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The Impact of Platform Information Sharing on Manufacturer's Choice of Online Distribution Mode and Green Investment

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Abstract: In this study, we consider a dual-channel supply chain structure where a manufacturer invests in green products and distributes them to green-conscious consumers through an offline retailer and an online platform. The manufacturer has the flexibility to choose sales via either a wholesale mode or an agency selling mode on the online platform channel. The platform can obtain private information and decide whether to share it with the manufacturer. This study investigates the strategic interaction between the green manufacturer's decision to use an online sales mode and the online platform's strategy for information sharing. Our analysis reveals that under the wholesale price mode, the platform is willing to share demand information only when the manufacturer exhibits high investment efficiency. In contrast, under the agency selling mode, the platform always shares demand information regardless of the level of investment efficiency. Nevertheless, the manufacturer is discouraged from opting for the agency selling mode due to the higher commission rate. Interestingly, we observe that when the value of information is sufficiently high, the manufacturer still tends to prefer the agency selling mode, despite the added cost of the higher commission fee. Additionally, the offline retailer always benefits from the information sharing conducted by the online platform. Finally, our extended model indicates that the timing of information-sharing decisions has a significant impact on the manufacturer's choice of mode.

Keywords: consumer green awareness; information sharing; sales mode; dual channel

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1. Introduction

The deterioration of the environment has become increasingly evident in recent years, which has also led to a significant rise in public awareness of environmental issues [1]. Furthermore, the concept of sustainability has been firmly established in various facets of human life. As a result, more and more consumers are becoming environmentally conscious and are increasingly inclined to favor and purchase environmentally friendly or green products offered by manufacturers [2]. According to a survey conducted by the BBMG Conscious Consumer Report, over 67% of respondents expressed a preference for purchasing green products and 51% of them were willing to pay higher prices for green products [3]. Another a survey conducted across nine developed countries also revealed that 50% of the respondents expressed a preference for purchasing environmentally friendly products. Furthermore, 24% of the respondents were even willing to pay a premium to purchase such products, although it was found that the willingness to pay for sustainable products may vary across different categories and industries [4]. Due to consumers' escalating consciousness about environmental protection, a notable concern for firms nowadays is enhancing the environmental friendliness of their products to minimize their impact on the environment and improve their environmental image. In practice, a growing number of manufacturers have already actively engaged in green investments and incorporated environmental activities into their supply chains in order to provide environmentally friendly products and services. These efforts encompass green R&D, green design, green manufacturing, green recycling, and other activities [5]. For instance, renowned fashion brands like H&M and Nike incorporate organic cotton and various other green, sustainable materials into their products [6]. Major home appliance manufacturers such as Haier, Gree, and Midea have also invested significant resources in research and development to produce energy-saving refrigerators, washing machines, air conditioners, and other household appliances, to reduce carbon emissions and energy consumption [7]. Beverage enterprises like Coca-Cola Company have installed large-scale solar and wind power-generation facilities in their global factories to replace traditional fossil fuel power generation [8]. It goes without saying that investing in green production can significantly help manufacturers shape their public image and gain a competitive edge. However, green production requires a large investment while the economic returns depend on market demand and consumers' attitudes. Therefore, the profit-oriented manufacturer must carefully balance the revenue generated from environmentally conscious consumers with the cost of technological development, to determine the optimal level of product greenness. This paper focuses on the manufacturer's optimal decision-making on green effort.

Platform retailing has experienced a surge in the e-commerce industry throughout the past few years. The U.S. Census Bureau reports that e-commerce sales totaled USD 871 billion in 2021 and have been growing at an average rate of 16% each year since 2011 [9]. Nowadays, online shopping has become one of the main ways for consumers to shop. To cater to consumers' needs and expand their market reach, green manufacturers increasingly tend to adopt a dual-channel operating strategy by retaining traditional offline channels while simultaneously exploring online platform sales channels such as JD, Alibaba and Amazon. This strategy is employed by numerous manufacturers such as Apple, Midea and Xiaomi [10]. Online retail platforms commonly present manufacturers with two alternative selling formats to choose from: the agency selling format and the wholesale price contract, also referred to as the reselling format [11], which differs from traditional offline retailers who only offer the wholesale format. Under the agency selling format, the online platform retailer serves as a marketplace where manufacturers sell their products directly to consumers. In turn, the manufacturer pays the online platform a certain percentage of their sales revenue. For example, PepsiCo sells its products on JD.com [12]. Under the reselling format, the platform retailers, similar to traditional retailers, procure products from manufacturers and subsequently resell them to consumers. For example, HP sells its products to Amazon [12]. Because a manufacturer's choice of selling format can lead to distinct market structures, this, in turn, directly impacts the decision-making and profitability of all supply chain participants. Therefore, it is very important for green manufacturers to carefully select the optimal selling format, which is a research focus in this paper.

In addition, compared to traditional offline retailers and manufacturers, online platforms are usually equipped with advanced information technology, such as data analytics tools, meaning they can gather and analyze various data—including consumers' purchase details, customers' browsing histories, and sellers' sales data—and use those to make better market forecasts [13]. Meanwhile, manufacturers and offline retailers often lack this capability, thus failing to adequately understand market demand [8]. Consequently, this leads to demand information asymmetry between these parties and online platforms in the supply chain.

In practice, manufacturers' green investment can be significantly driven by accurate market forecasting information. When the market demand signal is strong, this indicates that green products are highly popular among consumers. This strong signal motivates manufacturers to increase green technological investment. But information asymmetry makes it difficult for manufacturers to appropriately adjust their prices and make green decisions. To help less informed manufacturers, recently, some platforms have started to share market information with their manufacturers. For instance, Amazon offers valuable market demand reports based on its extensive big data to its selected manufacturers [14]. Tmall, meanwhile, has established an open-access data platform known as Ali Index to help its manufacturers understand the market trends and make more informed decisions [13].

When online platforms share demand information, on the one hand, manufacturers who are informed can make more accurate decisions regarding product greenness decisions during the production process and sales quantities during the sales season, which may have a positive effect on retail platforms. On the other hand, manufacturers who possess additional market information can strategically adjust their wholesale prices, which may exacerbate double marginalization and hurt the retail platforms [15]. Moreover, due to potential information leakage, information sharing also changes the competition relationship between platforms and offline retailers, which can lead online platforms to lose their information advantage. As mentioned earlier, the manufacturer's choice of selling mode directly influences the decisions of the participants in the supply chain. It also has a significant impact on the platform's decisions around information sharing. Therefore, it is crucial for retail platforms to balance the positive and negative impacts of information sharing, especially when manufacturers engage in green production investment. Based on these considerations, we are motivated to gain insights about the impact of cooperation contracts on platform information sharing.

Based on above considerations, in this paper, we address the following research questions: in the context of an existing and well-established offline retail channel, how should the green manufacturer select the online selling mode? How does the sharing of demand information by online retail platforms vary based on the specific selling mode chosen by the manufacturer? How does information sharing influence the manufacturer's green efforts? How will the interaction between the manufacturer's choice of selling mode and the retail platform's information-sharing strategy affect the whole supply chain?

To answer the above questions, we analyze a green dual-channel supply chain, wherein a green manufacturer distributes its products through both online and offline retailers. First, the manufacturer chooses between the agency selling and reselling mode for his online retail channel. Then, the platform can choose whether to share market forecast information with the manufacturer before the platform observes the demand signal. Next, the manufacturer determines the optimal level of greenness and subsequently makes wholesale pricing decision. Finally, all firms make quantity decisions.

Our study has several key findings. When the manufacturer chooses the wholesale price mode, the platform is willing to share demand information only when the manufacturer demonstrates high investment efficiency. In contrast, under the agency selling mode, the platform always shares demand information. We also find that information sharing always benefits the offline retailer due to information leakage. The choice of sales mode for the manufacturer is influenced by investment efficiency, commission rate, and the value of information. When the commission rate is low, the manufacturer prefers the agency selling mode. However, interestingly, when the commission rate is high, the manufacturer might still prefer the agency selling mode if the value of information is significant. What is more, we also find that the timing of information-sharing decisions has a significant impact on the manufacturer's choice of mode.

The remainder of this study is organized as described below. In Section 2, we briefly review the related literature. In Section 3, we describe the game model. Section 4 presents the main equilibrium results. Section 5 offers a detailed analysis of the results. The equilibrium decisions are presented in Section 6. Section 7 contains an extension of the study. Numerical examples are given in Sections 8 and 9 summarizes the findings.

2. Literature Review

Our study mainly relates to three streams of the existing literature: green supply chain management, selling modes on e-commerce platforms, and supply chain information sharing.

As calls for environmental protection become louder, researchers are paying increasing attention to green supply chain management [16]. In this paper, we mainly focus on a specific aspect of green supply chain management, namely, manufacturers' green investment, with consideration of consumer environmental awareness. Ghosh and Shah [17] investigated how different channel structures affect the optimal level of greening in scenarios when the firms operate either independently or collaboratively. Swami and Shah [18] analyzed the supply chain structure involving a single manufacturer and retailer where both the manufacturer and retailer can invest in greening efforts and demonstrated that a two-part tariff contract can effectively coordinate the supply chain. Hong and Guo [19] took consumer reference behaviors into account to explore green product design and suggested that, in terms of environmental performance enhancements, a retailer-led supply chain surpasses a manufacturer-led one. Song and Gao [20] constructed a two-level supply chain to investigate the impact of revenue-sharing contracts on product greenness, green prices, and the profits of the members. Ghosh and Shah [21] examined the influence of cost-sharing contracts, when the cost-sharing ratio is determined by retailers or negotiated by both parties, on optimal decision-making within green supply chains. The aforementioned studies focused on a supply chain structure consisting of one manufacturer and one retailer. There are some studies that examined manufacturers' sales of green products through dual channels. Zhu and He [22] investigated the impact of channel structures, cost structures, and the types of competition on manufacturers' green efforts and showed that the double marginalization effect has an unexpected influence on the level of greenness of the product. Li et al. [23] explored whether a green manufacturer should add a direct channel, and revealed that the decision to pursue a dual-channel strategy is contingent upon the incurred greening cost. Furthermore, the study demonstrated that, when the manufacturer implements uniform pricing, channel encroachment can alleviate the double marginalization effect. Li et al. [24] developed a supply chain model with one manufacturer and two retailers and studied the impact of retailers' fairness concerns on the operational decisions of green supply chains. Shi et al. [25] considered a similar supply chain structure, in which the manufacturer or retailers can enhance products' green level by investing in green technology. Wang et al. [26] discussed the strategic interaction between manufacturers' sales mode selection and platform green packaging investment and showed that the manufacturer does not always benefit from the platform investing in green packaging. Zhang et al. [27] studied manufacturers' sustainable investment strategies and supply chain coordination strategies when both manufacturers and retailers can obtain a market signal. Similar to the above-mentioned relevant research, we also incorporate green products into our model. Additionally, unlike previous studies, we not only investigate the manufacturer's contract preference under an environment of information asymmetry but also examine its impact on the online retail platform's information-sharing decision.

