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The Implications of the Spillover Effect Related to Green Co-Creation in a Supply Chain

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Abstract: Driven by environmental concerns, firms close to end-users are increasingly co-creating with customers for green product development within their supply chains. However, a challenge called "spillover" can hinder the incentive for green co-creation by these firms. This paper examines the spillover issue in a dual-channel structure, where downstream firms implement co-creation with customers for green product development. Our findings indicate that spillover from green investments can negatively impact the investing firm's profits. However, in low-competition scenarios, spillover benefits the supplier and customers within the supply chain. Additionally, under specific circumstances, it can improve overall supply chain performance. Crucially, to safeguard the sustainability of green co-creation in supply chains and prevent detrimental co-destruction, we propose implementing revenue-sharing contracts that can generate Pareto improvements, benefiting all green supply chain members. As a result, unlike traditional intellectual property protection, which hinders spillover, this study offers an alternative strategy that is also somewhat complementary, promoting collaboration over restrictions to leverage the positive aspects of spillover.

Keywords: value co-creation; spillover effect; green supply chain; dual-channel structure

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1. Introduction

Driven by environmental concerns arising from economic activity in recent decades, consumers are increasingly demanding the use of "green components" throughout a product's life cycle, from design to disposal [1,2]. To meet this growing preference for sustainable products, firms are transforming their business models by embracing value co-creation with customers [3–7]. For example, after collaborating with consumers on their preferences, Adidas committed to using 100% Better Cotton Initiative cotton by 2018 and transitioning to fully recycled polyester by 2024 [8]. Undoubtedly, deeper insights into customers' needs are essential for firms to participate effectively in value co-creation and extract valuable knowledge [9–11].

As business operations have evolved from traditional models to become more customer-oriented, enterprises are now more attuned to the health and environmental concerns of their customers [12]. As a result, downstream firms, particularly those that interact directly with customers, are actively engaging in value co-creation to address their customers' green expectations [13]. For example, Walmart demonstrates its commitment to sustainability by directly engaging with customers to understand their environmental concerns. This approach allows them to tailor their initiatives, such as Project Gigaton, which aims to reduce CO_2 emissions from Walmart's global value chain by one billion metric tons by 2030. One way in which they are trying to achieve this is by transitioning to electric delivery vehicles. Walmart believes that Project Gigaton not only satisfies the growing demands of environmentally conscious consumers, but also brings economic advantages to businesses through sustainable practices [14].

It is important to note that green co-creation is a powerful tool for businesses to meet the growing demand for environmentally friendly products [3,15]; after all, the ultimate success of these green initiatives is determined by customers in the market [16]. By engaging in green co-creation, businesses not only meet the environmental expectations of their customers but also enhance their competitiveness. This enhancement comes from actively gathering and integrating green knowledge and ideas from a diverse range of sources [3–5].

As a process of knowledge exchange, green co-creation may face the potential risk of spillover—especially in the supply chain, where components are interconnected [17,18]. For example, while Project Gigaton has enabled Walmart to reduce its emissions by over 175 million metric tons of CO_2 equivalents, it also involves more than 3000 suppliers, who may distribute their own products to environmentally conscious consumers [14]. This creates a situation where suppliers could potentially free-ride on Walmart's co-creation efforts, reaping the benefits of green products without shouldering the development costs.

Existing research on spillover effects in green supply chains highlights the risk of "free-riding", where partners exploit a focal firm's knowledge gains or physical efforts without contributing [19–21]. Free-riding behavior among businesses can lead to significant issues, impacting both competitiveness and consumer satisfaction; this may, in turn, deter companies from adopting green practices [22]. A pertinent example is Tesla, which has pioneered the development of an extensive network of Supercharger stations to support its electric vehicles (EVs). This infrastructure investment has been considerable and largely financed by Tesla alone. However, to access up to USD 7.5 billion in federal funds designated for public charging networks, Tesla is required to make its system available to all users. Consequently, other automakers entering the EV market can leverage Tesla's established infrastructure without having made similar investments. This situation becomes particularly advantageous for these companies if they secure access to Tesla's Superchargers or if regional regulations mandate shared charging solutions, significantly benefiting these competitors [23].

Some studies suggest that green spillovers can lead to beneficial outcomes [24–26], while critics argue that they only result in negative effects [27]. However, the majority of scholars hold a mixed view [28,29], asserting that the outcomes of green spillovers depend on a variety of factors. Moreover, despite the lack of consensus on green spillovers, studies have rarely explored the intersection between green spillover and green co-creation in the supply chain. Another significant gap is that value co-creation, particularly emphasized within the service-dominant (S-D) logic framework, underscores the crucial roles of all stakeholders in a business process, from suppliers to customers [30–32]. Despite its importance, research focused on green co-creation within the supply chain is still limited.

To fill these research gaps, we developed a set of game-theoretic models in a dual-channel supply chain structure where a downstream focal firm, such as Walmart, engages in value co-creation with its customers to address green features in product development while its upstream suppliers can potentially free-ride on the co-creation efforts due to the spillover effects. More specifically, we intend to highlight the following research questions:

(1) What are the implications of the spillover effect on the green co-creation levels of the downstream firm and the consumers?
(2) What are the impacts of the spillover effect on the performance of different players in a green co-creation supply chain?

The major findings of our study on the spillover effect in green co-creation are twofold. While spillover can discourage the downstream focal firm from further co-creation investment, it may incentivize consumers to invest more in green co-creation. On the other hand, examining the performance of supply chain members, we see that the spillover of green co-creation can negatively impact the downstream firm but potentially benefit the suppliers, customers, and overall supply chain. Based on these findings, for green product development (GPD), we propose that policymakers should explore alternative approaches beyond strict intellectual property restrictions. One promising avenue is the encouragement of flexible contractual collaboration, such as revenue-sharing contracts, which can incentivize collaboration and achieve mutually beneficial outcomes for all participants in the supply chain.

The remainder of this paper is organized as follows: Section 2 reviews the pertinent literature. Section 3 elaborates on the model setting and relevant notations, and then the optimal results from the two models are compared and analyzed. Section 4 concludes the research and suggests some future directions.

2. Literature Review

2.1. Green Co-Creation in Supply Chains

Drawing on seminal works in service-dominant logic [30,33] and experience-dominant logic [34], value co-creation emerges as a collaborative process. Unlike traditional, firm-centric collaboration, value co-creation emphasizes equality among participants, typically firms and their customers. This means that both parties actively contribute to value creation through their interactions. Extensive research has demonstrated that value co-creation (VCC) offers significant benefits to participants in various respects, including lowering costs for firms [35], opening doors to a wider range of innovation sources [36], fostering stronger customer loyalty [37], and so on. From the perspective of research objects, both B2B and B2C contexts have been explored within the research on value co-creation in supply chains [38].

