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*Research article*

## **Eco-label selection and information sharing in green supply chains under demand uncertainty: A perspective on two types of green products**

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**Abstract:** In this study, we explored retailer's information sharing strategies for two types of green products with different cost structures; development-intensive green products (DIGPs) and marginal cost-intensive green products (MIGPs), as well as the eco-label choice dilemma faced by supply chain members of these two products between corporate self-label strategy (SLS) and government certification-label strategy (CLS). We considered a retail-channel green supply chain consisting of the government, a manufacturer, and a retailer, where the government implements environmental regulations, the manufacturer produces green products, and the retailer forecasts stochastic demand. We established a multistage game model of information sharing and non-sharing under the two eco-labels and derived the equilibrium solutions for the two products. The results showed that information asymmetry affects the greenness of DIGP under SLS, but does not change the greenness of MIGP. Information sharing always increases the manufacturer's profit while reducing the retailer's, with incremental gains and losses increasing as forecast accuracy improves. Furthermore, retailer's information sharing strategy does not alter MIGP stakeholders' eco-label preferences, but does influence DIGP manufacturer's eco-label choice. Notably, the government subsidizes green products, and the subsidy level is contingent on product characteristics and eco-label types. These results help enterprises develop appropriate product strategies and governments formulate effective eco-label policies.

**Keywords:** green supply chain; government intervention; green product design; eco-label selection; information sharing

**Mathematics Subject Classification:** 90B06

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## 1. Introduction

To address global climate challenges, governments worldwide have launched carbon peaking and carbon neutrality goals tailored to their national circumstances. By the end of 2021, 137 countries and regions had committed to carbon neutrality goals, covering 73% of global carbon emissions, of which more than 90% of these nations set the deadline for achieving carbon neutrality as 2050. Global carbon neutrality actions are accelerating economic low-carbon transformation, and consumer environmental awareness is increasingly rising, driving enterprises to implement sustainable product design and production.

According to Zhu and He [1], green products can be classified into development-intensive green products (DIGPs) and marginal cost-intensive green products (MIGPs). We start with emission control in the automotive industry to introduce these two types of green products. In 1970, the U.S. Congress issued the first automobile exhaust emission standards. To meet these standards quickly and control abatement costs effectively, automakers developed “production-intent technologies” that do not require major improvements to vehicle power systems and can be applied immediately, such as Chrysler and others installing catalytic converters to reduce vehicle carbon emissions or variable valve timing systems to improve vehicle fuel efficiency [2]. “Production-intent technology” is in the early stages of green technology development and does not require significant R&D and infrastructure investments. However, modifications to vehicle structure, self-made or outsourced devices, and additional assembly processes will increase the manufacturing cost per vehicle. These costs are proportional to vehicle output, so the emission reduction costs of vehicles mainly affect variable manufacturing costs. Therefore, we refer to green products whose green design primarily affects variable costs as MIGPs [3]. Today, achieving carbon neutrality necessitates zero vehicle exhaust emissions, posing challenges to “production-intent technologies”, and innovative “emerging technologies” are urgently needed to fundamentally change the driving mode of automobiles, such as Toyota’s hybrid electric vehicles and Tesla’s pure electric vehicles [4]. “Emerging technologies” require substantial upfront R&D investments and charging infrastructure development expenses to be technically applicable to vehicles and economically acceptable to consumers, so the emission reduction costs of vehicles are mainly fixed costs independent of vehicle volume. Therefore, we refer to green products whose green design primarily affects fixed costs as DIGPs [5].

Beyond the automotive industry, the distinction between DIGP and MIGP is also applicable to other industries. For example, in the electronics industry, the development of next-generation energy-efficient chips, low-power processors, and recyclable electronic components typically requires substantial upfront investments in process development, technological innovation, and production line upgrades. However, once the technology matures, the incremental manufacturing cost per device becomes relatively low. Consequently, the cost of green improvements is mostly fixed R&D and technology upgrade costs that are independent of output [6]. For instance, Apple and ELYSIS have been jointly investing for years in developing low-carbon aluminum for device casings<sup>1</sup>; Intel and TSMC have invested hundreds of billions of dollars in R&D of next-generation chip manufacturing processes, such as 3 nm and 5 nm nodes, to improve energy efficiency<sup>2</sup>. Therefore, green electronic products are typical examples of DIGP. In contrast, in industries such as organic textiles and eco-

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<sup>1</sup> [https://www.sohu.com/a/533100063\\_121124361](https://www.sohu.com/a/533100063_121124361).

<sup>2</sup> [https://www.thepaper.cn/newsDetail\\_forward\\_7301366](https://www.thepaper.cn/newsDetail_forward_7301366).

friendly paper products, green improvements are typically achieved through raw material substitution and production process improvements, such as the use of organic cotton, eco-friendly dyes, and biodegradable packaging materials [7,8]. Examples include H&M's eco-friendly clothing using recycled polyester and Tencel fibers<sup>3</sup>, as well as Breeze's "Wood Forest Zero-plastic Paper." The green costs associated with these products typically increase proportionally with production volume, which aligns with the characteristics of MIGP<sup>4</sup>. Given the distinct cost structures of DIGPs and MIGPs, we want to examine their production and pricing strategies under similar market conditions and policy environments to guide manufacturers in implementing diverse green product designs and assist governments in formulating differentiated environmental policies.

The green market is characterized by information asymmetry, where the environmental attributes of products are difficult for consumers to perceive, while producers have full knowledge of the environmental information of their products [9]. Eco-labels can convey product environmental quality to consumers, thereby serving as a signaling mechanism for enterprise green efforts [10]. In green markets, there are mostly two forms of eco-labels available to enterprises: The self-label strategy (SLS) and certification-label strategy (CLS). SLS enables companies to self-design and affix eco-labels to their products to declare products' environmental qualities. For example, Schneider Electric independently developed the Green Premium eco-label, which enables customers to readily understand the environmental impact of a product at each stage of its life cycle<sup>5</sup>. Through SLS, companies can show their unique product designs and achieve differentiated competition while providing environmental information that resonates with consumers' green preferences. However, self-declarations of enterprise environmental behavior may lead to undervalued product value and reduced consumer willingness to pay due to potential corporate credibility issues [11]. In contrast, CLS, initiated by governments and voluntarily adopted by enterprises, requires companies to obtain official eco-labels for their products through green certification by government-designated agencies, which can enhance market trust in corporate environmental behavior and eliminate consumer skepticism regarding product environmental quality. For example, 3M was awarded the "ENERGY STAR® Partner of the Year-Sustained Excellence Award" by the U.S. Environmental Protection Agency (EPA)<sup>6</sup>, BYD's "Seal" obtained the "Green Star" issued by the China National Certification and Accreditation Administration (CNCA)<sup>7</sup>, and Shenzhen DNS Industries CO., LTD received the world's first Nordic Swan Ecolabel for power banks<sup>8</sup>. Although CLS provides reliable guidance for consumers and alleviates greenwashing regulatory challenges for governments, it may constrain corporate green innovation due to fixed environmental information descriptions and potential tensions between government environmental standards and corporate green objectives, thus raising questions about the effectiveness of CLS in stimulating sustainable production<sup>9</sup>. Furthermore, government fiscal measures, such as preferential taxes or subsidies for green products, especially for CLS products, aim to promote the production and consumption of green products [12]. Therefore, we explore how manufacturers can

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<sup>3</sup> [https://bk.taobao.com/k/fuzhuangpinpai\\_1072/46f5791fffd5d1cfa5a8fc69226aa4ef.html](https://bk.taobao.com/k/fuzhuangpinpai_1072/46f5791fffd5d1cfa5a8fc69226aa4ef.html).

<sup>4</sup> <https://www.digitaling.com/projects/269331.html>.

<sup>5</sup> <https://www.schneider-electric.cn/zh/about-us/sustainability/green-premium-products/>.

<sup>6</sup> <https://www.prnasia.com/story/76982-1.shtml>.

<sup>7</sup> <https://www.sohu.com/a/677608733120077325>.

<sup>8</sup> <https://www.dnschina.com/show-152-84.html>.

<sup>9</sup> <https://www.triplepundit.com/story/2014/transparency-and-certification-yin-and-yangsustainability/58456>.

choose appropriate eco-label strategies for two types of green products in response to government fiscal policies, providing valuable insights for enterprises and regulators.

The market potential of green products is often uncertain, which is more common than exceptional, thus presenting challenges for companies developing new products or exploring new markets, as decisions must be made before this uncertainty is resolved. Consequently, supply chain members actively collect data to forecast product demand. Retailers, positioned supply chains downstream being closer to the end market, possess more comprehensive market data than manufacturers, enabling them to better predict demand fluctuations [13,14]. Therefore, we focus on retailers' demand forecasting information (DFI) and their information sharing strategies. Manufacturers' green product design and eco-label strategies affect not only their own profitability but also retailers' interests. To improve green supply chain performance, collaborative decision-making among supply chain members is essential, with information sharing serving as a key driver for supply chain coordination. Retailer DFI sharing is prevalent in retail channels, such as automakers regularly obtaining point-of-sale data directly from their dealers and large retailers like Costco and Target launching data-sharing programs with suppliers [15,16]. Despite the widespread practice of retailers' information sharing, its impact on manufacturers' sustainable product development and eco-label strategies remains underexplored in the literature. This research fills this gap to address practical challenges in business operations.

Based on the above facts, we identify the following management issues to be worth studying:

- (1) What are the optimal government policies and enterprise strategies for the two green products?
- (2) What information sharing arrangements do retailers implement for the two green products under different eco-labels? Does forecast accuracy affect the optimal decisions of each party? If so, how does accuracy affect their decisions?
- (3) What eco-label strategies do manufacturers choose for the two green products under different information situations? How do retailers' information sharing strategies affect manufacturers' product design decisions and eco-label preferences?
- (4) What environmental policies should governments develop to regulate enterprise sustainable production activities and promote consumer green consumption behaviors?
- (5) How can green supply chains be effectively managed to enhance profitability for stakeholders while promoting production sustainability under government regulations and demand uncertainty?

To address these questions, we adopt a game-theoretic method to derive equilibrium solutions and discuss managerial implications based on analysis results. We focus on a retail-channel green supply chain, where a manufacturer produces green products and wholesales them to a retailer, who subsequently sells the products to consumers. Additionally, the government enforces regulations to increase the market share of green products and improve social welfare (SW). Our purpose of this study is to explore the impact of government environmental policies, manufacturer eco-label strategies, and retailer information sharing on equilibrium outcomes. Specifically, we consider two options for the manufacturer, namely, a self-designing corporate eco-label (i.e., SLS) or adopting a government eco-label (i.e., CLS). We assume that the green market potential is stochastic, and the retailer can predict uncertain demand and independently decide whether to share its DFI with the manufacturer.