This paper also relates to the literature on selling contract choices, which has drawn much attention. Abhishek et al. [11] showed that agency selling is an effective sales strategy, and that the selection of this strategy by platforms primarily hinges on the intensity of competition and spillover effects within the market. Kwark et al. [28] demonstrated that product quality information and the alignment between the product and consumers' needs have a significant impact on the e-retailer's decision when choosing between a wholesale contract and agency selling contract. Zhang and Hou [29] argued that the manufacturer's contract selection primarily hinges on their brand advantage and product substitutability when a platform introduces its own private brand. Xu et al. [30] investigated cooperation mode selection for a manufacturer selling its products via offline channels and an online platform, operating within the constraints of a cap-and-trade regulation. They showed that, under certain circumstances, the two firms could achieve coordination through both modes despite demand disruptions. Tian et al. [31] investigated a supply chain wherein suppliers have the option to select either agency selling or reselling contracts. Their findings revealed that upstream competition can significantly mitigate the double marginalization effect observed in the reselling channel. Furthermore, they determine that a platform's optimal selling contract is contingent upon order fulfillment costs and the intensity of competition. Moreover, numerous papers have investigated the impact of several significant factors on the decision regarding the selling format, including upstream competition customer loyalty [32], asymmetric competition [33], bundling strategy [34], and services [35].

Those studies looked into how suppliers and platforms prefer different selling modes under varying conditions. But they overlooked the link between manufacturers' green investments and those sales modes. In addition, when there is information asymmetry, it makes it difficult for firms to make operational decisions. Therefore, we explore how information sharing and green investments interact and what new insights we can gain from it.

This study also contributes to the existing literature by examining vertical information sharing under demand uncertainty within supply chains. Some papers focused on the information-sharing strategies of retailers. For example, Li [36] explored the supply chain structure consisting of an upstream manufacturer and many downstream retailers, and showed that vertical information sharing benefits the manufacturer but hurts the retailers under a wholesale contract. Zhang [15] also considered vertical information exchange with duopoly retailers, and drew a similar conclusion to that of Li [36]. However, Li and Zhang [37] found that confidentiality encourages all supply chain members to share information, particularly when retail competition is intense. Yue and Liu [38] discussed information sharing in the context of a manufacturer's dual-channel supply chain. They demonstrated that, despite no explicit information sharing, the retailer still can infer the manufacturer's forecast signal through the wholesale price. Huang et al. [39] showed that when the manufacturer can endogenously choose channel encroachment, retailer information sharing can prevent manufacturer encroachment. Further literature examined the information-sharing strategy of manufacturers. For example, Gal-Or et al. [40] established a supply chain configuration consisting of a single manufacturer and two retailers, and delved into the manufacturer's strategy towards information sharing. Their findings revealed that the manufacturer preferred to collaborate with retailers who possessed less accurate information. Wang et al. [41] studied the issue of information sharing between a manufacturer and two retailers competing on prices and service efforts. They showed that the manufacturer's incentive to share information is influenced by the cost in terms of effort and the intensity of competition. The above studies primarily focused on traditional supply chains. With the development of e-commerce platforms, as mentioned earlier, information sharing based on these platforms has gained attention. Our work is also related to this stream of research. Liu et al. [42] investigated a supply chain consisting of numerous agency sellers and a single retail platform operating under conditions of demand information asymmetry. Their findings revealed that the platform had incentives to share crucial demand information with its sellers, ultimately leading to a scenario of Pareto improvement. Ha et al. [43] studied the impact of platform information sharing on manufacturers' decision to add agency channels. Chen et al. [44] conducted a comparative analysis of platforms' recommendation decisions and information-sharing strategies under the manufacturer's wholesale price mode versus the agency selling mode. Zhang et al. [10] studied the issue of manufacturers' entry into offline channels when the manufacturer sells products on a platform through the reselling mode or agency selling. Their results indicated that platform information sharing plays a crucial role. Wei et al. [45] studied the impact of platform information sharing on green manufacturers' expansion of agency selling channels in addition to reseller channels. Tsunoda and Zennyo [46] provided clarification on how the platform's sharing of information impacts the supplier's multi-channel management and also demonstrated that, when considering endogenous commissions, information sharing can enable manufacturers to transition from the wholesale mode to agency selling mode, resulting in a Pareto improvement for all firms. Recently, Tang et al. [47] studied the impact of platform information sharing on a manufacturer's choice of entry mode. Their findings revealed that the platform is more willing to share information to induce the manufacturer to enter the market through its agency channel if it possesses a significant selling cost advantage compared to the manufacturer or can internally determine the commission rate. While previous research papers have focused on the influence of information sharing on operational decisions, they have not yet delved into how information sharing affects manufacturers' green efforts and online contract choices. This is the focus of our paper. We summarize the representative studies that are most relevant to this paper in Table 1.

Table 1. Summary of the relevant literature.

	Dual Channel Supply Chain	Selling Contract Choice	Information Sharing	Green Supply Chain
Abhishek et al. [11]	√	√		
Li et al. [23]	√			√
Tian et al. [31]		√		
Tsunoda and Zennyo [46]	√	√	√	
Li and Zhang [37]	√		√	
Wei et al. [45]	√	√	√	
Zhang [15]	√		√	
Ghosh and Shah [17]				√
Wang et al. [26]	√			√
Zhang et al. [10]	√	√	√	
This paper	√	√	√	√

3. The Model

Consider a dual-channel supply chain consisting of a manufacturer, an online retailer, and an offline retailer. The manufacturer designs and produces green products and sells them through the two retail channels. The offline retailer adopts a traditional wholesale mode for procurement and sales to consumers. The online retailer has two sales modes available for the manufacturer to choose from: one is the agency selling mode, and the other is the traditional wholesale price mode. If the manufacturer chooses the wholesale price mode, the manufacturer determines the wholesale price w, and then the online retailer determines the sales quantity online. If the manufacturer chooses the agency selling mode, they can directly determine the online sales volume but must pay the platform a commission fee ϕ, which is a fraction of the revenue generated by the sales through the marketplace. We assume that the commission fee is exogenous, because the platform usually charges the same commission for all products within a certain category and does not change it frequently [48], for instance, JD.com sets the commission rate for most product categories ranging from 5% to 12% [31]. In this setting, we assume that the manufacturer chooses a sales mode in the initial stage, which is reasonable because sales mode selection is usually a long-term decision that is not easily changed. The channel structure is shown in Figure 1.

Consumers are green-conscious and can purchase products through online or offline channels. The higher the greenness of the product, the greater the utility for consumers. Following Singh and Vives [49], we can obtain the utility function of a representative consumer:

$$U = (a + \theta + \gamma e) \times (q_1 + q_2) - \frac{(q_1 + q_2)^2}{2} - p \times (q_1 + q_2) \tag{1}$$

The equation implies the representative consumer's utility increases in greening level but decreases in retail price. Maximizing the utility function above yields the demand function below:

$$p = a + \theta + \gamma e - q_1 - q_2 \tag{2}$$

where q_1 and q_2 are sales quantities in an offline store and online platform, respectively. p is the market clearing price. The random variable θ, with mean zero and variance σ^2, captures the market demand uncertainty. a is a basic market demand and we assume that σ is sufficiently small relative to a so that the probability of negative market demand can be ignored [37]. In addition, γe is the increased market demand due to green investment from the manufacturer. e denotes the green level of the product, and the higher the greenness of a product, the smaller its impact on the environment. γ is the consumers' green sensitivity coefficient, which represents the consumers' preference for green products and measures the impact of the green effort on demand.

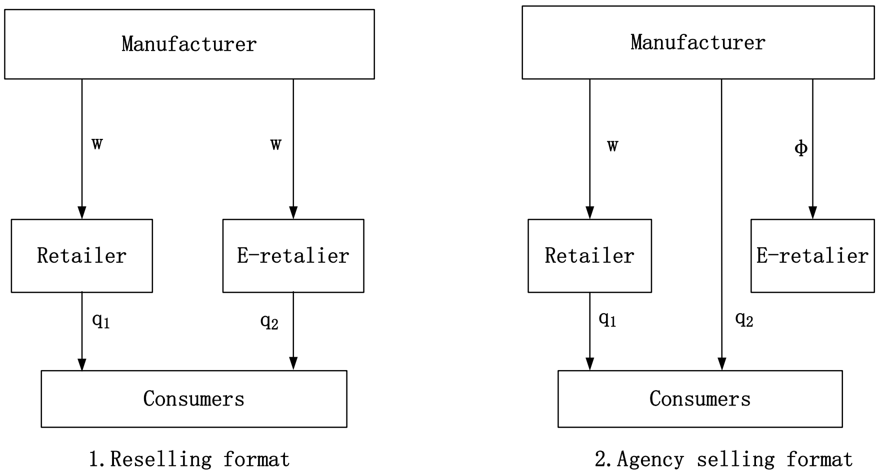

Figure 1. Channel structure.

To meet consumer green preferences, the manufacturer needs to invest in green technologies to produce green products. We assume that the green investment cost for the manufacturer is a quadratic function of the green level e, that is, ke^2, where k is the green investment coefficient, and the larger its value, the higher the cost [17]. This green investment cost function means green investment has the characteristic of diseconomies of scale, as is widely employed in the existing literature [18]. The marginal production cost for the manufacturer is constant and without loss of generality, so we normalize the cost to zero [48].

Due to the application of big data and other technologies, the online retailer often has a fairly accurate understanding of market demand, gained through historical sales' data analysis, customer research, and other methods. Therefore, we assume that the online retailer has access to a private imperfect demand signal Y, which is an unbiased estimator of θ $(E[\theta|Y] = 0)$, whereas the manufacturer and offline retailer do not have any private information. Based on the existing research on information sharing [36], we assume that our expectation of θ conditional on Y is a linear function of signal Y, that is, $E[Y|\theta] = \frac{1}{1+t\sigma^2}E[\theta] + \frac{t\sigma^2}{1+t\sigma^2}Y$, where $t = \frac{1}{E[Var[Y|\theta]]}$ represents the signal accuracy of Y. The size of t reflects the accuracy of the signal, and the larger the t, the better the accuracy of the signal. For ease of exposition, we define $\beta = \frac{t\sigma^2}{1+t\sigma^2}$, and then $E[Y|\theta] = \beta Y$. Before observing the actual value of Y, the platform can choose whether to share private information with the manufacturer. If the platform shares the information with the manufacturer, then the manufacturer sets the green level and makes other decisions based on the available information; otherwise, the supplier lacks certainty about the market. If the platform agrees to share information, we assume that information sharing is truthful due to the long-term partnership between the platform and manufacturer [43].