According to S-D logic, value co-creation highlights the essential roles of all stakeholders in a business process, ranging from suppliers to customers [30–32]. Green co-creation, a hot research topic in recent years [3,5,15,39], has seldom been studied in contexts that include both upstream and downstream stakeholders, such as in supply chains. This contrasts sharply with the abundant research on collaborations among various partners in the existing literature on green supply chains [13,40–42]. Li et al. [3] explored three distinct B2B co-creation strategies in this context, highlighting the potential for collaboration among various supply chain partners. Building on this, Shi et al. [5] employed an empirical approach to examine the effects of focal firms' co-creation with suppliers, competitors, and retailers. Ding et al. [15] focused on the livestock product supply chain, utilizing system simulation to investigate the impacts of cooperation between manufacturers, sellers, and customers on green innovation and supply chain health. Finally, Yao et al. [39] examined how suppliers' green innovation types influence consumers' willingness to participate in green co-creation. Their research considered the influence of the chain liability and green halo effects, suggesting that consumers' perceptions of a company's environmental practices throughout the supply chain can impact their behavior.

2.2. Inter-Channel Spillover in Supply Chains

In recent years, the issue of spillover among participants has attracted significant attention from researchers in the supply chain domain [43]. To be more specific, prior studies have primarily focused on investments and strategic areas such as R&D and knowledge [44,45], cost reduction [46], service [47,48], brand competition [49], advertising [50], and so on. Within the green supply chain, there is also a growing body of work exploring the spillover effects of green investments. For example, Chen et al. [21] examined manufacturer–retailer co-investment in green R&D in a two-echelon supply chain, while Zhang et al. [51] investigated the spillover effects of cross-channel return policies in a dual-channel structure. Considering spillover, Hsieh and Lathifah [20] analyzed how blockchain technology can facilitate informed decision-making in a dual-channel green supply chain. However, there is a widely recognized consensus that R&D spillover or knowledge spillover may benefit innovative and non-innovative firms alike due to knowledge leakage and externalities [52]. There is no consensus in the academic community regarding the effects of spillovers from green investments. Some studies suggest that green spillovers can lead to beneficial outcomes [24–26]. For example, Lu et al. [24] stated that a spillover effect occurs when consumers perceive a company's activities as promoting environmental protection or sustainability. This perception often leads them to view the company's brands and products more favorably. Conversely, critics argue that green spillovers only result in negative effects [27]. However, most scholars hold a mixed view [28,29], believing that the outcomes of green spillovers depend on various factors. Awasthy et al. [53] contend that the impact of spillovers, whether positive or negative, is influenced by consumer sensitivity to green products, the effectiveness of the firm's marketing and greening efforts, and the overall market dynamics, including competition. Liu and Zhu [54] suggested that the impact of green spillovers depends on whether they occur in a competitive context. Zhang et al. [19] consider the spillover to have dual impacts: while it can facilitate the spread of beneficial green innovations across the industry, it may also discourage investment in new technologies by diminishing the exclusive benefits that innovating firms gain from their investments.

Notably, despite the acknowledged importance of customers in the green supply chain, existing research rarely explores customer-related spillover effects. Furthermore, although some studies consider spillover relating to customer participation in the green supply chain [55], they typically view it as a one-sided involvement rather than an interaction between the firm and customers (i.e., co-creation). Our research bridges this gap by introducing green co-creation between the downstream firms and customers within a dual-channel supply chain as a source of spillover. In summary, a comparison of this study with the related literature is presented in Table 1.

Table 1. Position of this paper.

Literature	Green Co-Creation in Supply Chain	Inter-Channel Spillover in Supply Chain
Li, et al. [3], Ding, et al. [15], etc.	√	×
Hsieh and Lathifah [20], Chen, et al. [21], Lu, et al. [24], etc.	×	√
This paper	√	√

3. The Models

Relevant variables are listed in Table 2 below in order to help the reader better understand the model setting.

Table 2. Model notation.

Variable	Definition
a	Highest potential price in the market
i	The investment parameter of green co-creation activities
c	Transaction cost in direct channel
θ	Spillover rate of green co-creation
w	Wholesale price to focal firm set by supplier
V_c/V_f	Co-creation efforts invested by consumers/focal firm
P_f/P_s	Price of products sold by focal firm/direct channel of supplier
q_f/q_s	Sales of focal firm/direct channel of supplier
$\prod$	Profit of business entities (i.e., supplier or focal firm)
CS	Consumer surplus

3.1. *The Green Co-Creation Model with No Spillover Effect (Model N)*

In this section, we conceive a dual-channel structure model consisting of three participants: an upstream supplier ($S1$), a downstream focal firm ($F1$) that revises and then resales the green product, and a group of homogeneous customers ($C1$). To be more specific, the supplier has established a direct sale channel to compete with the focal firm while wholesaling the original non-green product to it simultaneously. As a response to the challenge sent by the supplier, the incumbent focal firm in the traditional channel also implements the value co-creation strategy by trying to develop a green product from the original one to increase its own competitiveness (see Figure 1). This model is relatively consistent across the retail and manufacturing sectors. For example, as a co-creative firm in the EV sector, NIO uses its showrooms, NIO Houses, to provide customers with an immersive experience and foster a strong user community. Meanwhile, NIO once had a contract manufacturing agreement with Jianghuai Automobile Co. (JAC) (Hefei, China), a traditional automaker, which also competes with NIO in the market with its own products.

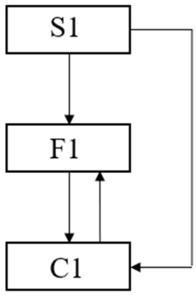

Figure 1. Model N.

Based on the dual-channel [56,57] and green supply chain literature [3,5,15,39], this article makes a few assumptions to clarify the situation.

Assumption 1. *Both the original and the green products can satisfy the basic demands of customers, and all produced products will be purchased. However, customers with a preference for green are willing to pay a higher price for green products.*

This is a critical issue if the vast majority of consumers prefer cheaper but less sustainable products, in which case there will not be sufficient demand for more sustainable but expensive alternatives. Consequently, companies that cause environmental damage have little economic incentive to invest in more sustainable technologies [58]. Similar settings are often adopted in the green supply chain literature. For example, Liu et al. [59] stipulated that when customers express their demand for greener products, manufacturers must comply and produce green products according to the demand.

Assumption 2. *In discussing channel efficiency, it is assumed that the product cost is zero. Transaction costs are introduced to highlight the differences between the traditional channel and the newly added direct channel.*

In the dual-channel supply chain structure, both the direct and retail channels source their products from the same supplier, allowing us to assume homogeneous production across channels. Consequently, following the classical framework used by Arya et al. [57], we simplified our model by assuming that the production cost is zero. However, to underscore differences in channel efficiency, transaction costs emerge as a crucial metric in supply chain research, as per transaction cost theory. Major studies suggest that downstream sellers are typically more familiar with customers than the newly added direct channels [60,61]. Therefore, we posit that the focal firm with higher channel efficiency incurs zero transaction costs, whereas the transaction costs for the direct channel are specifically denoted by c.

