be $p(w,e) = p_{sc}^C, v(w,e) = v_{sc}^C$. From this, we get $e^{TC} = e^C, w^{TC} = c$. Since the manufacturer is dominant, it can have all the profits obtained by the coordination, and the retailer can have the reserved profits. By $\pi_r^{TC} - S = \pi_r^{CM}$, we obtain S^{TC}.

(2) In RL, for the retailer is in the dominant position, we first consider the manufacturer's decisions. Let $\frac{\partial \pi_m^{TC}}{\partial e} = 0$, we have $e(p,v) = \frac{l_m(p-w)+(c-w)(l_r-1)}{2(1-l)r}$. To reach the level of profit in the case of integration, there should be $p = p_{sc}^C, v = v_{sc}^C, e(p,v) = e_{sc}^C$. From this, we get $w^{TC} = \frac{-ck^2+2a+c}{3-k^2}$. Since the retailer is dominant, it can have all the profits obtained by the coordination, and the manufacturer can have the reserved profits. By $\pi_m^{TC} - S = \pi_m^{CR}$, we obtain S^{TC}.

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References

Agrawal VV, Ferguson M, Toktay LB, Thomas VM (2011) Is leasing greener than selling? Manage Sci 58:523–533

Atkinson L, Rosenthal S (2014) Signaling the green sell: the influence of eco-label source, argument specificity, and product involvement on consumer trust. J Advert 43:33–45

Brooks C, Chen Z, Zeng Y (2018) Institutional cross-ownership and corporate strategy: the case of mergers and acquisitions. J Corp Finan 48:187–216

Cerqueti R, Rotundo G, Ausloos M (2020) Tsallis entropy for cross-shareholding network configurations. Entropy 22:676

Chen C (2001) Design for the environment: a quality-based model for green product development. Manage Sci 47:250–263

Chen J, Hu Q, Song J-S (2017) Effect of partial cross ownership on supply chain performance. Eur J Oper Res 258:525–536

Dong C, Liu Q, Shen B (2019) To be or not to be green? Strategic investment for green product development in a supply chain. Trans Res E: Logistics Trans Rev 131:193–227

Erdogmus I, Lak H, Çiçek M (2016) Attractive or credible celebrities: who endorses green products better? Procedia Soc Behav Sci 235:587–594

Fan Y, Ren M, Zhang J, Wang N, Zhang C (2022) Risk identification and assessment on green product certification — model construction and empirical analysis. J Clean Prod 370:133593

Gao K, Shen H, Gao X, Chan K (2019) The power of sharing: evidence from institutional investor cross-ownership and corporate innovation. Int Rev Econ Financ 63:284–296

Guo S, Choi T-M, Shen B (2020) Green product development under competition: a study of the fashion apparel industry. Eur J Oper Res 280:523–538

Hafezi M, Zhao X, Zolfagharinia H (2022) Together we stand? Co-opetition for the development of green products. Eur J Oper Res 306:1–22

He J, Huang J, Zhao S (2019) Internalizing governance externalities: the role of institutional cross-ownership. J Financ Econ 134:400–418

Heydari J, Bineshpour P, Walther G, Ülkü MA (2022) Reconciling conflict of interests in a green retailing channel with green sales effort. J Retail Consum Serv 64:102752

Hong Z, Guo X (2019) Green product supply chain contracts considering environmental responsibilities. Omega 83:155–166

Hussain J, Pan Y, Ali G, Xiaofang Y (2020) Pricing behavior of monopoly market with the implementation of green technology decision under emission reduction subsidy policy. Sci Total Environ 709:136110

Kou X, Liu H, Gao H, Liu H, Yu X (2022) Cooperative emission reduction in the supply chain: the value of green marketing under different power structures. Environ Sci Pollut Res 29:68396–68409

Li B, Wang H, Zheng W (2021a) Who will take on green product development in supply chains? Manufacturer or retailer. J Clean Prod 314:128000

Li G, Wu H, Sethi S, Zhang X (2021b) Contracting green product supply chains considering marketing efforts in the circular economy era. Int J Prod Econ 234:108041