The sequence of events is shown in Figure 2. In the first stage, the manufacturer chooses reselling (R) or agency selling (A). In the second stage, before observing the demand signal, the platform decides whether to share information with the manufacturer. In the third stage, the platform observes the demand signal Y and shares it with the manufacturer if an information-sharing agreement has been reached in the first stage. Otherwise, the platform keeps this demand signal Y private. In the fourth stage, if the manufacturer chooses the reselling mode in stage 1, the manufacturer first makes decisions on greenness and wholesale price, and then both the online retailer and the manufacturer make decisions on sales quantity. If the manufacturer chooses the agency selling mode in stage 1, the manufacturer first makes decisions on greenness and wholesale price, and then both the offline retailer and the manufacturer make decisions on sales quantity simultaneously. Finally, the fully demand is realized and the market is clear.

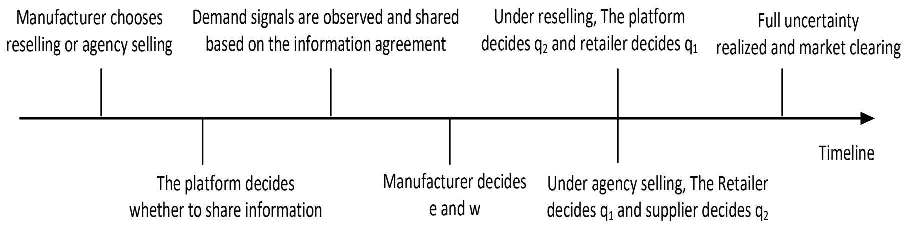

Figure 2. Timeline of events.

Formally, we use R(A) to denote the scenario of the manufacturer choosing the reselling (agency selling) mode and N(S) to represent a decision of no information sharing (information sharing). According to the different strategy choices of the players, there are four subgames based on our setting, and we use the first letter to represent the decision on sales mode and the second letter to represent the decision on information sharing, that is: reselling without information sharing (RN), reselling with information sharing (RS), agency selling without information sharing (AN), and agency selling with information sharing (AS). We assume that all participants are risk neutral and pursue the maximization of expected profits [43]. The notations we adopt in this paper are listed in Table 2.

Table 2. Notations.

Notation	Description
a	Base market demand
θ	Random variable with mean zero and variance σ^2
Y	Private demand signal, representing an unbiased estimator of θ
t	Forecast accuracy of the e-retailer
$\beta(t)$	Weight of Y in the conditional expectation $E[Y\|\theta]$
ϕ	Commission rate
k	Manufacturer's green investment coefficient
γ	Consumer's green preference coefficient
Π	Profit function
$E\Pi$	Expected profit function
p	Market clearing price
e	Manufacturer's green investment level
w	Wholesale price set by the manufacturer
q_1	Quantity of the product sold by offline retailers
q_2	Quantity of the product sold by online retailers/manufacturer

4. Equilibrium Analysis

In the following, we assume $k > max\left\{\frac{\gamma^2}{6}, \frac{5\gamma^2-4\gamma^2\phi}{20+4\phi}\right\}$; this assumption ensures that the manufacturer' profit function is concave and the cost of green investment is not too low [50]. The solution is reached by backward induction to find the subgame-perfect Nash equilibrium.

4.1. Scenario RN

In this case, the platform will not share any demand information with the manufacturer who adopts the reselling format. Given the wholesale price w and the green level e, the offline retailer and online platform simultaneously decide their optimal sales quantity to maximize their expected profits:

$$E[\Pi_1^{\mathrm{RN}}] = E[(a + \theta + \gamma e - q_1 - q_2 - w) \times q_1] \tag{3}$$

$$E[\Pi_2^{\mathrm{RN}}|Y] = E[(a + \theta + \gamma e - q_1 - q_2 - w) \times q_2|Y] \tag{4}$$

Because the offline retailer's payoff function is concave in q_1 and the online platform's payoff is concave in q_2, the first-order optimality condition yields their optimal responsive function $q_1 = \frac{1}{2}(a - w + e\gamma - E[q_2])$ and $q_2 = \frac{1}{2}(a - w + E[\theta|Y] + e\gamma - q_1)$. Jointly solving these two equations yields:

$$q_1 = \frac{1}{3}(a - w + e\gamma) \tag{5}$$

$$q_2 = \frac{1}{6}(2a - 2w + 3E[\theta|Y] + 2e\gamma) \tag{6}$$

Taking the offline retailer and platform's best response into account, the manufacturer sets w and e to maximize its expected profit:

$$E\Pi_M^{\mathrm{RN}} = E\left[w \times q_1 + w \times q_2 - k \times e^2\right] \tag{7}$$

We can easily determine that the Hessian matrix of $E\Pi_M^{\mathrm{RN}}$ with respect to w and e is negative definite when $k > \frac{\gamma^2}{6}$, which shows that the efficiency of green investment is not too high and also satisfies our assumption. Therefore, by applying the first-order optimality conditions to $E\Pi_M^{\mathrm{RN}}$, we can derive the optimal wholesale price w and green level e of the manufacturer under the reselling mode, as

$$w^{\mathrm{RN}} = \frac{3ak}{6k - \gamma^2} \tag{8}$$

$$e^{\mathrm{RN}} = \frac{a\gamma}{6k - \gamma^2} \tag{9}$$

When substituting the above equation into q_1 and q_2, we derive the equilibrium decisions, which are given as follows:

$$q_1^{\mathrm{RN}} = \frac{ak}{6k - \gamma^2} \tag{10}$$

$$q_2^{\mathrm{RN}} = \frac{2ak + 6k\beta Y - \beta Y\gamma^2}{12k - 2\gamma^2} \tag{11}$$

Without information sharing, the manufacturer's and the offline retailer's decisions are independent of demand signal Y, whereas the online retail platform's quantity decision is positively related to market demand signal Y. Based on the equilibrium decisions, we can compute the optimal ex ante profits for the manufacturer, offline retailer, online platform, and the whole supply chain, respectively, which are as follows:

$$E\Pi_M^{\mathrm{RN}} = \frac{a^2 k}{6k - \gamma^2} \tag{12}$$

$$E\Pi_1^{\mathrm{RN}} = \frac{a^2k^2}{\left(-6k+\gamma^2\right)^2} \tag{13}$$

$$E\Pi_2^{\mathrm{RN}} = \frac{a^2k^2}{\left(-6k+\gamma^2\right)^2} + \frac{\beta\sigma^2}{4} \tag{14}$$

$$E\Pi_{SC}^{\mathrm{RN}} = \frac{\beta\sigma^2}{4} + \frac{a^2k\left(8k-\gamma^2\right)}{\left(-6k+\gamma^2\right)^2} \tag{15}$$

4.2. Scenario RS

In this scenario, the manufacturer chooses to adopt the wholesale price/reselling contract, and the online retail platform agrees to share demand forecast information with the manufacturer. When the platform shares demand information with the manufacturer, the manufacturer determines the optimal wholesale price and greenness based on the demand signal. Due to our assumption of a linear information structure, although the online retailer does not share information with the offline retailer, the offline retailer can still infer market information from the wholesale price and product greenness that are observable, as set by the manufacturer. Therefore, in line with the previous literature (e.g., Li [14], Zhang [35], and Yue et al. [37]), we assume that the offline retailer can fully infer market demand information. That is to say, when the online retailer shares information with the manufacturer, supply chain members are transparent about market demand information. Given the wholesale price w and the green level e, the offline retailer and online platform simultaneously decide on the optimal sales quantity to maximize their expected profits:

$$E[\Pi_1^{\mathrm{RS}}|Y] = E[(a+\theta+\gamma e-q_1-q_2-w)\times q_1|Y] \tag{16}$$

$$E[\Pi_2^{\mathrm{RS}}|Y] = E[(a+\theta+\gamma e-q_1-q_2-w)\times q_2|Y] \tag{17}$$

It can be seen from the above formulas that when the platform shares demand information, offline and online retailers have symmetric information and an identical expected profit function structure. Solving the first-order conditions of (16) and (17) jointly yields the equilibrium retail order quantity, as follows:

$$q_1 = \frac{1}{3}(a-w+E[\theta|Y]+e\gamma) \tag{18}$$

$$q_2 = \frac{1}{3}(a-w+E[\theta|Y]+e\gamma) \tag{19}$$

Based on the retailers' best response, the manufacturer sets w and e to maximize its conditional expected profit:

$$E[\Pi_M^{\mathrm{RS}}|Y] = E[w\times q_1+w\times q_2-k\times e^2|Y] \tag{20}$$

Since the manufacturer's conditional expected profit function is a jointly concave function of w and e, solving its first-order optimality condition can lead to

$$w^{\mathrm{RS}} = \frac{3k(a+\beta Y)}{6k-\gamma^2} \tag{21}$$

$$e^{\mathrm{RS}} = \frac{(a+\beta Y)\gamma}{6k-\gamma^2} \tag{22}$$

Again, by substituting w^{RS} and e^{RS} back into retailers' best response functions q_1 and q_2, we derive the equilibrium decisions, which are given as follows:

$$q_1^{\mathrm{RS}} = \frac{k(a+\beta Y)}{6k-\gamma^2} \tag{23}$$

$$q_2^{\mathrm{RS}} = \frac{k(a+\beta Y)}{6k-\gamma^2} \tag{24}$$

With information sharing, the decisions of the e-retailer, the manufacturer, and the offline retailer positively respond to the demand signal Y. The rationale behind this is that, with information sharing, the manufacturer can more accurately assess demand fluctuations, which subsequently prompts them to make more responsive decisions regarding wholesale prices and green levels. Similarly, online and offline retailers, who possess symmetric information, will also actively respond to the signal. Based on the equilibrium decisions, we can determine the optimal ex ante payoffs for the three firms (manufacturer, offline retailer, and online platform) and the whole supply chain, which are as follows:

$$E\Pi_M^{\mathrm{RS}} = \frac{a^2 k}{6k-\gamma^2} + \frac{k\beta\sigma^2}{6k-\gamma^2} \tag{25}$$

$$E\Pi_1^{\mathrm{RS}} = \frac{a^2k^2}{\left(-6k+\gamma^2\right)^2} + \frac{k^2\beta\sigma^2}{\left(-6k+\gamma^2\right)^2} \tag{26}$$

$$E\Pi_2^{\mathrm{RS}} = \frac{a^2k^2}{\left(-6k+\gamma^2\right)^2} + \frac{k^2\beta\sigma^2}{\left(-6k+\gamma^2\right)^2} \tag{27}$$

$$E\Pi_{SC}^{\mathrm{RS}} = \frac{k\left(a^2+\beta\sigma^2\right)\left(8k-\gamma^2\right)}{\left(-6k+\gamma^2\right)^2} \tag{28}$$

Under the wholesale mode, by analyzing how investment cost and green preference impact optimal decisions, we can derive Lemma 1.