Assumption 3. *Both the focal firm and customers will jointly put their efforts into value co-creation as an investment in green product development (GPD) processes.* V_c *and* V_f *are introduced to express invested efforts from the customer side and that of the focal firm, respectively.*

Although green co-creation is currently a hot topic in research, studies focusing on green supply chain contexts are relatively scarce. There is also no consensus on how to depict green co-creation in existing research. Considering that our green co-creation involves green products and aims to highlight the characteristics of joint investment, we adopted the approach of Van den Broeke and Paparoidamis [62] to depict co-creation, as used in their studies on new product development in the supply chain.

As for the performance indicators related to co-creation, existing research within the supply chain varies depending on the study's purpose and context, featuring specific metrics such as tripartite participation costs [15], carbon emissions [3], and production flexibility [62]. More common indicators include participant profits or total investment amounts. Notably, considering that green co-creation in our study occurs in a B2C context, we introduce consumer surplus to measure the benefits that consumers gain from green co-creation. Moreover, as mentioned in Assumption 3, to emphasize that green co-creation results from joint investments by consumers and focal firms, which incur costs, we do not use the proportion of total investment to represent it [3,15]. Instead, we use V_c and V_f to denote green contributions from consumers and businesses, respectively [62]. Overall, this study aims to comprehensively assess the impact of green co-creation spillovers on the supply chain system and its members, using supplier and focal firm profits, consumer surplus, and co-creation investments as performance indicators.

Starting with the upstream supplier's demand, an inverse demand function is hereby conceived—that is, $P_s = a - q_f - q_s$, where P_s stands for the price of the product sold through the direct channel, while a is the maximum selling price of products in this market. Furthermore, q_f and q_s represent the product quantity sold to consumers through the downstream firm via the green channel and the direct channel, respectively. Another inverse demand function is introduced to delineate the demand for the green product on the traditional channel, namely, $P_f = a - q_f - q_s + V_c + V_f$. This study also introduces the profit of up/downstream firms (Π) and consumer surplus (CS) to express the gain or loss of the entities in the supply chain.

In addition, utilizing co-creation takes its toll on bringing advantages to implementers [63]. Therefore, participating in green co-creation activities incurs costs for participants. To express the costs incurred by green co-creation, we introduce iV_c^2 and iV_f^2 to represent the co-creative cost. It is worth mentioning that i indicates the investment parameter, whereas a higher investment parameter means a more intensive investment environment (a less intensive environment needs fewer efforts invested to achieve the same co-creation effect when compared with a more intensive one). Certainly, the investment parameter may vary between customers and firms. However, to avoid unnecessary complexity, we assume that both the focal firm and the consumers share the same co-creation environment, thereby having an identical investment parameter. The same simplification can also be seen in the works of Bhaskaran and Krishnan [64] and Van den Broeke and Paparoidamis [62].

The decision sequence of Model N is as follows: First, the firm and customers decide the level of effort (V_c and V_f) simultaneously. Second, the supplier is the next to decide the wholesale price (w). Third, the firm then sets the output of the green co-creative product (q_f) accordingly. Finally, the supplier will consider the output (q_s) of the origin product on the direct channel. Applying backward induction, the results of equilibrium solutions are listed in Table 3 (see the process of calculation in Appendix A).

Table 3. Equilibrium solutions.

Model N			
$p_{f1}*$	$\frac{3(c+2ci+a(-1+6i))}{36i-10}$	$V_{c1}*$	$\frac{2a+2c+9ai-3ci}{6i(-5+18i)}$
$p_{s1}*$	$\frac{3a+2c-9ai-3ci}{5-18i}$	$V_{f1}*$	$\frac{a-c+12ci}{3i(-5+18i)}$
$q_{f1}*$	$\frac{a+c(-1+12i)}{18i-5}$	$\Pi_{f1}*$	$\frac{(-2+9i)(a+c(-1+12i))^2}{18(5-18i)^2 i}$
$q_{s1}*$	$\frac{3(c-5ci+a(-1+3i))}{18i-5}$	$\Pi_{s1}*$	$\frac{a^2(7+9i(-5+9i))-2ac(7+27i(-2+3i))+7c^2(1+9i(-1+3i))}{(5-18i)^2}$
w_1*	$\frac{2a-2c-9ai+3ci}{5-18i}$	CS_1*	$\frac{(-1+18i)(c(2-3i)+a(-2+9i))^2}{36(5-18i)^2 i}$

Table 3. *Cont.*

		Model S	
$p_{f2}*$	$\frac{3(c(2+4i-3\theta)+a(-2+12i+(5-3\theta)\theta))}{72i-20+(28-17\theta)\theta}$	$V_{c2}*$	$\frac{4a-4c-18ai+6ci-6a\theta+2c\theta-9ai\theta+3ci\theta+2c\theta^2+2a\theta^3}{3i\left(20-72i-28\theta+17\theta^2\right)}$
$p_{s2}*$	$\frac{6a(6i-(-2+\theta)(-1+\theta))+c(-8+12i+(22-17\theta)\theta)}{72i-20+(28-17\theta)\theta}$	$V_{f2}*$	$\frac{2\left(2a-2c+24ci-3a\theta+c\theta-24ci\theta+c\theta^2+a\theta^3\right)}{3i\left(-20+72i+28\theta-17\theta^2\right)}$
$q_{f2}*$	$\frac{2\left(c(2-24i+\theta)+a\left(-2+\theta+\theta^2\right)\right)}{20-72i-(28-17\theta)\theta}$	$\Pi_{f2}*$	$\frac{2\left(9i-2(-1+\theta)^2\right)\left(c(2-24i+\theta)+a\left(-2+\theta+\theta^2\right)\right)^2}{9i(-20+72i+(28-17\theta)\theta)^2}$
$q_{s2}*$	$\frac{6\left(c(-2+10i+\theta)+a\left(2-6i-3\theta+\theta^2\right)\right)}{20-72i-(28-17\theta)\theta}$	$\Pi_{s2}*$	$\frac{4c^2\left(28+252i(-1+3i)-32\theta+90i\theta+13\theta^2\right)-8ac\left(28+324i^2-60\theta+(45-13\theta)\theta^2-9i(-4+\theta)(-6+5\theta)\right)}{(-20+72i+(28-17\theta)\theta)^2}+$ $\frac{4a^2\left(324i^2-18i(-1+\theta)(-10+7\theta)+(-1+\theta)^2(28+\theta(-32+13\theta))\right)}{(-20+72i+(28-17\theta)\theta)^2}$
w_2*	$\frac{4\left(a\left(9i-2(-1+\theta)^2\right)+c(2-3i-2\theta)\right)}{72i-20+(28-17\theta)\theta}$	CS_2*	$\frac{\left(72i-(2+\theta)^2\right)\left(a\left(-9i+2(-1+\theta)^2\right)+c(-2+3i+2\theta)\right)^2}{9i(-20+72i+(28-17\theta)\theta)^2}$

3.2. The Green Co-Creation Model with Spillover Effect (Model S)

Model S, influenced by the spillover effect, has a supply chain structure similar to that of Model N. The difference is that, in this study, we claim that the invested efforts from customers and the focal firm will partially spill over to the direct sale channel (see Figure 2). Thus, we introduce θ, the outgoing spillover rate used by Ding and Huang [65], to measure the gains of green co-creation spillover perceived by customers when they make purchases on another channel. As a result, the profit function of the supplier in Model S is obtained, which is $P_{s2} = a - q_{f2} - q_{s2} + \theta(V_{c2} + V_{f2})$. As for the focal firm, the profit function remains the same as presented in Model N, which is $P_{f2} = a - q_{f2} - q_{s2} + V_{c2} + V_{f2}$.