The contributions of this study are mostly as follows: First, we examine the cost characteristics of MIGP and DIGP and discuss their optimal product design strategies under demand uncertainty, thereby advancing the green product development research. We model the design problems of MIGP

and DIGP under environmental policies and information contexts. Researchers have inadequately explored the effects of demand uncertainty and cost differences on green product design. Second, we distinguish SLS and CLS and analyze associated government financial measures to guide governments in formulating reasonable environmental policies, thus enriching the green supply chain management literature. Our models reflect supply chain structures as firms adopt different eco-labels, revealing how eco-label adoption qualitatively alters supply chain game structure and stakeholder incentive patterns. However, most scholars have not effectively solved this problem. Third, researchers mostly focus on the effects of information sharing on pricing or ordering, while rarely discussing its impact on sustainable production decisions. We extend the information sharing literature by investigating how retailer's information sharing strategy affects manufacturer's green product design and pricing decisions, and obtain counterintuitive findings that can help companies develop effective sustainable strategies. Finally, the results show that eco-label strategy and information sharing are not only critical determinants affecting participant returns but also interactive factors shaping their decisions. To our knowledge, few researchers have explored this interaction and its implications. Although Zhu and He [1] and Gao et al. [5] provide insights into MIGP and DIGP, their findings are limited to deterministic demand settings, and the interaction between demand information sharing and eco-label selection has not been considered. In contrast, we incorporate the uncertainty of green demand into the selection of eco-labels, thereby systematically revealing the interaction between green product design and demand information sharing in uncertain market environments. To address real-world business challenges, we believe it is necessary to examine the interplay between these two strategies.

The remainder of this paper is organized as follows: In Section 2, we review the related literature. In Section 3, we describe the supply chain structure and construct the model. In Section 4, we examine the optimal decisions in the SLS and present several propositions for DIGP and MIGP. In Section 5, we examine the optimal decisions in the CLS and present several propositions for DIGP and MIGP. Furthermore, in Sections 4 and 5, we analyze a retailer information sharing strategy. In Section 6, we discuss stakeholders' eco-label strategies for the two products under varying information sharing strategies. In Section 7, we summarize the important conclusions, managerial implications, and future research. All solutions and proofs are provided in online Appendices A and B.

## 2. Literature review

We draw on and contribute to three literature streams: Green product development, government environmental regulations and information sharing in supply chains.

### 2.1. Green product development

Green product development is essential to green supply chain management, as it reshapes the functional attributes and environmental attributes of products and directly affects company's green investment. Considering cost structure differences during product design and production, Zhu and He [1] classified green products into MIGPs and DIGPs, and examined how supply chain structure and competition type affect their green design and investment strategies. Gao et al. [5] studied the design of MIGPs and DIGPs in direct-channel green supply chains under government intervention and found that compared with when manufacturers decide product greenness, government-set green standards can achieve higher greenness for DIGPs with lower subsidies, but higher subsidies for

MIGPs. Gao et al. [17] then extended this to a dual-channel green supply chain involving retail and direct channels, showing that stricter eco-label standards can enhance DIGP's environmental benefits but may not always promote MIGP's. Dey et al. [18] analyzed the impacts of power structure and strategic inventory on MIGPs and DIGPs under different procurement strategies, revealing that under retailer Stackelberg game, MIGP's greenness remains unaffected, while DIGP's greenness changes. Li et al. [19] explored the effects of retailer competition and fairness concern on green product design, finding that retailer's fairness concerns lead manufacturers to maintain MIGP's greenness but reduce DIGP's. Xue et al. [20] examined how different types of green innovation, retailers' green marketing efforts, and government interventions collectively affect environmental performance. Their results suggest that the combination of green marketing and eco-label policies generates greater economic benefits and social welfare for MIGP innovation, while this combination may not necessarily increase manufacturers' profits or overall social welfare in DIGP innovation. Quadir et al. [21] studied the impact of demand information sharing on the greening levels of MIGPs and DIGPs with downstream competition. They found that, in the absence of competition, information sharing is the unique equilibrium and enhances the greening level under DIGPs, whereas non-sharing is the unique equilibrium and improves the greening level under MIGPs. Zhao and Duan [22] examined the impacts of eco-label on firms, consumers, and the environment in differentiated markets under MIGPs and DIGPs. They found that for MIGPs, firms consistently adopt the identical certification strategy, whereas for DIGPs, asymmetric strategies may emerge in equilibrium under specific eco-standards. Jiang et al. [23] analyzed blockchain application strategies in MIGPs and DIGPs competition contexts, demonstrating that the decision to adopt blockchain hinges upon adoption costs, price competition intensity, and product cost structure, among which the cost investment coefficients of MIGPs and DIGPs play a pivotal role in determining the equilibrium strategy. Studies have shown that MIGPs and DIGPs often exhibit opposite outcomes under the same supply chain environment. However, some studies suggest that these two products may demonstrate similar performance in certain situations. Zhang et al. [24] compared the effects of two government subsidy policies (fixed-amount subsidies and discount subsidies) on MIGPs and DIGPs with and without subsidy budget constraints, indicating that with budget constraints, fixed-amount subsidies outperform discount subsidies in terms of unit greenness and overall greenness for MIGPs and DIGPs. Hua et al. [25] examined the effectiveness of subsidies, regulations, and hybrid intervention in promoting green production and found that hybrid intervention can achieve a win-win-win outcome for consumers, manufacturers, and the government for DIGPs and MIGPs, but green budget constraints will influence the government's optimal policy choice. Furthermore, Xu et al. [26] demonstrated that appropriate contract design can achieve Pareto improvements in MIGP supply chains under cap-and-trade regulation, while Hong and Guo [27] emphasized that contractual cooperation involving environmental responsibilities may not always benefit all DIGP stakeholders.

Researchers discuss MIGP and/or DIGP development from various perspectives, and consistently find that MIGPs and DIGPs mostly behave in opposite ways in the same supply chain environment, highlighting their distinct performances. Therefore, it is crucial to make targeted decisions for these two green products. Although the above studies reveal the differences between MIGPs and DIGPs, their conclusions are based on deterministic green demand, neglecting green demand uncertainty, and information asymmetry among supply chain members. This study contributes to the green product design literature by focusing on the performance of MIGPs and DIGPs under uncertain green demand

and developing economic models to attempt to answer our first research question: how do we determine the optimal greenness and environmental policies for these two products.

## *2.2. Government environmental regulations*

Government regulation plays a key role in green supply chain management, primarily involving political and financial measures such as taxes, subsidies, and cap-and-trade mechanisms to promote supply chain greening [28,29]. These policies encourage enterprises to actively green their products based on market responses, that is, manufacturers determine the greenness of their products. However, many countries have implemented voluntary eco-label schemes, where governments set environmental standards for green products, and manufacturers whose products meet the standards can apply for green certification to obtain official eco-labels [30]. Eco-label policies have fundamentally altered the supply chain game structure, and the impact of this change on green supply chains deserves further exploration. Walter and Chang [31] demonstrated that voluntary eco-certification can reduce environmental damage and improve consumer surplus, but may harm producer profitability, thereby discouraging socially optimal eco-standard adoption. Zhao and Duan [22] argued that although the introduction of eco-labels contributes to environmental improvement, higher eco-standards do not necessarily generate greater environmental outcomes. In highly competitive markets with strong consumer environmental awareness, partial adoption with stringent standards may be more effective than full adoption with less rigorous standards. Some scholars are dedicated to studying the selection of eco-label strategies. Gao et al. [5] compared two scenarios in which manufacturers actively determine product greenness and passively accept government green standards, and found that it is of great significance for governments to set green standards and provide environmental subsidies. Based on these findings, Gao et al. [17,32] explored dual-channel green supply chain management under “eco-label + subsidy” regulation, providing guidance for enterprise sustainable decision-making and government eco-label policy implementation. Lou et al. [33] analyzed the impact of consumer trust and consumer environmental awareness on firms’ choices between self-labels and certification-labels. They found that manufacturers prefer self-labels, while suppliers earn higher profits from certification-labels. When the cost of certification-labels and consumer trust are low, certification-labels generate higher social welfare than self-labels. Hou et al. [34] investigated the effect of government regulation on eco-label selection in competitive markets and found that industry-developed labels perform better in terms of firm economic returns, whereas government-established labels are more beneficial for social welfare but are less likely to be voluntarily adopted by firms. Furthermore, some researchers have explored measures that encourage enterprises to participate in green certification. Tang et al. [35] employed a game-theoretic model to analyze the effects of government fiscal subsidies and product access policies on the performance of green supply chains. Their results show that government intervention can effectively promote green production only when green access standards reach a certain threshold; under effective access conditions, the government must set appropriate green standards when implementing subsidy policies. Scott and Sesmero [36] highlighted that information-based eco-labels can help consumers choose reliable green products by alleviating quality skepticism, while environmental subsidies can incentivize enterprises to voluntarily participate in eco-certification. Mogyoros [37] examined the mechanisms by which certification marks and conventional marks function as eco-labels from legal and market perspectives, pointing out that consumer trust in green certification marks often stems more from brand image than from underlying environmental standards.

Consequently, brand building plays a crucial role in enhancing the credibility of eco-labels and promoting green consumption. Related literature underscores the effectiveness of eco-label policies in driving environmental improvements and the need of combining eco-labels with subsidies to promote green production.

In this study, we examine corporate self-label programs, where companies determine the greenness of their products, and government certification-label systems, where governments set green standards for products. Researchers mainly focus on how government regulations encourage corporate green certification, but ignore the impact of vertical interactions among supply chain members on manufacturers' eco-label choices. Here, we uniquely recognize that manufacturers' eco-certification decisions are influenced not only by upstream governments but also by downstream retailers, especially in the presence of information asymmetry. In addition to government regulation, we also incorporate retailer behavior to explore whether manufacturers retain greenness power under the combined effects of government financial intervention and retailer information sharing, providing valuable insights for eco-label system design.

### *2.3. Supply chain information sharing*

In recent decades, researchers have focused on demand forecasting and its sharing in supply chains. Liu and Özer [38] noted that manufacturers can directly access consumer demand signals when launching new products or developing new markets, while retailers cannot. Guo and Iyer [39] also argued that manufacturers possess superior market information than retailers and examined manufacturers' information sharing strategies. However, they ignored the possibility that retailers might infer manufacturers' private information from wholesale prices even if manufacturers do not share information. In some cases, retailers, being closer to consumers, may obtain more market information than manufacturers [13, 40–42]. Lee et al. [43] demonstrated that sharing retailers' demand information among supply chain partners can mitigate the bullwhip effect and improve supply chain efficiency. Guo [40] and Li [41] studied demand forecast sharing of competitive retailers and monopoly retailers, respectively, finding that information sharing consistently benefits manufacturers but may diminish the profits of retailers and supply chains, thus discouraging retailers from voluntary sharing. Researchers also focus primarily on retailers' information sharing incentives. Mittendorf et al. [44] examined the interaction between retailer information sharing and manufacturer demand-enhancing investments, demonstrating that manufacturers would increase investment based on retailers' information commitments, and retailers would voluntarily share information in response to manufacturers' demand-enhancing efforts. Zhang et al. [45] investigated manufacturers' after-sales service deployments and retailers' information sharing strategies, identifying the conditions under which retailers share demand information when manufacturers adopt different after-sales service deployments. Wei et al. [46] explored optimal sales patterns and information sharing strategies in green supply chains, determining the benefits of information sharing to e-retailers depend on specific supply chain parameters under different supplier sales patterns. Guo et al. [47] examined the interaction between retailers' demand information sharing strategies and manufacturers' channel encroachment decisions. The results showed that sharing and withholding demand information may induce manufacturers to encroach on retail channels. Moreover, information sharing is not always beneficial to manufacturers, while concealing information is not necessarily detrimental to them. Liu et al. [48] investigated the interaction between platform information sharing strategies and manufacturer sales

mode choices in the supply chain, indicating that manufacturers can encourage platforms to share information by adopting an agency selling model, and platform information sharing, in turn, increases the likelihood that manufacturers choose the agency selling mode. Zhang et al. [49] analyzed retailers' demand information sharing decisions in a closed-loop supply chain. Their results demonstrate that information sharing depends on market demand levels and channel power structures. Specifically, when the manufacturer is not the dominant player in the supply chain, and market demand is relatively low, retailers are more likely to share information. Liu and Wang [50] studied demand information sharing strategies for different types of e-commerce platforms, including resale, commission, and hybrid platforms, and suggested that whether a platform shares information depends on the transaction patterns and the accuracy of demand signals. They further proposed corresponding contractual mechanisms to promote information sharing, thereby achieving win-win outcomes for all parties in the supply chain. Wang et al. [51] and Xu et al. [52] explored the impact of information sharing on green supply chain decisions in the context of government subsidies to consumers, and found that green production cost is a key factor affecting information sharing and that information sharing benefits green supply chain only when green production efficiency is sufficiently high.

