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# Agency, Reselling, or Hybrid: Strategic Channel Selection in a Green Supply Chain

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**Abstract:** This study explores the channel preference of a platform and a green manufacturer in an online market. The platform offers both the agency channel and the reselling channel, while the manufacturer designs a green product to improve the green effort and sells it through the platform. We find that the manufacturer's channel preference is determined by the interaction of the green investment, the commission rate, and the competition intensity. In contrast, the online platform prefers the hybrid channel when both the commission rate and green investment inefficiency are moderate but prefers the agency channel otherwise. Interestingly, the manufacturer can change its sales center between the reselling channel and the agency channel, thus resulting in a win–win outcome for the manufacturer and the platform by selecting the hybrid channel. This study reveals the benefits of green product selling in an online market and provides useful guidelines for green product manufacturers and platform managers in improving their strategic selling channel.

**Keywords:** channel structure; online platform; green investment; competition

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## 1. Introduction

The development of internet technology has driven consumers to switch to online e-commerce platforms for shopping. Statista reports that in 2021, the total net revenues of JD reached CNY 951.59 billion, while Amazon exceeded USD 469.82 billion [1,2]. The continuous growth of the online market has led numerous manufacturers to sell products through online e-commerce platforms. For instance, Adidas and Nike sell their product through online platforms such as JD and Tmall as well as their flagship stores. Another example is Vivo, which abandoned a single offline sales channel and explored the online market, achieving revenue and market share growth. Undoubtedly, manufacturers selling products through the online platform have become one of the most popular modes of commerce, including clothes, computers, smartphones, and other consumer products [3].

Online platforms generally have the agency channel and the reselling channel, which are different from the conventional offline sales channel. In the agency channel, the manufacturer directly sells products to consumers through the platform and pays a certain percentage of commission to the platform. For example, Coach, Crocs, and Burberry sell through eBay [4]. In the reselling channel, the platform operates as a reseller who buys products from the manufacturer and then resells them to consumers. For example, JD operates a self-operated business model, buying from manufacturers and reselling them to consumers. In practice, some platforms, such as Taobao and Zappos, only offer one of two channels and sell through the agency channel and the reselling channel, respectively. However, online retail platforms offering a hybrid channel (i.e., both agency and reselling channels) for the manufacturer have become popular, such as JD and Amazon [5,6]. For the platform that offers a hybrid channel, some manufacturers choose the hybrid channel while other manufacturers sell via only the reselling or agency channel [5]. Manufacturers expect to increase sales opportunities by selling the hybrid channel, whereas the competition between the two channels may cause sales in one channel to affect sales in the other [6]. Therefore, the underlying motivations for manufacturers such as Adidas and Skechers to sell through the hybrid channel on JD's website is not clear, and it is necessary to explore the firms' (i.e., the manufacturer's and platform's) channel selection with two alternative channels.

In addition to selling through the platform, the increasing environmental protection awareness of consumers drives the manufacturers to produce green products and thus improve their products' green efforts [7]. For example, Moutai improves the green effort of products by selecting organic raw materials and green recycling of waste from the consumption process, and Sprite uses renewable and recycled materials to make product packaging. Manufacturers improve green efforts not only to cater to customers' lifestyles but also to create more demand in their online channels. In practice, green products are usually produced with green materials and green equipment, which means that green products become costlier to produce for manufacturers, making the manufacturers encounter the cost inefficiency challenge [8]. However, green investment inefficiency may further affect the manufacturers' channel selection and the platforms' performance in the online market. For instance, Moutai sells its products only through the reselling channel in JD whereas Sprite sells through the hybrid channel in JD. Therefore, it is crucial to characterize the optimal selling channels for green manufacturers and understand how the market factors like green investment affect the platform's decisions.

The channel selections in the online market have received considerable attention in the recent literature. However, the channel selection issue of the green supply product with two alternative channels has been ignored. Most studies have discussed the channel selection of traditional e-commerce [9–11], green product design [12–14], and incentives for enterprises to choose channel structures [6,15–17]. As we observed earlier, online manufacturers such as Moutai and Sprite routinely invest in green products to stimulate sales in their channels, but it is not clear how such green investment affects the channel structure of the green product. Therefore, it is necessary to specifically analyze and discuss the interactive relationship between the manufacturer's green effort and the hybrid channel structure in the online platform market. In particular, our goal is to address the following issues:

(1) When should the manufacturer sell the green product through the hybrid channel?
(2) How do the commission rate and green investment inefficiency affect the channel preference of the online platform and manufacturer?
(3) Can online sales enable the manufacturer and online platform to achieve the win–win outcome?

In this paper, a manufacturer produces a green product and sells it through an online retail platform. We first derive the firms' profit in three channel structures, that is, the agency, the reselling, and the hybrid channel. After that, we concentrate on the firms' channel preferences and explore the effect of different factors on the firms' profits. The analysis leads to the following main findings.

(1) The interaction of the green investment inefficiency, the commission rate, and the competition intensity determines the manufacturer's channel preference. Interestingly, the manufacturer prefers the hybrid channel structure when both the green investment inefficiency and commission rate are moderate, and this channel preference changes with the competition intensity;
(2) The online retail platform never prefers the agency channel. In particular, the platform's optimal channel is reselling if the green investment inefficiency is high (low) and the commission rate is low (high);
(3) A relatively low commission rate leads to a win–win outcome for the platform and manufacturer by selecting the hybrid channel. However, the win–win outcome is less likely to arise in a fierce competition intensity market because fierce competition reduces the flexibility of the hybrid channel.

This paper contributes to the problem where the manufacturer sells the green product through the platform and strategically decides the selling channel with the platform. In contrast to the traditional e-commerce supply chain, our analysis shows that the green investment inefficiency of the product plays a crucial role in determining the firms' channel preferences. Taken together, this study provides a step toward understanding the selling channel issue in a green supply chain with an online platform. It also contributes to the hybrid channel literature by revealing how the interaction between green investment inefficiency and commission rate affects channel strategies.

The rest of this paper is organized as follows. Section 2 reviews the literature, and Section 3 demonstrates our model and assumption. Section 4 analyzes the equilibrium profits in three channel structures, and Section 5 presents the channel preference of firms. Section 6 concludes the paper and provides management insights. All proof results can be seen in Appendix A.

## 2. Literature Review

This work falls into two broad areas: channel selection with an online platform and green supply chain.

The first research stream closely related to ours is channel selection with an online platform. The agency channel and the reselling channel of an online platform have been widely discussed. For the monopoly market, factors that influence the platform to determine the channel structure include marketing information (e.g., Hagiu and Wright [18]), digital products (e.g., Tan and Carrillo [19]), and organizational structure of the supply chain (e.g., Shi et al. [20]). In contrast, competitive markets allow scholars to explore channel selection from the platform and/or manufacturer perspective. Abhishek et al. [6] consider a supply chain with one manufacturer selling to two competing online platforms, who choose one of the two selling channels in the spillover market. Kwark et al. [15] prove that when two manufacturers sell their products through the same platform, the review information has a significant influence on the channel selection of the online platform. Furthermore, Tian et al. [16] show that the selling channel decisions of competitive manufacturers depend on the cost of order fulfillment and the competition. Zhen and Xu [21] further examine the optimal channel preferences of the manufacturer and the retailer where both the manufacturer and retailer can use third-party (3P) platforms. They find that both the manufacturer and retailer prefer the 3P platforms if the channel competition and the agency fee are low. Recently, some papers extended the research question to the platform's financing format preference under a fixed reselling or agency channel (e.g., Ma et al. [22], Wang et al. [23], Gupta and Chen [24]). All the above works assume that the platform offers only one selling channel, whereas our work focuses on the platform offering two alternative selling channels to sellers.

There is only one paper considering the hybrid channel online platform supply chain. Ha et al. [5] investigate how the platform's service effort affects the online platform channel choice. Two factors distinguish our paper from the work of Ha et al. [5]. First, Ha et al. [5] focus on the platform's service effort, whereas our study focuses on a green supply chain where a manufacturer designs its product's green effort. Second, our work characterizes how the degree of competition intensity affects the channel selections in the green supply chain, which is not analyzed in their study. To our knowledge, this study is the first in the literature aimed at understanding how green investment inefficiency affects the channel choices of firms.

The second research stream closely related to ours comprises the green supply chain. In recent years, environmental problems have received growing attention, and firms have increased sales by developing green products. Most of the existing work on the green supply chain can be divided into two research perspectives, i.e., the manufacturer's perspective and the consumer's perspective. From the manufacturer's perspective, some of the literature investigates the relationship between green products and competitive advantage. Chiou et al. [25] find that the upstream manufacturer developing green products can acquire a competitive advantage. Based on this finding, Tseng et al. [26] further show that products with a high level of greenness generate less environmental pollution, thereby increasing the competitive advantage of manufacturers. Two factors distinguish our paper from the above two studies. First, our study explores the relationship between the competition and the flexibility of the hybrid channel in the green supply chain which Chiou et al. [25] and Tseng et al. [26] did not involve. Second, Chiou et al. [25] and Tseng et al. [26] focus on green innovation, but our study focuses on green investment inefficiency. In addition, several papers extend the aforementioned works by revealing how various factors affect the manufacturer's green product investment decisions, such as contract formats (e.g., Ghosh and Shah [27]), the efficiency of green product investment (e.g., An et al. [28]), and green standardization (e.g., Gao et al. [29]). From the consumer's perspective, studies focus on exploring the environmental awareness of the consumer. Liu et al. [30] study how the environmental awareness of the consumer affects market demand and operations decisions. Li et al. [31] show that the manufacturer has no incentive to encroach on the market with small consumer green awareness. Jin et al. [32] demonstrate that consumers' green awareness decides whether loan guarantee policy outperforms interest subsidy. However, these papers failed to consider channel selection with online platforms in the green supply chain, i.e., channel selection decisions when both the agency and the reselling channels are operated by the online platform, which is the focus of our paper.

In this paper, we capture some unique features of a green supply chain that, to our knowledge, have not been previously studied in the literature. First, this work contributes to the literature by displaying how the preference of the manufacturer and platform are influenced by a product's green cost inefficiency and commission rate, building on current green product developments. Second, the aforementioned papers ignore the effect of the green product on the hybrid channel structures; however, we combine the green product effect with the hybrid channel. Table 1 summarizes the main differences between our paper and the most relevant related literature.

**Table 1.** Position of this study in the existing literature.

| Relevant Literature | Green Supply Chain | Online Platform (Commission Rate) | Hybrid Channel | Competition Intensity |
|---|---|---|---|---|
| Ha et al. (2022) [5] | | √ | √ | |
| Tian et al. (2018) [16] | | √ | | √ |
| Zhen and Xu (2022) [21] | | √ | | √ |
| Yan et al. (2018) [7] | √ | | | √ |
| An et al. (2021) [28] | √ | | | |
| Li et al. (2021) [31] | √ | | | |
| Jin et al. (2022) [32] | √ | | | |
| This study | √ | √ | √ | √ |

## 3. Model

Consider a green supply chain consisting of an upstream manufacturer (M) and an online platform (E). The manufacturer sells a green product through the platform. Three possible channel structures exist: the agency (Model A), the reselling (Model R), and the hybrid channel (Model D). In Model A, the manufacturer determines the selling quantity and needs to pay the platform a commission $\gamma$ $(0 \leq \gamma < 1)$, where $\gamma$ is the proportion of the manufacturer's retail price. Following the literature on online platforms, we assume that $\gamma$ is exogenous [5,33]. This assumption is reasonable because the platform generally gives a commission rate to entire product categories and cannot change them. For instance, the commission rate values range from 6% to 25% of the sale price depending on the product category on Amazon, while for JD.com, the commission rate for most product categories ranges from 5% to 12%. In Model R, the platform buys the green product from the manufacturer at price w and then decides the selling quantity and resells it to the market. In Model D, the manufacturer sells through the hybrid channel. The supply chain structure is shown in Figure 1.

