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Article

Manufacturer's Green Production Strategies under Partial Vertical Shareholding

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Abstract

Strengthened environmental regulations, upgraded demand for green consumption, and the expansion of direct-to-consumer channels via the internet are driving corporate green transformation. However, rising green production costs are dampening companies' motivation to transition. How to enhance corporate incentives for green production while ensuring profitability has become a key issue in green supply chain management. This paper proposes an equity-based cooperation strategy among supply chain enterprises, constructing a two-tier supply chain model comprising green manufacturers and retailers. By integrating factors such as green products, channel competition, equity strategies, and direct sales, it examines the impact of retailers' partial vertical ownership over manufacturers. The analysis focuses on changes in product greenness, pricing decisions, and supply chain profitability under different scenarios. Findings indicate that heightened consumer green preferences benefit all supply chain participants; channel competition effects are constrained by direct sales costs; increased retailer ownership enhances overall supply chain profitability and mitigates the double marginalization effect. Furthermore, the impact on product greenness varies across channels, collectively highlighting the positive role of equity-based collaboration.

Keywords: green supply chain; partial vertical ownership; manufacturer intrusion; consumer green preference; channel competition.

1. Introduction

In recent years, rapid economic development has increasingly highlighted environmental issues stemming from industrialization. Problems such as ecological degradation, frequent natural disasters, resource scarcity, and human health concerns have intensified. To address these challenges, governments and international organizations have formulated environmental protection policies and regulations, encouraging enterprises to adopt green production methods to tackle pollution and carbon emissions. In 2024, China issued the "Green and Low-Carbon Transformation Industry Guidance Catalog (2024 Edition)" [1]. Later, the Opinions on Accelerating the Comprehensive Green Transformation of Economic and Social Development were further issued, making systematic arrangements for

accelerating this transformation. Recent research data from NielsenIQ and McKinsey indicates that high-income households, urban populations, and families with children are more inclined to purchase products with ESG claims, which also exhibit higher repurchase rates [2]. Domestically, according to the China E-commerce Green Development Report and the 2023 China Consumption Trends Report, over 60% of respondents are aware of and support green consumption. Among them, younger demographics like those born in the 1990s and 2000s demonstrate higher green consumption awareness, reaching 70% and 79% respectively. An increasing number of consumers are practicing green consumption by purchasing eco-friendly products and engaging in secondhand transactions. These figures underscore the public's growing awareness and desire for sustainable consumption, alongside the younger generation's proactive role in driving this shift. Furthermore, the Chinese government has intensified environmental oversight, rectifying non-compliant enterprises and accelerating the transition from traditional to green industries.

Since the mid-to-late 1990s, the proliferation of the Internet and the rapid development of e-commerce have made manufacturer direct selling increasingly prevalent. Manufacturer direct selling refers to a strategy in which manufacturers bypass intermediaries and sell products directly to end consumers, thereby enhancing supply chain efficiency and strengthening control over branding and customer relationships. To capitalize on these opportunities, direct selling has evolved into diverse forms. Many international brands, such as Dell, IBM, Nike, and Apple, as well as domestic firms including Xiaomi, Gree, Huawei, and Moutai, have adopted dual-channel structures that combine traditional wholesale–retail channels with online direct sales through proprietary platforms. In addition, some firms reinforce direct consumer engagement through social media and mobile applications, enabling personalized marketing and customized services [3].In practice, aggressive market expansion by manufacturers is often realized through direct selling. However, traditional retail channels retain advantages in physical coverage and regional market penetration, which remain critical for reaching geographically dispersed consumer segments. As a result, manufacturers frequently operate both traditional retail channels and direct sales channels simultaneously. This coexistence generates horizontal competition between channels, requiring manufacturers to carefully balance the efficiency gains from direct selling against the stability of retailer relationships.

However, in the context of green and low-carbon development, manufacturers must carefully evaluate the impact of green production costs on corporate profitability when developing new sales channels. Relying solely on internal resources and capabilities proves insufficient to adapt to rapidly changing market conditions. Increased green production costs may adversely affect short-term profits, potentially dampening manufacturers' enthusiasm for green production and thereby hindering the industry's green transformation. Against this backdrop, manufacturing enterprises must rethink the relationship between their own development and the evolution of competitive landscapes. They should continuously transcend organizational boundaries and actively engage in green collaboration with supply chain partners to achieve mutual benefits. Equity transactions within supply chains play a pivotal role as a financial tool [4]. The primary form of equity holding involves establishing strategic alliances through equity transactions, enabling upstream and downstream enterprises to jointly bear the costs and risks of green production. This effectively alleviates the economic pressure faced by manufacturing enterprises when pursuing emissions reductions independently. Inter-firm equity holdings represent a common phenomenon, primarily categorized into vertical and horizontal equity holdings. Vertical equity holdings refer to equity investments made between upstream and downstream enterprises within a supply chain, while horizontal equity holdings involve equity investments between different enterprises within the same industrial chain or sector. Vertical equity holdings are prevalent in industries such as automotive, energy, pharmaceuticals, and retail. In 2020, Alibaba acquired a 14.4% stake in XPeng Motors, while XPeng vehicles began selling on Alibaba's platforms. This marked Alibaba's entry into the new energy vehicle market, enabling resource integration and multi-faceted cooperation between the two companies to expand sales channels [5]. The Gree Dealer Alliance held an 8.91% stake in Gree Electric Appliances Inc. in 2019[6]. After a decade of R&D, Gree Electric unveiled its zero-carbon-source air conditioning technology, overcoming existing energy efficiency limitations and reducing carbon emissions from air conditioners by 85.7%. These strategic equity alliances effectively alleviate cash flow constraints for the invested companies while enabling retailers to better account for manufacturers' green investment

efforts. This fosters closer collaboration between upstream and downstream enterprises, increasing supply chain-wide profitability and making such arrangements highly favored by major corporations.

Therefore, within the context of green and low-carbon development, this paper integrates green products, channel competition, and equity strategies with direct sales models. It explores the impact of partial vertical holdings and different equity structures on manufacturers' green production and penetration strategies, optimal supply chain decisions, and profitability. By constructing a multi-agent game model for manufacturers' green production and penetration decisions based on partial vertical holdings, and comparing the model's equilibrium solutions, we expect to derive a series of interesting conclusions and management insights with practical value.

Against the backdrop of deepening green and low-carbon development strategies, the direct sales model has emerged as a critical choice for manufacturers to integrate channel resources and enhance market competitiveness. While partial vertical ownership serves as a key mechanism for supply chain collaboration, whether different ownership structures exert heterogeneous effects on manufacturers' green production decisions and channel penetration strategies remains unresolved. Based on this, this paper explicitly proposes the following core research questions: First, in scenarios where direct sales coexist with channel competition, does the introduction of partial vertical ownership by retailers drive manufacturers to enhance green production levels? Second, how does partial vertical ownership by retailers modulate manufacturers' channel penetration strategy choices, thereby influencing the decision-making logic of various supply chain entities? Third, what are the specific causal pathways through which partial vertical ownership by retailers and its structure influence core decision variables such as optimal pricing, green investments, and production volume within the supply chain? Can this achieve synergistic improvements in overall profits? By constructing a multi-agent game model, this paper provides actionable management insights for manufacturers' green production practices, channel layout optimization, and collaborative supply chain governance.

Currently, green and low-carbon economies represent significant developmental trends. The international community widely advocates reducing carbon emissions, protecting the environment, and promoting sustainable development. Building upon extensive research in green supply chains and manufacturer supply chain penetration, this paper examines green production and penetration strategies for manufacturers with partial vertical holdings in a green context. It provides theoretical foundations for channel member decision-making in green and low-carbon supply chains.

This paper constructs a two-tier supply chain model comprising a single green manufacturer and a single retailer. It assumes the manufacturer produces two substitutable products with differing levels of environmental sustainability, sold to consumers through competing channels: traditional retail and direct sales. Both the manufacturer and retailer are rational actors aiming to maximize profits. The manufacturer incurs costs for green R&D and direct sales, while consumers exhibit green preferences. Building upon this framework, the study introduces a partial vertical equity holding strategy by the retailer in the manufacturer to examine how such holdings influence supply chain decisions. Key factors including product greenness, channel competition, and consumer green preferences are incorporated into demand and profit functions for analysis.

By constructing a multi-agent game model for manufacturers' green production and penetration decisions based on partial vertical ownership, this study compares equilibrium outcomes across different decision scenarios. Findings reveal that partial vertical ownership effectively alleviates manufacturers' green investment pressures, reduces retailers' free-riding behavior, and enhances manufacturers' motivation for green production. Different ownership structures exert varying impacts on product greenness, wholesale prices, and retail prices. A reasonable vertical ownership ratio can balance channel competition and optimize overall supply chain profits. Consumer green preferences and channel competition intensity moderate the effectiveness of ownership strategies. Higher green preferences and more moderate channel competition amplify the positive impact of ownership strategies on the supply chain.

Theoretically, this study enriches and expands research on green production and intrusion strategies by manufacturers with partial vertical holdings in a green context. Existing green supply chain studies, both domestically and internationally, predominantly focus on single traditional retail channels, with limited research examining supply chains where manufacturers simultaneously engage in traditional

retail sales and direct market intrusion under green and low-carbon conditions. In most literature, green investment costs are borne solely by upstream enterprises. This paper proposes that, under manufacturer penetration scenarios, upstream and downstream enterprises share green investment costs through equity holdings. It further examines different equity participation models among supply chain members, potentially expanding research on manufacturer penetration within green supply chains. Among existing studies on equity strategies, few integrate equity partnerships with green contexts. This paper examines inter-firm equity arrangements and analyzes how consumer green preferences influence supply chain members' decisions and profits under green conditions, providing theoretical guidance for manufacturers implementing green production and penetration strategies.