In summary, considering retailers' ability to infer manufacturers' information and their information advantage of being closer to end markets, we focus on retailers' demand forecasting and its vertical sharing. Researchers have examined how retailer information sharing enhances manufacturer's operational efficiency but overlooked its impact on sustainable production decisions. We contribute to the information sharing literature by exploring how information sharing affects manufacturer's greenness decisions and identifying the conditions under which retailer's DFI sharing induces manufacturer to select different eco-labels.

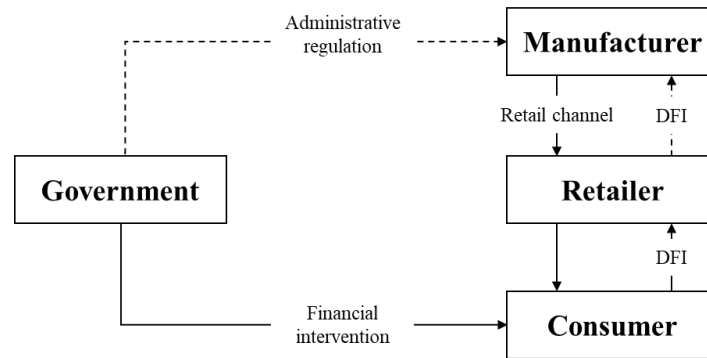
Table 1 summarizes work on green supply chain management and government regulation and compares it with this study. As shown in the table, related work primarily focuses on the performance of DIGPs/MIGPs under policies such as taxes/subsidies, carbon caps, and cap-and-trade. Although some researchers address both DIGPs and MIGPs, most do not consider government intervention due to the complexity of multi-product and multi-agent scenarios. Furthermore, most researchers assume deterministic green demand and rarely consider demand uncertainty, especially how retailer's DFI sharing affects green product design. As mentioned, eco-label policies represent a transfer of product greenness decision-making power from manufacturers to governments, and retailers can use information sharing to strategically induce manufacturers to retain or give up this right. Here, we address these gaps by incorporating green demand uncertainty, distinguishing DIGPs and MIGPs, and comparing SLS with CLS. We analyze how retailers' DFI sharing influences manufacturers' green designs and explore supply chain members' eco-label preferences under various information strategies. In the next section, we present models to address these issues.

**Table 1.** Comparison of this study with related literature.

Articles	Green product type		Environmental Policy			Demand uncertainty	Information sharing
	MIGPs	DIGPs	Tax /Subsidy	Cap/Cap-and-trade	Eco-label		
Xu et al. [26]	√			√			
Dong et al. [53]		√		√			
Walter and Chang [31]		√	√				
Zhu and He [1]	√	√					
Dey et al. [18]	√	√					
Li et al. [19]	√	√					
Jiang et al. [23]	√	√					
Xue et al. [20]	√	√					√
Zhao and Duan [22]	√	√					√
Zhang et al. [24]	√	√	√				
Gao et al. [5]	√	√	√				√
Gao et al. [17]	√	√	√				√
Hua et al. [25]	√	√	√				√
Quadir et al. [21]	√	√				√	√
This study	√	√	√		√	√	√

### 3. The model

Considering a green supply chain comprising the government, a manufacturer (she) and a retailer (he), the manufacturer produces green products, then wholesales them to the retailer, who finally sells them to consumers, while the government intervenes to promote supply chain development. The manufacturer can produce two types of green products, i.e., DIGP and MIGP, but not simultaneously. Government regulations include fiscal policies (i.e., taxes or subsidies) and administrative measures (i.e., setting environmental standards for green products). The former directly affects product prices, while the latter involves eco-labels voluntarily certified by enterprises. Moreover, the manufacturer can independently determine product greenness and establish self-label systems. For the two forms of eco-labels, if the manufacturer chooses certification-label, both financial and administrative policies will work; otherwise, government intervention can only be taxes or subsidies. In addition, the retailer predicts uncertain green demand and decides whether to share the DFI with the manufacturer. If the DFI is shared, the information is symmetric; otherwise, the manufacturer only has the common knowledge of market demand. The supply chain structure is shown in Figure 1.



**Figure 1.** Retail-channel supply chain structure.

Based on the above analysis, the manufacturer can produce DIGP and MIGP and choose SLS or CLS for each product, and the retailer can decide whether to share the DFI. Considering the different strategies of players, we mostly examine the following models: (1) Model NDS - the retailer does not share the DFI in DIGP under SLS. (2) Model SDS - the retailer shares the DFI in DIGP under SLS. (3) Model NMS - the retailer does not share the DFI in MIGP under SLS. (4) Model SMS - the retailer shares the DFI in MIGP under SLS. (5) Model NDC - the retailer does not share the DFI in DIGP under CLS. (6) Model SDC - the retailer shares the DFI in DIGP under CLS. (7) Model NMC - the retailer does not share the DFI in MIGP under CLS. (8) Model SMC - the retailer shares the DFI in MIGP under CLS. Furthermore, all players are risk-neutral and their goals are to maximize expected profits. Table 2 shows the eight models and corresponding strategies.

**Table 2.** Eight models and corresponding strategies.

		Product type	Information sharing strategy	Information sharing
		No information sharing		
Eco-label strategy	SLS	DIGP	Model NDS	Model SDS
		MIGP	Model NMS	Model SMS
	CLS	DIGP	Model NDC	Model SDC
		MIGP	Model NMC	Model SMC

Table 3 lists the symbols used in this study. Note that few green products are a mixture of DIGP and MIGP, and whether a product is DIGP or MIGP depends on its nature. Due to the different cost structures and product performance of the two products, the product utilities are not economically comparable. Therefore, we do not use different labels to distinguish the parameters of the two products, nor do we compare them.

**Table 3.** Notations and variables.

Symbol	Descriptions
Model parameters	
$D$	The total market demand, $D > 0$
$b$	Consumer sensitivity coefficient for a green product, $b > 0$
$f$	Fixed green manufacturing cost coefficient, $f > 0$
$v$	Variable green manufacturing cost coefficient, $v > 0$
$A$	Potential market size, a random variable, $A = a + \varepsilon_0$ , where $a$ is the mean of $A$ , representing the average market size, $A > 0$ , $a > 0$
$F$	Potential market size predicted by the retailer, $F = A + \varepsilon_1$ , $F > 0$
$\varepsilon_0$	Demand uncertainty, a random variable obeying a normal distribution with mean zero and variance $\sigma_0^2$ , $\sigma_0 > 0$
$\varepsilon_1$	Forecast error, a random variable obeying a normal distribution with mean zero and variance $\sigma_1^2$ , $\sigma_1 > 0$
$\rho$	The DFI accuracy of the retailer, $0 < \rho < 1$
$SW$	Social welfare, $SW > 0$
$\pi_i$ ( $i = r, m$ )	Net profit of the retailer ( $i = r$ ) or the manufacturer ( $i = m$ ), $\pi_i > 0$
$V_i^{xy}$	The value of information sharing for the retailer ( $i = r$ ) or the manufacturer ( $i = m$ ) in DIGP ( $x = D$ ) or MIGP ( $x = M$ ) under the SLS ( $y = S$ ) or the CLS ( $y = C$ )
Decision variables	
$p$	Retail price per unit of product before tax, $p > 0$
$w$	Wholesale price per unit of product, $w > 0$
$g$	Product green degree, $g \geq 0$
$t$	Environmental tax per unit of product

**Demand function.** Referring to Zhu and He [1] and Gao et al. [5], we assume market demand  $D$  is a function of retail price  $p$ , environmental tax  $t$ , and product greenness  $g$ . The demand function is  $D = A - p - t + bg$ , where  $b$  is the marginal effect of product greenness  $g$  on consumer demand, reflecting consumers' preference for green products. The demand intercept  $A$  is random, given by  $A = a + \varepsilon_0$ , where  $a$  represents the certain part of demand and  $\varepsilon_0$  is the uncertain factor of demand. Assume that  $\varepsilon_0$  follows a normal distribution with  $E(\varepsilon_0) = 0$  and  $Var(\varepsilon_0) = \sigma_0^2$  [54]. Furthermore, suppose  $a$  is much larger than  $\varepsilon_0$  to ensure non-negative equilibrium outcomes [55].

**Demand forecast.** Assume that the potential market size predicted by the retailer is  $F = A + \varepsilon_1$ , where  $\varepsilon_1$  is the prediction error following a normal distribution with  $E(\varepsilon_1) = 0$  and  $Var(\varepsilon_1) = \sigma_1^2$ . The random variables  $\varepsilon_0$  and  $\varepsilon_1$  are independent and  $E[A|F] = (1 - \rho)a + \rho F$ , where  $\rho = \frac{\sigma_0^2}{\sigma_0^2 + \sigma_1^2}$  is the accuracy of the DFI. The higher  $\rho$  is, the more reliable the DFI is, and vice versa. Moreover, we derive  $E[(F - a)^2] = \sigma_0^2 + \sigma_1^2$ ,  $E[A] = E[F] = E[F|A] = E[E[A|F]] = a$ . Assume that the retailer does not incur additional forecasting costs, and all parameters, except the DFI, are common knowledge among supply chain members [56].

**Green investment.** The cost of eco-label products includes green investment and eco-label fees. Green investment is reflected in increased green design and production costs. The design and production of DIGP mainly involve fixed costs unrelated to product output, so we model the variable green cost of DIGP as zero, while the fixed green cost is  $f g^2$  [1]. In contrast, MIGP's R&D cost is negligible compared to production cost, so we model the fixed green cost of MIGP as zero, while the

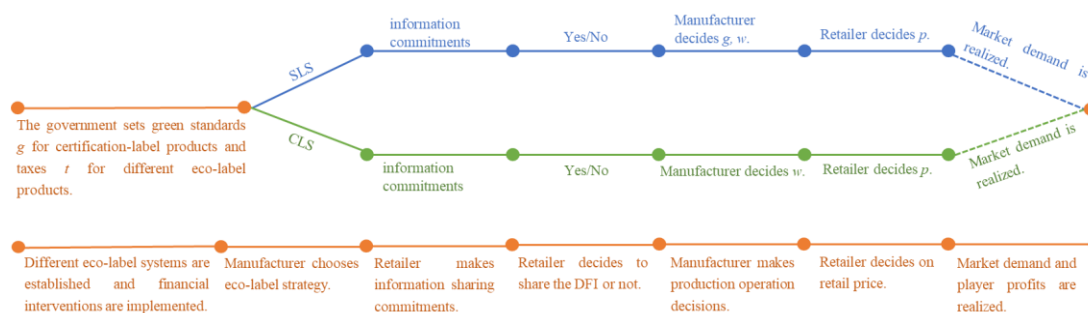
variable green cost is  $vg^2$  per unit of product [5]. Furthermore, assume that eco-label fee is a one-time fixed cost and retailer's marginal operating costs are constant. For simplicity, we normalize these costs to zero, and this simplification does not change our conclusions [57].