Lemma 1. *(1)* $\frac{\partial e^{Ri}}{\partial k} < 0$, $\frac{\partial w^{Ri}}{\partial k} < 0$, $\frac{\partial q_1^{Ri}}{\partial k} < 0$, $\frac{\partial q_2^{Ri}}{\partial k} < 0$, $\frac{\partial E\Pi_M^{Ri}}{\partial k} < 0$, $\frac{\partial E\Pi_1^{Ri}}{\partial k} < 0$ $\frac{\partial E\Pi_2^{Ri}}{\partial k} < 0$, $\forall i \in \{N,S\}$; *(2)* $\frac{\partial e^{Ri}}{\partial \gamma} > 0$, $\frac{\partial w^{Ri}}{\partial \gamma} > 0$, $\frac{\partial q_1^{Ri}}{\partial \gamma} > 0$, $\frac{\partial q_2^{Ri}}{\partial \gamma} > 0$, $\frac{\partial E\Pi_M^{Ri}}{\partial \gamma} > 0$, $\frac{\partial E\Pi_1^{Ri}}{\partial \gamma} > 0$ $\frac{\partial E\Pi_2^{Ri}}{\partial \gamma} > 0$, $\forall i \in \{N,S\}$.

This lemma is quite intuitive. A large k value indicates that the manufacturer's investment efficiency is low, which, in turn, leads to the manufacturer's lower willingness to invest in green efforts in order to save costs. Simultaneously, the smaller market size resulting from decreased investment leads retailers to reduce their order quantities as well. However, a higher level of green awareness drives manufacturers to increase their green investment to attract consumers. Meanwhile, it also induces the manufacturer to increase its wholesale prices to offset the cost of green investment and maintain its profit margin.

4.3. Scenario AN

Under the AN mode, the manufacturer chooses the agency selling mode and the platform does not share the demand information with the manufacturer. In this scenario, the platform remains neutral in quantity decisions, merely sharing in the sales revenue generated by the manufacturer. Given the wholesale price w and the green level e, the manufacturer decides the online sales quantity and the offline retailer decides the offline sales quantity simultaneously to maximize their respective expected profits:

$$E\Pi_M^{\mathrm{AN}} = E\Big[w \times q_1 + (1-\phi) \times (a+\theta+\gamma e - q_1 - q_2) \times q_2 - k \times e^2\Big] \tag{29}$$

$$E\Pi_1^{\mathrm{AN}} = E[(a+\theta+\gamma e-q_1-q_2-w)\times q_1] \tag{30}$$

Solving the first-order conditions associated with (29) and (30) jointly yields an equilibrium retail order quantity as a function of the wholesale price w and green level e:

$$q_1 = \frac{1}{3}(a-2w+e\gamma) \tag{31}$$

$$q_2 = \frac{1}{3}(a+w+e\gamma) \tag{32}$$

By anticipating the retailer's optimal retail quantity described above, the manufacturer sets w and e to maximize its expected profit:

$$E\Pi_M^{\mathrm{AN}} = E\left[w\times q_1+(1-\phi)\times(a+\theta+\gamma e-q_1-q_2)\times q_2-k\times e^2\right] \tag{33}$$

We can easily determine that the Hessian matrix of $E\Pi_M^{\mathrm{AN}}$ with respect to w and e is negative definite when $k > \frac{5\gamma^2-4\gamma^2\phi}{20+4\phi}$. By applying the first-order optimality conditions to $E\Pi_M^{\mathrm{RN}}$, we can derive the optimal wholesale price w and green level e of the manufacturer under the agency selling mode, as

$$w^{\mathrm{AN}} = \frac{2ak(5-2\phi)}{4k(5+\phi)+\gamma^2(-5+4\phi)} \tag{34}$$

$$e^{\mathrm{AN}} = \frac{5a\gamma-4a\gamma\phi}{20k-5\gamma^2+4k\phi+4\gamma^2\phi} \tag{35}$$

When substituting w^{RS} and e^{RS} back into retailers' best response functions q_1 and q_2, we derive the equilibrium decisions, which are given as follows:

$$q_1^{\mathrm{AN}} = \frac{4ak\phi}{4k(5+\phi)+\gamma^2(-5+4\phi)} \tag{36}$$

$$q_2^{\mathrm{AN}} = \frac{10ak}{4k(5+\phi)+\gamma^2(-5+4\phi)} \tag{37}$$

Without information sharing, the manufacturer's and the offline retailer's decisions are independent of the demand signal Y. Based on the optimal quantity decisions of the manufacturer and offline retailer, we can easily derive the optimal ex ante payoffs for supply chain members, which are as follows:

$$E\Pi_M^{\mathrm{AN}} = \frac{a^2k(5-4\phi)}{4k(5+\phi)+\gamma^2(-5+4\phi)} \tag{38}$$

$$E\Pi_1^{\mathrm{AN}} = \frac{16a^2k^2\phi^2}{\left(4k(5+\phi)+\gamma^2(-5+4\phi)\right)^2} \tag{39}$$

$$E\Pi_2^{\mathrm{AN}} = \frac{100a^2k^2\phi}{\left(4k(5+\phi)+\gamma^2(-5+4\phi)\right)^2} \tag{40}$$

$$E\Pi_{SC}^{\mathrm{AN}} = \frac{a^2k\left(-\gamma^2(5-4\phi)^2+20k(5+2\phi)\right)}{\left(4k(5+\phi)+\gamma^2(-5+4\phi)\right)^2} \tag{41}$$

4.4. Scenario AS

In this scenario, the manufacturer chooses to adopt an agency selling contract, and the online retail platform agrees to share forecast information with the manufacturer. Similar to Scenario RS, the offline retailer can infer the market demand signal shared by the platform from the wholesale price and product greenness set by the manufacturer. Given the wholesale price w and the green level e, the manufacturer determines its retail quantity for the online channel and the offline retailer determines the offline sales quantity to maximize their conditional expected profits as follows:

$$E\left[\Pi_M^{\mathrm{AS}}\middle|Y\right] = \left[w \times q_1 + (1-\phi) \times (a + \theta + \gamma e - q_1 - q_2) \times q_2 - k \times e^2 \middle| Y\right] \tag{42}$$

$$E\left[\Pi_1^{\mathrm{AS}}\middle|Y\right] = E[(a + \theta + \gamma e - q_1 - q_2 - w) \times q_1 | Y] \tag{43}$$

Solving these maximization problems yields the following:

$$q_1 = \frac{1}{3}(a - 2w + E[\theta|Y] + e\gamma) \tag{44}$$

$$q_2 = \frac{1}{3}(a + w + E[\theta|Y] + e\gamma) \tag{45}$$

Anticipating the retail quantity above, the manufacturer sets w and e to maximize its conditional expected profit:

$$E\left[\Pi_M^{\mathrm{AS}}\middle|Y\right] = \left[w \times q_1 + (1-\phi) \times (a + \theta + \gamma e - q_1 - q_2) \times q_2 - k \times e^2 \middle| Y\right] \tag{46}$$

by setting the wholesale price and green level to

$$e^{\mathrm{AS}} = \frac{(a + \beta Y)\gamma(5 - 4\phi)}{20k - 5\gamma^2 + 4k\phi + 4\gamma^2\phi} \tag{47}$$

$$w^{\mathrm{AS}} = \frac{2k(a + \beta Y)(5 - 2\phi)}{4k(5 + \phi) + \gamma^2(-5 + 4\phi)} \tag{48}$$

Again, by substituting w^{RS} and e^{RS} back into retailers' best response functions q_1 and q_2, we derive the equilibrium decisions, which are given as follows:

$$q_1^{\mathrm{AS}} = \frac{4k(a + \beta Y)\phi}{4k(5 + \phi) + \gamma^2(-5 + 4\phi)} \tag{49}$$

$$q_2^{\mathrm{AS}} = \frac{10k(a + \beta Y)}{4k(5 + \phi) + \gamma^2(-5 + 4\phi)} \tag{50}$$

With information sharing, the decisions of the e-retailer, the manufacturer, and the offline retailer positively respond to the demand signal Y. This is because a larger Y indicates a higher likelihood of high demand, resulting in a higher value of green investment for the manufacturer. Based on the equilibrium decisions, we can derive the respective optimal ex ante profits for the manufacturer, online platform, and offline retailer:

$$E\Pi_M^{\mathrm{AS}} = \frac{a^2k(5 - 4\phi)}{4k(5 + \phi) + \gamma^2(-5 + 4\phi)} + \frac{k\beta\sigma^2(5 - 4\phi)}{4k(5 + \phi) + \gamma^2(-5 + 4\phi)} \tag{51}$$

$$E\Pi_1^{\mathrm{AS}} = \frac{16a^2k^2\phi^2}{(4k(5 + \phi) + \gamma^2(-5 + 4\phi))^2} + \frac{16k^2\beta\sigma^2\phi^2}{(4k(5 + \phi) + \gamma^2(-5 + 4\phi))^2} \tag{52}$$

$$E\Pi_2^{\mathrm{AS}} = \frac{100a^2k^2\phi}{(4k(5 + \phi) + \gamma^2(-5 + 4\phi))^2} + \frac{100k^2\beta\sigma^2\phi}{(4k(5 + \phi) + \gamma^2(-5 + 4\phi))^2} \tag{53}$$

$$E\Pi_{SC}^{\mathrm{AS}} = \frac{k\left(a^2 + \beta\sigma^2\right)\left(-\gamma^2(5 - 4\phi)^2 + 20k(5 + 2\phi)\right)}{(4k(5 + \phi) + \gamma^2(-5 + 4\phi))^2} \tag{54}$$

Under the agency selling mode, based on the above results, we analyze the monotonicity of the decisions with respect to the commission rate, investment efficiency, and consumers' green awareness, which is shown in Lemma 2:

Lemma 2. *(1)* $\frac{\partial e^{Ai}}{\partial \phi} < 0$, $\frac{\partial w^{Ai}}{\partial \phi} < 0$, $\frac{\partial q_2^{Ai}}{\partial \phi} < 0$, *when* $k < \frac{\gamma^2}{4}$, $\frac{\partial q_1^{Ai}}{\partial \phi} < 0$, *otherwise,* $\frac{\partial q_1^{Ai}}{\partial \phi} > 0$, $\frac{\partial E\Pi_M^{Ai}}{\partial \phi} < 0$, *when* $k < \frac{\gamma^2}{4}$, $\frac{\partial E\Pi_1^{Ai}}{\partial \phi} < 0$, *otherwise,* $\frac{\partial E\Pi_1^{Ai}}{\partial \phi} > 0$, *when* $k > \frac{-5\gamma^2-4\gamma^2\phi}{-20+4\phi}$, $\frac{\partial E\Pi_2^{Ai}}{\partial \phi} > 0$, *otherwise,* $\frac{\partial E\Pi_2^{Ai}}{\partial \phi} < 0$, $\forall i \in \{N,S\}$; *(2)* $\frac{\partial e^{Ai}}{\partial k} < 0$, $\frac{\partial w^{Ai}}{\partial k} < 0$, $\frac{\partial q_2^{Ai}}{\partial k} < 0$, $\frac{\partial q_1^{Ai}}{\partial k} < 0$, $\frac{\partial E\Pi_M^{Ai}}{\partial k} < 0$, $\frac{\partial E\Pi_1^{Ai}}{\partial k} < 0$, $\frac{\partial E\Pi_2^{Ai}}{\partial k} < 0$, $\forall i \in \{N,S\}$; *(3)* $\frac{\partial e^{Ai}}{\partial \gamma} > 0$, $\frac{\partial w^{Ai}}{\partial \gamma} > 0$, $\frac{\partial q_2^{Ai}}{\partial \gamma} > 0$, $\frac{\partial q_1^{Ai}}{\partial \gamma} > 0$, $\frac{\partial E\Pi_M^{Ai}}{\partial \gamma} < 0$, $\frac{\partial E\Pi_1^{Ai}}{\partial \gamma} > 0$, $\frac{\partial E\Pi_2^{Ai}}{\partial \gamma} > 0$, $\forall i \in \{N,S\}$;

Lemma 2 demonstrates that, regardless of the information-sharing decision, the green level, wholesale price, and sales quantity of the manufacturer all decrease as the commission rate increases. However, when the manufacturer's investment efficiency is high, the sales quantity of the offline retailer actually increases with the commission rate. This is because, as the commission rate rises, the profit taken away by the platform increases, decreasing the manufacturer's online profits, which reduces the incentive for manufacturer to invest, resulting in a reallocation of sales quantity towards offline retailers. Meanwhile, when the manufacturer has a high investment efficiency, the decrease in green investments is relatively small. Consequently, to maintain sales and profitability, the manufacturer lowers the wholesale price to induce the offline retailer to order more. In addition, under the agency selling mode, the optimal decisions of all supply chain members decrease with k, while increasing with γ. This conclusion is consistent with the wholesale mode.

5. Equilibrium Information-Sharing Strategy

In this section, we analyze the platform's optimal information-sharing strategy. This strategy depends on the selling mode choice that the manufacturer commits to in stage 1. The value of information sharing lies in the expected profit difference between implementing an information-sharing strategy and not implementing one. By comparing the equilibrium expected profits of supply chain members under both scenarios of information sharing and non-sharing, we produced Proposition 1, as follows.

Proposition 1. *Under the wholesale mode, the impacts of information sharing on supply chain members are as follows:*

(a) *The platform is willing to share demand information with the manufacturer when* $k < \frac{\gamma^2}{4}$*; otherwise, the platform will keep it private.*
(b) *Information sharing is always beneficial to the manufacturer and offline retailer, that is,* $E\Pi_M^{RS} > E\Pi_M^{RN}$; $E\Pi_1^{RS} > E\Pi_1^{RN}$.
(c) *Information sharing benefits the supply chain if and only if* $k < \gamma^2 + \frac{1}{2}\sqrt{3}\gamma^2$*; otherwise, it hurts the supply chain.*

See Appendix A for the proof of Proposition 1. Proposition 1 reveals key insights into the dynamics of information sharing under the wholesale mode. Specifically, Proposition 1 (a) shows that the platform is willing to share demand information only when $k < \frac{\gamma^2}{4}$; that is to say, when the manufacturer has a higher investment efficiency, the platform can benefit from sharing information. Otherwise, information sharing hurts the platform. This is because, on the one hand, information sharing encourages the manufacturer to increase their green efforts in response to demand signals, thereby expanding the market and better satisfying consumer demand. On the other hand, it also prompts the manufacturer to raise wholesale prices in response to demand signals, which makes double marginalization more pronounced, ultimately hurting the retailer. When $k < \frac{\gamma^2}{4}$, the benefits brought by the market expansion effect outweigh the negative impact caused by the double marginalization effect, and hence the platform is willing to share information. On the contrary, when $k > \frac{\gamma^2}{4}$, the manufacturer's green investment efficiency is not high, but the negative impact of double marginalization remains significant; therefore, it is better for the retailer to withhold market forecasting rather than share it.

Proposition 1 (b) demonstrates that if the platform shares market forecasting information, it is always beneficial to both the manufacturer and the offline retailer. This is because information sharing eliminates the manufacturer's information disadvantage, thereby enabling it to adjust the wholesale price and green investment level in response to demand fluctuations after receiving the demand signal. This adjustment benefits the manufacturer. Meanwhile, due to the leakage effect, the offline retailer can gain access to demand information from the wholesale price and green level. Furthermore, with increased information transparency, the offline retailer's quantity decision can align more closely with market fluctuations, thereby benefiting the offline retailer as well.

Based on the previous analysis, we know that the value of information sharing to the supply chain depends on its net effect on the manufacturer, online platform, and offline retailer. Proposition 1 (c) shows that, when $k < \frac{\gamma^2}{4}$, information sharing benefits all supply chain members. However, when $\frac{\gamma^2}{4} < k < \gamma^2 + \frac{1}{2}\sqrt{3}\gamma^2$, platform information sharing hurts the online platform but still benefits the manufacturer and offline retailer. Furthermore, the overall benefits of information sharing for both the manufacturer and offline retailer outweigh the losses incurred by the platform retailer. Therefore, the entire supply chain benefits from information sharing. Finally, when $k > \gamma^2 + \frac{1}{2}\sqrt{3}\gamma^2$, information sharing hurts the supply chain and there are no incentive measures that can persuade the platform to engage in information sharing.

By analyzing the impact of manufacturers' investment efficiency and consumers' green preferences on the value of platform information sharing for supply chain members under the wholesale mode, we arrive at Lemma 3, which shows that the value of information sharing increases with consumer green preference and decreases with the cost of the manufacturer's green investment.

Lemma 3. *(1)* $\frac{\partial\left(E\Pi_M^{RS} - E\Pi_M^{RN}\right)}{\partial k} < 0$, $\frac{\partial\left(E\Pi_{R1}^{RS} - E\Pi_{R1}^{RN}\right)}{\partial k} < 0$, $\frac{\partial\left(E\Pi_{R2}^{RS} - E\Pi_{R2}^{RN}\right)}{\partial k} < 0$;
(2) $\frac{\partial\left(E\Pi_M^{RS} - E\Pi_M^{RN}\right)}{\partial \gamma} > 0$, $\frac{\partial\left(E\Pi_{R1}^{RS} - E\Pi_{R1}^{RN}\right)}{\partial \gamma} > 0$, $\frac{\partial\left(E\Pi_{R2}^{RS} - E\Pi_{R2}^{RN}\right)}{\partial \gamma} > 0$.

Next, by analyzing the impact of demand signal accuracy on the profits of supply chain members, we obtain Lemma 4.

Lemma 4. *If the platform shares demand information, the increased signal accuracy (larger t) benefits all parties involved—the manufacturer, offline retailer, online retailer, and the supply chain overall. However, if the platform does not share demand information, the manufacturer and offline retailer remain indifferent, while the platform alone benefits.*

In the following, we further analyze the platform's information-sharing strategy under the agency format. The impact of information sharing is characterized as follows.

Proposition 2. *Under the agency selling mode, the platform is willing to share demand information with the manufacturer. Information sharing can be beneficial not just for the online platform but also for the offline retailer and the manufacturer.*

See Appendix A for the proof of Proposition 2. Proposition 2 suggests that, when the manufacturer opts for the agency selling mode, sharing demand information becomes the optimal choice for the platform, and it can benefit not only the online platform but also the offline retailer and the manufacturer alike. The existing literature [46] suggests that, in the absence of green investment, platforms are willing to share market demand information when manufacturers opt for the agency selling model. Our research demonstrates that this finding remains valid even in the presence of green investment. In fact, the essence of the agency selling mode is profit sharing. Therefore, under a fixed commission rate, the objectives of the platform and the manufacturer are aligned. If the platform fails to share demand information, the manufacturer, which lacks the flexibility to adjust its decision-making in response to demand information, is forced to rely solely on market expectations when making operational decisions. This, in turn, results in a loss of profits for the manufacturer, which ultimately leads to a reduction in the profits allocated to the platform. On the contrary, with information sharing, the manufacturer becomes informed due to access to shared information and can determine the optimal green level and sales quantity effectively, and thus benefit from this sharing. As a result, the platform's profits also increase. In addition, the offline retailer also benefits from information sharing. The main reason lies in the fact that with information sharing, the informed manufacturer is able to make more informed and strategic green investment decisions. This, in turn, has the potential to expand market demand, ultimately benefiting the offline retailer. Additionally, as the offline retailer is able to infer market information, it can make responsive quantity decisions. Consequently, the overall impact of information sharing turns out to be advantageous for the offline retailer.

By analyzing the impact of the manufacturers' investment efficiency, consumers' green preferences, and the platform commission rate on the value of platform information sharing for supply chain members under the agency selling mode, we arrive at Lemma 5.

Lemma 5. *(a)* $\frac{\partial\left(E\Pi_M^{AS}-E\Pi_M^{AN}\right)}{\partial\phi} < 0$*, when* $k > \frac{\gamma^2}{4}$, $\frac{\partial\left(E\Pi_{R1}^{AS}-E\Pi_{R1}^{AN}\right)}{\partial\phi} > 0$*, when* $k > \frac{-5\gamma^2-4\gamma^2\phi}{-20+4\phi}$, $\frac{\partial\left(E\Pi_{R2}^{AS}-E\Pi_{R2}^{AN}\right)}{\partial\phi} > 0$*; (b)* $\frac{\partial\left(E\Pi_M^{AS}-E\Pi_M^{AN}\right)}{\partial\gamma} > 0$, $\frac{\partial\left(E\Pi_M^{AS}-E\Pi_M^{AN}\right)}{\partial\gamma} > 0$, $\frac{\partial\left(E\Pi_M^{AS}-E\Pi_M^{AN}\right)}{\partial\gamma} > 0$*; (c)* $\frac{\partial\left(E\Pi_M^{AS}-E\Pi_M^{AN}\right)}{\partial k} < 0$, $\frac{\partial\left(E\Pi_M^{AS}-E\Pi_M^{AN}\right)}{\partial k} < 0$, $\frac{\partial\left(E\Pi_M^{AS}-E\Pi_M^{AN}\right)}{\partial k} < 0$*;*

Lemma 5 shows that the impact of the commission rate on the value of information sharing differs for different firms. Lemma 5 (a) suggests that as the commission rate increases, the value of information sharing decreases for the manufacturer. This result is intuitive. As an increasing commission rate lowers the manufacturer's profit and green investment, the value of information also decreases. However, the impact of the commission rate on the value of information sharing for the platform and the offline retailer depends on the investment efficiency of the manufacturer. When the investment efficiency of the manufacturer is low, the value of information sharing for the offline retailer increases as the commission rate increases. This is because as the commission rate increases, the online sales quantity of the manufacturer decreases, and at the same time, its green investments also decrease. Consequently, the offline retailer can increase its sales quantity, but the wholesale price increases relatively less. This, in turn, leads to an increase in the value of information. Similarly, when the investment efficiency of manufacturers is low, the value of information sharing to the platform increases as commission rate increases. However, when manufacturer's efficiency is high, an increasing commission rate causes a significant decrease in the level of greenness of the manufacturer, leading to a decrease in the value of information sharing to the platform. Lemma 5 (b) (c) illustrate that the value of information sharing increases with consumer green preference and decreases with the cost of the manufacturer's green investment.