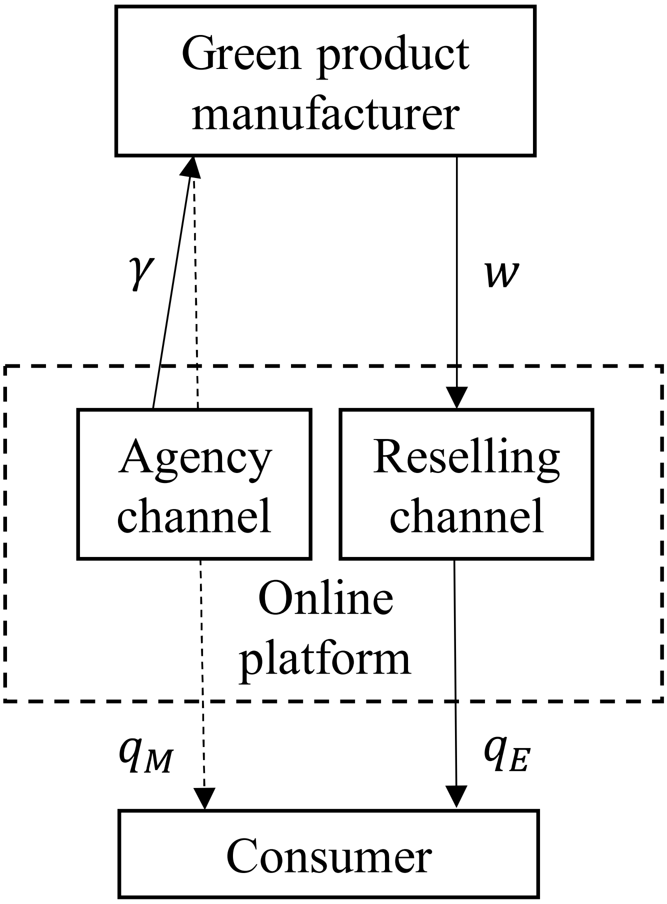



**Figure 1.** Market structure: The online retail platform in a green supply chain.

For the hybrid channel structurer, the demand function is $p_i = a - q_i - \beta q_j + \tau\theta$ $(i, j = M, E; i \neq j)$, where $a$ is the demand potential; $p_i$ and $q_i$ represent the retail price and sales quantity for firm $i$, $i = M$ represents the manufacturer, and $i = E$ represents the platform; $\beta \in (0, 1)$ reflects the degree of competition intensity; $\theta$ stands for the green effort, i.e., the level of manufacturers to design and produce the green products [7,26]; and $\tau$ measures the consumer's green sensitivity. This linear demand function reflects that the manufacturer's green effort can enhance demand [26,34]. Notice that $q_M$ and $q_E$ denote the manufacturer's quantity and the platform's quantity, respectively. Thus, in the agency channel structure $q_E = 0$, the demand function is $p = a - q_M + \tau\theta$; in the reselling channel structure $q_M = 0$, the demand function is $p = a - q_E + \tau\theta$. We use $\frac{1}{2}k\theta^2$ to measure the green investment cost incurred by the manufacturer, and this cost format has been widely used in the product's environmental improvement literature [26,35]. Alternatively, $k$ can be interpreted as the green investment inefficiency, where a higher $k$ means a more inefficient green upgrade and a larger cost of green effort [36]. In addition, a higher $\theta$ means the manufacturer is willing to pay a larger cost for the design of the green products and produce. We developed a multistage game for each of the three channel structures. Based on equilibrium profits, we explore the firm's preference for the channel structure. The decision sequence of each channel structure is given as follows and shown in Figure 2.

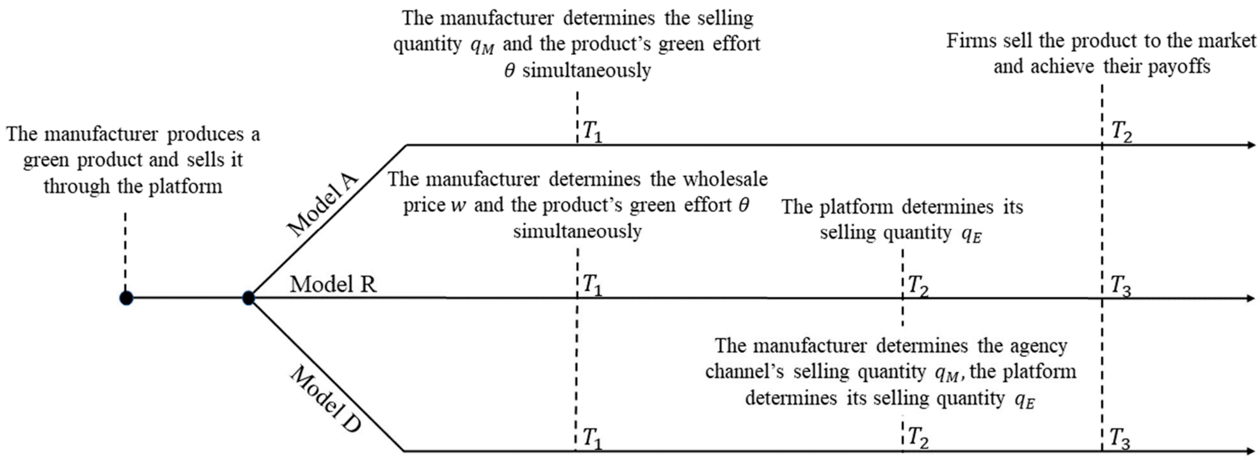



**Figure 2.** Timeline of decisions.

In Model A, the manufacturer sets the quantity $q_M$ and the green effort $\theta$ simultaneously at time $T_1$, and then the manufacturer sells the product to the market and both firms achieve their payoffs.

In Model R, the manufacturer simultaneously sets the wholesale price $w$ and the green effort $\theta$ at time $T_1$; at time $T_2$, the platform sets its selling quantity $q_E$; and at time $T_3$, the platform sells the product to the market and both firms achieve their payoffs.

In Model D, the manufacturer simultaneously sets the wholesale price $w$ and the product's green effort $\theta$ at time $T_1$; at time $T_2$, the platform and the manufacturer determine the reselling channel's selling quantity $q_E$ and the agency channel's selling quantity $q_M$, respectively; at time $T_3$, both firms sell the product to the market and achieve their payoffs.

Let A, R, and D stand for Model A, Model R, and Model D, respectively. We use $\Pi_I^Z$ to represent the profits of firms, where the superscript $Z \in \{A, R, D\}$ represents the corresponding channel structure and the subscript $I \in \{M, E\}$ stands for the manufacturer and the platform, respectively. For example, $\Pi_M^D$ represents the profit of the manufacturer in the hybrid channel structure. A summary of the notation used is presented in Table 2.

**Table 2.** Notation.

| Notation | Meaning |
|---|---|
| $\gamma$ | Commission rate |
| $w$ | Wholesale price |
| $\beta$ | The degree of competition intensity |
| $k$ | The cost parameter of green effort which reflects the green investment inefficiency |
| $\theta$ | The green effort |
| $\tau$ | The consumer's green awareness sensitivity |
| $q_M$ | Manufacturer's quantity |
| $q_E$ | Platform's quantity |
| $\Pi_M$ | Profit of the manufacturer |
| $\Pi_E$ | Profit of the platform |

## 4. Equilibrium Decisions and Profits

In the following, we focus on $k > K \equiv max\left\{\frac{\tau^2}{4}, \bar{k}\right\}$, where $\bar{k} = \frac{\tau^2[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2]}{2[8-(3+\gamma)\beta^2]}$. This assumption guarantees the positive profits for each channel structure and the green investment inefficiency is not too low, which is common in practice [26,37].

### *4.1. Model A*

In this setting, the manufacturer's profit is $\Pi_M^A = (1-\gamma)(a - q_M + \tau\theta)q_M - \frac{k\theta^2}{2}$ and the platform's profit is $\Pi_E^A = \gamma(a - q_M + \tau\theta)q_M$.

**Lemma 1.** *In Model A, the equilibrium decisions are given by*

$$\theta^A = \frac{a\tau(1-\gamma)}{2k-\tau^2(1-\gamma)}, q_M^A = \frac{ak}{2k-\tau^2(1-\gamma)} \tag{1}$$

*and the firms' profits are given by*

$$\Pi_M^A = \frac{ka^2(1-\gamma)}{2k-\tau^2(1-\gamma)},\ \Pi_E^A = \frac{\gamma a^2 k^2}{[2k-\tau^2(1-\gamma)]^2} \tag{2}$$

Lemma 1 states that the product's green effort and the quantity constantly decrease in $k$. This result suggests that the manufacturer's higher green investment inefficiency results in higher green effort and selling quantity. Similarly, they also decrease in the commission rate $\gamma$. Furthermore, $\Pi_M^A$ and $\Pi_E^A$ decrease in the green investment inefficiency $k$, but $\Pi_M^A$ decreases and $\Pi_E^A$ increases in $\gamma$. A higher green investment inefficiency leads to lower profit of the platform because it results in lower green product effort and selling quantity.

*4.2. Model R*

In this setting, the manufacturer's profit is $\Pi_M^R = wq_E - \frac{k\theta^2}{2}$, and the platform's profit is $\Pi_E^R = (a - q_E + \tau\theta - w)q_E$.

**Lemma 2.** *In Model R, the equilibrium decisions are given by*

$$\theta^R = \frac{a\tau}{4k-\tau^2},\ w^R = \frac{2ak}{4k-\tau^2},\ q_E^R = \frac{ak}{4k-\tau^2} \tag{3}$$

*and the firms' profits are given by*

$$\Pi_M^R = \frac{ka^2}{2(4k-\tau^2)},\ \Pi_E^R = \frac{a^2k^2}{(4k-\tau^2)^2} \tag{4}$$

Similar to Lemma 1, Lemma 2 still states that the green effort and the selling quantity still decrease in $k$. We see from (3) that $w^R$ constantly decreases in $k$, which means that the larger green investment inefficiency may benefit the platform because it lowers the double-marginalization effect [5,10,20]. Furthermore, the profits of the manufacturer and platform decrease in $k$.

*4.3. Model D*

In this setting, the manufacturer's profit is $\Pi_M^D = wq_E + (1-\gamma)(a - q_M - \beta q_E + \tau\theta)q_M - \frac{k\theta^2}{2}$, and the platform's profit is $\Pi_E^D = (a - q_E - \beta q_M + \tau\theta - w)q_E + \gamma(a - q_M - \beta q_E + \tau\theta)q_M$.