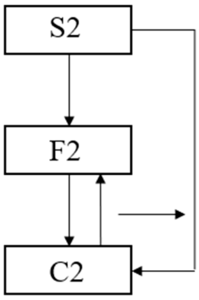

Figure 2. Model S.

Model S has the same decision timing as Model N. The optimal equilibrium solutions, obtained by backward induction, are shown in Table 3 (see calculation in Appendix A).

3.3. Analysis

3.3.1. The Comparison of Investment in Green Co-Creation Efforts

The level of investment in green co-creation is not only a variable that participants in this study must initially decide on; it also serves as an essential performance indicator for the success of the co-creation process. Since green co-creation brings costs to the focal firm and customer, these co-creation participants will also change the level of investment according to the actual performance of green co-creation. Given the insufficient research on green co-creation spillovers in the supply chain, we can draw insights from findings related to investment spillovers within the supply chain. In academia, the effects of spillover on investment in the dual-channel supply chain are two-sided. On the one hand, as presented by Bernstein et al. [66], some of the research states that the spillover will hinder the competitiveness of investors, for competitors obtain benefits from the investment without paying the cost, thereby decreasing the investment willingness of investors. On the other hand, others, such as Xia and Niu [47], have reported that investors may invest more when spillover is present. To better examine this contradiction and explore the effects of spillover on green co-creation, we compare the expressions of V_c and V_f in Model N with those in Model S. The first proposition of this study is as follows:

Proposition 1. *The existence of spillover will discourage the firm from investing co-creation efforts in the green co-creation process, while the discouragement of investment on the customer side only appears under a certain threshold of co-creation parameters and spillover rates.*

Specifically, on the customer side, we find that the decrease in investment happens when $\frac{1}{3} < i < \frac{1}{2}$ and $0 < \theta < \theta_1$. Under other circumstances, customers will invest more efforts into co-creation. It should be noted that the effects of the co-creation effort spillover on customers and firms are distinct. For customers, although some of the invested efforts may spill over to the direct sale channel, the benefits of green co-creation will eventually come back to customers as the end-users. According to social support theory, the support that an individual receives from society fosters a positive outlook. In light of this theory, customers actively engage in the co-creation of green value through the successful implementation of green practices [16]. The more they invest, the more benefits they gain in both channels. However, for the focal company, this spillover is purely negative. The more the company invests in co-creation with customers, the more their direct competitors benefit for free. This weakens the focal company's competitive edge.

To be specific, we find that the focal firm decreases its input during the value co-creation once the spillover effect exists ($V_{f1} > V_{f2}$). This result is coherent with the findings of Bernstein et al. [66], who suggested that spillover will undermine the benefit to the investor; thus, the firm will lower its investment to avoid helping its competitors (i.e., direct channel of the supplier). Spillover itself is a critical issue in innovation activities that will change the competitive landscape [67]. In this case, the focal firm in our setting may reduce its resource commitment due to competitive considerations. However, even with the reasonable ground that the focal firm may reduce its green investment level, some research implies that increasing the resource investment is another option. For example, Ofek et al. [68] found that offline stores under the "brick-and-click" strategy tend to offer more in-store assistance to regain competitiveness once challenged by the online channel. Arya and Mittendorf [69] also state that partial forward integration (dual-channel structure included) often leads market participants to increase their investment. There is no need to mention that value co-creation itself is a powerful measure for its implementers to increase their competitiveness. For the downstream firm, increasing the investment in the GPD process can boost their competitiveness significantly [70], so it is rational for the downstream firm to invest more efforts to further amplify this effect when investment from the customer side is witnessed.

However, there were no signs in our study that the focal firm has tried to increase its investment efforts to enhance the traditional channel, even if the level of spillover is insignificant. Current research indicates that, in a competitive environment, downstream firms may reduce their investments due to risk aversion and strategic financial considerations, fearing that the intensified competition will prevent them from recouping these investments [71]. In the realm of green investment, a similar phenomenon has been observed. Xu et al. [72] reported that as suppliers gain competitive advantages, downstream firms may be disincentivized from making similar investments. This reluctance often arises if they perceive an inability to compete effectively or if they believe that the returns on their green investments are undermined by the actions of suppliers.

To examine whether the supplier obstructs the firm from investing more effort into green co-creation, we shift our focus to the difference in wholesale price between Model N and Model S. It can be seen that the supplier with spillover chooses to decrease the wholesale price when $\{\frac{1}{3} < i < 1 \ \& \ \frac{9ai-6a}{4+15i} < c < c_1 \ \& \ 0 < \theta < \theta_2\}$; otherwise, the wholesale price will be raised. It can be said that the supplier decreases the wholesale price for the downstream firm when green co-creation is favored by the environment while asking for a higher price under spillover when the environment is not as suitable for co-creation. Noticeably, the supplier profits from both the direct sale channel and the traditional channel; as mentioned above, the spillover effect also allows the direct sale channel to proportionally enjoy the benefits of the green investment from customers and the focal firm. Under this circumstance, the reduction in wholesale price indicates that the supplier tries to alleviate the pressure faced by the focal firm when the supplier can sufficiently benefit from the spilled co-creation efforts; however, it should be noted that the supplier will attempt to extract the benefits from the traditional channel directly by increasing the wholesale price when the spilled co-creation efforts become less effective due to the environment.

3.3.2. The Comparison of Channel Decisions

In order to study the impact of the spillover effect on the two channels in the supply chain, we examine the selling price of the firm and the supplier between Model N and Model S (i.e., $p_{f2} - p_{f1}$ and $p_{s2} - p_{s1}$). Although Zhang et al. [73] stated that the price of the product sold in the invested channel will still increase with the investment level in the event of spillover, our study finds a contradictory result in an asymmetric channel power scenario. This brings us to our second proposition:

Proposition 2. *The spillover will cause a decrease in green products' prices even if the investors have invested more efforts into co-creation. Conversely, the direct channel will have a higher price when the spillover effect appears.*

According to Zhang et al. [73], the retail channel in a dual-channel platform can still raise the price when the spillover effect appears, as the investment in the retail channel will increase the demand on the whole system. However, our study reports that this conclusion may not be universal to all dual-channel contexts. Specifically, it is true that investment from the firm side will shrink after spillover; nevertheless, the decrease in green products' prices continues even after an increase in total investment has been observed (i.e., $V_{c2} + V_{f2} > V_{c1} + V_{f1}$; see details in Appendix A) when the spillover effect is present.