Lemma 6. *If the platform shares demand information, the increased signal accuracy benefits all parties involved. However, if the platform does not share demand information, the manufacturer, offline retailer, and the platform remain indifferent.*

If the platform shares information with the manufacturer, due to information leakage, the offline retailer can also infer the market demand, thus leading to transparency of information in the supply chain. Accordingly, the value of information sharing increases with signal accuracy because all firms can respond more accurately to demand changes.

However, when the platform chooses not to share information, the manufacturer and offline retailer must make decisions without access to market demand information. In such a case, the expected payoffs of the manufacturer and offline retailer are independent of the demand signal, while the platform's payoff is contingent upon the manufacturer's online earnings. This means that the platform's expected payoff is not directly influenced by the demand signal.

6. Manufacturer Mode Selection Strategy

In this section, we analyze the manufacturer's optimal sales mode selection strategy based on the anticipation of the platform's information-sharing decision.

When the manufacturer chooses the wholesale format, from Proposition 1, we can learn that the manufacturer's optimal expected payoff is

$$E\Pi_M^{\mathrm{R}} = \begin{cases} E\Pi_M^{\mathrm{RS}}, k < \frac{\gamma^2}{4} \\ E\Pi_M^{\mathrm{RN}}, k > \frac{\gamma^2}{4} \end{cases} \tag{55}$$

When the manufacturer chooses the agency selling mode, the manufacturer's optimal expected profit is

$$E\Pi_M^{\mathrm{A}} = E\Pi_M^{\mathrm{AS}} \tag{56}$$

By comparing the expected profits of the manufacturer under different strategies, we can obtain the equilibrium strategy, which is summarized in Proposition 3.

Proposition 3. *(a) When $0 < \phi < \frac{5}{14}$, the manufacturer chooses the agency selling model, and the online platform shares demand information. (b) When $\frac{5}{14} < \phi < 1$ and $k < \frac{\gamma^2}{4}$, the manufacturer chooses the wholesale mode, and the online platform shares demand information. On the other hand, if $k > \frac{\gamma^2}{4}$, whether the manufacturer selects the wholesale mode depends on the value of $\beta\sigma^2$:*

(1) If $\beta\sigma^2 < \frac{5a^2-14a^2\phi}{-15+12\phi}$, the manufacturer chooses the wholesale mode, and the online platform does not share demand information.

(2) If $\frac{5a^2-14a^2\phi}{-15+12\phi} < \beta\sigma^2 \leq \frac{5a^2-14a^2\phi}{-5+4\phi}$ and $k < \frac{-5\beta\gamma^2+4\beta\gamma^2\phi}{-10a^2-30\beta+28a^2\phi+24\beta\phi}$, the manufacturer still chooses the wholesale mode, and the online platform does not share demand information. However, if $k > \frac{-5\beta\gamma^2+4\beta\gamma^2\phi}{-10a^2-30\beta+28a^2\phi+24\beta\phi}$, the manufacturer opts for the agency selling mode, and the online platform shares demand information.

(3) Finally, if $\beta\sigma^2 > \frac{5a^2-14a^2\phi}{-5+4\phi}$, regardless of other conditions, the manufacturer chooses the agency selling mode, and the online platform shares demand information.

See Appendix A for the proof of Proposition 3. Based on Proposition 3, Figure 3 graphically illustrates the equilibrium outcome resulting from the interaction between the manufacturer sales mode choice and platform information-sharing strategy. Proposition 3 demonstrates that when the platform's commission rate is sufficiently low, the manufacturer consistently opts for the agency selling mode. This result is highly intuitive, as a lower commission rate means the manufacturer needs to allocate less profit to the platform. Moreover, under the agency selling mode, the platform always shares information, thereby enabling the manufacturer to make optimal decisions based on more accurate market conditions, ultimately leading to improved profits. Furthermore, the agency selling mode eliminates the double marginalization effect, enhancing the efficiency of the online channel and consequently allowing the manufacturer to realize greater profits. On the other hand, when the commission rate is relatively high, intuitively, the manufacturer may choose the wholesale pricing mode to avoid paying excessive profits to the platform. Proposition 1, however, indicates that the manufacturer's sales mode is also influenced by the manufacturers' investment efficiency and information accuracy. When the platform's commission rate is high, the manufacturer can choose between the wholesale price mode and the agency selling mode. If the manufacturer opts for the wholesale price mode, it avoids paying higher commissions to the platform. However, the platform will only share information with the manufacturer when the manufacturer's investment efficiency is high under the wholesale price mode. Therefore, if the manufacturer has a high investment efficiency, the wholesale price mode becomes the optimal choice. Conversely, if the manufacturer's investment efficiency is low, the platform will not share information under the wholesale price mode. In the commission mode, however, the platform is willing to share information. From the previous Propositions 1 and 2, we know that the manufacturer always benefits from information sharing. Consequently, the manufacturer must carefully evaluate the benefits of receiving information versus the disadvantages of paying higher commissions. Specifically, when the accuracy of information is extremely high ($\beta\sigma^2 > \frac{5a^2-14a^2\phi}{-5+4\phi}$) and its value is sufficient, despite the involvement of high commissions, manufacturers may still prefer to choose the agency selling mode to induce the platform to share demand information.

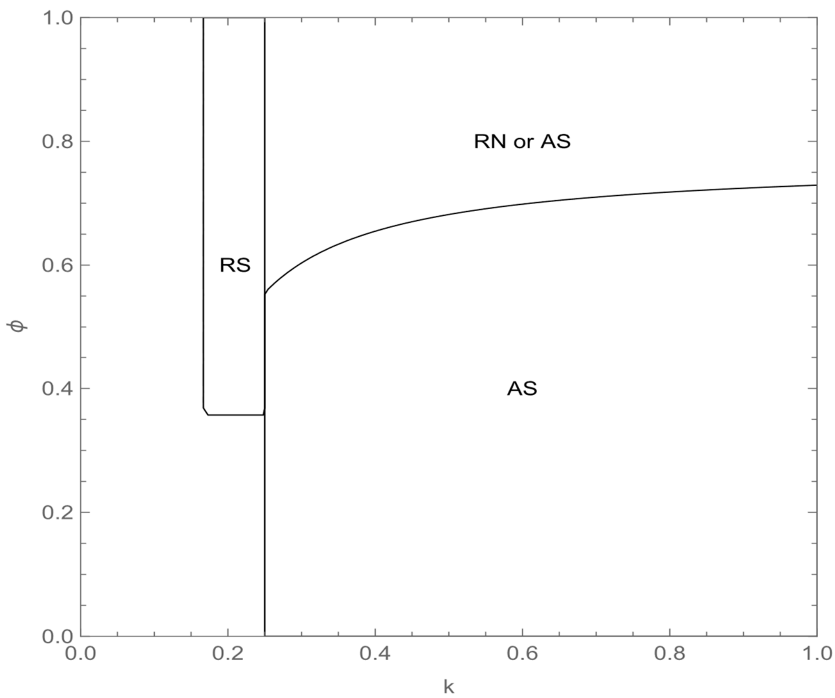

Figure 3. Equilibrium strategy.

7. Extension

In the basic model, we assume that the manufacturer first decides on the sales format, and then the platform decides on the information-sharing strategy. In this section, however, we consider a different decision sequence where the platform first decides on the information-sharing strategy, followed by the manufacturer's decision on the sales format. The remaining decision-making sequences are identical to those in the main model.

Under the given information-sharing strategy, by comparing the expected profits of manufacturers in both the agency selling mode and the wholesale pricing mode, we can obtain the following proposition.

Proposition 4. *Regardless of whether the platform shares demand information with the manufacturer, the manufacturer prefers the wholesale pricing mode when* $\phi > \frac{5}{14}$*, and they prefer the agency selling mode when* $\phi < \frac{5}{14}$*.*

See Appendix A for the proof of Proposition 4. Proposition 4 demonstrates that if the platform first decides on an information-sharing strategy, then the manufacturer's selling mode preference is not affected by the information-sharing strategy. This result differs from Proposition 3. Proposition 3 suggests that if the manufacturer's choice of sales mode precedes the platform's decision on information sharing, the manufacturer can strategically choose a sales mode, taking into account the accuracy of information, to encourage the platform to share information. However, Proposition 4 indicates that when information sharing occurs before the manufacturer's sales mode choice, the manufacturer cannot induce the platform to share information. Therefore, the manufacturer's sales mode selection becomes solely dependent on the size of the platform's commission.

Proposition 5. *When $\phi < \frac{5}{14}$, the platform chooses to share demand information with the manufacturer. When $\phi > \frac{5}{14}$, the platform only shares demand information with the manufacturer if $k < \frac{\gamma^2}{4}$.*

See Appendix A for the proof of Proposition 5. According to Proposition 5, the platform tends to share demand information when the commission is low, as in this scenario, the manufacturer is inclined towards choosing the agency selling mode. Sharing information is beneficial for the platform because accurate market information incentivizes the manufacturer to make better decisions that lead to higher sales. However, when the commission is high, the manufacturer is more likely to opt for the wholesale price mode. In such a case, the platform will only share information if the manufacturer's green investment efficiency is relatively high.

8. Numerical Examples

In this section, we employ numerical analysis to explore the impact of relevant parameters on the profits of supply chain members.

In Figure 4, we depict the ex ante profits of individual supply chain members, alongside the overall total profit of the supply chain, under the wholesale pricing mode, considering scenarios with and without information sharing.