**Lemma 3.** *In Model D, the equilibrium decisions are given by*

$$\theta^D = \frac{a\tau\left[12 - 8(\gamma+\beta) + \beta^2(1+\gamma)^2\right]}{k[16 - 2(3+\gamma)\beta^2] - \tau^2\left[12 - 8(\gamma+\beta) + \beta^2(1+\gamma)^2\right]} \tag{5}$$

$$w^D = \frac{ak\left[8 + \beta^3(1+\gamma)^2 - 4\beta(2\gamma+\beta)\right]}{k[16 - 2(3+\gamma)\beta^2] - \tau^2\left[12 - 8(\gamma+\beta) + \beta^2(1+\gamma)^2\right]} \tag{6}$$

$$q_M^D = \frac{ak[8 - 2\beta - (1+\gamma)\beta^2]}{k[16 - 2(3+\gamma)\beta^2] - \tau^2\left[12 - 8(\gamma+\beta) + \beta^2(1+\gamma)^2\right]} \tag{7}$$

$$q_E^D = \frac{4ak(1-\beta)}{k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]} \tag{8}$$

*and the firms' profits are given by*

$$\Pi_M^D = \frac{a^2k\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}{2k[16-2(3+\gamma)\beta^2]-2\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]} \tag{9}$$

$$\Pi_E^D = \frac{a^2k^2\left[\gamma\beta^4(5+\gamma)(1+\gamma)+16\beta^2(1-\gamma^2)+4\gamma(2\beta^3-13\beta^2+16)+16(1-2\beta)\right]}{\left[k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]^2} \tag{10}$$

In the hybrid channel structure, $\theta^D$, $w^D$, $q_E^D$, and $q_M^D$ decrease in $k$, and the profits of players also decrease in $k$. To better understand the benefit of the hybrid channel, we have the following:

**Corollary 1.** *(a)* $\frac{\partial\theta^D}{\partial\gamma} < 0$; $\frac{\partial w^D}{\partial\gamma} < 0$; $\frac{\partial q_M^D}{\partial\gamma} < 0$; $\frac{\partial q_E^D}{\partial\gamma} > 0$ *if* $\gamma > \gamma_q$, *otherwise,* $\frac{\partial q_E^D}{\partial\gamma} < 0$ *; (b)* $\frac{\partial\Pi_M^D}{\partial\gamma} < 0$; $\frac{\partial\Pi_E^D}{\partial\gamma} > 0$ *if* $k > k_E$, *otherwise,* $\frac{\partial\Pi_E^D}{\partial\gamma} < 0$.

From part (a), we note that $\theta^D$ decreases in $\gamma$. Furthermore, $w^D$ also decreases in $\gamma$, which means that the effect of double-marginalization becomes weaker as $\gamma$ increases. Moreover, $q_M^D$ decreases in $\gamma$, but $q_E^D$ increases in $\gamma$ only if the commission rate is relatively large because the manufacturer shifts the sales center from the agency channel to the reselling channel. We refer to this sales shifting as the channel flexibility effect [5], which could help both firms use channels more efficiently.

From part (b), $\Pi_M^D$ constantly decreases in $\gamma$ because a large commission rate lowers the double-marginalization effect, which hurts the manufacturer more than the benefit of the channel-flexibility effect. Interestingly, $\Pi_E^D$ increases in $\gamma$ if the green investment inefficiency is sufficiently large. In such a case, the platform benefits from both the weakness of the double-marginalization effect and channel-flexibility effect if $\gamma$ is large; when $\gamma$ is small, although the selling quantities decrease in $\gamma$ and intensify the competition between the two channels, the positive effect of the decreasing double-marginalization effect always dominates the negative effect of the competition intensity and thus benefits the platform.

## 5. Equilibrium Channel Structure

In this section, we first compare the equilibrium decisions in different channel structures, and then discuss the optimal channel strategy of the manufacturer and platform.

### *5.1. For the Equilibrium Decisions*

Let $k_e = \frac{\tau^2\left[\beta^2(1+\gamma)^2-4\beta-8\gamma+8\right]}{2\beta(8-3\beta-\beta\gamma)}$, $k_w = \frac{\tau^2(2-\beta)\left[\beta^2(1+\gamma)^2-8\gamma-4(\beta-2)\right]}{4k\beta\left[8\gamma+\beta(1-\gamma)-\beta^2(1+\gamma)^2\right]}$, and $\psi = \frac{16-5\beta^2-\sqrt{256-288\beta^2+128\beta^3-15\beta^4}}{4\beta^2}$.

The following proposition compares the equilibrium decisions in different channel structures.

**Proposition 1.** *(a) The product's green effort:* $\theta^A > \theta^R$ *if* $\frac{1}{2} < \gamma < 1$; $\theta^A < \theta^D$ *always holds;* $\theta^R > \theta^D$ *if* $\psi < \gamma < 1$. *(b) Wholesale price:* $w^R < w^D$ *if* $K < k < k_w$ *and* $\gamma < \psi$; *otherwise,* $w^R \geq w^D$. *(c)* $q_M^A > q_E^R$ *if* $0 < \gamma < \frac{2k}{\tau^2}$; $q_M^A < q_M^D$ *if* $K < k < \frac{\tau^2(2-\beta-\beta\gamma)}{2\beta}$ *and* $\gamma < \min\left\{\frac{4-3\beta}{2\beta}, 1\right\}$; $q_E^R < q_E^D$ *if* $K < k < k_e$ *and* $\gamma < \psi$.

Proposition 1(a) shows the comparative results of the green effort. We find that when $\gamma$ is high, the green effort is higher in Model A than Model R. Furthermore, the manufacturer always has an incentive to improve the green effort in Model D than in Model A. Moreover, the green effort is higher in Model D than Model R if $\gamma$ is low. This is because the large commission rate leads to a stronger channel-flexibility effect and drives the manufacturer to reduce green effort to benefit from the channel-flexibility effect in Model D.

Proposition 1(b) shows that the hybrid channel strengthens the wholesale price when $\gamma$ and $k$ are low. When $\gamma$ is low, the manufacturer depends heavily on the agency channel, and a low green investment inefficiency incentivizes the manufacturer to exert more green effort and thus enhances the wholesale price. However, when $\gamma$ is large, the manufacturer depends heavily on the reselling channel and thus lowers the wholesale price to shift sales to the reselling channel.

For Proposition 1(c), the result is intuitive. When $\gamma$ is low, the sales of the manufacturer are higher in Model A than the platform in Model R. However, the channel-flexibility effect may create more sales compared with a single channel; hence, the selling quantity in Model D is higher than the single channel.

*5.2. For the Manufacturer*

Let $k_N = \frac{\tau^2(1-\gamma)}{2(3-4\gamma)}$, $k_M = \frac{\tau^2(1-\gamma)\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}{2[\gamma^2\beta^2+2\gamma(\beta^2-4)+8\beta-7\beta^2+4]}$, and $\varphi = \frac{4-\beta^2-2\sqrt{4-3\beta^2-2\beta^3+2\beta^4}}{\beta^2}$.

The following proposition compares the manufacture's profit in different channel structures.

**Proposition 2.** *(a)* $\Pi_M^A > \Pi_M^R$ *if* $k > k_N$ *and* $\gamma < \frac{3}{4}$*; otherwise,* $\Pi_M^A \leq \Pi_M^R$*; (b)* $\Pi_M^A > \Pi_M^D$ *if* $k > k_M$ *and* $\gamma < \varphi$*; otherwise,* $\Pi_M^A \leq \Pi_M^D$*; (c)* $\Pi_M^R > \Pi_M^D$ *if* $\gamma > \psi$ *and* $\Pi_M^R \leq \Pi_M^D$ *otherwise.*

Proposition 2(a) shows that the manufacturer achieves higher profit in Model A than that in Model R if the green investment inefficiency is high but the commission rate is low. In this case, the manufacturer has less incentive to exert more green effort and thus benefits from a larger profit from the agency channel. However, when $\gamma$ is high, the major profit is occupied by the platform, and the manufacturer charges a higher wholesale price to benefit from the double-marginalization in Model R.

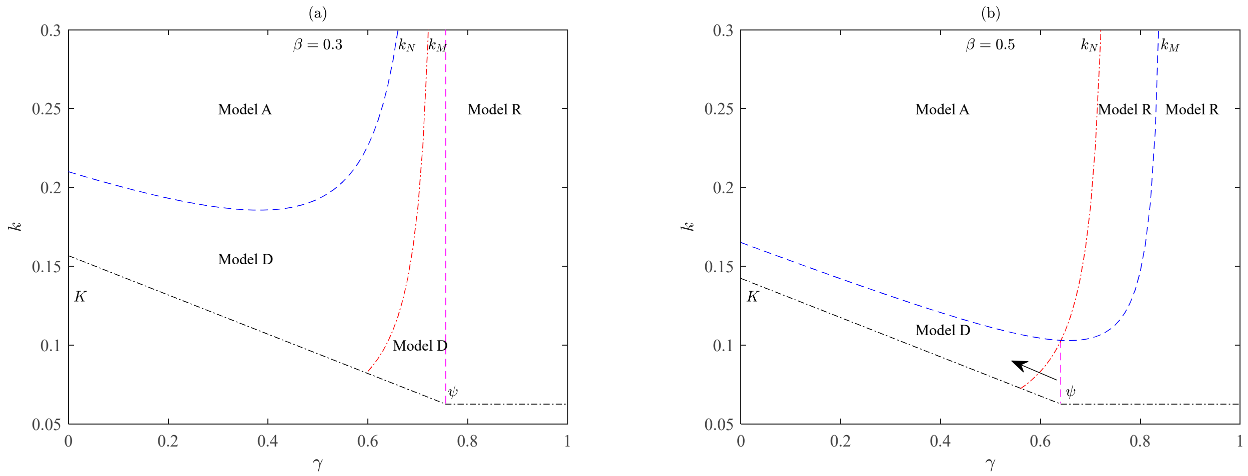
For Proposition 2(b), the manufacturer benefits more in Model A than in Model D if the green investment inefficiency is high but $\gamma$ is low. In this setting, the agency channel can take full advantage of the low commission rate in Model A, and a high green investment inefficiency drives the manufacturer to reduce the wholesale price. However, when $\gamma$ is high, the manufacturer benefits from the channel-flexibility effect and thus creates more profit for the manufacturer in Model D compared with Model A. In addition, the effect of double-marginalization becomes weak as the commission rate increases. That is, the stronger channel-flexibility effect, together with the weaker double-marginalization, drives the manufacturer to benefit more in Model D than Model A.

Proposition 2(c) states that the manufacturer benefits more in Model R than in Model D if $\gamma$ is high. When $\gamma$ is high, the manufacturer prefers to charge a lower wholesale price to benefit from the channel-flexibility effect in Model D. However, the manufacturer benefits from the stronger double-marginalization effect in Model R, and this benefit always dominates the channel-flexibility effect in Model D.

Let $\beta_M = \frac{64-28\sqrt{2}}{79}$; we characterize the manufacture's channel preference as follows:

**Proposition 3.** *(a) Suppose* $\beta < \beta_M$*,* $k_M > k_N$ *always holds such that the manufacturer prefers Model A if* $k > k_M$ *and* $\gamma < \varphi$*, prefers Model R if* $\gamma > \psi$*, and prefers Model D otherwise. (b) Suppose* $\beta < \beta_M$*, the manufacturer prefers Model A if* $k > max\{k_M, k_N\}$ *and* $\gamma < \frac{3}{4}$*, prefers Model R if* $k < k_N$ *and* $\gamma > \psi$*, and prefers Model D otherwise.*

Proposition 3 shows that the manufacturer's channel preference is determined by the competition intensity, commission rate, and green investment inefficiency. For a better understanding, we plotted Figure 3a with $\beta = 0.3$ and $\tau = 0.5$, and Figure 3b with $\beta = 0.5$ and $\tau = 0.5$; the experimental data are from Hong et al. [35] and Hong and Guo [37], which are commonly used in the operations management literature. We can show that $\psi > \frac{3}{4} > \varphi$ and $k_N > k_M$ in the lower competition intensity case with $\beta = 0.3$, and $\varphi > \frac{3}{4} > \psi$ in the higher competition intensity case with $\beta = 0.5$.




The lower competition intensity case with $\beta = 0.3$ The higher competition intensity case with $\beta = 0.5$

**Figure 3.** Manufacturer's channel preference.

Figure 3 enables us to investigate how different factors affect the manufacturer's preference. First, the manufacturer always prefers Model A when $\gamma$ is low and the green investment inefficiency is high. This is because the manufacturer benefits from a large share of profit and selling quantity in Model A compared to others. Moreover, the manufacturer decides its sell quantity by itself in Model A, thereby enhancing the response to the market. As the green investment inefficiency decreases, both the low green investment inefficiency and commission rate help the manufacturer to enhance the channel-flexibility effect, and together with the positive influence of double-marginalization, the manufacturer is more efficient in Model D.