**Social welfare.** Following Dobbs [58] and Walls and Palmer [59], we integrate “consumer surplus ( $CS$ ), supply chain member surplus ( $MS$ ), economic influence ( $EI$ ), and environmental benefits ( $EB$ )” to model social welfare ( $SW$ ).  $CS$  represents the budget surplus when consumers purchase products at prices lower than their maximum willingness to pay, calculated as  $CS = \frac{D^2}{2}$  [60].  $MS$  captures the additional revenue when supply chain members sell products at prices higher than their minimum acceptable prices, calculated as  $MS = \pi_m + \pi_r$  [61].  $EI$  quantifies fiscal policy impacts, expressed as  $EI = tD$  [62].  $EB$  denotes the environmental improvements from green product production and consumption, expressed as  $EB = gD$  [5]. In summary, we model the government objective as maximizing  $SW = CS + MS + EI + EB$ .

**The sequence of events.** The game process and decision sequence are as follows:

- (1) The government sets environmental standards for green products and offers voluntary certified eco-labels to manufacturers. Concurrently, the manufacturer can establish her own eco-label systems to declare product sustainability. Furthermore, the government imposes taxes on consumers.
- (2) The manufacturer chooses the eco-label strategy between SLS and CLS.
- (3) The retailer commits to whether to share the DFI with the manufacturer.
- (4) The retailer predicts green demand and shares (or not) the DFI.
- (5) If the manufacturer chooses SLS, she needs to determine the greenness  $g$  and wholesale price  $w$  of self-label products; if the manufacturer adopts CLS, she needs to decide only the wholesale price  $w$  for certification-label products.
- (6) The retailer sets the retail price  $p$ , and then market demand and profits are realized.

The game begins with the government as the Stackelberg leader of the supply chain, and the timeline of this dynamic game is shown in Figure 2.



**Figure 2.** Sequence of the events.

#### 4. Models in SLS

In SLS, the manufacturer determines product greenness. Price, greenness, and tax decisions are studied, and the impact of information sharing on the green product design of the manufacturer and the information sharing strategy of the retailer are derived.

#### 4.1. The DIGP Models

In this section, we consider the manufacturer's product as DIGP. First, the government sets the tax. Second, the retailer shares (or not) the DFI with the manufacturer based on his information sharing commitment. Third, the manufacturer determines the greenness and wholesale price of DIGP. Finally, the retailer decides the retail price. The objective functions of the government, manufacturer and retailer are as follows:

$$\max_t SW = (p + t + g)(A - p - t + bg) + \frac{1}{2}(A - p - t + bg)^2 - fg^2 \quad (1)$$

$$\max_{g,w} \pi_m = w(A - p - t + bg) - fg^2 \quad (2)$$

$$\max_p \pi_r = (p - w)(A - p - t + bg) \quad (3)$$

Using the backward induction, the equilibrium outcomes of model NDS and model SDS are shown in Table 4.

**Table 4.** Optimal solutions for DIGP under SLS.

Solutions	Model NDS	Model SDS
$t^*$	$\frac{2(3f + b)a}{b^2 + 2b - 2f}$	$\frac{2(3f + b)a}{b^2 + 2b - 2f}$
$g^*$	$\frac{ba}{2f - b^2 - 2b}$	$\frac{ba}{2f - b^2 - 2b} + \frac{b(F - a)\rho}{8f - b^2}$
$w^*$	$\frac{4fa}{2f - b^2 - 2b}$	$\frac{4fa}{2f - b^2 - 2b} + \frac{4f(F - a)\rho}{8f - b^2}$
$p^*$	$\frac{6fa}{2f - b^2 - 2b} + \frac{(F - a)\rho}{2}$	$\frac{6fa}{2f - b^2 - 2b} + \frac{6f(F - a)\rho}{8f - b^2}$
$D^*$	$\frac{2fa}{2f - b^2 - 2b} + \frac{(F - a)\rho}{2}$	$\frac{2fa}{2f - b^2 - 2b} + \frac{2f(F - a)\rho}{8f - b^2}$
$E[\pi_r^*]$	$\frac{4f^2a^2}{(2f - b^2 - 2b)^2} + \frac{\rho\sigma_0^2}{4}$	$\frac{4f^2a^2}{(2f - b^2 - 2b)^2} + \frac{4f^2\rho\sigma_0^2}{(8f - b^2)^2}$
$E[\pi_m^*]$	$\frac{f(8f - b^2)a^2}{(2f - b^2 - 2b)^2}$	$\frac{f(8f - b^2)a^2}{(2f - b^2 - 2b)^2} + \frac{f\rho\sigma_0^2}{8f - b^2}$
$E[SW^*]$	$\frac{fa^2}{2f - b^2 - 2b}$	$\frac{fa^2}{2f - b^2 - 2b}$

**Lemma 1.** For DIGP in SLS, when the retailer shares the DFI with the manufacturer:

- (1)  $g^{SDS^*}$ ,  $w^{SDS^*}$ ,  $p^{SDS^*}$ , and  $D^{SDS^*}$  are increasing in  $\rho$  if  $F > a$  and decreasing otherwise.
- (2)  $E[\pi_r^{SDS^*}|F]$  and  $E[\pi_m^{SDS^*}|F]$  are increasing in  $\rho$ .

When the retailer shares the DFI, if  $F > a$ , it indicates an optimistic green demand. As forecast accuracy improves, the manufacturer will enhance the greenness of DIGP. Although increased green costs lead to higher product prices, consumer purchasing intention remains strong, boosting the expected profits of the manufacturer and the retailer. Conversely,  $F < a$  reflects insufficient green demand. As forecast accuracy rises, the manufacturer will reduce the greenness of DIGP to minimize

green investment, resulting in lower product prices and consumer demand, while the expected profits of the manufacturer and the retailer will increase. This is because when the retailer communicates demand information to the manufacturer, the manufacturer can effectively adjust product designs to align with consumer preferences. Therefore, regardless of demand conditions, the manufacturer benefits from improved DFI accuracy, which enables her to capture market dividends during high demand and avoid investment losses during low demand.

#### 4.2. The MIGP Models

In this section, we focus on the manufacturer's product as MIGP, and the timing of the game is similar to DIGP. The objective functions of the government, manufacturer, and retailer are as follows:

$$\max_t SW = (p + t + g - vg^2)(A - p - t + bg) + \frac{1}{2}(A - p - t + bg)^2 \quad (4)$$

$$\max_{g,w} \pi_m = (w - vg^2)(A - p - t + bg) \quad (5)$$

$$\max_p \pi_r = (p - w)(A - p - t + bg) \quad (6)$$

Using the backward induction, the equilibrium outcomes of model NMS and model SMS are shown in Table 5.

**Table 5.** Optimal solutions for MIGP under SLS.

Solutions	Model NMS	Model SMS
$t^*$	$-\frac{12av + 8b + 3b^2}{4v}$	$-\frac{12av + 8b + 3b^2}{4v}$
$g^*$	$\frac{b}{2v}$	$\frac{b}{2v}$
$w^*$	$\frac{8av + 4b + 3b^2}{4v}$	$\frac{8av + 4b + 3b^2}{4v} + \frac{(F - a)\rho}{2}$
$p^*$	$\frac{6av + 3b + 2b^2}{2v} + \frac{(F - a)\rho}{2}$	$\frac{6av + 3b + 2b^2}{2v} + \frac{3(F - a)\rho}{4}$
$D^*$	$\frac{4av + 2b + b^2}{4v} + \frac{(F - a)\rho}{2}$	$\frac{4av + 2b + b^2}{4v} + \frac{(F - a)\rho}{4}$
$E[\pi_r^*]$	$\frac{(4av + 2b + b^2)^2}{16v^2} + \frac{\rho\sigma_0^2}{4}$	$\frac{(4av + 2b + b^2)^2}{16v^2} + \frac{\rho\sigma_0^2}{16}$
$E[\pi_m^*]$	$\frac{(4av + 2b + b^2)^2}{8v^2}$	$\frac{(4av + 2b + b^2)^2}{8v^2} + \frac{\rho\sigma_0^2}{8}$
$E[SW^*]$	$\frac{(4av + 2b + b^2)^2}{32v^2}$	$\frac{(4av + 2b + b^2)^2}{32v^2}$

**Lemma 2.** For MIGP in SLS, when the retailer shares the DFI with the manufacturer:

- (1)  $g^{SMS^*}$ , excluding  $\rho$ , depends only on the variable green manufacturing cost coefficient ( $v$ ) and the consumer green sensitivity coefficient ( $b$ ).
- (2)  $w^{SMS^*}$ ,  $p^{SMS^*}$  and  $D^{SMS^*}$  are increasing in  $\rho$  if  $F > a$  and decreasing otherwise.
- (3)  $E[\pi_r^{SMS^*} | F]$  and  $E[\pi_m^{SMS^*} | F]$  are increasing in  $\rho$ .

Demand forecasting enables the retailer to track fluctuant green market trends, while information sharing empowers the manufacturer to optimize production and pricing strategies, enabling firms to seize market opportunities during “short supply” ( $F > a$ ) and reduce investment losses during “oversupply” ( $F < a$ ). Furthermore, improved DFI accuracy can increase gains or reduce losses. Unlike the DIGP supply chain where the manufacturer dynamically adjusts DIGP’s greenness based on the retailer’s DFI, in the MIGP supply chain, the manufacturer maintains MIGP’s greenness regardless of the DFI conditions and its accuracy.

### 4.3. Retailer information sharing strategy

By comparing the equilibrium results of DIGP and MIGP with and without information sharing, we examine the impacts of information sharing on product greenness and pricing strategies and derive the values of information sharing.

#### 4.3.1. Information role and sharing strategy for DIGP

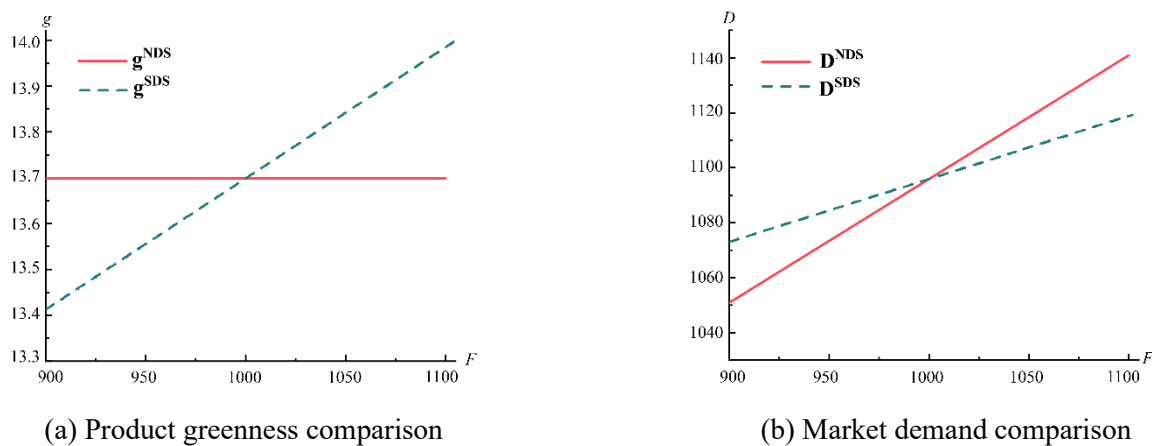
**Proposition 1.** *Compared with the information asymmetry situation of DIGP, if  $F > a$ , we have  $g^{SDS^*} > g^{NDS^*}$ ,  $w^{SDS^*} > w^{NDS^*}$  and  $p^{SDS^*} > p^{NDS^*}$ , while  $D^{SDS^*} < D^{NDS^*}$ ; otherwise,  $g^{SDS^*} < g^{NDS^*}$ ,  $w^{SDS^*} < w^{NDS^*}$ ,  $p^{SDS^*} < p^{NDS^*}$ , and  $D^{SDS^*} > D^{NDS^*}$ .*