As the price in our setting directly reflects on the demand function (e.g., $P_{f2} = a - q_{f2} - q_{s2} + V_{c2} + V_{f2}$), the quantity decisions made by the firm and supplier determine the green product price. Hence, by examining the number of products sold from two channels, we can find something interesting:

Corollary 1. *The appearance of spillover discourages the sales of the green product even if the total investment increases, while the sales of the direct channel are boosted.*

Based on Corollary 1, a transfer of sales from the green channel to the direct channel can be confirmed. According to Appendix A, the increase in total investment will only happen when $\frac{7}{12} < i < 1$ *and* $0 < c < c_2$ & $\theta_3 < \theta < 1$. With the expression of $\Delta P_f = (q_{f1} - q_{f2}) + (q_{s1} - q_{s2}) + (V_{c2} + V_{f2} - V_{c1} - V_{f1})$, it is easy to conclude that the increase in sales in the direct channel exceeds the decrease in sales in the traditional channel when the total investment increases. As a result, we find that the spillover effect helps the direct channel occupy more of the investment-generated demand than the traditional channel. In other words, we can observe that, due to spillover effects, even price-sensitive direct sales channels have developed certain green attributes, attracting some customers who initially sought out green product channels. Consequently, from a pricing strategy perspective, it is strategic for downstream firms to adopt a penetration pricing strategy, offering lower prices on green products. According to existing research, this strategy enables firms to expand their market share by appealing to both green-oriented and general customers with competitive pricing [24].

In conclusion, the spillover will have a negative effect on the traditional channel, in terms of both sales and price, while benefiting the direct channel. Although the investors may put more efforts into the green co-creation, the beneficiary ends up being the supplier due to the unbalanced channel power.

3.3.3. The Comparison of Profits

To further explore the effects of green spillover, we specifically examined the performance of the focal firm, the supplier, and customers before and after the spillover (i.e., $\Pi_{f2} - \Pi_{f1}$ and $\Pi_{s2} - \Pi_{s1}$ and $CS_2 - CS_1$). Then, we propose the following:

Proposition 3. *The performance of the focal firm will be worse as long as the spillover appears, while there are thresholds of transaction cost that allow the supplier and customer to be better off after the spillover.*

Proposition 3 reveals a bitter truth for the downstream firm: the negative effect derived from spillover outweighs the positive effect of green co-creation. Combined with insights from Proposition 2, it can be observed that the focal company's profits decline even as its total investment in green co-creation increases. Although prevailing views suggest that green investments generally benefit the investing firm [74,75], this counterintuitive phenomenon warrants further investigation.

The decline in the focal firm's performance stems from factors identified in Propositions 1 and 2: the selling price and sales of green products decrease due to competition from upstream suppliers in the context of spillover effects. Consequently, green co-creation spillovers negatively impact the focal firm's performance in two primary ways: First, competitive dilution occurs as spillovers enable suppliers to benefit from green practices without incurring comparable costs, thereby eroding the competitive edge of the initial investor. Second, market saturation emerges as suppliers harness the advantages of green co-creation due to spillovers, resulting in a market flooded with products featuring green attributes. This saturation drives down profit margins and poses significant challenges for the investing firm in recovering its costs and achieving superior performance.

However, this also proves that the spillover effect can be beneficial for other players in the supply chain. To be more specific, Figures 3 and 4 show that when $c \in (0, c_3)$ and $c \in (0, c_4)$, the profit of the supplier and consumer surplus will be higher after the spillover.

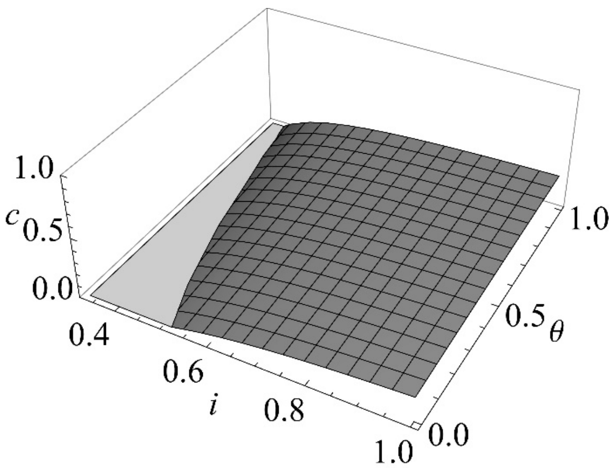

Figure 3. The difference in the supplier's profit between Model S and Model N (a = 1).

It should be noted that the profit of the supplier consists of direct channel and wholesale parts. Based on Proposition 2 and Corollary 1, the sales of the direct channel will be promoted by the spillover. Hence, the unprofitable situation of the supplier is caused by the wholesale part. The main reason for this is the aforementioned sale loss in the green channel, regardless of the change in wholesale price. According to Figure 4, the consumer surplus will only improve when the co-creative parameter is relatively high and when transaction costs in the direct sale channel are low. Based on this result and Corollary 1, we can infer that the increase in consumer surplus after spillover is mainly derived from the incremental sales in the direct channel.

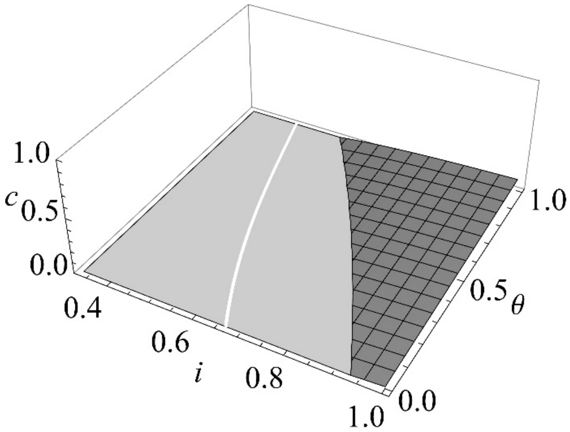

Figure 4. The difference in consumer surplus between Model S and Model N (a = 1).

This finding of our study is consistent with the research of Xia and Niu [47], who claimed that channel power is a vital factor influencing the performance of dual-channel players in the context of spillover. However, the content of channel power in our setting was different from theirs. To further investigate the effect of green spillover on the dual-channel setting, we compare the performance of the whole system and make the following proposition:

Proposition 4. *The performance of the whole system can be better after spillover if* $0 < c < c_5$.