Second, if $\gamma$ is large, the manufacturer selects Model R to avoid the profit loss. Under this condition, the online platform prefers to charge a lower wholesale price to benefit from the channel-flexibility effect in Model D. However, the manufacturer benefits from the stronger double-marginalization effect of Model R, and this benefit always dominates the channel-flexibility effect of Model D.

Third, by comparing Figure 3a with Figure 3b, we can explore the impact of competition intensity on the manufacturer's channel preference. We note that as the competition increases, the manufacturer prefers to select Model A and Model R but is less likely to select Model D. The reasons are presented below. Firstly, the channel-flexibility effect decreases in the competition intensity in Model D, which hurts the manufacturer. Secondly, more intense competition also reduces the double-marginalization effect in Model D. Therefore, these two negative effects in Model D push the manufacturer to Model A and Model R.

### 5.3. For the Platform

Let $k_F = \frac{\tau^2\left(3\gamma-1-\sqrt{4\gamma^3-4\gamma^2+\gamma}\right)}{2(4\gamma-1)}$ and $k_T = \frac{\tau^2\left(3\gamma-1+\sqrt{4\gamma^3-4\gamma^2+\gamma}\right)}{2(4\gamma-1)}$. The following proposition compares the platform's profit between Model A and Model R.

**Proposition 4.** *(a) When $\gamma < \frac{1}{4}$, $\Pi_E^A > \Pi_E^R$ if $K < k < k_F$ and $\Pi_E^A \leq \Pi_E^R$ otherwise; (b) when $\frac{1}{4} \leq \gamma \leq \frac{1}{2}$, $\Pi_E^A > \Pi_E^R$ always holds; (c) when $\frac{1}{2} < \gamma < 1$, $\Pi_E^A > \Pi_E^R$ if $\max\{K, k_T\} < k$ and $\Pi_E^A \leq \Pi_E^R$ otherwise.*

Proposition 4 states how the commission rate and green investment inefficiency affect the platform's channel preference between Model A and Model R. As Figure 4 shows, when $\gamma$ is small, the platform prefers Model R if the green investment inefficiency is high. Although the manufacturer exerts higher green effort to enhance the selling quantity in Model A, a high inefficiency always leads to a lower selling price, which hurts the platform. When $\gamma$ is large and green investment inefficiency is low, the platform benefits from a higher selling quantity in Model R than Model A. Figure 4 also shows that the platform can avoid the effect of double-marginalization by selling through the agency channel if both the commission rate and green investment inefficiency are moderate. In such a case, a moderate commission rate ensures that the selling quantity is not too low in Model A and enables the platform to share sufficient sales profits. Furthermore, we find that the platform is more likely to benefit from Model R if the green investment inefficiency is high because the double-marginalization effect decreases in $k$.

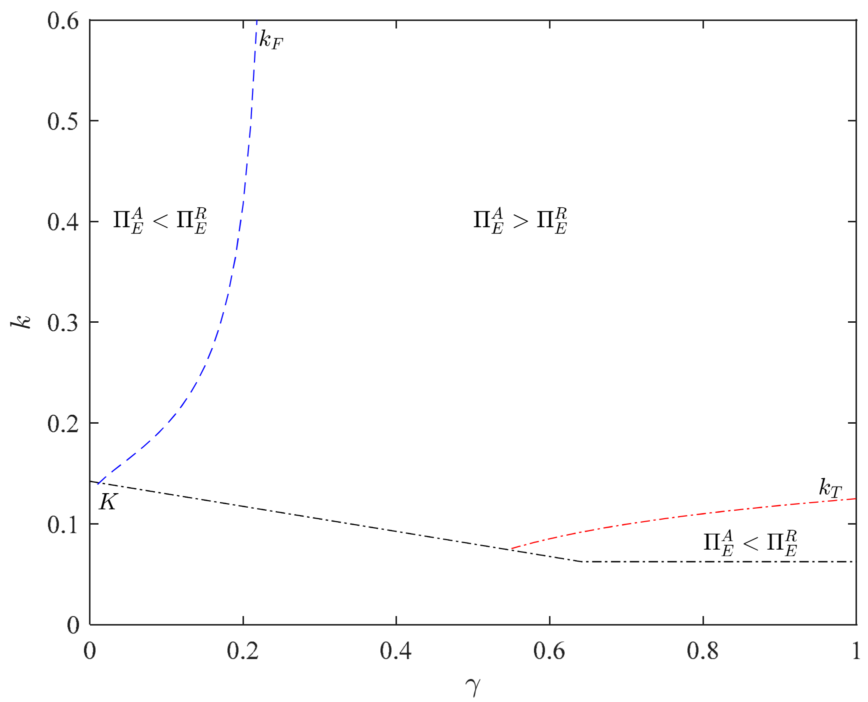



**Figure 4.** The comparison of the platform's profit between Model A and Model R.

The following proposition compares the platform's profit between Model A and Model D.

**Proposition 5.** *Compared with Model A, the platform always benefits from Model D.*

By comparing Model A and Model D, Proposition 5 sheds light on the platform always prefers Model D, which is illustrated in Figure 5. When $\gamma$ is low, the hybrid channel leads to large total sales in Model D, which incentivizes the platform towards free rides on the product's green effort in Model D compared to Model A. As $\gamma$ increases, the product's green effort decreases in both Model A and Model D, but this reduction in Model D is less than Model A because of the channel-flexibility effect. The higher green effort of the product drives the platform to be more efficient in Model D than Model A. The results prove that both the channel-flexibility effect and the channel competition effect dominate the double-marginalization effect.

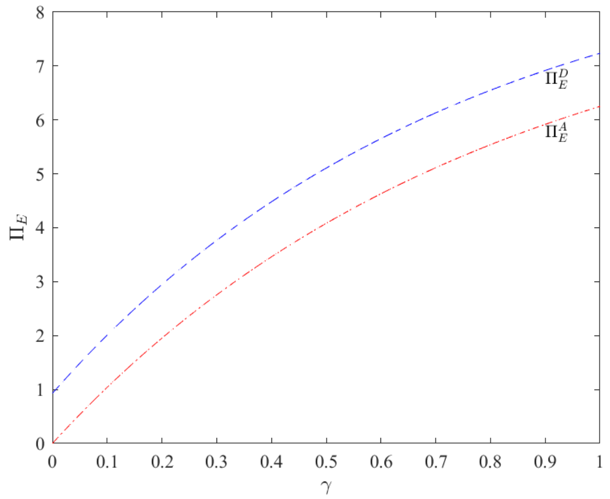



**Figure 5.** The comparison of the platform's profit between Model A and Model D.

The following proposition compares the platform's profit between Model D and Model R.

**Proposition 6.** *There exists a threshold $\phi < \psi$ such that: (a) when $\gamma < \phi$, $\Pi_E^D > \Pi_E^R$ if $K < k < k_S$ and $\Pi_E^D \leq \Pi_E^R$ otherwise; (b) when $\phi < \gamma < \psi$, $\Pi_E^D > \Pi_E^R$ always holds; (c) when $\psi < \gamma < 1$, $\Pi_E^D > \Pi_E^R$ if $max\{K, k_D\} < k$ and $\Pi_E^D \leq \Pi_E^R$ otherwise.*

Proposition 6 implies how $\gamma$ and $k$ affect the platform's channel preference between Model R and Model D, which is shown in Figure 6. When $\gamma$ is low and $k$ is high, the channel-flexibility effect is relatively low, and wholesale prices are lower in Model R than Model D. Moreover, high green investment inefficiency results in higher selling quantity in Model R than Model D. Therefore, Model R is the optimal model for the platform. In comparison, when $\gamma$ is high and $k$ is low, the reselling channel mitigates inefficiencies caused by high $\gamma$; the product's green effort is higher in Model R than Model D, which could stimulate the platform's free rides on the higher demand marked by the manufacturer. When $\gamma$ and $k$ are moderate, the channel-flexibility effect in Model D dominates the double-marginalization effect, which creates greater profit for the platform than that in Model R.

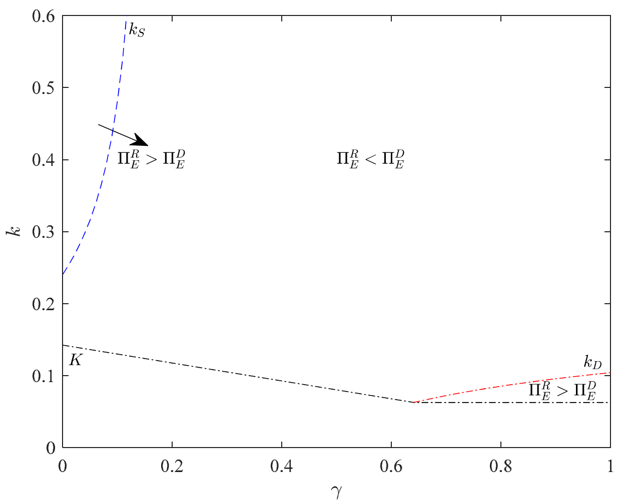



**Figure 6.** The comparison of the platform's profit between Model R and Model D.

We characterize the platform's channel preference as follows:

**Proposition 7.** *The platform prefers Model D if (a) $\gamma < \phi$ and $K < k < k_S$ or (b) $\gamma > \psi$ and $max\{K, k_D\} < k$; otherwise, the platform prefers Model R.*

Proposition 7 shows that the platform's channel preference is determined by $\gamma$ and $k$. We mapped Figure 7 to obtain a better understanding of these results. We find that the optimal channel structure for the platform is either Model R or Model D, which also means that Model A is not the best choice. When the green investment inefficiency $k$ is high but the commission rate $\gamma$ is low, the effect of double-marginalization is lower in Model R, which benefits the platform. Additionally, this benefit is greater than the channel-flexibility effect in Model D; hence, Model R is the platform's optimal choice. Conversely, a large $\gamma$ lowers the double-marginalization effect, while a low green investment inefficiency increases the selling quantity in Model R. Thus, Model R is still the optimal channel choice. When $\gamma$ and $k$ are moderate, the channel-flexibility effect in Model D dominates the double-marginalization effect, which creates greater profit for the platform than that in Model R.