Li Q, Guan X, Shi T, Jiao W (2020) Green product design with competition and fairness concerns in the circular economy era. Int J Prod Res 58:165–179

Li Z, Pan Y, Yang W, Ma J, Zhou M (2021c) Effects of government subsidies on green technology investment and green marketing coordination of supply chain under cap-and-trade mechanism. Energy Economics 101:105426

Liu G, Yang H, Dai R (2020) Which contract is more effective in improving product greenness under different power structures: revenue sharing or cost sharing? Comput Ind Eng 148:106701

Ma P, Li KW, Wang Z-J (2017) Pricing decisions in closed-loop supply chains with marketing effort and fairness concerns. Int J Prod Res 55:6710–6731

Mu Z, Li Q, Dai G, Li K, Zhang G, Zhang F (2022) Government subsidy policy and online selling strategy in a platform supply chain with green R&D and DDM activities. Sustainability 14(15):9658

Qiao A, Choi SH, Pan Y (2021) Multi-party coordination in sustainable supply chain under consumer green awareness. Sci Total Environ 777:146043

Rahbar E, Wahid N (2011) Investigation of green marketing tools' effect on consumers' purchase behavior. Bus Strat Ser 12:73–83

Ranjan A, Jha JK (2019) Pricing and coordination strategies of a dual-channel supply chain considering green quality and sales effort. J Clean Prod 218:409–424

Ren D, Guo R, Lan Y, Shang C (2021) Shareholding strategies for selling green products on online platforms in a two-echelon supply chain. Trans Res E: Logistics Trans Rev 149:102261

Rizzi F, Gigliotti M, Runfola A, Ferrucci L (2022) Don't miss the boat when consumers are in-store! Exploring the use of point-of-purchase displays to promote green and non-green products. J Retail Consum Serv 68:103034

Shen B, Cao Y, Xu X (2020) Product line design and quality differentiation for green and non-green products in a supply chain. Int J Prod Res 58:148–164

Shi J (2019) Contract manufacturer's encroachment strategy and quality decision with different channel leadership structures. Comput Ind Eng 137:106078

Shi J, Yang D, Zheng Z, Zhu Y (2022) Strategic investment for green product development and green marketing in a supply chain. J Clean Prod 366:132868

Sun R, Ding Y, Wen C, Gao K (2022) Research on cross-shareholding behavior of Chinese listed companies. J Invest Manag 11:25–32

Taylor T (2002) Supply chain coordination under channel rebates with sales effort effects. Manage Sci 48:992–1007

Tian J, Cao W, Ji X (2021) Is cross-shareholding conducive to corporate sustainability? Evidence from the environmental investment of Chinese listed firms. Front Psychol 12:789811

Wang L, Song Q (2020) Pricing policies for dual-channel supply chain with green investment and sales effort under uncertain demand. Math Comput Simul 171:79–93

Wei Z, Huang Y (2022) Supply chain coordination under carbon emission tax regulation considering greening technology investment. Int J Environ Res Public Health 19(15):9232

Xia Q, Zhi B, Wang X (2021) The role of cross-shareholding in the green supply chain: green contribution, power structure and coordination. Int J Prod Econ 234:108037

Xiao T, Choi TM (2019) Quality, greenness, and product line choices for a manufacturer with environmental responsibility behaviors. IEEE Trans Eng Manage 67:1–15

Zeng H, Jiang D, Li Y (2022) Cooperative and non-cooperative green advertising in the low-carbon supply chain under monopoly or competitive market. Sustainability 14(15):9190

Zhang S, Meng Q (2021) Electronics closed-loop supply chain value co-creation considering cross-shareholding. J Clean Prod 278:123878

Zhang X, Chen T, Shen C (2020) Green investment choice in a duopoly market with quality competition. J Clean Prod 276:124032

Zhu J, Gao Y, Shi Y, Paul SK (2022) Green investment mechanism considering supply chain risk aversion and negotiating power. Comput Ind Eng 171:108484