Most manufacturers face resource and support constraints in green production. They must bear substantial green investment costs before producing eco-friendly products. When wholesaling these products to downstream retailers, manufacturers risk retailers free riding on their green efforts to capture sales profits. Equity cooperation between upstream and downstream enterprises not only helps upstream firms share the costs of green product investments and mitigate retailers' free-riding behavior, thereby boosting upstream green investment incentives, but also fosters more sustainable, efficient, innovative, and market-competitive business models. Against the backdrop of green and low-carbon development, this paper examines how partial vertical equity-based green production and penetration strategies by manufacturers impact the environmental performance, wholesale prices, retail prices, and profits of supply chain members for two product types. It offers management insights to enhance manufacturers' green production incentives and mitigate free riding, providing practical guidance.

The study examines variations in key factors including product greenness, green R&D costs, direct sales costs, consumer green preferences, channel competition, and equity stakes. It investigates whether partial vertical equity holdings and different equity structures influence decision-making among supply chain members when manufacturers adopt penetration strategies while maintaining traditional retail partnerships. The manufacturer's penetration strategy is manifested through establishing direct sales channels. When considering partial vertical equity ownership strategies, the study primarily examines whether equity cooperation between manufacturers and retailers during direct channel development can mitigate the double marginal effect in the supply chain under green conditions. It also investigates the impact of different ownership structures on product greenness, retail prices, and member profit levels within the supply chain. This paper incorporates the aforementioned key factors as parameters within demand and profit functions, analyzing how critical variables—such as channel competition and consumer green preferences—influence optimal supply chain decisions. For upstream green manufacturers, enhancing product greenness inevitably incurs additional green investment costs, increasing financial pressure. Simultaneously, establishing direct sales channels requires certain direct sales costs. Once manufacturers open direct sales channels, they inevitably encroach upon traditional retail channels, triggering competition between the two channels. Furthermore, increased product greenness positively stimulates demand among consumers with green preferences.

2. Literature Review

This study focuses on green supply chain contexts, primarily examining manufacturer incursion and partial cross-ownership strategies between enterprises. To thoroughly explore the research background and current landscape, this section synthesizes domestic and international research trends in related fields, providing a reliable foundation for subsequent investigations.

2.1. Green Supply Chain Research

The concept of green supply chains was first proposed by the Manufacturing Institute at Michigan State University, also referred to as environmental supply chains or eco-friendly supply chains. It aims to promote supplier development through comprehensive, systematic, and organic methods, thereby achieving efficient environmental conservation, energy savings, and sustainable development goals. Management issues within green supply chains have increasingly become a hot topic in academic research. Much of the related research has primarily focused on two aspects: green product pricing decisions within the supply chain and green cost decisions.

As environmental concerns intensify, consumer demand for eco-friendly products continues to rise.

Therefore, adopting green supply chain pricing strategies not only meets consumer needs and enhances product competitiveness but also builds corporate reputation, earning consumer trust and support. Meng et al. [7] developed a green supply chain model incorporating consumer green preferences based on Stackelberg game theory, while also considering government green subsidies to investigate green product pricing strategies. Building upon this, Long et al. [8] integrated corporate green sensitivity and consumer green preferences into a tertiary manufacturing closed-loop supply chain. They constructed Stackelberg game models under government subsidies, featuring manufacturer-led and retailer-led scenarios, to examine how supply chain members' green attitudes influence product pricing behavior. In terms of multi-channel, Rahmani et al. [9] studied how to address the challenges of carbon reduction and pricing in the face of market demand disruption when adopting a dual channel strategy in the supply chain. In domestic research, Zhang and Han [10] observed that under carbon tax policies, producers gradually reduce product prices and patent fees as consumer environmental awareness increases. Wu YP [11] found that when considering retailer risk aversion and big data marketing, different risk-averse behaviors affect product greenness, supply chain pricing, and total supply chain profits, enabling overall supply chain Pareto improvement under certain conditions. Liang and Hu [12] studied the issue of distrust in the recycling process of green products and analyzed the impact of retailers and third-party recycling on the pricing of green products through whether manufacturers use blockchain technology.

Research on green supply chain investment costs is crucial for corporate decision-making and strategy formulation. It helps enterprises evaluate the economic benefits of green supply chains and supports sustainable development. Chen and Uly [13] examined the impact of consumer environmental awareness and government incentive-penalty policies, finding that incentive-penalty mechanisms can enhance corporate returns and green initiatives. Based on consumer green awareness, Wang et al. [14] examined decision-making and coordination issues in green e-commerce supply chains where green manufacturers balance product greenness and service levels while considering fairness. They constructed centralized and decentralized models with and without fairness concerns, respectively, and analyzed their implications. Heydari et al. [15] established a coordinated, environmentally friendly decision model for a three-tier dual-channel supply chain where manufacturers produce and sell goods with a certain level of greenness to distributors possessing both electronic and retail channels. Yi et al. [16] examined the impact of green subsidies and emission taxes on green technology development within a supply chain comprising manufacturers and retailers, where manufacturers are responsible for green technology investments and retailers handle marketing and sales to consumers with green preferences. Beyond the green production costs associated with R&D for green products, supply chain costs encompass green transportation, green packaging, and green storage. Rossi et al. [17] proposed an approach based on quantifying the economic sustainability of new logistics models, enabling sustainable perishable food transportation and eliminating barriers to implementing multimodal transport for perishables. Domestic research on green R&D costs includes Pan et al. [18], who constructed four game models under a carbon trading system: one where retailers do not share manufacturers' costs, and three where retailers share manufacturers' green technology R&D costs, production costs, and carbon trading costs, examining different cost-sharing contract choices. Li et al. [19] examined inter-chain competition between two green supply chains and the sharing of green R&D costs among manufacturers and retailers within each chain. Using a non-cooperative-cooperative dual-type game approach, they investigated equilibrium prices and optimal profits in supply chains where competition and cooperation coexist. Shang and Chen [20] established a cost-sharing game model for R&D expenses between manufacturers and retailers within a green supply chain context. Through numerical simulation, they determined the optimal allocation range for retailers' R&D costs. Similarly, regarding other green costs, Shi and Wang [21] constructed a structural model for the green supply chain of prefabricated buildings, providing support and decision-making basis for its optimized management, while offering relevant suggestions for operational issues. Jiang et al. [22] addressed the dynamic route optimization problem for vehicles under green and low-carbon conditions, effectively reducing total route costs using an improved adaptive genetic algorithm, offering insights for enterprise distribution challenges.

Existing research in the field of green supply chains has produced numerous studies that simultaneously address product pricing decisions and green investment cost decisions. These studies primarily focus on core issues such as optimizing pricing strategies for various supply chain entities and

designing green cost allocation mechanisms. However, existing research generally shares a common limitation: most literature implicitly assumes that green investment costs are borne solely by upstream enterprises. It fails to consider alleviating the green investment burden on upstream enterprises through vertical supply chain collaboration mechanisms, nor does it deeply explore the impact pathways of vertical collaboration models on the decision-making behaviors and profit distribution among all members of the entire supply chain.

Compared to prior studies, this research uniquely contributes by simultaneously addressing dual decision dimensions—product pricing and green investment cost—while challenging the conventional assumption that green investment costs are solely borne by upstream firms. It innovatively proposes partial vertical equity holding strategies, detailing their implementation pathways and operational mechanisms to systematically examining how vertical equity holdings influence pricing decisions, green investment choices, and profit levels across upstream and downstream supply chain members. This fills a gap in existing research by linking vertical equity collaboration with dual decision-making in green supply chains, offering new theoretical perspectives and practical pathways for alleviating green investment pressures and optimizing overall green supply chain operational efficiency.

2.2. Related Research on Shareholding Strategies

In supply chains, mutual equity holdings refer to the establishment of equity relationships among different enterprises through the purchase of shares in other companies. Such holdings can be unilateral—where one firm acquires shares in another—or reciprocal, involving mutual share purchases between two firms.

In unilateral equity holdings, the literature refer to upstream suppliers or manufacturers holding equity in downstream retailers or distributors as forward equity holdings, while downstream enterprises holding unilateral equity in upstream enterprises is termed reverse equity holdings. Numerous scholars have conducted extensive research on this topic. Kang and Zhang [23] established a forward-holding service supply chain and developed a financing decision model for financial leasing and installment factoring financing, examining the impact of profitability and equity ratios on these financing methods. Regarding reverse-holding research, Fu et al. [24] examined scenarios where downstream firms hold equity in upstream firms. They found that downstream firms can share in upstream profits determined by their equity stakes and provide essential support for enhancing upstream production efficiency, thereby benefiting the entire supply chain system. In domestic research, He et al. [25] examined supplier equity holdings in retailers within supplier-dominated Stackelberg games, finding that increased supplier equity boosts demand across channels and supply chain profits while harming retailers. Fan et al. [26] studied retailer equity holdings in manufacturers' emission reduction investments, discovering that equity strategies simultaneously enhance environmental standards and corporate economic benefits, thereby improving supply chain emission reduction outcomes. Yang et al. [27] found that when downstream firms face capacity constraints, backward ownership facilitates collusion among upstream firms but weakens their incentive for capacity investment. Conversely, forward ownership promotes competition among upstream firms and strengthens their incentive for capacity investment.