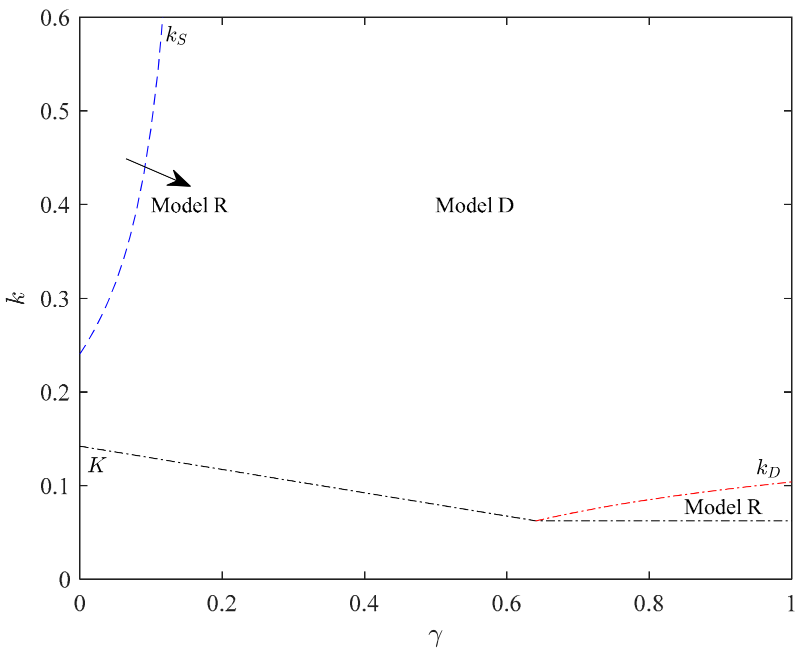


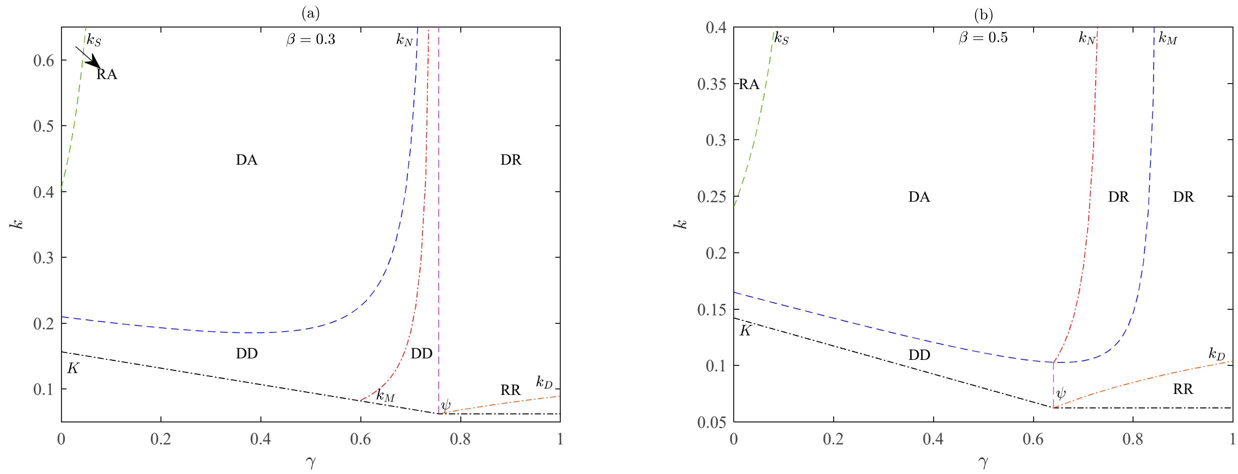

**Figure 7.** Platform's channel preference.

Figure 7 allows us to explore the effect of the green investment inefficiency and commission rate on the platform's channel preference. Furthermore, the platform is more likely to benefit from Model R as the green investment inefficiency is high because the double-marginalization effect becomes smaller as $k$ increases. Furthermore, $k_S$ and $k_D$ increase in $\gamma$, which means that the platform is more likely to benefit from Model R as $\gamma$ increases.

Combining the results in Proposition 3 and Proposition 7, the following conclusions can be drawn.

**Proposition 8.** *Both the platform and manufacturer prefer Model D if $k < k_M$ and $\gamma < \psi$ or Model R.*

Based on the firms' profits, five regions are finally formed, as shown in Figure 8. When $\gamma$ is low, both the manufacturer and platform prefer Model D. From our numerical analysis, when the degree of competition intensity increase, the area of DD decreases. This is probably because the higher degree of competition reduces channel-flexibility, which reduces the efficiency of Model D. Interestingly, a higher commission rate and green investment efficiency lead the manufacturer and platform to choose Model R, and the area of RR decreases with the competition intensity increase.




The lower competition intensity case with $\beta = 0.3$ The higher competition intensity case with $\beta = 0.5$

**Figure 8.** Equilibrium channel structure.

When the manufacturer and platform select Model D, the channel-flexibility of the hybrid channel can give the manufacturer more incentive to handle the higher level of the green product when compared with the single channel. Furthermore, the manufacturer gives the platform a free ride to produce green products. However, the higher degree of competition reduces the channel-flexibility, which leads to the manufacturer choosing Model R rather than Model D. In this circumstance, so as to maximize the platform and manufacturer's profit, the hybrid channel should maintain appropriate competition.

The manufacturer should control the green investment inefficiency within the low range when the degree of competition and commission rate are low. When $\gamma$ increases, the manufacturer can appropriately increase the green investment inefficiency, but this decision makes the manufacturer encounter a lower profit. In addition, the manufacturer and the platform prefer Model R when the commission rate is high. In this case, the manufacturer should seek the low green investment inefficiency to compensate for the loss caused by the high commission rate. When the degree of competition intensity increases, the low green investment inefficiency benefits the manufacturer. For the platform, a low commission rate can help the platform achieve greater profit because of the channel-flexibility in Model D. Meanwhile, a low green investment inefficiency and low commission rate help the manufacturer and the platform achieve a win–win outcome in Model D. This finding also provides a rationale for platforms not to set a high commission rate.

### *5.4. Managerial Implications and Discussion*

Our results provide useful insights for the platform and manufacturer to develop their channel strategies. Manufacturers such as Moutai and Sprite produce and sell green products on online platforms to attract more consumers in exchange for reputation and sales. Additionally, online platforms such as JD and Amazon charge different commission rates according to product categories, and the efficiency of green products may also affect this commission rate. Our formal analysis not only supports the practice evidence that the manufacturer and platform may select the channel strategically (i.e., Moutai and Sprite, JD and Amazon) but also offers several theoretical predictions (about how competition and green cost efficiency affect the firms' channel preference) for empirical validation. From the competition perspective, appropriate competition between the agency channel and reselling channel can help the manufacturer and platform expand the opportunity for a win–win outcome in Model D. In addition, fierce competition reduces the chance for firms to achieve a win–win outcome in Model D. However, higher competition may improve the opportunity to achieve a win–win outcome in Model R. From the platform's perspective, it is important to determine the appropriate commission rate, which is critical for the manufacturer's channel decision. When the commission rate is within reasonable limits, the feasible cost range of the green product is larger than before, which can increase the willingness of manufacturers to cooperate. From the manufacturer's perspective, it is necessary to adjust the cost efficiency of green products according to the channel strategy and commission rate and maximize profit within reasonable costs. From the literature's perspective, existing studies [5,6,15–17] discuss how market factors (e.g., information, organizational structure, order fulfillment cost, and service effort) affect the channel selection of the upstream manufacturer or downstream platform but do not simultaneously consider the interaction of hybrid channels, green cost effectiveness, and competition. This study is the first in the literature aimed at understanding how the interference of the above three factors affects the channel choices of firms.

## 6. Conclusions

Motivated by the popularity of online platform sales and consumer's environmental awareness, we studied channel preferences of the green manufacturer and online platform. The findings are summarized below.

First, the channel preference of the manufacturer depends on the green investment inefficiency and commission rate. Especially, the green production manufacturer prefers the hybrid channel when green investment inefficiency and commission rate are moderate. This structure occurs because of the channel-flexibility effect. Moreover, low competition intensity drives the manufacturer to try the hybrid channel.

Second, the online retail platform only selects the reselling channel or the hybrid channel. Especially, the effect of double-marginalization is lower in the reselling channel, which creates greater profit for the platform when the commission rate is low but the green investment inefficiency is high, or the commission rate is high but the green investment inefficiency is low. However, the hybrid channel drives the platform to benefit from the channel-flexibility effect when the commission rate and green investment inefficiency are moderate.

Third, the manufacturer and online platform can achieve a "win–win" outcome in Model D if the commission rate is low. However, excessive competition together with a larger commission rate reduce the possibility of achieving this equilibrium outcome. To avoid channel conflict and achieve a win–win outcome, the platform should charge a reasonable commission rate, and the manufacturer should control the green product investment according to the commission rate; for example, using various production technologies to reduce resource waste in the production process and to lower the cost of the green product.

There are several promising directions for future research. First, we assume that the online platform buys the green product from a monopoly manufacturer. In fact, platforms can source the product from different firms. It is interesting to explore how the competition between upstream firms affects the optimal channel preference. Second, we only consider the online selling channel. However, the firms may also have an offline channel. For example, Adidas sells its products through both Tmall and physical stores. If the manufacturer has an offline channel, the platform might charge a low commission rate to drive the manufacturer to sell more through the online channel. Therefore, it is worth extending this work to the case of the traditional offline channel and examining whether the key findings will change. Finally, empirical studies can be used to explore whether the theoretical results in our model still hold in practice.

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**Data Availability Statement:** Not applicable.

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## Appendix A

**Proof of Lemma 1.** At time T1, the manufacturer decides the first order condition of $\Pi_M^A$ yields $\frac{\partial \Pi_M^A}{\partial q_M} = (1-\gamma)(a - 2q_M + \tau\theta) = 0 \Leftrightarrow q_M = \frac{a+\tau\theta}{2}$, $\frac{\partial \Pi_M^A}{\partial \theta} = \tau q_M(1-\gamma) - k\theta = 0 \Leftrightarrow \theta = \frac{\tau q_M(1-\gamma)}{k}$. The second-order yields $\frac{\partial^2 \Pi_M^A}{\partial q_M^2} = -2(1-\gamma)$, $\frac{\partial^2 \Pi_M^A}{\partial \theta^2} = -k$, $\frac{\partial^2 \Pi_M^A}{\partial q_M \partial \theta} = \tau(1-\gamma)$, and $\frac{\partial^2 \Pi_M^A}{\partial \theta \partial q_M} = \tau(1-\gamma)$. Thus, we have $|H| = 2k(1-\gamma) - \tau^2(1-\gamma)^2 > 0 \Leftrightarrow k > \frac{\tau^2(1-\gamma)}{2}$. Substituting $q_M$ into $\theta$, we have $\theta^A = \frac{a\tau(1-\gamma)}{2k-\tau^2(1-\gamma)}$. Substituting $\theta^A$ into $q_M$, we have $q_M^A = \frac{ak}{2k-\tau^2(1-\gamma)}$. The manufacturer's profit is $\Pi_M^A = (1-\gamma)(a - q_M + \tau\theta)q_M - \frac{k\theta^2}{2} = \frac{ka^2(1-\gamma)}{2k-\tau^2(1-\gamma)}$ and the platform's profit is $\Pi_E^A = \gamma(a - q_M + \tau\theta)q_M = \frac{\gamma a^2 k^2}{[2k-\tau^2(1-\gamma)]^2}$. For the sensitivity analysis, we have $\frac{\partial \theta^A}{\partial k} < 0$, $\frac{\partial q_M^A}{\partial k} < 0$, $\frac{\partial \Pi_M^A}{\partial k} < 0$, $\frac{\partial \Pi_E^A}{\partial k} < 0$; $\frac{\partial \theta^A}{\partial \gamma} < 0$, $\frac{\partial q_M^A}{\partial \gamma} < 0$, $\frac{\partial \Pi_M^A}{\partial \gamma} < 0$, $\frac{\partial \Pi_E^A}{\partial \gamma} < 0$. □