When the retailer shares the DFI, compared to the non-sharing scenario, if  $F > a$ , DIGP’s greenness and price rise, while demand falls; if  $F < a$ , the greenness and price decrease, whereas demand increases. This reveals that higher product greenness may not necessarily boost green consumption during strong demand, but reducing greenness to lower prices can stimulate demand during weak periods. In other words, the relationship between product greenness and market demand is jointly influenced by market signals and price mechanisms. To clarify the economic intuition behind Proposition 1, we analyze the result from the perspectives of green cost structure and market expectations. First, the cost of DIGP mainly consists of fixed R&D investment, which does not vary with production volume. Therefore, when determining product greenness, the manufacturer is essentially making a fixed investment decision, and the recovery of this investment depends heavily on market size. When the retailer predicts favorable prospects for green market ( $F > a$ ), higher expected sales can effectively spread DIGP’s fixed green investments. Optimistic market signals will motivate the informed manufacturer to increase product greenness, thereby enhancing her brand image and high-end competitiveness. However, since high greenness products entail higher investments, from the second-order condition  $f > \frac{b(b+1)}{2}$ , when manufacturer green investment efficiency is low and consumer environmental awareness is insufficient, consumers prioritize price over environmental attributes. Although price increase may dampen some demand, profit growth mainly stems from high-end green premium rather than simple sales expansion.

Conversely, when the retailer predicts unfavorable prospects for green market ( $F < a$ ), DIGP’s fixed cost cannot be effectively amortized through future sales. In this situation, the informed manufacturer will reduce product greenness to alleviate the fixed investment burden, and the resulting price reduction effectively attracts price-sensitive consumers, thereby preventing a sharp drop in demand and potentially boosting sales. Therefore, when the manufacturer adopts SLS for DIGP, the decision regarding product greenness essentially reflects a fixed investment adjustment mechanism based

on market expectations rather than simply pursuing environmental performance. Companies should not blindly pursue high greenness and high returns, but should improve their green production capabilities and design products that align corporate sustainability goals and consumer willingness to pay.

To further illustrate the above results that the retailer's information-sharing strategy affects the manufacturer's DIGP decisions, we conduct numerical experiments to validate and interpret the theoretical findings. Given the difficulty of obtaining real industry data, we refer to datasets used in other related studies. The basic parameters are set as follows:  $a = 1000$ ,  $b = 5$ ,  $f = 200$ ,  $v = 1$ ,  $\sigma_0 = 400$ , and  $\rho = 0.9$  [1,5,17]. Unless otherwise specified, these values are applied throughout the paper. Figure 3 depicts the changes in product greenness and market demand under different information scenarios and DFI conditions.



**Figure 3.** Comparison of DIGP's greenness and market demand under different information scenarios and DFI conditions ( $a = 1000$ ,  $b = 5$ ,  $f = 200$ ,  $v = 1$ ,  $\sigma_0 = 400$ , and  $\rho = 0.9$ ).

It should be particularly noted that reducing product greenness in pessimistic market prospects does not mean that the manufacturer is abandoning the high-end green market. From a dynamic strategic perspective, green manufacturing enterprises must maintain continuous investment capacity in an environment characterized by rapid technological iteration and frequent policy adjustments. During periods of weak demand, launching products with slightly lower greenness but higher cost–performance ratios to attract price-sensitive consumers can help firms maintain cash flow and strengthen capital accumulation, thereby laying the foundation for future technological upgrades. For example, in the new energy vehicle industry, some companies expand their consumer base by launching models with moderate driving ranges and lower prices during periods of subsidy reductions or demand fluctuations to maintain market share while continuing to invest in the development of high-end models. Similarly, some electronics manufacturers initially consolidate mid-to-low-end markets through technological accumulation and scale expansion, and subsequently launch high-end green products to enhance their brand premium, thereby achieving parallel development of green technology upgrades and market segmentation.

**Proposition 2.** *When the manufacturer adopts SLS for DIGP, we can get the values of information sharing as (1)  $V_r^{DS} < 0$ ,  $\frac{\partial V_r^{DS}}{\partial \rho} < 0$ ; and (2)  $V_m^{DS} > 0$ ,  $\frac{\partial V_m^{DS}}{\partial \rho} > 0$ .*

Proposition 2(1) characterizes a benchmark scenario in which there are no side payments, coordination contracts, or other compensation mechanisms between the manufacturer and the retailer, and the power dynamics among supply chain members are not considered. Under this setting, sharing the DFI with the manufacturer reduces the retailer's expected profit. Information sharing enables the manufacturer to adjust DIGP's greenness and wholesale pricing after observing market conditions. While optimizing product green performance can increase market sales by adapting to consumer preferences, the manufacturer's opportunistic wholesale pricing intensifies the double marginalization effect in the green supply chain. Since the manufacturer reaps most of the incremental gains from information sharing through wholesale price adjustments, the distribution of information benefit becomes highly asymmetrical, which weakens the retailer's incentive to share DFI. In addition, due to low manufacturer investment efficiency in DIGP and insufficient consumer sensitivity to SLS products, the potential benefits of information sharing from increased green demand are dwarfed by the amplified double marginalization it causes. Therefore, information sharing is detrimental to the retailer, leaving the retailer without incentives to share information in the absence of compensation. This is consistent with Mittendorf et al. [55], who found that retailers tend to retain their private information when manufacturers are inefficient in demand enhancing activities. Notably, when  $V_r^{DS} < 0$ , it is easy to prove that  $\frac{\partial V_r^{DS}}{\partial \rho} < 0$  also holds, which means that if information sharing does not yield additional benefits to the retailer, then improving forecast accuracy will exacerbate the adverse effects. This phenomenon is known as the "precision trap" [62]. This occurs because higher DFI accuracy raises retailer's information collection and processing costs while incentivizing manufacturer's strategic information exploitation. Thus, the retailer should weigh the forecast costs and information benefits rather than blindly pursuing high forecast precision. This finding also helps explain why retailers rarely improve forecast precision or share high-quality demand information unconditionally in practice; instead, such information is typically shared only when there are compensation mechanisms or long-term partnerships.

Proposition 2(2) indicates that information sharing increases the manufacturer's expected profit, and more accurate DFI enhances this positive effect. The integration of downstream supply chain information enables the manufacturer to optimize product greenness and adjust pricing strategies. Therefore, information sharing is always in the manufacturer's interest.

#### 4.3.2. Information role and sharing strategy for MIGP

**Proposition 3.** *Compared with the information asymmetry situation of MIGP:*

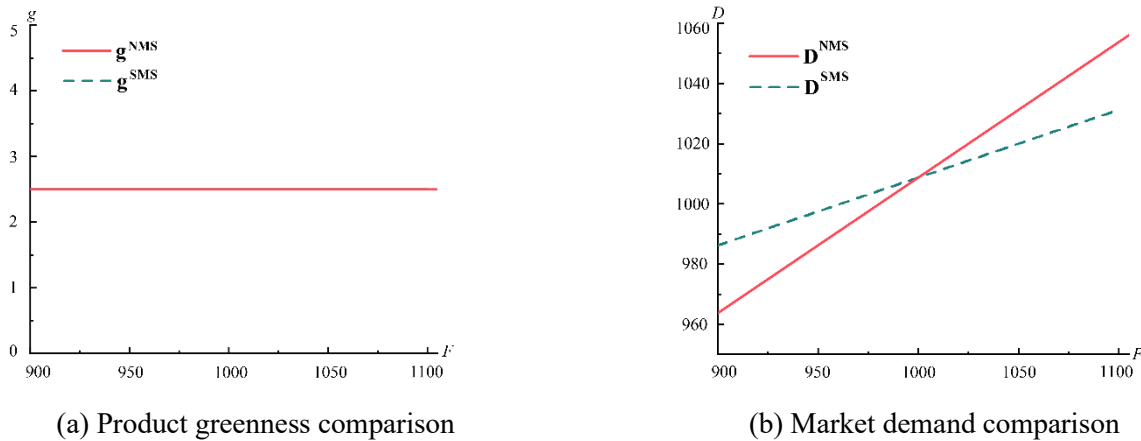
(1) *If  $F > a$ , we have  $w^{SMS^*} > w^{NMS^*}$ , and  $p^{SMS^*} > p^{NMS^*}$ , whereas  $D^{SMS^*} < D^{NMS^*}$ ; otherwise,*

*$w^{SMS^*} < w^{NMS^*}$ ,  $p^{SMS^*} < p^{NMS^*}$ , and  $D^{SMS^*} > D^{NMS^*}$ .*

(2) *The optimal greenness is not affected by  $F$  and  $a$ , we have  $g^{SMS^*} = g^{NMS^*}$ .*

The retailer's information sharing strategy affects MIGP supply chain members' decisions, and this impact on MIGP green design and market demand is shown in Figure 4, which primarily hinges on the retailer's green demand forecasts. As expected, higher prices during high demand suppress product sales, while lower prices in low demand periods stimulate green consumption. Therefore, companies can leverage DFI to formulate appropriate pricing strategies to offset green costs and

achieve profit goals. It is worth noting that the manufacturer's optimal decision regarding MIGP greenness remains unchanged regardless of the DFI sharing. Moreover, the optimal greenness depends on the trade-off between green benefits and green costs, that is, the consumer preference for greenness ( $b$ ) and the marginal cost of achieving greenness ( $v$ ). Thus, even if there is no information sharing leading to information asymmetry among supply chain members, MIGP's design will not be affected by imperfect information.



**Figure 4.** Comparison of MIGP's greenness and market demand under different information scenarios and DFI conditions ( $a = 1000$ ,  $b = 5$ ,  $f = 200$ ,  $v = 1$ ,  $\sigma_0 = 400$ , and  $\rho = 0.9$ ).

**Proposition 4.** *When the manufacturer adopts SLS for MIGP, we can get the values of information sharing as (1)  $V_r^{MS} < 0$ ,  $\frac{\partial V_r^{MS}}{\partial \rho} < 0$ ; and (2)  $V_m^{MS} > 0$ ,  $\frac{\partial V_m^{MS}}{\partial \rho} > 0$ .*

Proposition 4 indicates that in the MIGP scenario, without additional compensation or coordination mechanisms, the retailer's DFI sharing reduces his expected profit but increase the manufacturer's, with the incremental losses and gains from information sharing growing as DFI accuracy improves. Therefore, the retailer should be cautious of the "precision trap" by investing rationally in demand forecasting to reduce rising costs and information exploitation risks. Unlike the DIGP scenario where the manufacturer adjusts product greenness based on the retailer's DFI to control green investment, Proposition 3 suggests that the manufacturer, without altering MIGP's greenness, adjusts its wholesale price to maximize profit. Despite MIGP's mature technology and efficient investments, severe double marginalization occurs because price adjustments outpace demand responses. Consequently, in the absence of effective incentive or compensation mechanisms, the retailer is unlikely to benefit from information sharing and will rationally choose not to disclose private demand forecasts. This also implies that, in practice, the realization of information sharing typically relies on additional institutional arrangements.