In cross-shareholding arrangements, two or more companies establish mutual equity relationships by purchasing each other's shares. This form of ownership aims to strengthen collaboration, share resources, and foster the formation of long-term cooperative relationships. Scholars have also conducted extensive research on cross-shareholding. Xia et al. [28] examined the impact of cross-shareholding on pricing strategies, carbon emissions reduction, and profits under two distinct supply chain models with different power structures: manufacturer-dominated supply chains and retailer-dominated supply chains. Ren et al. [29] examined the effects of equity stakes on green investment, pricing, and profits while discussing participants' strategic preferences. They found that when both cross-shareholding ratios are sufficiently low, the cross-shareholding strategy yields the optimal profit enhancement for both parties. Wu et al. [30] examined the combined effects of vertical cross-shareholding and external financing on the ordering strategy of capital-constrained retailers. They found that under cross-shareholding, retailers place more orders when either their own funds or external financing is sufficient, achieving a win-win outcome for both suppliers and retailers. In domestic research, Xia et al. [31] introduced cross-shareholding strategies into manufacturers' emission reduction decisions under carbon trading

mechanisms. They found that cross-shareholding alters the impact of carbon trading prices on manufacturers' emission reductions, increases per-unit emission reductions and market demand, and under certain conditions lowers wholesale and retail prices while boosting profits for both manufacturers and retailers, thereby achieving supply chain coordination. Wu et al. [32] examined the moderating effect of capacity sharing and cross-shareholding strategies on competition among airlines. Under cross-shareholding arrangements, firms were willing to adopt capacity sharing strategies at moderate cross-shareholding ratios when capacities were symmetric; however, they were reluctant to implement capacity sharing when capacities were asymmetric. Shi et al. [33] examined the profit distribution of inter-firm cross-shareholding and equilibrium strategies under Bertrand oligopoly markets. Findings indicate that cross-shareholding exhibits anti-competitive and pro-cooperative effects in substitute markets, elevating equilibrium prices while reducing output levels and creating a win-win scenario.

While research on equity strategies is extensive, most studies focus on single-channel equity arrangements, with limited literature integrating equity cooperation with green contexts. Under green economic frameworks, research combining dual-channel supply chains with equity cooperation remains scarce. This paper examines the impact of partial vertical equity holdings between firms and consumer green preferences on decision-making and profits within dual-channel supply chains. It enriches research on inter-firm equity cooperation and offers insights for related managerial operations.

2.3. Literature Summary

Reviewing the above literature reveals that research on green supply chains has achieved certain results. The core of green supply chain research focuses on two key decision-making dimensions: green product pricing and green investment costs. Scholars have largely drawn on game theory, incorporating factors such as consumer green preferences, government policies, and channel structures into their analyses to explore the impact of pricing optimization and the design of cost-sharing mechanisms. However, existing research has clear limitations. It generally assumes that green investment costs are borne solely by upstream firms, fails to explore the role of vertical supply chain collaboration in alleviating the investment burden on upstream firms, and lacks a systematic analysis of how such collaboration influences the decision-making and profit-sharing mechanisms among supply chain members. Research on corporate equity holding strategies is divided into two categories: unilateral equity holding and cross-shareholding. Existing studies have examined the effects of different equity models on supply chain financing, production efficiency, emission reduction investments, pricing, and corporate competition, confirming the positive significance of moderate equity ratios in enhancing supply chain efficiency and achieving coordination. However, most relevant research focuses on single-channel equity arrangements, with few studies integrating equity cooperation with the context of the green economy, and even fewer that combine dual-channel supply chains, consumer green preferences, and equity cooperation. This study achieves an innovative integration of two major fields, with its core contributions manifested as follows: it challenges the traditional assumption that green investment costs are borne solely by upstream entities, incorporating product pricing and green investment cost decisions into a unified analytical framework; It innovatively proposes a partial vertical equity holding strategy, systematically analyzing its operational mechanisms and impacts on upstream and downstream pricing, green investment, and profits within the green supply chain; by integrating dual-channel supply chains with consumer green preferences, it analyzes the interactive effects between these factors and equity strategies, filling a research gap in equity cooperation within dual-channel supply chains under the green economy framework, and providing new theoretical perspectives and practical references for the development of vertical collaboration in green supply chains.

3. Manufacturer Green Production and Intrusion Strategy Model Under Partial Vertical Ownership by Retailer

3.1. Model Description

As consumer preferences for green products intensify and low-carbon policies advance, a manufacturer faces pressure to invest in emissions reduction. However, undertaking such investments

alone imposes significant financial strain, and a retailer may engage in free-riding after reductions occur, dampening manufacturer's investment incentives. This section investigates how supply chain collaboration—specifically equity partnership strategies—can reduce a manufacturer's standalone emission reduction costs, enhance the robustness of inter-firm cooperation, and strengthen overall supply chain competitiveness. Practical examples include Alibaba's equity stake in XPeng Motors and Gree Electric Appliances' dealerships holding shares in Gree, where retailer's equity investments alleviate manufacturer's emission reduction burdens.

Against the backdrop of a dual green channel, consumers' green awareness can drive them to purchase green products priced higher than conventional alternatives. Consequently, under the influence of this green consciousness, enterprises producing green products can expand their market demand. A Green manufacturer sell two distinct green-level products through traditional offline retail channels and online direct sales channels respectively, creating a competitive relationship between the two channels. Product demand across both channels is determined by product green level and price, with the demand function defined as follows:

$$q_m^{BR} = Q - p_m^{BR} + k(p_r^{BR} - p_m^{BR}) + \lambda[\theta_m^{BR} - k(\theta_r^{BR} - \theta_m^{BR})] \quad (1)$$

$$q_r^{BR} = Q - p_r^{BR} + k(p_m^{BR} - p_r^{BR}) + \lambda[\theta_r^{BR} - k(\theta_m^{BR} - \theta_r^{BR})] \quad (2)$$

Here, Q represents market size, p_m^{BR} and p_r^{BR} denote the manufacturer's and retailer's retail prices respectively, and k is the competition coefficient between the two channels, indicating the intensity of competition. When k=0, it signifies that these two channels are completely independent. λ is the sensitivity coefficient for consumer demand for green products; the larger λ is, the greater the consumer demand for green products. $\theta_i^{BR}(i = \mathrm{r}, \mathrm{m})$ represents the greenness of the two products.

The article sets the cost of manufacturer's investment in product greenness as $C(\theta_i^{BR}) = \frac{1}{2}\beta(\theta_i^{BR})^2$ [34], where the parameter β represents the cost coefficient of manufacturer's green investment, and θ_i^{BR} denotes the greenness of two products. It is straightforward to derive that its value range is $0 < \theta_i^{BR} < 1$. The larger θ_i^{BR} is, the higher the environmental friendliness of the product and the more beneficial it is to the environment. Differentiating the green investment cost $C(\theta_i^{BR})$ with respect to greenness θ_i^{BR} yields: $\frac{\partial C(\theta_i^{BR})}{\partial \theta_i^{BR}} > 0$. This indicates that green costs increase as greenness increases. For goods sold through direct sales channels, manufacturers incur a fixed direct sales cost per unit c^{BR}, which is dependent on the volume of demand.

This section examines vertical equity holdings by retailer in manufacturer, where retailer hold a partial stake in manufacturer, denoted by h . Under partial ownership, a retailer incurs equity payment costs to a manufacturer while receiving h of the manufacturer's profits from . In this supply chain model, the retailer holds dominant influence, possessing greater autonomy when considering its own interests. Furthermore, the retailer's equity stake in the manufacturer mitigates some of the pressure on the manufacturer to reduce emissions independently[26][28]. The retailer pays an equity cost to acquire the manufacturer's shares, and a manufacturer can invest these funds into green R&D for its products.

This section introduces equity ownership ratios. Under retailer dominance, it examines how increasing equity ratios impacts the profits of individual supply chain members and the overall supply chain profitability. Specifically, the equity ratio is incorporated into the manufacturer's profit function. This analysis investigates whether a manufacturer holds equity and how the magnitude of their equity stake influences decisions within the dual-channel supply chain. This study assumes equity payment costs are one-time expenses that do not influence decision-making parameters for supply chain members. To simplify calculations, equity payment costs are excluded from the profit function formula [35].

In a retailer partial ownership model, the retailer holds a dominant position and thus acts as the leader in the Stackelberg game, with a manufacturer as the follower. The game sequence is illustrated in Figure 1: In the first stage, the retailer, as the leader, makes the initial decision to determine the product markup$z$, which represents the retailer's marginal profit. In the second stage, based on the retailer's decision, the manufacturer, as the follower, makes its decision to determine the greenness level θ_i of the two channel products and the wholesale price $w$of the green product. In the third stage, a manufacturer

makes its decision for the direct sales channel based on the situation in the traditional channel, determining the retail price p_m for the direct sales channel. The supply chain model diagram is shown in Figure 2.