**Proof of Lemma 2.** At time T2, the platform decides $q_E$. The first order condition of $\Pi_E^R$ yields $\frac{\partial \Pi_E^R}{\partial q_E} = a - 2q_E + \tau\theta - w = 0 \Leftrightarrow q_E = \frac{a+\tau\theta-w}{2}$. Substituting $q_E$ into $\Pi_M^R$, we have $\Pi_M^R = wq_E - \frac{k\theta^2}{2} = \frac{w(a+\tau\theta-w)-k\theta^2}{2}$. At time T1, the manufacturer decides $w$ and $\theta$. The first order condition of $\Pi_M^R$ yields $\frac{\partial \Pi_M^R}{\partial w} = \frac{a+\tau\theta-2w}{2} = 0 \Leftrightarrow w = \frac{a+\tau\theta}{2}$, $\frac{\partial \Pi_M^R}{\partial \theta} = \frac{\tau w - 2k\theta}{2} = 0 \Leftrightarrow \theta = \frac{\tau w}{2k}$. The second-order yields $\frac{\partial^2 \Pi_M^R}{\partial w^2} = -1$, $\frac{\partial^2 \Pi_M^R}{\partial \theta^2} = -k$, $\frac{\partial^2 \Pi_M^A}{\partial w \partial \theta} = \frac{\tau}{2}$, $\frac{\partial^2 \Pi_M^A}{\partial \theta \partial w} = \frac{\tau}{2}$. Thus, we have $|H| = k - \frac{\tau^2}{4} > 0 \Leftrightarrow k > \frac{\tau^2}{4}$. Substituting $w$ into $\theta$, we have $\theta^R = \frac{a\tau}{4k-\tau^2}$. Substituting $\theta^R$ into $w$, we have $w^R = \frac{2ak}{4k-\tau^2}$. Substituting $\theta^R$ and $w^R$ into $q_E$, we have $q_E^R = \frac{ak}{4k-\tau^2}$. The manufacturer's profit is $\Pi_M^R = wq_E - \frac{k\theta^2}{2} = \frac{ka^2}{2(4k-\tau^2)}$ and the platform's profit is $\Pi_E^R = (a - q_E + \tau\theta - w)q_E = \frac{a^2k^2}{(4k-\tau^2)^2}$. For the sensitivity analysis, we have $\frac{\partial \theta^R}{\partial k} < 0$, $\frac{\partial w^R}{\partial k} < 0$, $\frac{\partial q_E^R}{\partial k} < 0$, $\frac{\partial \Pi_M^R}{\partial k} < 0$, $\frac{\partial \Pi_E^R}{\partial k} < 0$. □

**Proof of Lemma 3.** At time T2, the manufacturer decides $q_M$ and the platform decides the $q_E$. The first order condition of $\Pi_M^D$ and $\Pi_E^D$ yields $\frac{\partial \Pi_M^D}{\partial q_M} = 0 \Leftrightarrow q_M = \frac{a-\beta q_E+\tau\theta}{2}$ and $\frac{\partial \Pi_E^D}{\partial q_E} = 0 \Leftrightarrow q_E = \frac{a-(1+\gamma)\beta q_M+\tau\theta-w}{2}$. Substituting $q_M$ into $q_E$, we have $q_E = \frac{[2-\beta(1+\gamma)](a+\tau\theta)-2w}{4-(1+\gamma)\beta^2}$. Substituting $q_E$ into $q_M$, we have $q_M = \frac{(2-\beta)(a+\tau\theta)+\beta w}{4-(1+\gamma)\beta^2}$. Substituting $q_E$ and $q_M$ into $\Pi_M^D$, we have $\Pi_M^D = w\frac{[2-\beta(1+\gamma)](a+\tau\theta)-2w}{4-(1+\gamma)\beta^2} + (1-\gamma)\left(\frac{(2-\beta)(a+\tau\theta)+\beta w}{4-(1+\gamma)\beta^2}\right)^2 - \frac{k\theta^2}{2}$. At time T1, the manufacturer decides $w$ and $\theta$. The first order condition of $\Pi_M^D$ yields $\frac{\partial \Pi_M^D}{\partial w} = 0 \Leftrightarrow w = \frac{\left[8-4\beta(\beta+2\gamma)+(1+\gamma)^2\beta^3\right](a+\tau\theta)}{2[8-(3+\gamma)\beta^2]}$, $\frac{\partial \Pi_M^D}{\partial \theta} = 0 \Leftrightarrow \theta = \frac{2a\tau(2-\beta)(1-\gamma)(2-\beta)+\tau w\left[8+(1+\gamma)^2\beta^3-4\beta(\beta+2\gamma)\right]}{k[4-(1+\gamma)\beta^2]^2-2\tau^2(1-\gamma)(2-\beta)^2}$. The second-order is given as follows: $\frac{\partial^2 \Pi_M^D}{\partial w^2} = \frac{-2\left[8-(3+\gamma)\beta^2\right]}{[4-(1+\gamma)\beta^2]^2}$, $\frac{\partial^2 \Pi_M^D}{\partial \theta^2} = \frac{2\tau^2(1-\gamma)(2-\beta)^2-k\left[4-(1+\gamma)\beta^2\right]^2}{[4-(1+\gamma)\beta^2]^2}$, $\frac{\partial^2 \Pi_M^D}{\partial \theta \partial w} = \frac{\tau\left[8+(1+\gamma)^2\beta^3-4\beta(\beta+2\gamma)\right]}{[4-(1+\gamma)\beta^2]^2}$ and $\frac{\partial^2 \Pi_M^D}{\partial w \partial \theta} = \frac{\tau\left[8+(1+\gamma)^2\beta^3-4\beta(\beta+2\gamma)\right]}{[4-(1+\gamma)\beta^2]^2}$. We can verify that $|H| > 0$ always holds if $k > \frac{\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}{2[8-(3+\gamma)\beta^2]}$. Substituting $w$ into $\theta$, we have $\theta^D = \frac{a\tau\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}{k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}$. Substituting $\theta^D$ into $w^D$, we have $w^D = \frac{ak\left[8+\beta^3(1+\gamma)^2-4\beta(2\gamma+\beta)\right]}{k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}$. Substituting $\theta^D$ and $w^D$ into $q_E$ and $q_M$, we have $q_E^D = \frac{4ak(1-\beta)}{k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}$, $q_M^D = \frac{ak\left[8-2\beta-(1+\gamma)\beta^2\right]}{k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}$. The profits of the manufacturer and platform are given as follows $\Pi_M^D = \frac{a^2k\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}{2k[16-2(3+\gamma)\beta^2]-2\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}$, $\Pi_E^D = \frac{a^2k^2\left[\gamma\beta^4(5+\gamma)(1+\gamma)+16\beta^2\left(1-\gamma^2\right)+4\gamma\left(2\beta^3-13\beta^2+16\right)+16(1-2\beta)\right]}{\left[k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]^2}$. For the sensitivity analysis, we have $\frac{\partial\theta^D}{\partial k} < 0$, $\frac{\partial w^D}{\partial k} < 0$, $\frac{\partial q_M^D}{\partial k} < 0$, $\frac{\partial q_E^D}{\partial k} < 0$, $\frac{\partial \Pi_M^D}{\partial k} < 0$, $\frac{\partial \Pi_E^D}{\partial k} < 0$. □

**Proof of Corollary 1.** (a) We have $\frac{\partial\theta^D}{\partial\gamma} = -\frac{2a\tau k\left[\beta^4\gamma^2+6\beta^4\gamma+5\beta^4+8\beta^3-16\beta^2\gamma-52\beta^2+64\right]}{\left[k\left[16-2(3+\gamma)\beta^2\right]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]^2} < 0$ $\frac{\partial w^D}{\partial\gamma} = \frac{2ak\left(4\beta^4\gamma\tau^2-\beta^5k\gamma^2-6\beta^5k\gamma-5\beta^5k+4\beta^4\tau^2-12\beta^3\gamma\tau^2-4\beta^4k\right)}{\left(\beta^2\gamma^2\tau^2+2\beta^2\gamma\tau^2+2\beta^2k\gamma+\beta^2\tau^2+6\beta^2k-8\beta\tau^2-8\gamma\tau^2+12\tau^2-16k\right)^2} + \frac{2ak\left(16\beta^3k\gamma-12\beta^3\tau^2+8\beta^2\gamma\tau^2+40\beta^3k-8\beta^2\tau^2+8\beta^2k+48\beta\tau^2-64\beta k-32\tau^2\right)}{\left(\beta^2\gamma^2\tau^2+2\beta^2\gamma\tau^2+2\beta^2k\gamma+\beta^2\tau^2+6\beta^2k-8\beta\tau^2-8\gamma\tau^2+12\tau^2-16k\right)^2}$. Solving $\frac{\partial w^D}{\partial\gamma} = 0$, we can get two roots $k_1 = 0, k_2 = \frac{4\tau^2\left(\beta^4\gamma+\beta^4-3\beta^3\gamma-3\beta^3+2\beta^2\gamma-2\beta^2+12\beta-8\right)}{\beta(\beta^4\gamma^2+6\beta^4\gamma+5\beta^4+4\beta^3-16\beta^2\gamma-40\beta^2-8\beta+64)} < 0$. Therefore, $\frac{\partial w^D}{\partial\gamma} < 0$ always hold; $\frac{\partial q_M^D}{\partial\gamma} = \frac{ak\left(-\beta^4\gamma^2\tau^2-2\beta^4\gamma\tau^2-\beta^4\tau^2-4\beta^3\gamma\tau^2+4\beta^4k-12\beta^3\tau^2+16\beta^2\gamma\tau^2-4\beta^3k+36\beta^2\tau^2+16\beta\tau^2-64\tau^2\right)}{\left(\beta^2\gamma^2\tau^2+2\beta^2\gamma\tau^2+2\beta^2k\gamma+\beta^2\tau^2+6\beta^2k-8\beta\tau^2-8\gamma\tau^2+12\tau^2-16k\right)^2}$. Solving $\frac{\partial q_M^D}{\partial\gamma} = 0$, we have two roots, $k_3 = -\frac{\tau^2\left(\beta^4\gamma^2+2\beta^4\gamma+\beta^4+4\beta^3\gamma+12\beta^3-16\beta^2\gamma-36\beta^2-16\beta+64\right)}{4\beta^3(1-\beta)}$ and $k_4 = 0$. Because $k > K$ and $k_3 < 0$, we have $\frac{\partial q_M^D}{\partial\gamma} < 0$ always hold; $\frac{\partial q_E^D}{\partial\gamma} = \frac{8ak(\beta-1)\left(4\tau^2-\beta^2k-\beta^2\tau^2-\beta^2\gamma\tau^2\right)}{(\beta^2\gamma^2\tau^2+2\beta^2\gamma\tau^2+2\beta^2k\gamma+\beta^2\tau^2+6\beta^2k-8\beta\tau^2-8\gamma\tau^2+12\tau^2-16k)^2}$. Solving $\frac{\partial q_E^D}{\partial\gamma} = 0$, we can get one root: $\gamma_q = \frac{4\tau^2-\beta^2k-\beta^2\tau^2}{\beta^2\tau^2}$. Therefore, $\frac{\partial q_E^D}{\partial\gamma} < 0$ if $\gamma > \gamma_q$; otherwise, $\frac{\partial q_E^D}{\partial\gamma} \leq 0$. (b) We have $\frac{\partial\Pi_M^D}{\partial\gamma} = -\frac{a^2k^2\left(\beta^4\gamma^2+6\beta^4\gamma+5\beta^4+8\beta^3-16\beta^2\gamma-52\beta^2+64\right)}{(\beta^2\gamma^2\tau^2+2\beta^2\gamma\tau^2+2\beta^2k\gamma+\beta^2\tau^2+6\beta^2k-8\beta\tau^2-8\gamma\tau^2+12\tau^2-16k)^2} < 0$, $\frac{\partial\Pi_E^D}{\partial\gamma} = \frac{a^2k^2M(k)}{Z(k)}$, where $Z(k) = \beta^2\gamma^2\tau^2 + 2\beta^2\gamma\tau^2 + 2\beta^2k\gamma + \beta^2\tau^2 + 6\beta^2k - 8\beta\tau^2 - 8\gamma\tau^2 + 12\tau^2 - 16k < 0$ and $M(k) = \beta^6\gamma^4\tau^2 + 10\beta^6\gamma^3\tau^2 - 2\beta^6k\gamma^3 - 12\beta^6\gamma^2\tau^2 + 18\beta^6k\gamma^2 + 2\beta^6\gamma\tau^2 - 48\beta^5\gamma^2\tau^2 + 24\beta^4\gamma^3\tau^2 + 62\beta^6k\gamma + 5\beta^6\tau^2 - 112\beta^5\gamma\tau^2 + 192\beta^4\gamma^2\tau^2 + 30\beta^6k - 16\beta^5k\gamma - 32\beta^5\tau^2 - 48\beta^4k\gamma^2 + 192\beta^4\gamma\tau^2 + 48\beta^5k - 280\beta^4k\gamma - 120\beta^4\tau^2 + 448\beta^3\gamma\tau^2 - 192\beta^2\gamma^2\tau^2 - 456\beta^4k + 640\beta^3\tau^2 - 992\beta^2\gamma\tau^2 + 384\beta^2k\gamma - 368\beta^2\tau^2 + 1152\beta^2k - 1024\beta\tau^2 + 512\gamma\tau^2 + 1024\tau^2 - 1024k$. Solving $M(k) = 0$, we can get only one root $k_E = \frac{\tau^2\left(\beta^6\gamma^4+10\beta^6\gamma^3+12\beta^6\gamma^2-2\beta^6\gamma+48\beta^5\gamma^2-24\beta^4\gamma^3-5\beta^6+112\beta^5\gamma-192\beta^4\gamma^2+32\beta^5-192\beta^4\gamma\right)}{2\left(\beta^6\gamma^3+9\beta^6\gamma^2+31\beta^6\gamma+15\beta^6-8\beta^5\gamma-24\beta^4\gamma^2+24\beta^5-140\beta^4\gamma-228\beta^4+192\beta^2\gamma+576\beta^2-512\right)} + \frac{\tau^2\left(120\beta^4-448\beta^3\gamma+192\beta^2\gamma^2-640\beta^3+992\beta^2\gamma+368\beta^2+1024\beta-512\gamma-1024\right)}{2\left(\beta^6\gamma^3+9\beta^6\gamma^2+31\beta^6\gamma+15\beta^6-8\beta^5\gamma-24\beta^4\gamma^2+24\beta^5-140\beta^4\gamma-228\beta^4+192\beta^2\gamma+576\beta^2-512\right)}$. Therefore, we have $\frac{\partial\Pi_E^D}{\partial\gamma} > 0$ if $k > k_E$; otherwise, $\frac{\partial\Pi_E^D}{\partial\gamma} \leq 0$. □