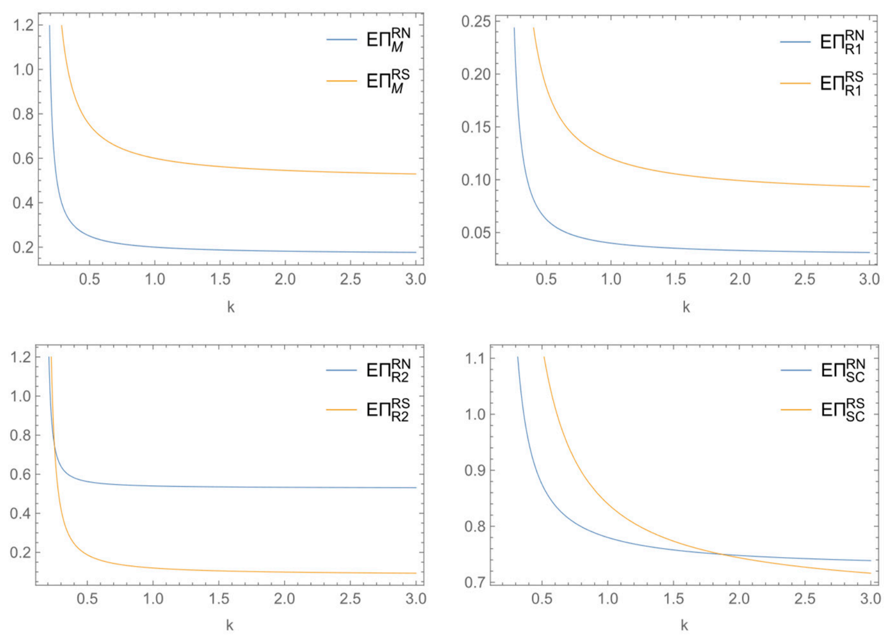

Figure 4. The impact of k on the expected profits of supply chain members under the wholesale mode ($a = 1,\ \beta = 20,\ \sigma = 1/\sqrt{10},\ \gamma = 1$).

From Figure 4, we can see that as k increases, the expected profits of all parties in the supply chain either with or without information sharing will decrease. In addition, when k is small, the profits of the online retailer and the overall supply chain are higher in the case of information sharing. When k is large, the profits of the online retailer and the overall supply chain, individually, are higher in the absence of information sharing. However, the profits of the manufacturer and the offline retailer are always higher in the case of information sharing. This result is consistent with Proposition 1 and Lemma 1.

In Figure 5, we depict the ex ante profits of individual supply chain members, alongside the overall total profit of the supply chain, under the agency selling mode, considering scenarios with and without information sharing.

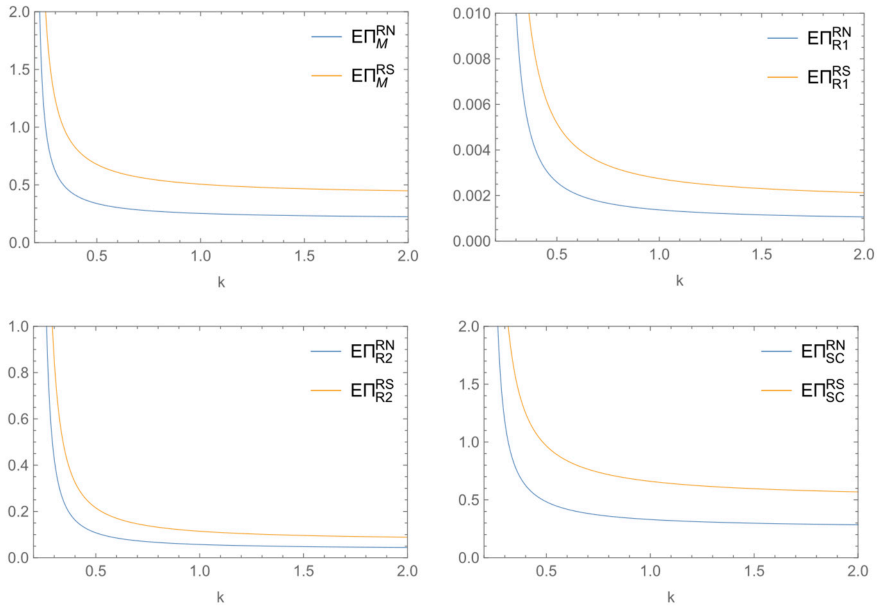

Figure 5. The impact of k on the expected profits of supply chain members in the agency selling mode ($a = 1,\ \beta = 20,\ \sigma = 1/\sqrt{10},\ \gamma = 1$).

From Figure 5, similar to the wholesale price mode, we can see that as k increases, the expected profits of all parties in the supply chain either with or without information sharing will decrease. Unlike in the former case, the expected profits of all members are higher when information is shared compared to when it is not. We can also observe that as k increases, the incremental profits gained by each member under information sharing, compared to those without sharing, become increasingly smaller. In other words, the value of information sharing diminishes as k becomes larger. This result is consistent with Proposition 2 and Lemma 5.

To examine the impact of the commission rate (ϕ) on supply chain performance, in Figures 6 and 7, we set the values of k to 1 and 0.24, respectively and depict the ex ante profits of individual supply chain members, alongside the overall total profit of the supply chain, under the agency selling mode, considering scenarios with and without information sharing.

From Figure 6, when the efficiency of green investment is low, we observe that the manufacturer's profits decrease as the commission rate increases. Conversely, the profits of online and offline retailers increase as the commission rate rises. The overall profit of the supply chain decreases slightly with the increase in the commission rate. This is because as the commission rate increases, the manufacturer reduces the wholesale price for the offline retailer, which leads to an increase in offline retail sales and subsequently boosts the profits of the offline retailer. From Figure 7, it can be seen that when the efficiency of green investment is low, the profits of all supply chain members decrease as the commission rate increases. This is because the increase in commission suppresses the manufacturer's green investment, thereby harming all members.

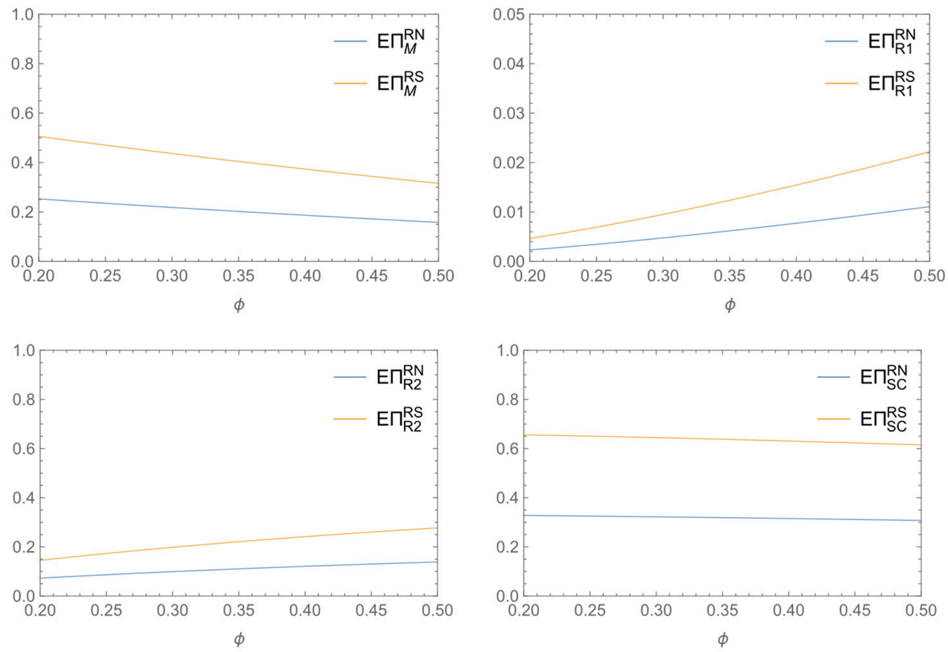

Figure 6. The impact of ϕ on the expected profits of supply chain members under the agency selling mode ($a = 1,\ \beta = 20,\ \sigma = 1/\sqrt{10},\ \gamma = 1,\ k = 1$).

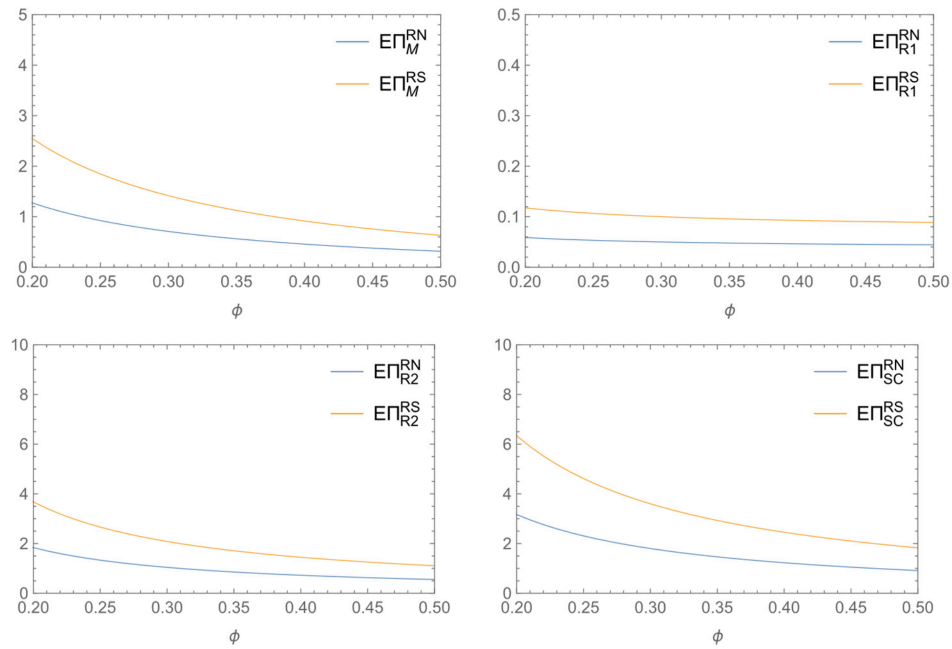

Figure 7. The impact of ϕ on the expected profits of supply chain members under the agency selling mode ($a = 1,\ \beta = 20,\ \sigma = 1/\sqrt{10},\ \gamma = 1,\ k = 0.24$).

9. Conclusions

In this paper, we have investigated the interplay between a green manufacturer's online selling mode selection and an online retail platform's information sharing, taking into account the manufacturer's green investment. Specifically, the manufacturer invests in green products and distributes them to green-conscious consumers through an offline retailer and an online platform. The manufacturer can choose the wholesale price mode or agency selling mode on the online platform channel. The platform can obtain private information and decide whether to share it with the manufacturer. We have investigated four scenarios and derived equilibrium solutions, demonstrating how investment efficiency, commission rate, and information accuracy influence the manufacturer's choice of mode.