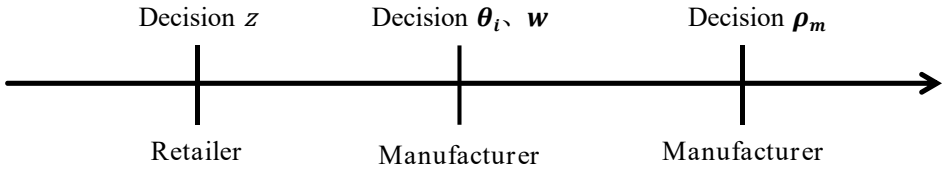


Figure 1. Game Sequence for the Partially Owned Retailer Model

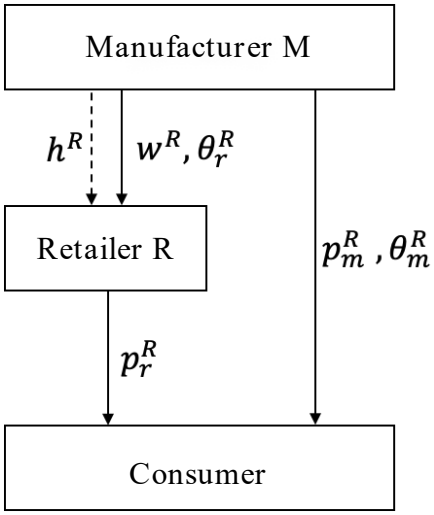


Figure 2. Retailer Partial Ownership Manufacturer Model

The superscript R denotes the retailer-dominant partial ownership model. In this model, the demand functions and profit functions for the manufacturer and the retailer are respectively:

$$q_m^R = Q - p_m^R + k(p_r^R - p_m^R) + \lambda[\theta_m^R - k(\theta_r^R - \theta_m^R)] \tag{3}$$

$$q_r^R = Q - p_r^R + k(p_m^R - p_r^R) + \lambda[\theta_r^R - k(\theta_m^R - \theta_r^R)] \tag{4}$$

$$\max\Pi_m^R = (1 - h^R)[w^R q_r^R + (p_m^R - c^R)q_m^R - \frac{1}{2}\beta(\theta_r^R)^2 - \frac{1}{2}\beta(\theta_m^R)^2] \tag{5}$$

$$\max\Pi_r^R = h^R[w^R q_r^R + (p_m^R - c^R)q_m^R - \frac{1}{2}\beta(\theta_r^R)^2 - \frac{1}{2}\beta(\theta_m^R)^2] + (p_r^R - w^R)q_r^R \tag{6}$$

$p_r^R = w^R + z^R$, wherez^R represents the markup added by a retailer to the manufacturer's wholesale price.

3.2. Notations

The notations and their corresponding meanings discussed in this section are shown in Table 3-1:

Table 3-1. Notations and Their Descriptions

Notations	Descriptions
Parameter	
Q	Market Potential Capacity
λ	Green preference coefficient for green products among consumers, $0 \leq \lambda \leq 1$
k	Competition coefficient between two channels,$0 \leq k \leq 1$
h^R	Equity ratio ,$0 \leq h^R \leq 1$
β	Manufacturer's green investment cost coefficient,$\beta > 0$
c^R	Unit fixed direct sales cost,$c^R > 0$
z^R	The markup added by retailer to the wholesale price, i.e., marginal profit
Decision variables	
p_i^R	Retail price for each supply chain member,$i = r, m$
w^R	Manufacturer's wholesale price
θ_i^R	Product greenness,$i = r, m$
Dependent variable	
q_i^R	Demand functions for different sales channels,$i = r, m$
Π_i^R	Profit functions of supply chain members,$i = r, m$

3.3. Model Solution

First, solve the non-equity model dominated by retailer. Supply chain members aim to maximize their respective profits. Using the inverse solution method, solve for the second derivative of the manufacturer's profit function with respect to the online retail price p_m^{BR} :

$$\frac{\partial(\Pi_m^R)^2}{\partial^2 p_m^R} = (2k+2)(h^R - 1) < 0 \tag{7}$$

This indicates that Π_m^R is a concave function with respect to p_m^R , implying the existence of a maximum point. Setting the first derivative of the manufacturer's profit function equal to zero yields the optimal solution forp_m^R :

$$p_m^R = \frac{Q+\lambda[\theta_m^R+k(\theta_m^R-\theta_r^R)]+k(w^R+z^R)+kw^R+c^R(k+1)}{2k+2} \tag{8}$$

Substituting the optimal solution for the online retail pricep_m^R into the manufacturer's profit function allows the manufacturer to determine the product's wholesale price (w^R) and the product's greenness (θ_i^R), with the decision objective being to maximize the manufacturer's own profit:

$$\max\Pi_m^R = w^R\{Q - p_r^R + k(p_m^M - p_r^M) + \lambda[\theta_r^M - k(\theta_m^M - \theta_r^M)]\} + (p_m^M - c^M)\{Q - p_m^M + k(p_r^M - p_m^M) + \lambda[\theta_m^M - k(\theta_r^M - \theta_m^M)]\} - \frac{1}{2}\beta(\theta_r^M)^2 - \frac{1}{2}\beta(\theta_m^M)^2 \tag{9}$$

Solve for the Hessian matrix of the manufacturer's profit function with respect to the wholesale price (w^R) and the product's greenness (θ_i^R):

$$H = \begin{bmatrix} \frac{(16k+8)(h^R-1)}{4(k+1)} & 0 & \frac{-\lambda(2k+1)(h^R-1)}{k+1} \\ 0 & \frac{-(h^R-1)(k\lambda^2-2\beta+\lambda^2)}{2} & \frac{k\lambda^2(h^R-1)}{2} \\ \frac{-\lambda(2k+1)(h^R-1)}{k+1} & \frac{k\lambda^2(h^R-1)}{2} & \frac{(h^R-1)(-2k^2\lambda^2+4\beta k+4\beta)}{4(k+1)} \end{bmatrix} \tag{10}$$

Perform a negative definite test on the Hessian matrix to ensure alternating signs in its principal minors. For the first-order Hessian matrix: $H(1,1) = \frac{(16k+8)(h^R-1)}{4(k+1)} < 0$; for the second-order Hessian matrix:$H(1:2,1:2) = \frac{(2k+1)(h^R-1)^2(2\beta-k\lambda^2-\lambda^2)}{k+1} > 0$. Let$2\beta - k\lambda^2 - \lambda^2 > 0$, yielding$\beta > \frac{\lambda^2(k+1)}{2}$. Thus, when $\beta > \beta_1 = \frac{\lambda^2(k+1)}{2}$ holds, $H(1:2,1:2) > 0$. For the third-order Hessian matrix:$H(1:3,1:3) = \frac{-(h^R-1)^3(2k+1)(-\lambda^2+2\beta)(2k\lambda^2-2\beta+\lambda^2)}{2(k+1)}$. Let$(-\lambda^2 + 2\beta)(2k\lambda^2 - 2\beta + \lambda^2) < 0$, yielding $\beta > \frac{\lambda^2(2k+1)}{2}$ or $0 < \beta < \frac{\lambda^2}{2}$. Compared to β_1 , β satisfies $\beta > \beta_2 = \frac{\lambda^2(2k+1)}{2}$ when $H(1:3,1:3) < 0$, confirming the Hessian matrix is negative definite.

The manufacturer's profit function is a concave function with respect to wholesale price (w^R) and product greenness (θ_i^R). Setting the first derivatives equal to zero and solving simultaneously yields the following optimal solution:

$$w^R = \frac{2\beta^2(Q-z^R)+\beta\lambda^2[(z^R+c^R-2Q)k+z^R-Q]}{(\lambda^2-2\beta)[(2k+1)\lambda^2-2\beta]} \tag{11}$$

$$\theta_r^R = -\frac{2\beta\lambda[k(z^R-c^R)+z^R-Q]-\lambda^3(2k+1)(z^R-Q)}{(\lambda^2-2\beta)[(2k+1)\lambda^2-2\beta]} \tag{12}$$

$$\theta_m^R = \frac{2\beta\lambda[k(z^R-c^R)-c^R+Q]+\lambda^3(2k+1)(c^R-Q)}{(\lambda^2-2\beta)[(2k+1)\lambda^2-2\beta]} \tag{13}$$

Substituting the optimal solutions for the wholesale price (w^R) and the product's greenness (θ_i^R), we solve for the second derivative of the retailer's profit function with respect to the markup (z^R) under the traditional channel in the first stage:

$$\frac{\partial(\Pi_r^R)^2}{\partial^2 z^R} < 0 \tag{14}$$

This demonstrates that Π_r^R is a concave function with respect toz^R , indicating the existence of a maximum point. Setting the first derivative of the retailer's profit function equal to zero yields the optimal solution forz^R :

$$z^R = \frac{(1-h^R)[Q\lambda^2(2k+1)-2\beta(c^Rk+Q)]}{(2-h^R)[(2k+1)\lambda^2-2\beta(k+1)]} \tag{15}$$

Substituting the optimal markup (z^R) back into the equation yields the equilibrium result, as shown in Theorem 3.1.

Theorem 3.1: In the retailer's equity strategy model under manufacturer intrusion, the equilibrium solutions for decision variables and the profit functions of both manufacturer and retailer are as follows:

$\Pi_{\mathrm{m}}^{\mathrm{R}}=\frac{\beta\left(h^{R}-1\right)\left[4\beta^{2}C_{1}+\lambda^{4}(2k+1)^{2}C_{2}-4\beta(2k+1)\lambda^{2}C_{3}\right]}{2(h^{R}-2)^{2}A}$;$\Pi_{\mathrm{r}}^{\mathrm{R}}=\frac{\beta\left[4\beta^{2}C_{4}+\lambda^{4}(2k+1)^{2}C_{5}-4\beta(2k+1)\lambda^{2}C_{6}\right]}{2(h^{R}-2)^{2}A}$;

$p_{r}^{R}=\frac{(1-h^{R})\left[Q\lambda^{2}(2k+1)-2\beta\left(c^{R}k+Q\right)\right]}{(2-h^{R})\left[(2k+1)\lambda^{2}-2\beta(k+1)\right]}+\frac{\beta\left[4\beta^{2}C_{7}+\lambda^{4}(2k+1)C_{8}-2\beta\lambda^{2}C_{9}\right]}{(h^{R}-2)A}$;$p_{m}^{R}=\frac{2\beta^{2}\lambda^{2}C_{11}+C_{12}-\lambda^{4}(2k+1)\beta C_{10}}{(2-h^{R})A}$;

$w^{R}=\frac{\beta\left[4\beta^{2}C_{7}+\lambda^{4}(2k+1)C_{8}-2\beta\lambda^{2}C_{9}\right]}{(h^{R}-2)A}$;$\theta_{m}^{R}=\frac{\lambda\left[4\beta^{2}C_{13}+\lambda^{4}(2k+1)^{2}\left(c^{R}-Q\right)\left(h^{R}-2\right)-2\beta(2k+1)\lambda^{2}C_{14}\right]}{(h^{R}-2)A}$;

$\theta_{r}^{R}=\frac{\lambda[(2k+1)Q\lambda^{2}-2\beta\left(kc^{R}+Q\right)]}{(h^{R}-2)(\lambda^{2}-2\beta)[(2k+1)\lambda^{2}-2\beta]}$;$q_{m}^{R}=\frac{\beta\left[4\beta^{2}C_{13}+\lambda^{4}(2k+1)^{2}\left(Q-c^{R}\right)\left(h^{R}-2\right)-2\beta\lambda^{2}(2k+1)C_{14}\right]}{(2-h^{R})A}$;

$q_{r}^{R}=\frac{\beta[(2k+1)Q\lambda^{2}-2\beta\left(kc^{R}+Q\right)]}{(h^{R}-2)(\lambda^{2}-2\beta)[(2k+1)\lambda^{2}-2\beta]}$.