**Proof of Proposition 1.** (a) We have $\theta^A - \theta^R = -\frac{2a\tau k(2\gamma-1)}{(\gamma\tau^2-\tau^2+2k)(4k-\tau^2)}$. Because $\gamma\tau^2 - \tau^2 + 2k < 0$, $4k - \tau^2 > 0$, we have $\theta^A < \theta^R$ iff $0 < \gamma < \frac{1}{2}$. We can verify that $\theta^A - \theta^D = \frac{-8a\tau k\left(\beta^2-2\beta+1\right)}{[2k-\tau^2(1-\gamma)]\left[k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]} < 0$ always holds, which means that $\theta^A < \theta^D$ always holds. We have $\theta^R - \theta^D = \frac{2a\tau k\left(-2\beta^2\gamma^2-5\beta^2\gamma-5\beta^2+16\beta+16\gamma-16\right)}{(4k-\tau^2)\left[k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]}$. Solving $-2\beta^2\gamma^2 - 5\beta^2\gamma - 5\beta^2 + 16\beta + 16\gamma - 16 = 0$, we can get two roots, $\gamma' = \frac{16-5\beta^2+\sqrt{-15\beta^4+128\beta^3-288\beta^2+256}}{4\beta^2} > 1$ and $\psi = \frac{16-5\beta^2-\sqrt{-15\beta^4+128\beta^3-288\beta^2+256}}{4\beta^2}$. Hence, $\theta^R < \theta^D$ iff $0 < \gamma < \psi$. (b) To compare $w^R$ and $w^D$, we have $w^R - w^D = \frac{ak\left[4k\beta\left[8\gamma+\beta(1-\gamma)-\beta^2(1+\gamma)^2\right]+\tau^2(\beta-2)\left[\beta^2(1+\gamma)^2-8\gamma-4(\beta-2)\right]\right]}{(4k-\tau^2)\left[k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]}$. Thus, we only need to check the value of $D(k) = 4k\beta\left[8\gamma + \beta(1-\gamma) - \beta^2(1+\gamma)^2\right] + \tau^2(\beta-2)\left[\beta^2(1+\gamma)^2 - 8\gamma - 4(\beta-2)\right]$. Notice that $8\gamma+\beta(1-\gamma)-\beta^2(1+\gamma)^2>0$ and solving $R(\gamma)=(\beta-2)\left[\beta^2(1+\gamma)^2-8\gamma-4(\beta-2)\right]=0$, we have two roots: $\gamma_w=\frac{4-\beta^2-2\sqrt{\beta^3-4\beta^2+4}}{\beta^2}$ and $\gamma_o=\frac{4-\beta^2+2\sqrt{\beta^3-4\beta^2+4}}{\beta^2}>1$. Thus, we have $R(\gamma)<0$ iff $0<\gamma<\gamma_w$. We separately discuss two cases: (1) When $0<\gamma<\gamma_w$, solving $D(k)=0$, we have $k_w=\frac{\tau^2(2-\beta)\left[\beta^2(1+\gamma)^2-8\gamma-4(\beta-2)\right]}{4\beta\left[8\gamma+\beta(1-\gamma)-\beta^2(1+\gamma)^2\right]}$. Thus, $w^R>w^D$ if $k>k_w$; otherwise, $w^R\leq w^D$. (2) When $\gamma_w\leq\gamma<1$, we have $w^R>w^D$ always holds. We can verify that $k_w>K$ if $\gamma<\psi<\gamma_w$. Therefore, $w^R<w^D$ if $\{K<k<k_w,\gamma<\psi\}$; otherwise, $w^R\geq w^D$. (c) We have $q_M^A-q_E^R=\frac{ak(2k-\gamma\tau^2)}{[2k-\tau^2(1-\gamma)](4k-\tau^2)}$. Thus, $q_M^A>q_E^R$ iff $0<\gamma<\frac{2k}{\tau^2}$. To compare $q_M^A$ and $q_M^D$, we have $q_M^A-q_M^D=\frac{2ak\left[2\beta k(1-\beta)+\tau^2(\beta-1)(2-\beta-\beta\gamma)\right]}{[2k-\tau^2(1-\gamma)]\left[k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]}$. Thus, we only need to check $N(k)=2\beta k(1-\beta)+\tau^2(\beta-1)(2-\beta-\beta\gamma)$. Clearly, $(\beta-1)(2-\beta-\beta\gamma)<0$, and $1-\beta>0$. Solving $N(k)=0$, we have one root: $k_m=\frac{\tau^2(2-\beta-\beta\gamma)}{2\beta}>0$. Therefore, $q_M^A<q_M^D$ iff $\{K<k<k_m,\gamma<\min\{\gamma_m,1\}\}$, where $\gamma_m=\frac{4-3\beta}{2\beta}$ and $\gamma<\min\{\gamma_m,1\}$ guarantees $k_m>K$. We have $q_E^R-q_E^D=\frac{ak\left[2\beta(8-3\beta-\beta\gamma)k+\tau^2\left[4\beta+8\gamma-8-\beta^2(1+\gamma)^2\right]\right]}{(4k-\tau^2)\left[k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]}$. Thus, we only need to check $X(k)=2\beta(8-3\beta-\beta\gamma)k+\tau^2\left[4\beta+8\gamma-8-\beta^2(1+\gamma)^2\right]$. Notice that $2\beta(8-3\beta-\beta\gamma)>0$ and solving $P(\gamma)=4\beta+8\gamma-8-\beta^2(1+\gamma)^2=0$, we have the following two roots: $\gamma_e=\frac{4-\beta^2-2\sqrt{\beta^3-4\beta^2+4}}{\beta^2}$ and $\gamma_E=\frac{4-\beta^2+2\sqrt{\beta^3-4\beta^2+4}}{\beta^2}>1$. Thus, we have $P(\gamma)\geq0$ if $\gamma_e\leq\gamma<1$ and $p(\gamma)<0$ if $0<\gamma<\gamma_e$. We separately discuss two cases: (1) when $0<\gamma<\gamma_e$, solving $X(k)=0$, we have $k_e=\frac{\tau^2\left[\beta^2(1+\gamma)^2-4\beta-8\gamma+8\right]}{2\beta(8-3\beta-\beta\gamma)}$. Because $k>K\equiv max\left\{\frac{\tau^2}{4},\bar{k}\right\}$, comparing $k_e$ with $K$, we have $k_e-\frac{\tau^2}{4}=\frac{\tau^2\left(2\beta^2\gamma^2+5\beta^2\gamma+5\beta^2-16\beta-16\lambda+16\right)}{4\beta(8-3\beta-\beta\gamma)}$. Thus, we have $k_e>\frac{\tau^2}{4}$ if $0<\gamma<\psi$ and $k_e<\frac{\tau^2}{4}$ if $\psi<\gamma<1$, where $\psi=\frac{16-5\beta^2-\sqrt{256-288\beta^2+128\beta^3-15\beta^4}}{4\beta^2}$. $k_e-\bar{k}=\frac{2\tau^2\left(-2\beta^3\gamma^2-5\beta^3\gamma+2\beta^2\gamma^2-5\beta^3+5\beta^2\gamma+21\beta^2+16\beta\gamma-32\beta-16\gamma+16\right)}{\beta(8-3\beta-\beta\gamma)[8-(3+\gamma)\beta^2]}$. Thus, we have $k_e>\bar{k}$ if $0<\gamma<\psi$ and $k_e<\bar{k}$ if $\psi<\gamma<1$. *In summary*, there exists a threshold $k_e$ such that $q_E^R<q_E^D$ if $K<k<k_e$; and $q_E^R>q_E^D$ otherwise. (2) When $\gamma_e\leq\gamma<1$ we have $q_E^R>q_E^D$ always holds. Therefore, $q_E^R<q_E^D$ if $\{K<k<k_e,\gamma<\psi\}$; otherwise, $q_E^R>q_E^D$. □