In short, the spillover effect would not bring Pareto improvement spontaneously due to the "lose-win" outcome for the focal firm and the supplier. However, it can improve the performance of the dual-channel system as a whole when the transaction cost is small. Proposition 4 elevates the significance of engaging in green co-creation for enterprises to a new level. In previous research, the impact of green co-creation on the performance of implementers was a primary focus. However, the influence of value co-creation essentially needs to be cross-functional and interdepartmental to affect all stakeholders [32]. This result also highlights the social significance of green co-creation; that is, it is undertaken for the welfare of the entire system, not just for the implementers.

To better delineate how the strength of spillover and the co-creative environment influence the performance of the different participants in the supply chain, we present Figure 5.

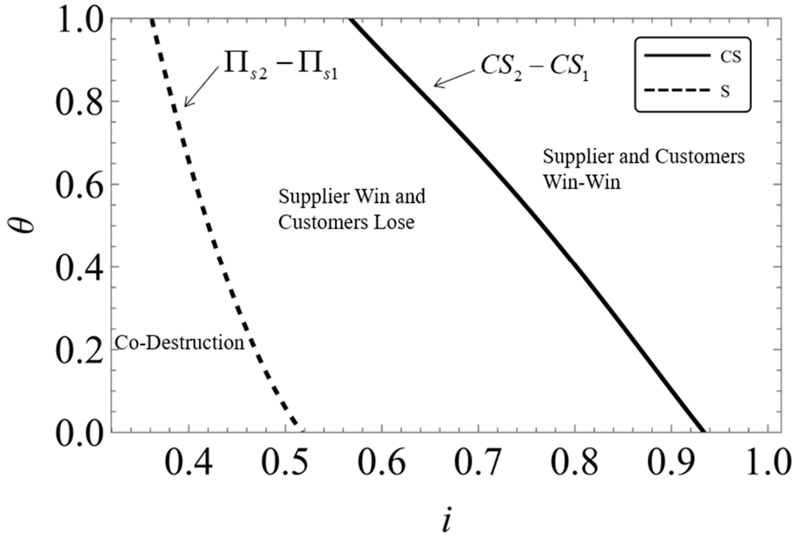

Figure 5. The profitability thresholds of the supplier and customers (a = 1; c = 0).

Figure 5 shows that when both the green channel and the direct channel have strong competitiveness, an unexpected result is obtained:

Corollary 2. *The spillover may bring a co-destruction effect on supply chain members' performance.*

As a result, this study also relates to the study of Daunt and Harris [76], which stated that co-destruction and co-creation can be simultaneously brought by "showrooming" with the offline retailer's efforts from a green supply chain-based view. This not only fills a theoretical gap regarding the spillover effects of green co-creation but also provides insights for managers. Although green co-creation is considered to enhance a firm's competitiveness [3,77], it can create a disadvantageous situation for members of the supply chain in environments with competitive upstream players due to its susceptibility to spillover effects. In practice, to maximize the benefits and minimize the drawbacks of green co-creation, it is essential to implement governance measures that reduce instances of co-destruction.

3.3.4. The Revenue-Sharing Contract

Building on prior findings (Propositions 3 and 4), while the downstream firm always experiences losses due to spillover effects, these effects can also benefit suppliers and customers, and they may even enhance the entire supply chain's performance. Traditionally, policymakers have focused on intellectual property protection to prevent potential co-destruction and safeguard investors in green co-creation. This raises a longstanding debate in patent law: does it facilitate or impede the spread of technological benefits? [78]. This question is especially relevant in the sustainability sector, where it is essential for sustainable technologies to be effectively transferred to places where they can be fully utilized. One type of market failure is characterized by the presence of demand for green products, yet firms may hesitate to invest due to concerns about not recouping costs or achieving sufficient profits [58]. From this scenario, two distinct perspectives emerge: One side argues that intellectual property or patent protection protects the interests of green technology's inventors, thereby promoting the development of green technologies. Conversely, some critics contend that if green technologies are not shared, they fail to fulfill their role in fostering sustainable development.

However, within the context of our research, it was found that legally preventing spillover effects directly would result in a reduction in the overall welfare of the system, for this approach only shields the investing firm and overlooks the positive aspects of spillover. To ensure that all supply chain members benefit from green co-creation spillover, according to our observations (see Figure 6), a revenue-sharing contract can be proposed.

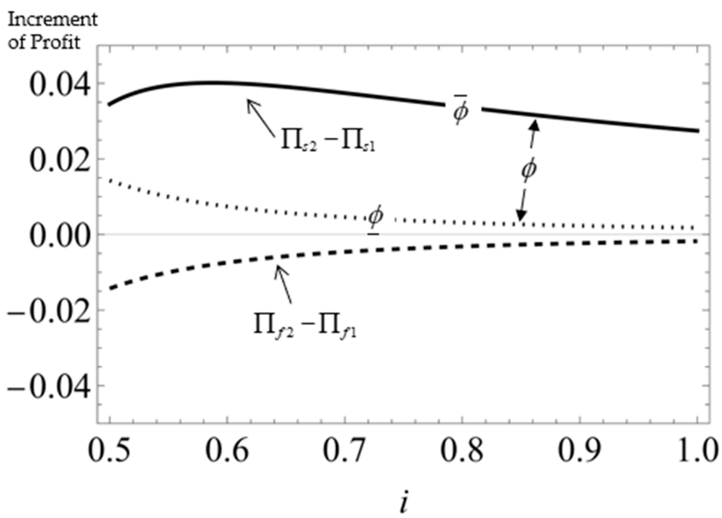

Figure 6. The profitability thresholds of the supplier and customers (a = 1; c = 0.01; $\theta = 0.5$).

Proposition 5. *When the supplier agrees to a revenue-sharing contract with the sharing parameter of* $\underline{\phi} < \phi < \overline{\phi}$*, the Pareto improvement occurs.*

The revenue-sharing contract leads the supplier to share extra revenue generated from green co-creation spillover with the focal firm to compensate for the losses, but it does not change the optimal decisions for all parties. Consequently, by redistributing profits between the free-riding supplier and the co-creating focal firm, the contract ensures that no participant is disadvantaged by spillover, ultimately leveraging the spillover effect on overall supply chain performance.

4. Discussion and Conclusions

The key findings and managerial insights of this study are summarized below. First, the spillover inhibits the investment in green co-creation by the downstream focal firm but encourages consumers to invest more when the direct channel has advantages. In addition, the focal firm reduces its investment not only because the spillover will benefit the direct channel competitor at no cost but also because the upstream supplier will use its pricing power to manipulate the focal firm for its own interests.

Second, the emergence of spillover will cause the green channel to suffer losses in both price and sales, while the non-green products in the direct channel will increase in price and sales. It is worth mentioning that we found that the increase in the total investment efforts will only occur when the spillover coefficient is significant, and the benefits brought by the increase in investment will flow more to the direct channel due to the spillover effect, which, in turn, intensifies the imbalance between the two channels.