In practice, all the above parameters are greater than zero. Therefore, the direct sales cost must satisfy $0<c^{R}<c_{d}^{R}$. At this point, the equilibrium solutions of the model are all greater than zero, with the specific expressions as follows:

$$0<c^{R}<c_{d}^{R}=\frac{-Q[(2k+1)\lambda^{2}-2\beta][\left(\lambda^{2}-2\beta\right)(2k+1)h^{R}-2(2k+1)\lambda^{2}+2\beta(3k+2)]}{4\beta^{2}(k^{2}-2h^{R}k+4k-h^{R}+2)-\lambda^{4}(2k+1)^{2}(h^{R}-2)+4\beta\lambda^{2}(h^{R}-2)(k+1)(2k+1)} \tag{16}$$

The expression for A、C_1-C_{14} in the equilibrium solution is detailed in the appendix.

Proposition 1: In the retailer-equity model, as consumers' green preference λ increases, both a manufacturer profits and a retailer profits rise.

Proposition 1 indicates that all parties in a retailer-owned supply chain can benefit from higher consumer green preferences. Theorem 3.1 shows that the first derivatives of the greenness of both products, the wholesale price, and the retail prices in both channels with respect to the consumer green preference coefficient are all greater than zero. This implies that increased consumer attention to green products encourages manufacturer to prioritize green products, thereby enhancing product greenness. As product greenness increases, both wholesale and retail prices rise. Consequently, both manufacturer and retailer achieve higher profits. In summary, under retailer ownership, supply chain members can collectively increase profits by guiding consumers toward heightened green awareness.

Proposition 2: In the retailer-shareholding model, as channel competition intensifies k , the following relationship holds:

a) In traditional channels, the wholesale price, green rating, and demand for the product increase;

b) In traditional channels, the retail price of products decreases;

c) In direct sales channels, when direct sales costs are at $0<c^{R}<c_{pm}^{R}$, the product's environmental friendliness, retail price, and demand increase; when $c_{pm}^{R}<c^{R}<c_{d}^{R}$, the product's environmental friendliness, retail price, and demand decrease, where $c_{pm}^{R}=\frac{Q(1-h^{R})[2\beta-(2k+1)\lambda^{2}]^{2}}{\lambda^{4}(2k+1)^{2}(2-h^{R})+4\beta^{2}(k^{2}+2k-h^{R}+2)-4\beta\lambda^{2}(2k+1)(k-h^{R}+2)}$;

d) The manufacturer's profit gradually increases; when direct sales costs are $0<c^{R}<c_{mr}^{R}$, the retailer's profit decreases, and when $c_{mr}^{R}<c^{R}<c_{d}^{R}$, the retailer's profit increases, where $c_{mr}^{R}=\frac{Q(1-h^{R})[2\beta-(2k+1)\lambda^{2}]}{h^{R}[(2k+1)\lambda^{2}-2\beta]-2\left[(2k+1)\lambda^{2}-\beta(k+2)\right]}$.

Proposition 2 indicates that when retailer holds equity in a manufacturer, lower direct sales costs prompt a manufacturer to enhance product greenness in direct channels to expand demand, thereby raising retail prices. For traditional channels, intensified competition similarly drives a manufacturer to

increase product greenness, raising wholesale prices. To compete with direct channels, the retailer then lower retail prices, resulting in reduced profits as competition intensifies. When direct sales costs are high, a manufacturer reduce the environmental credentials of products in the direct sales channel to cut costs, diminishing the channel's competitiveness and reducing demand. To maintain sales in this channel, manufacturer lower retail prices to attract consumers. For traditional channels, manufacturer maintains unchanged strategies. With the reduced environmental credentials of direct-to-consumer products, traditional channel offerings gain significant competitive advantage. As competition intensify and retailer further lower retail prices, demand for traditional channel products far exceeds levels seen when direct-to-consumer costs were lower. Retailer begins to profit, with increased margins.

Proposition 3: In the retailer equity model, the impact of equity ratioh^R on optimal decisions is as follows:

a. In the traditional channel, as the ownership ratioh^R increases, the product's wholesale price, environmental friendliness, and demand rise, while the retail price decreases.

b. In direct sales channels, the retail price, greenness, and demand for the product all decrease.

Proposition 3 indicates that in the retailer-equity-holding manufacturer model, retailer as supply chain leaders hold advantages in traditional channels compared to direct sales channels. Proposition 3(a) reflects that as the equity stake increases, the manufacturer can alleviate the financial pressure of green production by obtaining one-time equity payments from a retailer. This enhances the product's greenness in traditional channels, leading to increases in both wholesale price and demand. Concurrently, channel competition drives down the retail price. Proposition 3(b) demonstrates that as the equity stake increases, a retailer receives equity dividends from manufacturer's profits as compensation. To maximize their own profits, manufacturer consequently reduce green investments in direct sales channels, diminishing the environmental performance of direct-sold products. Against the backdrop of heightened consumer environmental awareness, demand for these products declines as consumers increasingly prioritize purchasing green products. The decline in product greenness, coupled with channel competition, also leads to a gradual reduction in the retail prices of direct-sale channel products. Therefore, in the retailer-manufacturer equity model, a manufacturer must comprehensively consider multiple factors when adjusting their decisions.

Proposition 4: In the retailer-shareholding model, the impact of the shareholding ratioh^R on the profits of supply chain members is as follows:

a. As the ownership percentage increases, one retailer profits gradually rise while a manufacturer profits gradually decline.

b. As the equity ratio increases, the total profit of the supply chain rises.

Proposition 4(a) indicates that in a supply chain where retailer holds equity in manufacturer, retailer's profits comprise two parts: dividends from the manufacturer's equity stake and profits from traditional channel sales. Proposition 3(a) shows that demand in traditional channels increases with higher equity stakes. Since retailer maximizes marginal price, their retail prices must exceed wholesale prices, leading to rising profits. For manufacturer, higher equity stakes mean larger dividends paid to retailer, causing their profits to decline continuously. Proposition 4(b) indicates that although manufacturer's profits decrease with rising equity stakes in the supply chain, the increase in retailer profits exceeds the decline in manufacturer profits. Consequently, overall supply chain profits exhibit an upward trend. Retailer should act as supply chain leaders, optimizing profit distribution by adjusting equity stakes.

Corollary 1: When the equity payment cost satisfies $W^R \epsilon [\underline{W^R}, \overline{W^R}]$, both a manufacturer and a retailer can increase their profits, prompting them to jointly consider adopting an equity strategy.

As shown in Corollary 1, when the retailer’s equity payment costs fall within a certain range, both the

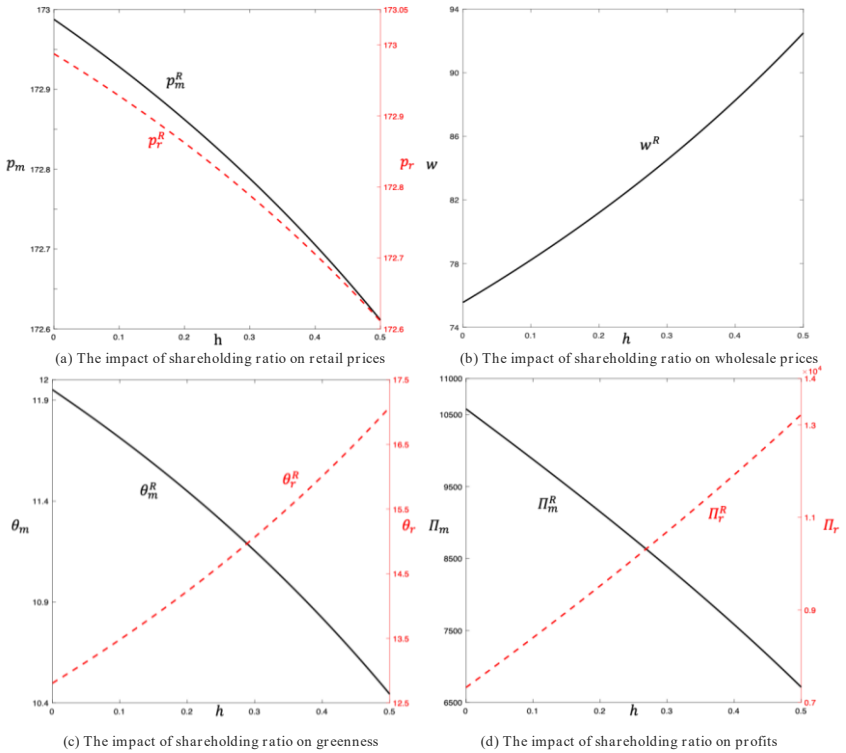
manufacturer's and the retailer's profits increase, thereby fulfilling the original objective of the equity participation strategy and achieving a win-win outcome for both parties. This also provides valuable insights for pricing equity payments between companies.