**Proof of Proposition 2.** (a) We have $\Pi_M^A-\Pi_M^R=\frac{ka^2\left[2k(3-4\gamma)+\tau^2(\gamma-1)\right]}{2(4k-\tau^2)[2k-\tau^2(1-\gamma)]}$. Because $k>max\left\{\frac{\tau^2}{4},\bar{k}\right\}$, we only need to check $H(k)=2k(3-4\gamma)+\tau^2(\gamma-1)$. Solving $H(k)=0$ yields one root $k_N\equiv\frac{\tau^2(1-\gamma)}{2(3-4\gamma)}$. We separately discuss three cases: (1-1) When $0<\gamma<\frac{3}{4}$, $\Pi_M^A<\Pi_M^R$ if $K<k<k_N$; otherwise, $\Pi_M^A>\Pi_M^R$. (1-2) When $\frac{3}{4}<\gamma<1$, $\Pi_M^A<\Pi_M^R$ always hold. (1-3) When $\gamma=\frac{3}{4}$, $H(k)=\tau^2(\gamma-1)<0$. Thus, $\Pi_M^A<\Pi_M^R$. Therefore, we have $\Pi_M^A>\Pi_M^R$ iff $\left\{k>k_N,\gamma<\frac{3}{4}\right\}$. (b) We have $\Pi_M^A-\Pi_M^D=a^2k\frac{2k\left[\gamma^2\beta^2+2\gamma\left(\beta^2-4\right)+8\beta-7\beta^2+4\right]-\tau^2(1-\gamma)\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}{2[2k-\tau^2(1-\gamma)]\left[k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]}$. Let $T(\gamma)=\gamma^2\beta^2+2\gamma\left(\beta^2-4\right)+8\beta-7\beta^2+4$ and solving $T(\gamma)=0$ yields two roots $\varphi=\frac{4-\beta^2-2\sqrt{4-3\beta^2-2\beta^3+2\beta^4}}{\beta^2}$ and $\gamma_H=\frac{4-\beta^2+2\sqrt{4-3\beta^2-2\beta^3+2\beta^4}}{\beta^2}>1$. Thus, $T(\gamma)>0$ if $\gamma<\varphi$ and $T(\gamma)<0$ if $\gamma>\varphi$. We separately discuss three cases: (2-1) When $\gamma<\varphi$, we have $T(\gamma)>0$. In order to compare $\Pi_M^A$ and $\Pi_M^D$, we only need to check $2k\left[\gamma^2\beta^2+2\gamma\left(\beta^2-4\right)+8\beta-7\beta^2+4\right]-\tau^2(1-\gamma)\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]$. Solving this equation, we have $k_M=\frac{\tau^2(1-\gamma)\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]}{2[\gamma^2\beta^2+2\gamma(\beta^2-4)+8\beta-7\beta^2+4]}$. Thus, $\Pi_M^A>\Pi_M^D$ if $k>k_M$ and $\Pi_M^A<\Pi_M^D$ if $k<k_M$. (2-2) When $\gamma>\varphi$, we have $T(\gamma)<0$. Thus, $\Pi_M^A<\Pi_M^D$. (2-3) When $\gamma=\varphi$, we have $T=0$. Thus, $\Pi_M^A<\Pi_M^D$. Therefore, combining the results in (2-1), (2-2), and (2-3) we have $\Pi_M^A<\Pi_M^D$ if $\gamma\geq\varphi$ or $\{\gamma<\varphi,k<k_M\}$; $\Pi_M^A>\Pi_M^D$ if $\{\gamma\langle\varphi,k\rangle k_M\}$. (c) We have $\Pi_M^R-\Pi_M^D=\frac{k^2a^2\left[16(\gamma+\beta)-16-\left(5+5\gamma+2\gamma^2\right)\beta^2\right]}{(4k-\tau^2)\left[k[16-2(3+\gamma)\beta^2]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]}$. Solving $16(\gamma+\beta)-16-\left(5+5\gamma+2\gamma^2\right)\beta^2=0$ yields two roots: $\psi=\frac{16-5\beta^2-\sqrt{256-288\beta^2+128\beta^3-15\beta^4}}{4\beta^2}$ and $\gamma_P=\frac{16-5\beta^2+\sqrt{256-288\beta^2+128\beta^3-15\beta^4}}{4\beta^2}>1$. Hence, $\Pi_M^R>\Pi_M^D$ if $\gamma>\psi$. □

**Proof of Proposition 3.** The results of Proposition 3 come from Proposition 2. □

**Proof of Proposition 4.** Comparing the platform's profits under Model A and R, we have $\Pi_E^A - \Pi_E^R = \frac{a^2k^2\left[\gamma\left(4k-\tau^2\right)^2-\left[2k-\tau^2(1-\gamma)\right]^2\right]}{\left[2k-\tau^2(1-\gamma)\right]^2\left(4k-\tau^2\right)^2}$. Solving $Y(k) = \gamma\left(4k-\tau^2\right)^2 - \left[2k-\tau^2(1-\gamma)\right]^2 = 0$ yields two roots $k_T = \frac{\tau^2\left(3\gamma-1+\sqrt{4\gamma^3-4\gamma^2+\gamma}\right)}{2(4\gamma-1)}$ and $k_F = \frac{\tau^2\left(3\gamma-1-\sqrt{4\gamma^3-4\gamma^2+\gamma}\right)}{2(4\gamma-1)}$. When $\gamma \in \left(0, \frac{1}{4}\right)$, $Y(k)$ is a quadratic function with the opening downward about $k$ and $k_T < k_F$. When $\gamma \in \left(\frac{1}{4}, 1\right)$, $Y(k)$ is a quadratic function with the opening upward about $k$ and $k_T > k_F$. When $\gamma = \frac{1}{4}$, we have $\bar{k} > \frac{3}{8}\tau^2 > \frac{5}{16}\tau^2$ and $Y(k) = \tau^2\left(k - \frac{5}{16}\tau^2\right) > 0$. We separately discuss four cases: (1-1) When $\gamma \in \left(0, \frac{1}{4}\right)$ and $k \in (k_T, k_F)$, $Y(k) > 0$, thus $\Pi_E^A > \Pi_E^R$; (1-2) When $\gamma \in \left(0, \frac{1}{4}\right)$ and $k \in (0, k_T) \cup (k_F, +\infty)$, $Y(k) < 0$, thus $\Pi_E^A < \Pi_E^R$; (1-3) When $\gamma \in \left(\frac{1}{4}, 1\right)$ and $k \in (k_F, k_T)$, $Y(k) < 0$, thus $\Pi_E^A < \Pi_E^R$; (1-4) When $\gamma \in \left(\frac{1}{4}, 1\right)$ and $k \in (0, k_F) \cup (k_T, +\infty)$, $Y(k) > 0$, thus $\Pi_E^A > \Pi_E^R$. When $\gamma < \frac{1}{4}$, we have $k_T < \frac{\tau^2}{4}$ always hold; when $\gamma > 0.5$, we have $k_F < \frac{\tau^2}{4}$, and when $\gamma = \frac{1}{4}$, we have $k_F = k_T = \frac{\tau^2}{4} \leq K$. □

**Proof of Proposition 5.** Comparing the platform's profits under Model A and D, we have $\Pi_E^A - \Pi_E^D = \frac{4a^2k^2(\beta-1)^2\left[\gamma\beta^2\left(3\gamma^2\tau^4+2\gamma\tau^4-\tau^4+8k\tau^2(1+\gamma)+4k^2\right)-8\beta\gamma\tau^4+4\tau^4\left(7\gamma-5\gamma^2-1\right)+4\tau^2(4k-12k\gamma)-16k^2\right]}{\left[2k-\tau^2(1-\gamma)\right]^2\left[k\left[16-2(3+\gamma)\beta^2\right]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]^2}$. Thus, we only need to check the value of $Z(k) = \gamma\beta^2\left(3\gamma^2\tau^4 + 2\gamma\tau^4 - \tau^4 + 8k\tau^2(1+\gamma) + 4k^2\right) - 8\beta\gamma\tau^4 + 4\tau^4\left(7\gamma - 5\gamma^2 - 1\right) + 4\tau^2(4k - 12k\gamma) - 16k^2$. Because $\Delta_Z = \beta^4\gamma^4 + 6\beta^4\gamma^3 + 5\beta^4\gamma^2 + 8\beta^3\gamma^2 - 16\beta^2\gamma^3 - 52\beta^2\gamma^2 + 16\beta^2\gamma - 32\beta\gamma + 64\gamma^2 + 16\gamma > 0$. Thus, we have the following two roots $k_H = \frac{\tau^2\left(2\beta^2\gamma^2+2\beta^2\gamma-12\gamma+4+\Delta_Z\right)}{2(4-\beta^2\gamma)}$ and $k_L = \frac{\tau^2\left(2\beta^2\gamma^2+2\beta^2\gamma-12\gamma+4-\sqrt{\Delta_Z}\right)}{2(4-\beta^2\gamma)}$. Clearly, $k_H > k_L$ and we can verify that $k_H < \bar{k} < K$. Thus, $\Pi_E^A < \Pi_E^D$ always hold. □

**Proof of Proposition 6.** Comparing the platform's profits under Model R and D, we have $\Pi_E^R - \Pi_E^D = \frac{a^2k^2\left[\begin{array}{c}\left[k\left[16-2(3+\gamma)\beta^2\right]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]^2\\ -\left(4k-\tau^2\right)^2\left[\gamma\beta^4(5+\gamma)(1+\gamma)+16\beta^2\left(1-\gamma^2\right)+4\gamma\left(2\beta^3-13\beta^2+16\right)+16(1-2\beta)\right]\end{array}\right]}{\left(4k-\tau^2\right)^2\left[k\left[16-2(3+\gamma)\beta^2\right]-\tau^2\left[12-8(\gamma+\beta)+\beta^2(1+\gamma)^2\right]\right]^2}$. Thus, we only need to check the value of $F(k) = \left[k\left[16-2(3+\gamma)\beta^2\right] - \tau^2\left[12 - 8(\gamma+\beta) + \beta^2(1+\gamma)^2\right]\right]^2 - \left(4k-\tau^2\right)^2\left[\gamma\beta^4(5+\gamma)(1+\gamma) + 16\beta^2\left(1-\gamma^2\right) + 4\gamma\left(2\beta^3 - 13\beta^2 + 16\right) + 16(1-2\beta)\right]$. Because $\Delta_F = \left[\left(\gamma^2 + \frac{5}{2}\gamma + \frac{5}{2}\right)\beta^2 - 8\beta - 8\gamma + 8\right]^2\left[\left(\gamma^3 + 6\gamma^2 + 5\gamma\right)\beta^4 + 8\beta^3\gamma + \left(16 - 52\gamma - 16\gamma^2\right)\beta^2 - 32\beta + 64\gamma + 16\right] > 0$ $k_D = \frac{3\tau^2\left[\beta^4(1+\gamma)\left(\gamma^2+\frac{14}{3}\gamma+1\right)+\beta^3\left(\frac{8}{3}\gamma-8\right)+\beta^2\left(20-16\gamma^2-44\gamma\right)+64\gamma-\frac{64}{3}\right]}{\beta^4(8\gamma^3+46\gamma^2+28\gamma-18)+64\beta^3\gamma+\beta^2(224-384\gamma-128\gamma^2)-256\beta+512\gamma} + \frac{2\tau^2\sqrt{\Delta_F}}{\beta^4(8\gamma^3+46\gamma^2+28\gamma-18)+64\beta^3\gamma+\beta^2(224-384\gamma-128\gamma^2)-256\beta+512\gamma}$, $k_S = \frac{3\tau^2\left[\beta^4(1+\gamma)\left(\gamma^2+\frac{14}{3}\gamma+1\right)+\beta^3\left(\frac{8}{3}\gamma-8\right)+\beta^2\left(20-16\gamma^2-44\gamma\right)+64\gamma-\frac{64}{3}\right]}{\beta^4(8\gamma^3+46\gamma^2+28\gamma-18)+64\beta^3\gamma+\beta^2(224-384\gamma-128\gamma^2)-256\beta+512\gamma} - \frac{2\tau^2\sqrt{\Delta_F}}{\beta^4(8\gamma^3+46\gamma^2+28\gamma-18)+64\beta^3\gamma+\beta^2(224-384\gamma-128\gamma^2)-256\beta+512\gamma}$. (a) Let $k_D - \frac{\tau^2}{4}$; $k_S - \frac{\tau^2}{4}$, we can get two roots: $\psi = \frac{16-5\beta^2-\sqrt{256-288\beta^2+128\beta^3-15\beta^4}}{4\beta^2}$ and $\gamma_2 = \frac{16-5\beta^2+\sqrt{256-288\beta^2+128\beta^3-15\beta^4}}{4\beta^2} > 1$. (b) Let $M = \beta^4\left(8\gamma^3 + 46\gamma^2 + 28\gamma - 18\right) + 64\beta^3\gamma + \beta^2\left(224 - 384\gamma - 128\gamma^2\right) - 256\beta + 512\gamma$, we can verify that only one root $\phi < \psi$ exists by solving $M = 0$. Thus, we have $M < 0$ iff $\gamma < \phi$, which means that $k_D < k_S$; otherwise, $k_D \geq k_S$. Therefore, when $\gamma < \psi$, we have $k_D < \bar{k}$ always hold. When $\gamma > \psi$, we have $k_S < \frac{\tau^2}{4}$, and when $\gamma = \psi$, we have $k_D = k_S \leq K$. Thus, combining the results in (a) and (b), we have the Proposition 6. □

**Proof of Proposition 7.** The proof of Proposition 7 is the combination of Proposition 4, Proposition 5, and Proposition 6. □

**Proof of Proposition 8.** Combining Proposition 3 and Proposition 7 leads to Proposition 8. □

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