Propositions 2 and 4 jointly show that, despite the significant differences in cost structures between DIGP and MIGP, in a baseline information sharing scenario without considering additional incentives or compensation, retailer's DFI sharing will consistently increase manufacturer's expected profit while reducing its own. Consequently, the retailer has no incentive to share DFI. However, this conclusion does not deny the prevalence of information sharing in practice; on the contrary, it helps

explain why companies often implement institutional arrangements to support information sharing. For example, Costco offers data-sharing programs to suppliers in exchange for side payments, Walmart employs revenue sharing contracts to promote information sharing, and JD.com initially refused to share information with Media and Dell but later chose to do so. In practice, information sharing in supply chains is often accompanied by direct compensation, coordinated contracts, institutional arrangements based on long-term cooperation, or channel power structures. Through profit redistribution or dynamic incentives, these mechanisms can effectively address retailers' participation and incentive-compatibility constraints under different circumstances. Therefore, by identifying the conditions under which retailers may be disadvantaged by information sharing, we provide a clear theoretical basis for understanding why manufacturers need to design compensation mechanisms to facilitate information sharing in practice.

**Corollary 1.** *For DIGP and MIGP in SLS, whether the retailer shares the DFI or not, the government's optimal decision on  $t$  and the expected  $SW$  remains unchanged, and  $t$  acts as a subsidy.*

Since government environmental regulations precede enterprise economic activities, government decisions and  $SW$  are not affected by retailer information sharing, and  $t$  serves as a subsidy to support green production and consumption. Furthermore,  $t^*$  and  $E[SW^*]$  correlate with consumer environmental awareness  $b$ . Specifically,  $\frac{\partial t^*}{\partial b} < 0$  and  $\frac{\partial E[SW^*]}{\partial b} > 0$  indicate that improving consumer green awareness will increase subsidy expenditures and reduce government revenue, but will positively impact overall  $SW$ . This arises because the government's goals consider not only  $EI$  but also  $CS$ ,  $PS$ , and  $EB$ . Although higher consumer green awareness reduces government fiscal surplus ( $EI$ ), the rise of green consumption optimizes consumer welfare ( $CS$ ), corporate profits ( $PS$ ), and environmental performance ( $EB$ ). The gains from promoted  $CS$ ,  $PS$ , and  $EB$  outweigh the losses in reduced  $EI$ , thus enhancing  $SW$ .

## 5. Models in CLS

In CLS, the government sets product green standards, and the manufacturer makes her product greenness barely meet these standards to obtain official eco-label and reduce investment. It should be noted that in this model, as the Stackelberg leader of the supply chain, the government determines the green standard  $g$  to maximize  $SW$  in anticipation of the manufacturer's and retailer's reactions. Firms then make production and pricing decisions based on the predetermined standards to maximize their respective expected profits. Government environmental policies and enterprise pricing decisions are studied, and the impact of information sharing on manufacturer's pricing strategy and the information sharing strategy of the retailer are revealed.

### 5.1. The DIGP Models

In this section, we discuss the scenario where the manufacturer produces DIGP. First, the government sets green standards for MIGP manufacturers and imposes environmental taxes on DIGP consumers. Second, the retailer shares (or not) the DFI based on his information sharing commitment. Third, given eco-label and financial regulations, the manufacturer produces MIGP and determines its wholesale price. Finally, the retailer decides the market price. The objective functions of the

government, manufacturer, and retailer are as follows:

$$\max_{t,g} SW = (p + t + g)(A - p - t + bg) + \frac{1}{2}(A - p - t + bg)^2 - fg^2 \quad (7)$$

$$\max_w \pi_m = w(A - p - t + bg) - fg^2 \quad (8)$$

$$\max_p \pi_r = (p - w)(A - p - t + bg) \quad (9)$$

Using the backward induction, the equilibrium outcomes of model NDC and model SDC are shown in Table 6.

**Table 6.** Optimal solutions for DIGP under CLS.

Solutions	Model NDC	Model SDC
$t^*$	$\frac{(1 + b + 6f)a}{1 + 2b + b^2 - 2f}$	$\frac{(1 + b + 6f)a}{1 + 2b + b^2 - 2f}$
$g^*$	$\frac{(1 + b)a}{2f - b^2 - 2b - 1}$	$\frac{(1 + b)a}{2f - b^2 - 2b - 1}$
$w^*$	$\frac{4fa}{2f - b^2 - 2b - 1}$	$\frac{4fa}{2f - b^2 - 2b - 1} + \frac{(F - a)\rho}{2}$
$p^*$	$\frac{6fa}{2f - b^2 - 2b - 1} + \frac{(F - a)\rho}{2}$	$\frac{6fa}{2f - b^2 - 2b - 1} + \frac{3(F - a)\rho}{4}$
$D^*$	$\frac{2fa}{2f - b^2 - 2b - 1} + \frac{(F - a)\rho}{2}$	$\frac{2fa}{2f - b^2 - 2b - 1} + \frac{(F - a)\rho}{4}$
$E[\pi_r^*]$	$\frac{4f^2a^2}{(2f - b^2 - 2b - 1)^2} + \frac{\rho\sigma_0^2}{4}$	$\frac{4f^2a^2}{(2f - b^2 - 2b - 1)^2} + \frac{\rho\sigma_0^2}{16}$
$E[\pi_m^*]$	$\frac{f(8f - 1 - 2b - b^2)a^2}{(2f - b^2 - 2b - 1)^2}$	$\frac{f(8f - b^2 - 2b - 1)a^2}{(2f - b^2 - 2b - 1)^2} + \frac{\rho\sigma_0^2}{8}$
$E[SW^*]$	$\frac{fa^2}{2f - b^2 - 2b - 1}$	$\frac{fa^2}{2f - b^2 - 2b - 1}$

## 5.2. The MIGP Models

In this section, we discuss the scenario where the manufacturer produces MIGP, and the timing of the game is similar to DIGP. The objective functions of the government, manufacturer, and retailer are as follows:

$$\max_{t,g} SW = (p + t + g - vg^2)(A - p - t + bg) + \frac{1}{2}(A - p - t + bg)^2 \quad (10)$$

$$\max_w \pi_m = (w - vg^2)(A - p - t + bg) \quad (11)$$

$$\max_p \pi_r = (p - w)(A - p - t + bg) \quad (12)$$

Using the backward induction, the equilibrium outcomes of model NMC and model SMC are shown in Table 7.

**Lemma 3.** For DIGP and MIGP in CLS, when the retailer shares the DFI with the manufacturer,

- (1)  $w^{S^*}$ ,  $p^{S^*}$ , and  $D^{S^*}$  are increasing in  $\rho$  if  $F > a$  and decreasing otherwise;  
 (2)  $E[\pi_r^{S^*}|F]$  and  $E[\pi_m^{S^*}|F]$  are increasing in  $\rho$ .

When the retailer shares the DFI, an optimistic DFI ( $F > a$ ) leads to increased product price and consumer demand as forecast accuracy improves, thereby boosting firm's expected profits. In contrast, a pessimistic DFI ( $F < a$ ) results in reduced product price and market sales as forecast accuracy improves, while firm expected profits still increase. The positive effects of demand forecasting and information sharing on business decisions is obvious, which enhances supply chain members' abilities to respond to green demand fluctuations, and improving forecast capabilities can strengthen these positive effects.

**Table 7.** Optimal solutions for MIGP under CLS.

Solutions	Model NMC	Model SMC
$t^*$	$\frac{12av + 5 + 8b + 3b^2}{4v}$	$\frac{12av + 5 + 8b + 3b^2}{4v}$
$g^*$	$\frac{1 + b}{2v}$	$\frac{1 + b}{2v}$
$w^*$	$\frac{8av + 3 + 6b + 3b^2}{4v}$	$\frac{8av + 3 + 6b + 3b^2}{4v} + \frac{(F - a)\rho}{2}$
$p^*$	$\frac{3av + 1 + 2b + b^2}{v} + \frac{(F - a)\rho}{2}$	$\frac{3av + 1 + 2b + b^2}{v} + \frac{3(F - a)\rho}{4}$
$D^*$	$\frac{4av + 1 + 2b + b^2}{4v} + \frac{(F - a)\rho}{2}$	$\frac{4av + 1 + 2b + b^2}{4v} + \frac{(F - a)\rho}{4}$
$E[\pi_r^*]$	$\frac{(4av + 1 + 2b + b^2)^2}{16v^2} + \frac{\rho\sigma_0^2}{4}$	$\frac{(4av + 1 + 2b + b^2)^2}{16v^2} + \frac{\rho\sigma_0^2}{16}$
$E[\pi_m^*]$	$\frac{(4av + 1 + 2b + b^2)^2}{8v^2}$	$\frac{(4av + 1 + 2b + b^2)^2}{8v^2} + \frac{\rho\sigma_0^2}{8}$
$E[SW^*]$	$\frac{(4av + 1 + 2b + b^2)^2}{32v^2}$	$\frac{(4av + 1 + 2b + b^2)^2}{32v^2}$

### 5.3. Retailer information sharing strategy

By comparing the equilibrium results of DIGP and MIGP with and without information sharing, we explore the impacts of information sharing on product pricing strategies and derive the values of information sharing.

**Proposition 5.** For DIGP and MIGP in CLS, compared with the situation of information asymmetry, if  $F > a$ , we have  $w^{S^*} > w^{N^*}$  and  $p^{S^*} > p^{N^*}$ , whereas  $D^{S^*} < D^{N^*}$ ; otherwise,  $w^{S^*} < w^{N^*}$ ,  $p^{S^*} < p^{N^*}$ , and  $D^{S^*} > D^{N^*}$ .

Unlike the SLS scenario where the manufacturer controls product greenness, in the CLS scenario where the government sets product green standards, the manufacturer neither improves product greenness to attract consumers during high demand nor lowers product greenness to reduce green investment during low demand. The manufacturer will make the greenness of DIGP and MIGP merely

meet green standards, and then adjust wholesale prices to cope with demand fluctuations. Note that even with high green demand, increasing product prices are inadvisable. The second order condition of DIGP,  $f > \frac{(1+b)^2}{2}$ , indicates that the cost increase from green production outweighs the demand boost from green consumption, leading to price increases and demand decreases. Therefore, the manufacturer should focus on reducing R&D and manufacturing costs to make DIGP affordable to general consumers [1].

**Proposition 6.** *When the manufacturer adopts CLS for DIGP and MIGP, we can get the values of information sharing as (1)  $V_r < 0$ ,  $\frac{\partial V_r}{\partial \rho} < 0$ ; and (2)  $V_m > 0$ ,  $\frac{\partial V_m}{\partial \rho} > 0$ .*

Information sharing enables the manufacturer to optimize decisions, thereby diminishing the retailer's profit margins, with higher information accuracy amplifying the manufacturer's gains and the retailer's losses. Consequently, in green supply chains, retailers rarely voluntarily share DFI without incentives, and even if they do share, they must be cautious of the "precision trap". Therefore, motivating retailers to share demand information is crucial for manufacturers in green product development.