3.4. Numerical Simulation

Through constructing and solving the aforementioned retailer equity model, several research conclusions are drawn. This section provides a more intuitive analysis of the impact of key parameters—such as the equity ratio h^R and channel competition coefficient k —on the decision-making of a manufacturer and a retailer.

3.4.1. Impact of Shareholding Ratio

To validate the validity of the above conclusions, a numerical simulation analysis was conducted on the holding ratio h . To simplify the case study and ensure the validity and representativeness of the simulation results, the parameter values in this section are determined based on the research scenario of supply chain equity cooperation and channel decision-making, drawing upon relevant supply chain management theories, standard settings from core journal literature, and empirical data from typical industries. The consumer online order volume, representing market demand, is set at $Q = 240$. This value is selected by referencing the actual order characteristics of the fast-moving consumer goods industry and the range of demand parameters used in similar supply chain decision-making simulation studies, thereby ensuring alignment with the research scenario and industry representativeness; The cost coefficient of the manufacturer's green investment, $\beta = 3$, follows the conventional range of 2–5 for sensitivity coefficients in the supply chain Stackelberg game model, balancing the rationality of variable interactions with simulation objectivity, and is consistent with the sensitivity settings for supply chain member behavioral responses in existing research; $k = 0.5, \lambda = 0.5$, which align with standard supply chain simulation parameter conventions and the moderate influence levels of variables observed in industry empirical studies, balancing simulation complexity with the authenticity of results[36]; the equity holding ratio $h^R \in (0,0.5)$ corresponds to the common range for equity partnerships among supply chain enterprises in reality, with the partner holding less than 50% of the shares to maintain the independence of both parties[37]. Since direct sales costs satisfy $0 < c^R < c_d^R$, the unit direct sales cost is assumed to be 100. The specific simulation results are shown in Figure 3.



(a) The impact of shareholding ratio on retail prices

(b) The impact of shareholding ratio on wholesale prices

(c) The impact of shareholding ratio on greenness

(d) The impact of shareholding ratio on profits

Figure 3. Impact of Shareholding Ratio h^R

As shown in Figure 3(c), increasing retailer ownership shares leads to higher product greenness in traditional channels and lower greenness in direct sales channels. This occurs because a manufacturer holding retailer shares must allocate portions of their profits to retailer. For traditional channels, a manufacturer enhances product greenness by wholesaling to retailer, enabling retailer to share part of the green investment costs, as illustrated in Figure 3(b). For direct sales channels, however, further increasing green investments to enhance product greenness would raise costs. Moreover, at a given level of direct sales costs, the initial difference in product greenness between direct and traditional channels is not significant. As the equity stake increases, the profits required to be shared with retailer also rise. Therefore, to reduce costs, manufacturer decreases green investments in direct sales channels, leading to lower product greenness. As shown in Figure 3. (a), the retail price of products decreases with increasing equity ownership. In direct sales channels, the reduced product greenness leads to lower retail prices. In traditional channels, retailer gain higher profits from manufacturer through increased equity ownership. Thus, appropriately lowering prices to attract consumer demand does not diminish retailer's total profits. Figure 3.(d) shows that as the equity stake increases, retailer profits rise continuously while manufacturer profits decline. This occurs because the model excludes one-time equity payment costs from the manufacturer's profit function, as these costs do not influence supply chain members' decisions. Consequently, manufacturer profits decrease due to dividends paid to retailer. In reality, equity payment costs must be considered. As concluded in Corollary 1, manufacturer and retailer will only adopt equity strategies when equity payment costs fall within a specific range. Thus, Figure 3 validates Propositions 3. and 4.

3.4.2.Impact of Consumer Green Preference

This section conducts a numerical simulation analysis of the consumer green preference coefficientλ . To simplify the example, we assume $Q = 240, \beta = 3, k = 0.5, h^R = 0.2$, the consumer green preference coefficient$\lambda \in (0,1)$, and since direct sales costs satisfy$0 < c^R < c_d^R$, we assume a unit direct sales cost of 100. The specific simulation results are shown in Figure 4.:

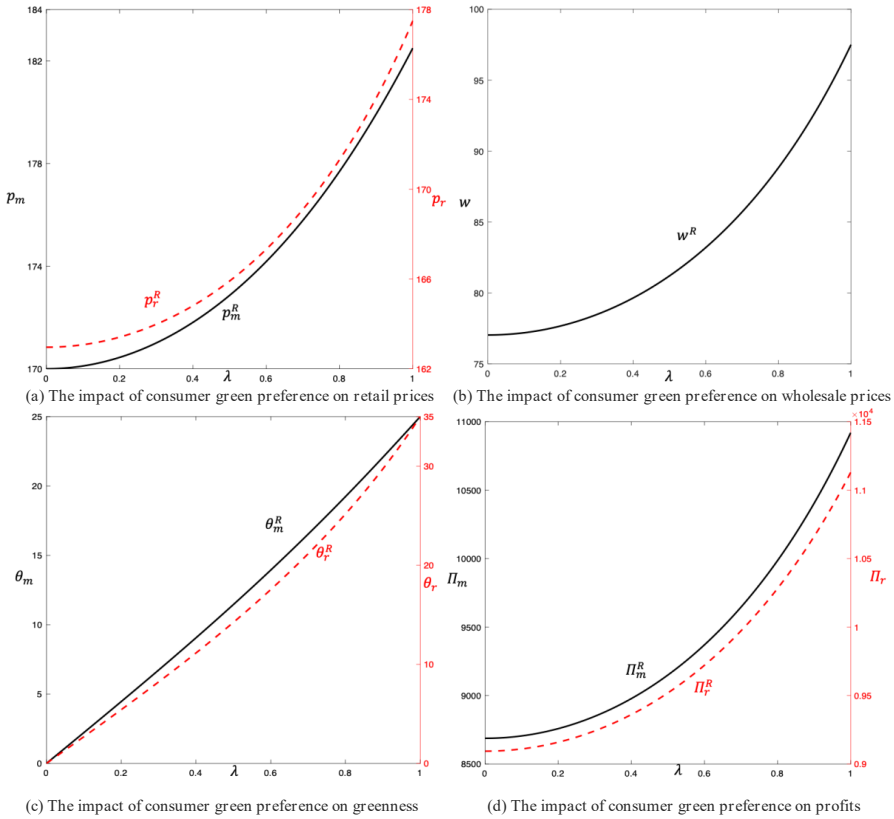
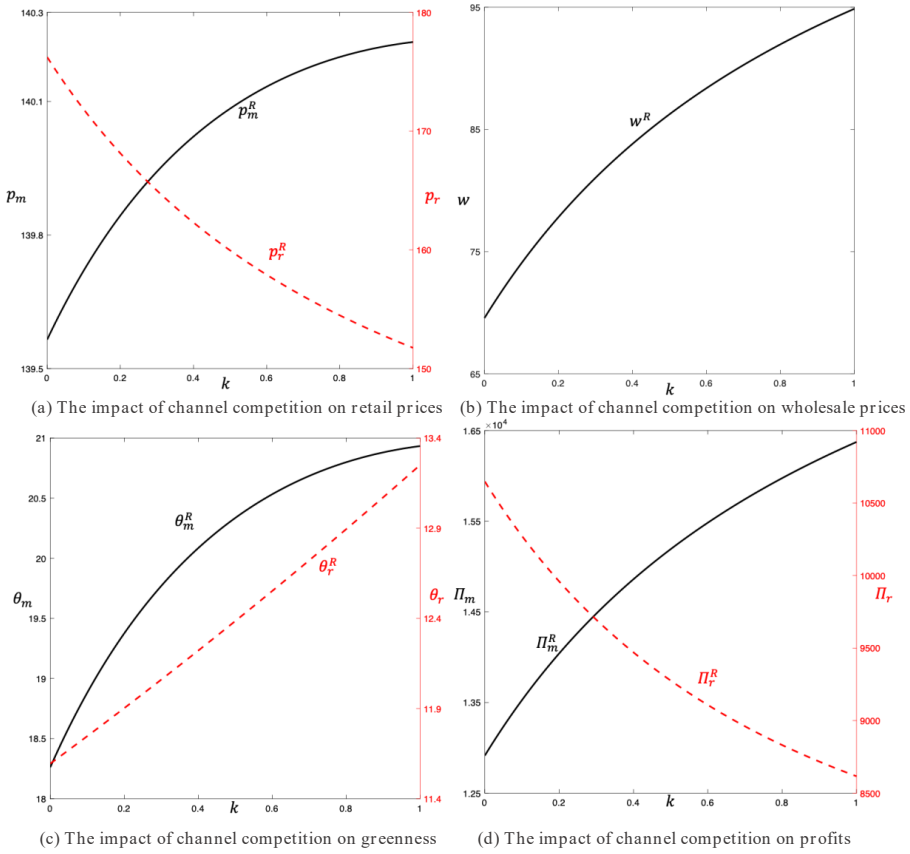


Figure 4. Impact of Consumer Green Preference λ

As shown in Figure 4(a), because consumers are willing to pay extra for green products, both direct and traditional channel retail prices increase as consumer green preference rises. Figure 4(c) reveals that as consumer green preferences increase, the environmental sustainability of products in both direct and traditional channels also improves. This implies manufacturer incurs higher green production costs, consequently raising wholesale prices as shown in Figure 4(b). As consumer preference for green products increases, both the retail price and demand for the product rise, leading to an upward trend in profits for both manufacturer and retailer, as shown in Figure 4(d). This also validates Proposition 1.