Our results indicate that when the manufacturer opts for the wholesale price mode, the platform has an incentive to share demand information primarily when the manufacturer's investment efficiency is high. Conversely, if the manufacturer chooses the agency selling mode, the platform is always willing to share demand information. Regardless of which mode the manufacturer chooses, the sharing of information by the platform always helps the manufacturer to improve the green degree of its products, and at the same time, benefits the offline retailer. When the commission rate of the platform is low, the manufacturer prefers to choose the agency selling mode. When the commission rate of the platform is high, however, the situation becomes more complex. The investment efficiency of the manufacturer, along with the value of platform information, plays a crucial role in determining the manufacturer's sales mode. If the value of information is sufficiently high, the manufacturer still tends to prefer the agency selling mode, despite the added cost of the higher commission fee. If we alter the order of decision-making between sales mode selection and information sharing, we can conclude that information sharing does not impact the manufacturer's choice of sales mode.

Based on the analysis above, this paper can provide several managerial insights for the firm mode selection and platform information sharing. For the online platform, when a green manufacturer opts for the agency selling mode, it should actively collaborate with the manufacturer to share market demand information. However, if the manufacturer chooses the wholesale mode, the platform must carefully weigh up the manufacturer's investment efficiency before deciding whether to share information. For the green manufacturer, if the commission rate offered by the platform is low, there is no doubt that the agency selling mode is the preferred choice. On the other hand, if the commission rate is high, the manufacturer must evaluate the accuracy of the platform's information. If the information accuracy is sufficiently high, the manufacturer can confidently proceed with the agency selling mode. Moreover, different decision sequences can lead to different equilibrium outcomes, and therefore, firms should carefully consider this aspect. Our results indicate that when the manufacturer makes the decision regarding the sales mode first, it may lead to better outcomes for all parties involved.

Our study has several limitations. Currently, we present two options for the manufacturer to consider when selling online: the agency selling mode and wholesale pricing mode. Future studies could explore the possibility of implementing both modes simultaneously online. Additionally, we have assumed a direct leakage of information, which is a standard assumption in the literature [15,36]. Future studies could delve into signaling that incorporates the wholesale price and greenness level.

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Appendix A

Proof of Proposition 1. (a) From (27) and (14), we have $E\Pi_2^{RS} - E\Pi_2^{RN} = \frac{a^2k^2}{(-6k+\gamma^2)^2} + \frac{k^2\beta\sigma^2}{(-6k+\gamma^2)^2} - \left(\frac{a^2k^2}{(-6k+\gamma^2)^2} + \frac{\beta\sigma^2}{4}\right) = -\frac{\beta\left(32k^2-12k\gamma^2+\gamma^4\right)\sigma^2}{4(6k-\gamma^2)^2}$.

The sign of $-\frac{\beta\left(32k^2-12k\gamma^2+\gamma^4\right)\sigma^2}{4\left(6k-\gamma^2\right)^2}$ depends on the sign of $32k^2-12k\gamma^2+\gamma^4$. We can easily ascertain that $E\Pi_2^{\mathrm{RS}}-E\Pi_2^{\mathrm{RN}}>0$ if $k<\frac{\gamma^2}{4}$; otherwise, $E\Pi_2^{\mathrm{RS}}-E\Pi_2^{\mathrm{RN}}<0$.

(b) From (25) and (12), we have $E\Pi_{\mathrm{M}}^{\mathrm{RS}}-E\Pi_{\mathrm{M}}^{\mathrm{RN}}=\frac{a^2k}{6k-\gamma^2}+\frac{k\beta\sigma^2}{6k-\gamma^2}-\frac{a^2k}{6k-\gamma^2}=\frac{k\beta\sigma^2}{6k-\gamma^2}>0$. Thus, we have $E\Pi_{\mathrm{M}}^{\mathrm{RS}}>E\Pi_{\mathrm{M}}^{\mathrm{RN}}$. From (26) and (13), We have $E\Pi_1^{\mathrm{RS}}-E\Pi_1^{\mathrm{RN}}=\frac{a^2k^2}{\left(-6k+\gamma^2\right)^2}+\frac{k^2\beta\sigma^2}{\left(-6k+\gamma^2\right)^2}-\left(\frac{a^2k^2}{\left(-6k+\gamma^2\right)^2}\right)=\frac{k^2\beta\sigma^2}{\left(-6k+\gamma^2\right)^2}>0$. Thus, we have $E\Pi_1^{\mathrm{RS}}>E\Pi_1^{\mathrm{RN}}$.

(c) From (28) and (15), We have $E\Pi_{\mathrm{SC}}^{\mathrm{RS}}-E\Pi_{\mathrm{SC}}^{\mathrm{RN}}=\frac{k\left(a^2+\beta\sigma^2\right)\left(8k-\gamma^2\right)}{\left(-6k+\gamma^2\right)^2}-\left(\frac{\beta\sigma^2}{4}+\frac{a^2k\left(8k-\gamma^2\right)}{\left(-6k+\gamma^2\right)^2}\right)=-\frac{\beta\left(4k^2-8k\gamma^2+\gamma^4\right)\sigma^2}{4\left(-6k+\gamma^2\right)^2}$. The sign of $-\frac{\beta\left(4k^2-8k\gamma^2+\gamma^4\right)\sigma^2}{4\left(-6k+\gamma^2\right)^2}$ depends on the sign of $4k^2-8k\gamma^2+\gamma^4$. We can easily ascertain that $E\Pi_{\mathrm{SC}}^{\mathrm{RS}}-E\Pi_{\mathrm{SC}}^{\mathrm{RN}}>0$ if $k<\gamma^2+\frac{1}{2}\sqrt{3}\gamma^2$; otherwise, $E\Pi_{\mathrm{SC}}^{\mathrm{RS}}-E\Pi_{\mathrm{SC}}^{\mathrm{RN}}<0$. This completes the proof.□

Proof of Proposition 2. From (38)–(41) and (51)–(54), we obtain

$$E\Pi_{\mathrm{M}}^{\mathrm{AS}}-E\Pi_{\mathrm{M}}^{\mathrm{AN}}=-\frac{k\beta\sigma^2(-5+4\phi)}{4k(5+\phi)+\gamma^2(-5+4\phi)}>0$$

$$E\Pi_1^{\mathrm{AS}}-E\Pi_1^{\mathrm{AN}}=\frac{16k^2\beta\sigma^2\phi^2}{\left(4k(5+\phi)+\gamma^2(-5+4\phi)\right)^2}>0$$

$$E\Pi_2^{\mathrm{AS}}-E\Pi_2^{\mathrm{AN}}=\frac{100k^2\beta\sigma^2\phi}{\left(4k(5+\phi)+\gamma^2(-5+4\phi)\right)^2}>0$$

$$E\Pi_{\mathrm{SC}}^{\mathrm{AS}}-E\Pi_{\mathrm{SC}}^{\mathrm{AN}}=\frac{k\beta\sigma^2\left(-\gamma^2(5-4\phi)^2+20k(5+2\phi)\right)}{\left(4k(5+\phi)+\gamma^2(-5+4\phi)\right)^2}>0$$

Thus, we obtain Proof of Proposition 2. This completes the proof.□

Proof of Proposition 3. (a) When $k<\frac{\gamma^2}{4}$, from (55) and (56), we have $E\Pi_{\mathrm{M}}^{\mathrm{RS}}-E\Pi_{\mathrm{M}}^{\mathrm{AS}}=-\frac{2k^2\left(a^2+Y^2\right)(-5+14\phi)}{(6k-\gamma^2)(4k(5+\phi)+\gamma^2(-5+4\phi))}$. It is easy to verify that if $0<\phi<\frac{5}{14}$, and then $E\Pi_{\mathrm{M}}^{\mathrm{RS}}-E\Pi_{\mathrm{M}}^{\mathrm{AS}}<0$; otherwise, $E\Pi_M^{\mathrm{RS}}-E\Pi_M^{\mathrm{AS}}>0$

(b) When $k<\frac{\gamma^2}{4}$, from (55) and (56), we have $E\Pi_{\mathrm{M}}^{\mathrm{AS}}-E\Pi_{\mathrm{M}}^{\mathrm{RS}}=\frac{k\left(2a^2k(5-14\phi)-\beta\sigma^2\left(6k-\gamma^2\right)(-5+4\phi)\right)}{(6k-\gamma^2)(4k(5+\phi)+\gamma^2(-5+4\phi))}$. The sign of $\frac{k\left(2a^2k(5-14\phi)-\beta\sigma^2\left(6k-\gamma^2\right)(-5+4\phi)\right)}{(6k-\gamma^2)(4k(5+\phi)+\gamma^2(-5+4\phi))}$ depends on the sign of $2a^2k(5-14\phi)-\beta\sigma^2\left(6k-\gamma^2\right)(-5+4\phi)$. By employing straightforward algebraic manipulations, we can easily obtain Proposition 3. This completes the proof.□

Proof of Proposition 4. If the platform shares demand information with the manufacturer, from (51) and (25), we obtain

$$E\Pi_{\mathrm{M}}^{\mathrm{AS}}-E\Pi_{\mathrm{M}}^{\mathrm{RS}}=\frac{2k^2\left(a^2+\beta\right)(5-14\phi)}{(6k-\gamma^2)(4k(5+\phi)+\gamma^2(-5+4\phi))}$$

Since k $>\max\left\{\frac{\gamma^2}{6},\frac{5\gamma^2-4\gamma^2\phi}{20+4\phi}\right\}$, it is easy to verify that if $0<\phi<\frac{5}{14}$, then $E\Pi_M^{AS}-E\Pi_M^{RS}>0$; otherwise, $E\Pi_M^{AS}-E\Pi_M^{RS}<0$;

If the platform does not share demand information with the manufacturer, from (12) and (38), we obtain

$$E\Pi_{\mathrm{M}}^{\mathrm{RN}} - E\Pi_{\mathrm{M}}^{\mathrm{AN}} = \frac{2a^2k^2(-5+14\phi)}{(6k-\gamma^2)(4k(5+\phi)+\gamma^2(-5+4\phi))}$$

It is easy to verify that if $0 < \phi < \frac{5}{14}$, then $E\Pi_{M}^{\mathrm{RN}} - E\Pi_{M}^{\mathrm{AN}} < 0$; otherwise, $E\Pi_{M}^{\mathrm{RN}} - E\Pi_{M}^{\mathrm{AN}} > 0$. This completes the proof.□

Proof of Proposition 5. If $\phi < \frac{5}{14}$, from (40) and (53), we obtain

$$E\Pi_{2}^{\mathrm{AS}} - E\Pi_{2}^{\mathrm{AN}} = \frac{100k^2\beta\sigma^2\phi}{(4k(5+\phi)+\gamma^2(-5+4\phi))^2} > 0$$

If $\phi > \frac{5}{14}$, from (14) and (27), we obtain $\mathrm{E}\Pi_{2}^{\mathrm{RS}} - \mathrm{E}\Pi_{2}^{\mathrm{RN}} = -\frac{\beta(32k^2-12k\gamma^2+\gamma^4)\sigma^2}{4(6k-\gamma^2)^2} > 0$ if $k < \frac{\gamma^2}{4}$. This completes the proof.□

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