**Corollary 2.** *For DIGP and MIGP in CLS, whether the retailer shares the DFI or not, the government's optimal decisions on  $t$  and  $g$  and the expected  $SW$  remains unchanged, and  $t$  acts as a subsidy.*

Since the government's development plan is not affected by enterprise economic behaviors, its optimal decisions and  $SW$  remain unchanged regardless of the information transmission between enterprises. Furthermore,  $\frac{\partial t^*}{\partial b} < 0$ ,  $\frac{\partial g^*}{\partial b} > 0$ , and  $\frac{\partial E[SW^*]}{\partial b} > 0$  imply that higher market appeal of DIGP and MIGP leads to more government subsidies, stricter green standards, and greater  $SW$ . Consumer environmental awareness positively impacts the overall  $SW$  of green supply chains. Moreover, while it temporarily reduces the fiscal surplus ( $EI$ ), it fosters the long-term achievement of the economic goals ( $PS$ ), social goals ( $CS$ ), and environmental goals ( $EB$ ) of sustainable supply chains.

The above theoretical analysis demonstrates that information sharing benefits the manufacturer at the retailer's expense under various eco-label strategies. Thus, the manufacturer favors information transparency, while the retailer prefers to retain DFI, which is true in both DIGP and MIGP scenarios. Additionally, it raises the question of whether participants are motivated to choose different eco-label strategies under varying information arrangements. Therefore, further investigation is needed into how the retailer's information sharing strategy affects stakeholders' eco-label choices.

## 6. Eco-label selection strategy

Although the retailer tends to withhold DFI in SLS and CLS scenarios, supply chain members may have different eco-label preferences. The retailer can use information to strategically influence manufacturer's eco-label selection so that the manufacturer's decisions is in his favor. Thus, it is necessary to analyze stakeholders' eco-label choices under different information sharing scenarios.

### 6.1. Eco-label strategy for DIGP supply chain

By comparing the optimal decisions and expected profits of SLS and CLS models, the following propositions describe the strategy differences and eco-label preferences of DIGP supply chain members under various information scenarios.

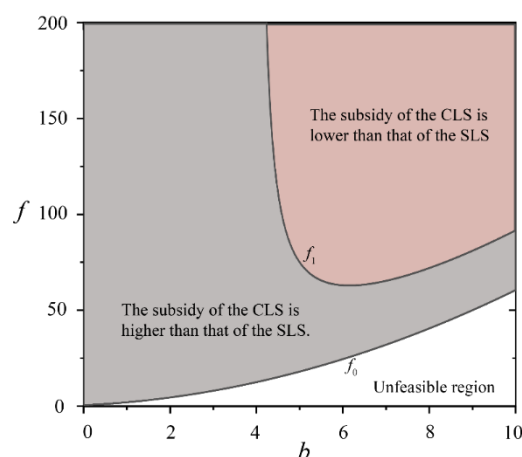
First, we discuss the scenario without information sharing.

**Proposition 7.** *When the retailer does not share the DFI for DIGP:*

- (1) *If the consumer green sensitivity is low, the government subsidy for CLS is higher than that for SLS. If the consumer green sensitivity is high, the government subsidy for CLS is higher than that for SLS only when the fixed green manufacturing cost is low; otherwise, the subsidy for CLS is lower.*
- (2) *The greenness, wholesale price, retail price, and market demand of CLS are higher than those of SLS.*

Government subsidies for CLS may be higher or lower than for SLS, depending on consumer green sensitivity and fixed green manufacturing cost, as shown in Figure 5. When consumer green sensitivity is low, CLS receives higher subsidies (i.e., the left region in Figure 5), indicating that CLS can stimulate consumer purchasing enthusiasm when DIGP market appeal is weak. To better understand why the government provides higher subsidies for CLS when consumer green sensitivity is low, we analyze this issue from the perspective of the government's objective function. The government's  $SW$  considers not only  $EI$  but also  $CS$ ,  $PS$ , and  $EB$ . When consumer environment sensitivity is low, firms lack sufficient incentives to undertake high-level green investments, and  $EB$  cannot be realized spontaneously through market mechanisms. By increasing subsidies for CLS products, the government can reduce the actual price paid by consumers and thereby increase  $CS$ ; furthermore, it can alleviate enterprises' fixed green investment burden and increase  $PS$ . More importantly, improving product greenness significantly enhances  $EB$ . Therefore, although higher subsidy expenditures reduce  $EI$ , the combined increases in  $CS$ ,  $PS$ , and  $EB$  are sufficient to offset the reduction in  $EI$ , thereby achieving a net increase in  $SW$ . In addition, compared to SLS, CLS involves government-established green standards and certification supervision, which can effectively prevent companies from "greenwashing". Consequently, when consumer environmental awareness is insufficient, the government subsidizes CLS more than SLS. This policy choice is not simply artificial market stimulation, but reflects an institutional policy response aimed at correcting environmental externalities and maximizing  $SW$ .

In contrast, when consumer green sensitivity is high, CLS subsidy remains higher than SLS if DIGP costs are low (i.e., the lower right region in Figure 5); otherwise, CLS subsidy is lower (i.e., the upper right region in Figure 5). This suggests that when the DIGP market appeal is high, the government can adjust subsidy intensity based on DIGP costs to favor CLS products. Additionally, CLS products are greener than SLS products, and higher greenness requires more costs, so it is reasonable that CLS products are priced higher. Since CLS subsidy may be lower than SLS, the market demand for CLS products remains higher due to increased consumer environmental awareness, reflecting that consumers prefer government-designed DIGP. Therefore, CLS products are more competitive than SLS products in green markets.



**Figure 5.** Government subsidy comparison for DIGP under different eco-labels ( $a = 1000$ ,  $v = 1$ ,  $\sigma_0 = 400$ , and  $\rho = 0.9$ ).

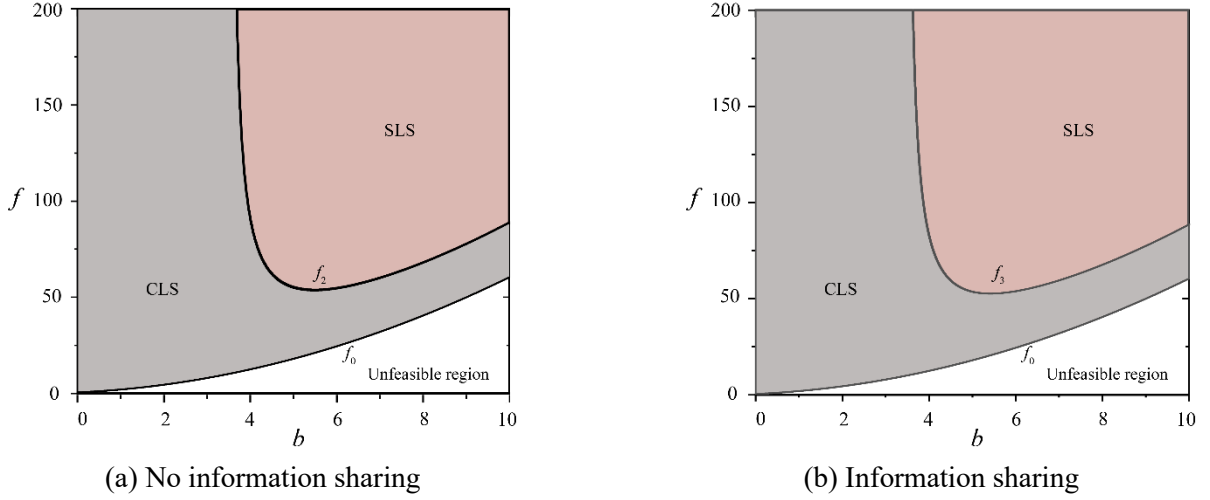
It should be noted that the efficiency gap identified in Proposition 7 appears to stem from the difference in eco-label type; however, it fundamentally arises from the difference in the allocation of product greenness decision-making power. In the CLS scenario, the government sets the green product standard to maximize social welfare, resulting in relatively high product greenness. In contrast, in the SLS scenario, the manufacturer independently determines the product's green level with the goal of profit maximization and may choose a lower green level when balancing production costs and subsidies. Therefore, the efficiency gap between CLS and SLS essentially reflects the structural difference in the allocation of product greenness decision-making power, namely, that the government centrally sets green standards to optimize social welfare, while enterprises make decentralized environmental performance decisions to maximize their own profits.

**Proposition 8.** *When the retailer does not share the DFI in DIGP supply chain, the eco-label preferences of the participants are:*

(1) *The government and the retailer prefer CLS.*

(2) *When the consumer green sensitivity is low, the manufacturer prefers CLS; when the consumer green sensitivity is relatively high, the manufacturer prioritizes CLS if the fixed green manufacturing cost is low, and SLS otherwise.*

Proposition 8 reveals that the government and retailer favor CLS, while the manufacturer's eco-label preference depends on consumer green sensitivity and fixed green manufacturing cost, as shown in Figure 6(a). When consumer green sensitivity is low, the manufacturer benefits more from CLS due to its higher subsidy (i.e., the left region in Figure 6(a)). When consumer green sensitivity is high, if fixed green manufacturing cost is low, the undifferentiated competitive CLS becomes the manufacturer's best choice (i.e., the lower right region in Figure 6(a)), as she not only enjoys higher CLS subsidy but also provides green products that meet certification standards at a lower cost, thus having stronger market competitiveness. Conversely, higher fixed green manufacturing cost leads the manufacturer to retain DIGP greenness decision-making power to control investments and benefit higher SLS subsidy (i.e., the upper right region in Figure 6(a)).



**Figure 6.** The manufacturer's eco-label preferences for DIGP with and without information sharing ( $a = 1000$ ,  $v = 1$ ,  $\sigma_0 = 400$ , and  $\rho = 0.9$ ).

Proposition 8 further demonstrates that the preferences of different participants for eco-label types are closely related to the allocation of product greenness decision-making power. The government prefers CLS because its goal is to maximize social welfare. The retailer also prefers CLS, as it leads to higher market demand. In contrast, the manufacturer's preference depends on whether she retains product greenness decision-making power under different institutional settings and the resulting profits. Therefore, the choice of eco-label type essentially reflects how the decision-making power of product greenness is allocated.

In summary, the efficiency gap between CLS and SLS identified in Propositions 7 and 8 is not merely the differences in eco-label types, but reflects the comparison of two distinct governance structures for green products. One is the government-led centralized structure that optimizes social welfare by setting product green standards, while the other is the enterprise-led decentralized structure in which enterprises determine the greenness of their products to maximize profits. Consequently, the efficiency gap fundamentally stems from how decision-making power over product greenness is allocated between the government and enterprises, which helps reveal how institutional design influences green supply chain performances.

Next, we discuss the information sharing scenario.