Third, the existence of the spillover can improve the performance of the supplier, consumers, and even the entire supply chain system at the expense of the downstream firm's performance. In addition, it must be noted that the spillover may incur co-destruction, which is mainly caused by over-competition between two channels. Therefore, even when knowledge spillover exists, green co-creation can be a valuable strategy for firms that integrate both upstream and downstream operations in their supply chain. In these cases, an acceptable loss in the downstream business (where the competitor might benefit from spillover) can be outweighed by the overall benefit for the entire integrated supply chain.

Fourth, implementing a revenue-sharing contract can significantly mitigate the negative impacts of spillover from green co-creation. This approach allows the supplier to share a portion of the additional profits generated by the spillover with the downstream focal firm, compensating for its losses. This creates a Pareto improvement, where all supply chain members benefit from the positive aspects of green co-creation spillover.

4.1. Theoretical Implications for the Literature

This study makes two main theoretical contributions to the literature: First, although green co-creation has become a hot topic in corporate green strategy research in recent years, few studies have been conducted in the supply chain context, which is more aligned with the characteristics of value co-creation and involves both upstream and downstream stakeholders. This research helps fill that gap, especially by introducing green co-creation within competitive dual-channel supply chain structures involving upstream and downstream firms. Second, while there is no consensus in academia on the spillover effects of green investments, this study investigates the spillover effects of green co-creation, jointly invested by consumers and businesses, and uncovers its varied impacts on different stakeholders within the supply chain under various circumstances.

4.2. Managerial Implications for Practice

From a management perspective, the analysis in this study reveals several important insights for businesses operating in competitive environments, particularly those pursuing green strategies in the retail and manufacturing sectors. We have found that green co-creation, when accompanied by spillovers, is not a "cure-all". Instead, it can act as a double-edged sword. On the one hand, spillovers allow the green efforts derived from co-creation to enhance the overall welfare of the system, aligning with the social effects of green strategies. On the other hand, the presence of spillovers can impair the performance of investing firms, necessitating governance measures that leverage the benefits of spillovers while mitigating their negative impacts. Our findings indicate that traditional legal measures to prevent spillovers might eliminate the negative effects of green co-creation spillover but also block its positive contributions. Therefore, we suggest adopting contractual governance mechanisms, such as revenue-sharing agreements, to create win–win situations. The example of NIO and Jianghuai Automobile that we mentioned in this article serves as an excellent illustration. After engaging in an extended and in-depth collaboration, they did not rely on patents to prevent potential knowledge leaks. Instead, they established two EV manufacturing facilities through a joint venture in 2018 and 2022, known as the F1 and F2 plants, respectively.

4.3. Limitations and Future Research

This study could also be extended in the following directions in the future: First, this study views green co-creation as a universal effect. According to current empirical research, value co-creation may affect various aspects of the performance of the implementers (e.g., marketing, innovation, and so on). Thus, it may be interesting to characterize the types of green co-creation spillover in future research. Second, as the multichannel strategy is now implemented by online platforms such as Amazon, Taobao, and JD.com, green co-creation in the context of such platforms is a noteworthy topic.

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Appendix A

Appendix A.1. The Equilibrium of Model N

With the sequence given and backward induction applied, the supplier needs to decide on the sale of the original product on the direct channel (q_{s1}) to maximize its profit when acknowledging the sale on the traditional channel (q_{f1}). Thus, the problem of the supplier is as follows:

$$\max_{q_{s1}} \Pi_{s1} = w_1 q_{f1} + (a - q_{f1} - q_{s1} - c) q_{s1} \tag{A1}$$

Performing the optimization in Equation (A1), the optimal output of the supplier is as follows:

$$q_{s1}(q_{f1}) = \frac{1}{2}\left(a - c - q_{f1}\right) \tag{A2}$$

Substituting Equation (A2) into the profit function of the firm, $\Pi_{f1} = \left(\left(a - q_{f1} - q_{s1} + V_{c1} + V_{f1}\right) - w\right)q_{f1} - iV_{f1}^2$, yields

$$q_{f1}(w_1;V) = \frac{1}{2}\left(a + c + 2V_{c1} + 2V_{f1} - 2w_1\right) \quad \text{(A3)}$$

Substituting Equation (A2) and Equation (A3) back to Equation (A1), and then solving its first-order condition, we obtain

$$w_1(V) = \frac{1}{6}\left(3a - c + 2V_{c1} + 2V_{f1}\right) \quad \text{(A4)}$$

In the end, referring to the optimal value co-creation effort, both the firm and customers need to make decisions about their investment level considering their own benefits. For consumers, the profit is denoted by consumer surplus; that is, $CS_1 = \frac{1}{2}\left(q_{f1} + q_{s1}\right)^2 - iV_{c1}^2$. After substituting the optimal quantity of the supplier, firm, and wholesale price from Equations (A2)–(A4) into the expression of Π_{f1} and CS_1, performing the first-order condition, and solving them simultaneously, we have

$$V_{c1}^* = \frac{2a - 2c - 9ai + 3ci}{6i(5 - 18i)} \text{and } V_{f1}^* = \frac{a - c + 12ci}{3i(18i - 5)} \quad \text{(A5)}$$

The remaining equilibrium solutions are easy to obtain (see Table 3 in the main text).

Appendix A.2. The Equilibrium of Model S

Model S has the same decision timing as Model N. Thus, by utilizing backward induction, we can solve the following problem of the supplier:

$$\max_{q_{s2}} \Pi_{s2} = wq_{f2} + \left(a - q_{f2} - q_{s2} + \theta(V_{c2} + V_{f2}) - c\right)q_{s2} \quad \text{(A6)}$$

The optimal output of the direct sale channel is obtained by performing the first-order condition of q_{s2} as follows:

$$q_{s2}(q_{f2};V) = \frac{1}{2}\left(a - c + V_{c2}\theta + V_{f2}\theta - q_{f2}\right) \quad \text{(A7)}$$

Substituting Equation (A7) into the firm's profit function, $\Pi_{f2} = \left(\left(a - q_{f2} - q_{s2} + V_{c2} + V_{f2}\right) - w_2\right)q_{f2} - iV_{f2}^2$, we obtain

$$q_{f2}(w_2;V) = \frac{1}{2}\left(a + c + 2V_{c2} + 2V_{f2} - 2w_2 - V_{c2}\theta - V_{f2}\theta\right) \quad \text{(A8)}$$

Correspondingly, to obtain the optimal wholesale price sold to the firm, we can substitute Equations (A7) and (A8) into the expression of Π_{s2} and perform the optimization:

$$w_2(V) = \frac{1}{6}\left(3a - c + 2V_{c2} + 2V_{f2} + V_{c2}\theta + V_{f2}\theta\right) \quad \text{(A9)}$$

Hence, the expression of consumer surplus is $CS_2 = \frac{1}{2}\left(q_{f2} + q_{s2}\right)^2 - iV_{c2}^2$. Substituting Equations (A7)–(A9) into the expression of the firm's profit and consumer surplus and then simultaneously solving the results of the first-order conditions of V_c and V_f, we now have

$$\begin{aligned} V_{c2}^* &= \frac{4a-4c-18ai+6ci-6a\theta+2c\theta-9ai\theta+3ci\theta+2c\theta^2+2a\theta^3}{3i(20-72i-28\theta+17\theta^2)} \\ V_{f2}^* &= \frac{2\left(2a-2c+24ci-3a\theta+c\theta-24ci\theta+c\theta^2+a\theta^3\right)}{3i(-20+72i+28\theta-17\theta^2)} \end{aligned} \quad \text{(A10)}$$

The rest of the equilibrium solutions of Model S can be easily obtained by substituting Equation (A10) and are listed in Table 3.