3.4.3.Impact of Channel Competition

This section conducts a numerical simulation analysis of the channel competition coefficient k between direct sales and traditional channels. To simplify the example, this subsection assumes $Q = 240, \beta = 3, \lambda = 0.5, h^R = 0.2$, with the channel competition coefficient $k \in (0,1)$ for both channels. Since direct sales costs satisfy $0 < c^R < c_d^R$, and the magnitude of direct sales costs affects product price, greenness, and one retailer profits, this section assumes unit direct sales costs of 30 and 150, representing scenarios with relatively low and high direct sales costs. The specific simulation results are shown in Figure 5.:



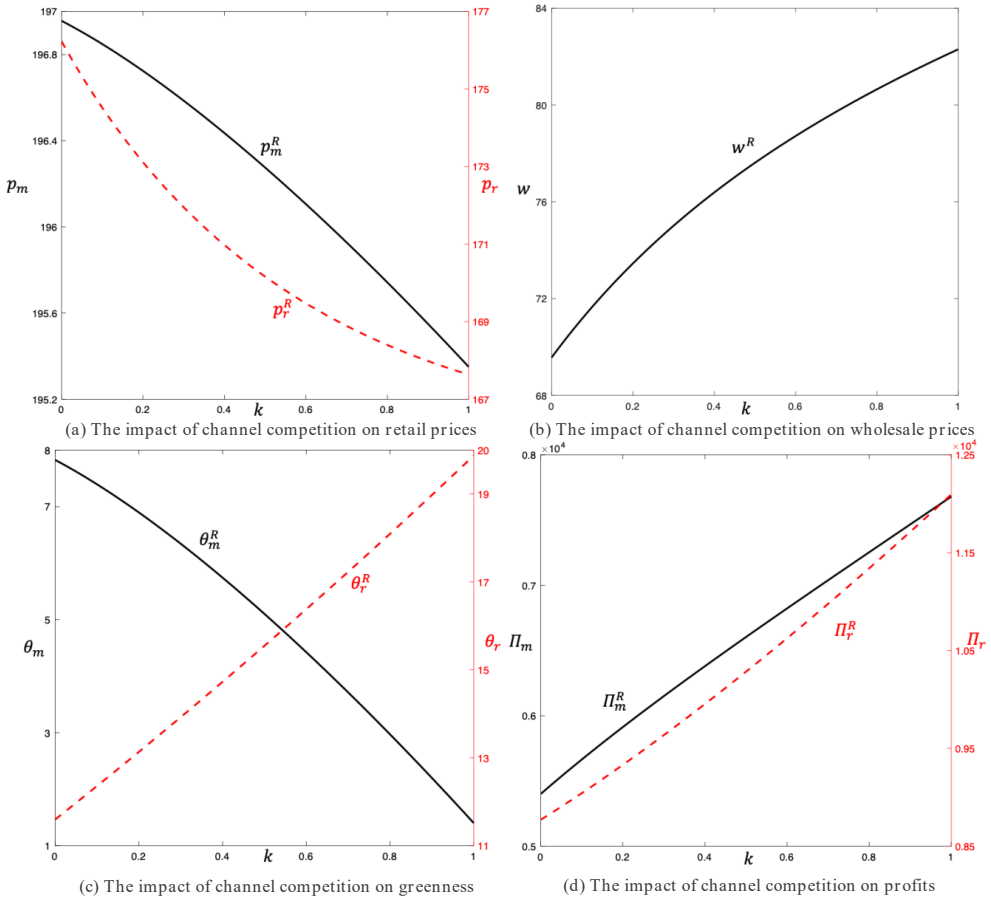
(a) The impact of channel competition on retail prices (b) The impact of channel competition on wholesale prices

(c) The impact of channel competition on greenness (d) The impact of channel competition on profits

Figure 3. Impact of Channel Competition k (c is relatively small)

As shown in Figure 5.(c), when unit direct sales costs are low, the environmental performance of products in both traditional and direct sales channels increases with intensified channel competition. This occurs because lower direct sales costs allow manufacturer to allocate more funds toward green product investments to enhance competitiveness. However, products in the direct sales channel exhibit higher environmental performance relative to those in the traditional channel. As shown in Figure 5. (a), due to the higher product greenness in direct sales channels, the products themselves possess greater

competitive advantages. Although channel competition intensifies, the inherent competitiveness of the products allows direct sales channel products to capture significant market share without relying on price competition. Consequently, the retail prices of these products continue to rise. To expand their market share, retailer is compelled to lower prices to attract consumers. As shown in Figure 5. (b), wholesale prices in traditional channels rise with intensifying competition. Since product greenness increases, wholesale prices also climb. Figure 5. (d) illustrates that when manufacturer's direct sales costs are low, profits steadily increase as channel competition intensifies, driven by rising retail prices and demand growth. Conversely, retailer experiences declining profits due to higher wholesale costs and reduced retail prices.



(a) The impact of channel competition on retail prices

(b) The impact of channel competition on wholesale prices

(c) The impact of channel competition on greenness

(d) The impact of channel competition on profits

Figure 6. Impact of Channel Competition k (c is relatively large)

As shown in Figure 6. (c), when direct sales costs per unit are high, the environmental performance of products sold through direct channels declines as channel competition intensifies. This occurs because high direct sales costs prompt manufacturer to reduce environmental investments in direct channel products, thereby lowering overall direct channel costs. Conversely, the environmental performance of products sold through traditional channels improves as competition increases, since direct sales costs do not directly impact traditional channels. Figure 6. (b) shows that the wholesale price of green products also rises with intensified channel competition, mirroring the trend observed with low direct sales costs. As depicted in Figure 6. (a), products in direct sales channels, being less green than those in traditional channels, adopt price reductions to compete for market share. Against the backdrop of heightened competition, retailer similarly implement price cuts to compete with direct sales channels. As shown in Figure 6. (d), both one retailer's and one manufacturer's profits exhibit an upward trend, yielding results similar to those under the non-equity model with channel competition. Concurrently, Figures 5. and 6. validate Propositions 2 and 3.

4. Conclusion

This study introduces the equity ratio coefficient to examine how retailer's partial vertical equity investments in a manufacturer alleviate the latter's emissions reduction pressures while sharing a portion of the manufacturer's profits. In this supply chain, retailer acts as the dominant party and manufacturer as followers. Through analysis and related propositions, this paper reveals how equity ratios, consumer green awareness, and channel competition influence a manufacturer's supply chain penetration.

The study indicates that in supply chains with retailer equity participation, all parties benefit from higher consumer green preferences. Consumer green awareness is positively correlated with the green attributes of products in both channels, wholesale prices, retail prices, demand volume, and the profit levels of both supplier and retailer. The impact of channel competition depends on direct sales costs: when direct sales costs are low, the environmental friendliness and retail prices of products in the direct sales channel rise, and manufacturer profits increase; in the traditional channel, intensified competition leads to higher environmental friendliness and wholesale prices but lower retail prices, and retailers' equity returns are insufficient to offset the competitive impact, resulting in reduced profits; When direct sales costs are high, the competitiveness of the direct sales channel declines, leading to lower demand and retail prices. In the traditional channel, product eco-friendliness and wholesale prices rise, while retail prices fall due to competition; however, demand increases significantly, resulting in higher retailer profits. Although manufacturer must pay dividends, the gains from competition offset the dividend losses, and their profits still grow. When the equity ownership ratio increases, the environmental friendliness, wholesale prices, and demand for products in traditional channels rise, while retail prices fall due to competition. A retailer's profits trend upward due to equity dividends and increased sales volume in traditional channels; conversely, the environmental friendliness and demand for products in direct sales channels decline, and retail prices follow suit. A manufacturer's profits trend downward due to increased dividend payments, but overall supply chain profits rise because the increase in retailers' profits exceeds the loss in manufacturer's profits. Finally, numerical simulations verified the impact of equity ownership, consumer green preferences, and channel competition on the model's equilibrium solution, confirming the validity of the proposition.

In the context of green supply chains and manufacturer channel encroachment, this study examines how supply chain cooperation—particularly equity-based cooperation—can reduce manufacturer's standalone emission-reduction costs, strengthen inter-firm collaboration, and enhance overall supply chain competitiveness. Specifically, this study investigates the role of partial vertical equity ownership by retailer in shaping firms' strategic decisions, profit distribution, and overall supply chain performance. The main findings can be summarized as follows.

In the model where retailer partially holds equity in manufacturers, all supply chain participants also benefit from heightened consumer green preferences. The impact of channel competition on the supply chain similarly depends on the magnitude of direct sales costs within the direct channel. When direct sales costs are low, the environmental performance of products in the direct channel improves, retail prices rise accordingly, and manufacturer profits increase. For traditional channels, intensified competition leads to enhanced product environmental performance, higher wholesale prices, lower retail prices, and reduced profits. When direct sales costs are high, the environmental friendliness of products in direct sales channels decreases, demand falls, and retail prices drop. For traditional channels, product environmental friendliness still increases, wholesale prices rise accordingly, and retail prices decrease due to competition. However, demand increases, boosting retailer profits. For manufacturer, profits come from both direct sales and wholesale revenues through traditional channels, leading to overall profit growth. Furthermore, as the equity ratio increases, product greenness rises in traditional channels, driving up both wholesale prices and demand. Although retail prices decrease, retailer profits still increase. In direct sales channels, product greenness declines, demand decreases, and retail prices gradually fall, reducing manufacturer profits. However, overall supply chain profits increase. The study finds that equity-holding strategies between firms can lower wholesale prices. When equity stakes are low, wholesale prices are relatively lower in the retailer-held equity model. Simultaneously, equity holdings reduce retail prices; the lower selling prices in the retailer-held manufacturer equity model mitigate the dual marginal effects of pricing under this strategy.