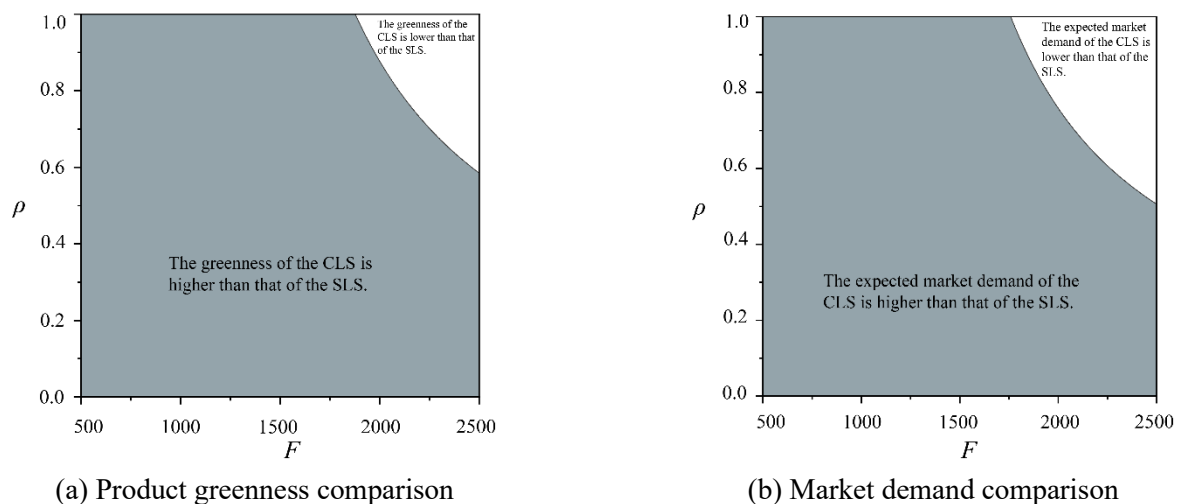
**Proposition 9.** *When the retailer shares the DFI for DIGP:*

- (1) *If the DFI is low, the greenness, wholesale price, retail price, and market demand of CLS are higher than those of SLS.*
- (2) *If the DFI is relatively high, the greenness, wholesale price, retail price, and market demand of CLS are higher than those of SLS only when the accuracy of the DFI is low; otherwise, the greenness, wholesale price, retail price, and market demand of CLS are lower than those of SLS.*

Government subsidy comparison for two eco-labels under information sharing aligns with Proposition 7 and is not repeated here. However, distinct from the non-sharing scenario, retailer information sharing affects the production and pricing decisions of DIGP under different eco-labels, depending on the size and accuracy of the DFI. Figure 7 illustrates the relationship between the greenness and market demand of two eco-labels under information sharing. Specifically, when the retailer predicts low demand, especially below the average market demand  $a$ , the manufacturer,

receiving low demand signals, will reduce green investment to mitigate the adverse effects of demand fluctuations, resulting in the greenness SLS products being lower than that of CLS products (i.e., the left region in Figure 7(a)). Moreover, higher CLS subsidy and/or consumer sensitivity to DIGP lead(s) to higher demand for CLS products (i.e., the left region in Figure 7(b)).

When the predicted market demand  $F$  significantly exceeds the average market demand  $a$ , if the DFI accuracy is also high, the manufacturer, receiving high demand signals, will design increased greenness products (i.e., the upper right region in Figure 7(a)), making them more attractive to green consumers (i.e., the upper right region in Figure 7(b)). Conversely, a less reliable DFI makes it difficult for the manufacturer to assess the true DIGP market situation, and a risk-neutral manufacturer will adopt conservative strategies, so the greenness of SLS products often falls below certification standards (i.e., the lower right region in Figure 7(a)). In this case, CLS products dominate the market due to the subsidy advantages or the manufacturer's misjudgment of insufficient DIGP demand (i.e., the lower right region in Figure 7(b)).



**Figure 7.** Product greenness and market demand comparisons for DIGP under different eco-labels with information sharing ( $a = 1000$ ,  $b = 5$ ,  $f = 200$ ,  $v = 1$ ,  $\sigma_0 = 400$ , and  $\rho = 0.9$ ).

**Proposition 10.** *When the retailer shares the DFI in DIGP supply chain, the eco-label preferences of the participants are:*

- (1) *The government and the retailer prefer CLS.*
- (2) *When the consumer green sensitivity is low, the manufacturer prefers CLS; when the consumer green sensitivity is relatively high, the manufacturer prefers CLS if the fixed green manufacturing cost is low, and SLS otherwise.*

Proposition 10 is similar to Proposition 8, but there are some differences. Figure 6(b) shows the manufacturer's eco-label strategy under information sharing. By comparing Figure 6(b) with Figure 6(a), since  $f_2 > f_3$ , it can be seen that the area of the SLS region in Figure 6(b) is larger than that in Figure 6(a), while the CLS region in Figure 6(b) is smaller. Thus, when consumer green sensitivity is relatively high, retailer's DFI sharing will shift manufacturer's eco-label preference from CLS to SLS, which indicates that information sharing expands the adoption of SLS.

## 6.2. Eco-label strategy for MIGP supply chain

The following propositions describe the eco-label decision differences and eco-label preferences of MIGP supply chain members under different information scenarios.

**Proposition 11.** *Whether the retailer shares the DFI for MIGP, the subsidy, greenness, wholesale price, retail price, and market demand of CLS are higher than those of SLS.*

The analysis of the MIGP models demonstrates that  $t$  consistently functions as a subsidy. Regardless of whether the retailer shares the DFI, the market price of CLS products is higher than that of SLS products. However, the greenness and subsidy of CLS products are also higher, resulting in greater market demand, indicating that CLS products are more popular with consumers.

**Proposition 12.** *Whether the retailer shares the DFI in MIGP supply chain, the government, the manufacturer, and the retailer always prefer CLS.*

Retailer information sharing does not alter manufacturer's eco-label preference for MIGP, and the greenness of MIGP determined by the government is more beneficial to all stakeholders. This is because MIGPs usually adopts mature technologies, where R&D and production inputs are no longer the major constraints on green performance, resulting in undifferentiated market competition. Higher CLS subsidies can attract more consumers to increase product sales, so the manufacturer and retailer prefer CLS. This explains why official eco-labels are commonly used for products like paper goods, cleaning supplies, and textiles.

In conclusion, the government and retailer consistently prefer CLS for DIGP and MIGP, regardless of DFI sharing. For MIGP, the manufacturer also prefers CLS, and her preference is unaffected by information transparency, so the eco-label strategies of MIGP supply chain members are consistent. However, for DIGP, the manufacturer does not always favor CLS, and retailer information sharing may increase manufacturer's inclination toward SLS, which is a disadvantage to the government and retailer.

## 7. Conclusions, implications, limitations, and future research

### 7.1. Conclusions

In this paper, we use economic models to study information transparency (i.e., information sharing and non-sharing) and eco-label selection (i.e., SLS and CLS) for two types of green products (DIGPs and MIGPs) in a retail-channel green supply chain. We determine the optimal subsidy, pricing, and greenness of both products and derive the equilibrium expected profits for all players. Based on these results, we analyze the information sharing strategies of the retailer under different eco-labels and explore the eco-label preferences of supply chain members under various information arrangements.

First, we analyze the impact of information sharing on the design and pricing decisions of two green products and retailer's information sharing strategies under different eco-labels. (1) When the retailer shares the DFI with the manufacturer, their profits are affected by forecast accuracy. Importantly, regardless of whether the DFI is positive or not, they always benefit from more accurate DFI, which is true in DIGP and MIGP scenarios. (2) Compared to no information sharing, positive DFI increases product prices but reduces green demand, and vice versa. (3) In SLS, supply chain

distortion caused by information asymmetry does not affect MIGP's greenness but changes DIGP's green design, depending on the retailer's market forecast. (4) Retailer information sharing increases the manufacturer's expected profit but reduces his own profit, with incremental gains and incremental losses growing with forecast accuracy. Hence, the retailer tends to withhold the DFI in DIGP and MIGP cases.

Next, we examine the strategic differences between two eco-labels and stakeholders' eco-label preferences for two products under different information scenarios. (5) The government subsidy for MIGP in CLS is higher than in SLS, while whether the subsidy for DIGP in CLS is higher than in SLS depends on consumer green sensitivity and fixed green costs. (6) For MIGP, regardless of DFI sharing, CLS generates increased greenness, market price, and green demand than SLS. For DIGP, CLS outperforms SLS without information sharing, but with information sharing, the relationship depends on the retailer's DFI and its accuracy. (7) Compared to the greenness determined by the manufacturer, the green standards set by the government are more beneficial to society and the retailer. This is true for MIGP manufacturers, but for DIGP manufacturers, it depends on consumer green sensitivity and fixed green costs. (8) Retailer information sharing affects DIGP manufacturer's eco-label preferences. Under information sharing, when consumer green sensitivity is either low or relatively high, manufacturer's preference shifts from CLS to SLS.

## 7.2. Managerial implications

In this study, we provide certain managerial insights for manufacturers, retailers, and governments in sustainable supply chain management. (1) When retailers share the DFI, even if the DFI is positive, manufacturers aiming to expand green market share should avoid arbitrarily raising product prices. Instead, manufacturers need to adopt strategic pricing to increase profits while maintaining sales. (2) Information sharing benefits manufacturers but squeezes retailers' profits, making retailers unwilling to share their DFI, so motivating retailers to share information is crucial for manufacturers in green product development. Manufacturers can provide compensation through mechanisms such as one-time transfer payments, wholesale price adjustments, or revenue sharing contracts. Alternatively, information sharing arrangements can be embedded within coordination contracts, such as VMI or CPFR, to incentivize retailer participation in information sharing. These mechanisms enable manufacturers to transfer some of the incremental gains from information sharing to retailers, thereby achieving incentive compatibility between the two parties. (3) The results guide enterprises in aligning green product development with supply chain information coordination. For MIGPs, manufacturers need to focus only on economic performance without changing MIGP's environmental goals, as optimal product greenness is unaffected by information sharing. However, For DIGPs, manufacturers need to balance the profitability and sustainability goals of supply chains. (4) Information sharing may harm retailers, while improved forecast accuracy will exacerbate losses and leading to the "precision trap", so retailers should invest in DFI with caution. (5) It is intuitive that government-set green standards benefit retailers, consumers, and society, while manufacturers owning green design rights can maximize their advantages. However, considering product market acceptance and green investment efficiency, it is better for DIGP manufacturers not to retain greenness rights unless the DFI shared by retailers is positive and accurate. However, manufacturers should choose to participate in green certification for MIGPs. (6) Due to the differences in cost structure and environmental performance between MIGPs and DIGPs, governments should formulate tailored

environmental policies, manufacturers should adopt suitable eco-label strategies, and retailers should implement appropriate information sharing programs.

### *7.3. Limitations and future research*

Although our work has drawn many valuable insights, some issues in green supply chain management need further study due to the limitations of this paper. First, we focus on retail-channel green supply chain, but in practice, direct and retail channels often coexist. Moreover, the following questions arise: Given the different information sharing strategies for retailers, will manufacturers consider opening online channels? How will supply chain members' eco-label preferences change in a dual-channel environment? Gao et al. [5] provided insights into a direct-channel, but they assumed deterministic demand scenarios. Second, we consider only retailer's demand forecast and, thus, ask the following questions: When manufacturer and retailer simultaneously observe market demand, how will they develop their respective information sharing plans? How will stakeholders' eco-label preferences change? These questions deserve further investigation. Third, the model assumes that the government acts as the Stackelberg leader. However, in practice, supply chains are not always government-led; there may also be manufacturer-led or retailer-led structures. Under different power structures, the sequence of pricing decisions and the mechanisms of profit allocation may change, affecting firms' green investment decisions and eco-label strategies. Therefore, incorporating power structures into the framework of eco-label selection and government intervention is a promising direction for future research. Finally, we assume that manufacturer's cost of accessing DFI is zero, while in reality, retailers typically do not share their DFI for free. Here, we do not address information sharing incentives in green supply chains, but this is worth exploring in future work.

### **Author contributions**

Ruirui Zhang: Conceptualization, methodology, software, writing—original draft, writing—review & editing; Zhongdong Xiao: Conceptualization, funding acquisition, supervision, validation; Xuedong Fei: Formal analysis, resources, validation; Guanghui Zhou: Supervision, validation.

### **Use of Generative-AI tools declaration**

The authors declare that they did not use any Generative-AI tools in the creation of this article.

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### **Conflict of interest**

All authors declare no conflicts of interest in this paper.

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