Companies may consider equity partnerships to enhance supply chain competitiveness and robustness. Equity-holding strategies between upstream and downstream enterprises not only increase mutual profits, achieving a "win-win" supply chain goal, but also lower product prices and mitigate the double marginal effect within the supply chain. Regarding manufacturer establishing direct sales channels, equity holdings can reduce the inherent advantages of direct sales channels, promote the development of traditional channels, strengthen cooperation between a retailer and a manufacturer, and enhance overall supply chain profitability. Equity strategies help a manufacturer alleviate the pressure of green investments, balance costs and benefits, and ensure long-term sustainable development across the supply chain. This not only aids enterprises in adapting to market changes but also demonstrates social and environmental responsibility. All parties in the supply chain should strengthen cooperation and coordination to jointly address market fluctuations, enhancing supply chain flexibility and responsiveness. Through strategies like equity partnerships, stakeholders can better share risks and strengthen resilience against market volatility. Consumers play a crucial role in advancing green supply chains. When making purchasing decisions, they should prioritize products' environmental attributes and choose goods produced by companies practicing green supply chain management.

This study analyzes scenarios based on the assumption of deterministic demand. However, actual market demand often involves randomness and uncertainty. Therefore, future research could further explore the impact of demand uncertainty on supply chain decisions and equity cooperation strategies to gain deeper insights. The model constructed here represents a manufacturer-intrusion supply chain involving one manufacturer and one retailer. Yet, in competitive market environments, supply chains are typically more complex. Future research could explore scenarios involving multiple retailers with a single manufacturer or a single retailer with multiple manufacturers, building more comprehensive and realistic supply chain models to provide deeper insights for supply chain management.

Author Contribution

Jin Li: Conceptualization, Formal analysis, Methodology, Validation, Writing–original draft, Writing–review & editing. Tianyu Jiang: Formal analysis, Investigation, Validation, Writing–original draft. Ali Diabat: Conceptualization, Formal analysis, Investigation, Supervision, Writing–review & editing.

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References

1. Central People's Government of the People's Republic of China. Notice of the National Development and Reform Commission and Other Departments on Issuing the "Guidance Catalog for Green and Low-Carbon Transition Industries (2024 Edition)" . (2024-2-2) [2024-4-18].
2. McKinsey & Company. Consumers are in fact buying sustainable goods: Highlights from new research. (2023-5-18)[2024-4-18].
3. Sohu. Nike's Social Media Strategy: An In-Depth Look at Advertising Campaigns and Metrics. (2023-7-7)[2024-4-18].
4. Xia Q, Zhi BD, Wang XJ. The role of cross-shareholding in the green supply chain: Green contribution, power structure and coordination. International Journal of Production Economics, 2021, 234:108037.
5. 36Kr. Xpeng Motors Files IPO Prospectus: First-Half Revenue of 1.003 Billion Yuan; Alibaba Holds 14.4% Stake as Largest External Shareholder. (August 8, 2020) [April 18, 2024].
6. The Paper. Gree Group Plans to Publicly Solicit Buyers for the Transfer of 15% of Gree Electric Appliances Shares. (April 8, 2019) [April 18, 2024].
7. Meng QF, Li MW, Liu WY, et al. Pricing policies of dual-channel green supply chain: Considering government subsidies and consumers' dual preferences. Sustainable Production and Consumption, 2021, 26:1021-1030.
8. Long QQ, Tao XY, Chen YT, et al. Exploring combined effects of dominance structure, green sensitivity, and green preference on manufacturing closed-loop supply chains. International Journal of Production Economics, 2022, 251:108537.
9. Rahmani K, Yavari M. Pricing policies for a dual-channel green supply chain under demand disruptions. Computers & Industrial Engineering, 2019, 127:493-510.
10. Zhang HC, Han XY. Optimization Strategy for Remanufacturing Systems Considering Consumer Environmental Awareness under Carbon Tax Policy. Operations Research and Management Science, 1-10.
11. Wu YP, Shui YS, Yuan BY, et al. Green Supply Chain Decision-Making and Coordination Considering Big Data Marketing and Risk Aversion. Operations Research and Management Science, 2022, 31(2):62.
12. Liang X, Hu X. Green Supply Chain Pricing Decisions Considering Blockchain and Product Recycling. Computer-Integrated Manufacturing Systems, 2023, 29(11):3851-3868.
13. Chen C, Ulya MA. Analyses of the reward-penalty mechanism in green closed-loop supply

chains with product remanufacturing. International Journal of Production Economics, 2019, 210:211-223.

14. Wang Y, Fan R, Shen L. Decisions and coordination of green e-commerce supply chain considering green manufacturer's fairness concerns. International Journal of Production Research, 2020, 58(24):7471-7489.

15. Heydari J, Govindan K, Aslani A. Pricing and greening decisions in a three-tier dual channel supply chain. International Journal of Production Economics, 2019, 217:185-196.

16. Yi YX, Wang YY, Fu CY, et al. Taxes or subsidies to promote investment in green technologies for a supply chain considering consumer preferences for green products. Computers & Industrial Engineering, 2022, 171:108371.

17. Rossi T, Pozzi R, Pirovano G, et al. A new logistics model for increasing economic sustainability of perishable food supply chains through intermodal transportation. International Journal of Logistics-Research and Applications, 2021, 24(4):346-363.

18. Pan C, Yang B, Feng H, et al. Selection of Different Cost-Sharing Contracts for Green Supply Chains under Carbon Trading Systems. Transactions of the Chinese Academy of Systems Engineering, 2023, 38(4):555-576.

19. Li MQ, Li DF, Nan JX. Green Supply Chain Decision-Making Considering Inter-chain Competition and Intra-chain R&D Cost Sharing: A Non-cooperative-Cooperative Dual Game Approach. Chinese Journal of Management Science, 1-13 [2024-01-01]

20. Shang WF, Chen YY. Research on Green Supply Chain Strategies Based on Consumer Environmental Awareness. Industrial Technology Economics, 2018, 37(8):103-108.

21. Shi ZW, Wang JR. Research on Sustainability Evaluation of Prefabricated Buildings from a Green Supply Chain Perspective. Journal of Engineering Management, 2020, 34(2):32-37.

22. Jiang GT, Ji JY, Dong JW. Dynamic Multi-Vehicle Route Optimization for Green Logistics Distribution. Theory and Practice of Systems Engineering, 1-28 [2024-04-26].

23. Kang K, Zhang LT, He MY, et al. Asset-light operation strategy for car-sharing model with vertical shareholding: financial leasing or installment factoring. International Journal of Production Research, 2022. DOI:10.1080/00207543.2022.2112104.

24. Fu H, Ma YK, Cai XQ. Downstream firm’s investment with equity holding in decentralized assembly systems. Omega-international Journal of Management Science, 2018, 75:27-56.

25. He LH, Liu ZY, Guo ZP. Pricing and Coordination Strategies for Retailers' Dual-Channel Supply Chains with Vertical Equity Holding in Suppliers. Journal of Systems Management, 2023, 32(5):880-888.

26. Fan WP, Wang XP, Liu MW, FH. Research on Supply Chain Coordination Optimization for Retailer-Owned Manufacturers' Emissions Reduction Investments. Theory and Practice of Systems Engineering, 2021, 41(9):2316-2326.

27. Yang JX, Zhang J. Competition Among Upstream Firms and Capacity Investment Effects Under Vertical Shareholding with Capacity Constraints. World Economy, 2020, 43(9):122-146.

28. Xia Q, Zhi BD, Wang XJ. The Role of Cross-Shareholding in the Green Supply Chain: Green Contribution, Power Structure, and Coordination. International Journal of Production Economics, 2021, 234:108037.

29. Ren D, Guo R, Lan Y, et al. Shareholding strategies for selling green products on online platforms in a two-echelon supply chain. Transportation Research Part E Logistics and Transportation

Review, 2021, 149(8):102261.

30. Wu DS, Zhang CH, Pan YC, et al. The supply chain effects on order strategy of cross-shareholdings. International Journal of Production Research, 2021, 59(22):6848-6863.

31. Xia LJ, Kong QY, Li YD, et al. Research on Low-Carbon Supply Chain Emissions Reduction and Pricing Decisions Considering Cross-Shareholdings. Chinese Journal of Management Science, 2021,29(4):70-81.

32. Wu YF, Liu H, Chen J. The Impact of Cross-Shareholdings Among Airlines on Capacity Sharing Strategies. Journal of Management Engineering, 2021, 35(2):221-232.

33. Shi Y, Wang XH, Gao HW. Pricing Strategies and Optimal Shareholding in Bertrand Oligopoly Markets with Cross-Shareholding. Chinese Journal of Management Science, 2021, 29(2):42-50.

34. Xiong F, Wei YY, Wang QL, et al. A Study on Pricing and Green Investment Decisions in Dual-Channel Green Supply Chains Considering Member Risk Aversion. Chinese Journal of Management Science, 2022, 30(8):267-276.

35. Li J, Yang X, Shi V, et al. Partial Centralization in a Durable-Good Supply Chain[J]. Production and Operations Management, 2023, 32(9):2775-2787.

36. Xu HT. Decision Analysis of the Three-Tier Supply Chain in Fresh Food E-commerce Under TPL. Industrial Engineering, 2022, 25(01): 75-82.

37. Wang YF, Yang L. A Study on the Impact of Supply Chain Equity Participation on Corporate Sustainability Performance. Industrial Technology and Economics. 2026, 45(02): 67-76.