Appendix A.3. The Feasible Range

To ensure the profitability of dual channels with or without the spillover effect of value co-creation, the investment parameter of value co-creation and the spillover rate, along with the transaction cost, need to meet the following condition:

$$\{\frac{1}{3} < i < 1 \text{ and } 0 < c \leq \frac{3ai - a}{5i - 1} = c_1 \text{ and } 0 < \theta \leq 1\}$$

1. Proof of Proposition 1

To compare the co-creation efforts invested by the firm and customers, we have

$$V_{c2} - V_{c1} = \frac{\theta\left(-3c(12 - 18\theta + i(-14 + 36i + 41\theta)) + a\left(-4 + 324i^2 - 34\theta + 20\theta^2 - 9i(14 + \theta(-17 + 8\theta))\right)\right)}{6i(-5 + 18i)(-20 + 72i + (28 - 17\theta)\theta)} \tag{A11}$$

$$V_{f2} - V_{f1} = \frac{\theta\left(-3c(-6 + 4i(5 + 72i - 20\theta) + 9\theta) + a\left(2 + (17 - 10\theta)\theta + 36i\left(-3 + \theta^2\right)\right)\right)}{3i(-5 + 18i)(-20 + 72i + (28 - 17\theta)\theta)} \tag{A12}$$

We find that Expression (A11) would be negative if

$$\{\frac{1}{3} < i \leq \frac{1}{36}\left(7 + \sqrt{65}\right) \;\&\; 0 < c \leq c_1 \;\&\; 0 < \theta < \theta_1\} \cup \{\frac{1}{36}\left(7 + \sqrt{65}\right) < i < \frac{1}{2} \;\&\; \frac{-2a - 63ai + 162ai^2}{18 - 21i + 54i^2} < c \leq c_1 \;\&\; 0 < \theta < \theta_1\}$$

We also know that

$$\theta_1 = \frac{-34a+54c+153ai-123ci}{8a(-5+18i)} - \frac{3}{8}\sqrt{\frac{164a^2-88ac+324c^2-164a^2i+1240aci-1476c^2i-4311a^2i^2-1878aci^2+1681c^2i^2+10368a^2i^3-3456aci^3}{a^2(-5+18i)^2}}$$

On the firm's side, the result of Expression (A12) is always negative within the feasible interval.

When comparing the wholesale price with and without the spillover effect, there is

$$w_2 - w_1 = \frac{\theta(6a(-4 + \theta) + 9ai(4 + \theta) - c(16 - 34\theta + i(60 + 51\theta)))}{(-5 + 18i)(-20 + 72i + (28 - 17\theta)\theta)} \tag{A13}$$

The result of Expression (A13) would be negative if

$$\{\tfrac{1}{3} < i \leq \tfrac{2}{5} \;\&\; 0 < c \leq c_1 \;\&\&\; 0 < \theta < 1\} \cup \{\tfrac{2}{5} < i \leq \tfrac{2}{3} \& \{0 < c < \tfrac{15ai-6a}{37i-6} \;\&\; 0 < \theta < \theta_2\} \cup$$
$$\{\tfrac{2}{5} < i \leq \tfrac{2}{3} \;\&\; \tfrac{15ai-6a}{37i-6} \leq c \leq c_1 \;\&\; 0 < \theta < 1\}\} \cup \{\tfrac{2}{3} < i < 1 \;\&\; \{\tfrac{9ai-6a}{4+15i} < c < \tfrac{15ai-6a}{37i-6} \;\&\; 0 < \theta < \theta_2\} \cup$$
$$\{\tfrac{15ai-6a}{37i-6} \leq c \leq c_1 \;\&\&\; 0 < \theta < 1\}\}$$

However, it is easy to find that when $\frac{1}{3} < i < 1$, $\frac{9ai-6a}{4+15i} < c < c_1$ and $0 < \theta < \theta_2$ satisfy the aforementioned condition.

2. Proof of Proposition 2

Analogous to the proof of Proposition 1, we can subtract the sale price of the supplier and that of the downstream firm between Model N and Model S, giving us

$$P_{s2} - P_{s1} = \frac{3\theta(c(-18 + i(104 - 85\theta) + 17\theta) + a(-2 - 7\theta + 3i(8 + 5\theta)))}{(18i - 5)(-20 + 72i + (28 - 17\theta)\theta)} \tag{A14}$$

$$P_{f2} - P_{f1} = \frac{3\theta(a(-22 - 6i(-2 + \theta) + 13\theta) + c(2 + 17\theta + 2i(-82 + 17\theta)))}{2(-5 + 18i)(-20 + 72i + (28 - 17\theta)\theta)} \tag{A15}$$

When $\{\frac{1}{3} < i < 1$ and $0 < c \le \frac{3ai-a}{5i-1} = c_1$ and $0 < \theta \le 1\}$, $P_{s2} - P_{s1} > 0$ always holds, while Expression (A15) is negative.

3. Proof of Corollary 1

As for the comparison of total investment, the difference is as follows:

$$V_{c2} + V_{f2} - (V_{c1} + V_{f1}) = \frac{\theta(3a(-38 + 36i + 17\theta) + c(-26 - 612i + 119\theta))}{2(-5 + 18i)(-20 + 72i + 28\theta - 17\theta^2)} \tag{A16}$$

To keep Expression (A16) positive, it needs to fit $\{\frac{7}{12} < i < 1$ and $0 < c < c_2 = \frac{36ai-21a}{204i-31}$ and $\frac{114a+26c-108ai+612ci}{51a+119c} = \theta_3 < \theta < 1\}$.

4. Proof of Proposition 3

The profit of the firm can be expressed as follows:

$$\begin{aligned}
&\Pi_{f2} - \Pi_{f1} = \frac{1}{18(5-18i)^2 i(-20+72i+(28-17\theta)\theta)^2}\theta(-16(-5+18i)(a+c(-1+12i))\\
&(a(2+27i(-1+6i)) + 3c(6+i(-77+270i))) - 4(3a^2(-94+3i(217+36i(-14+27i)))\\
&+2ac(682+27i(-371+12i(134+9i(-23+24i)))) - 9c^2(98+i(-2549+4i(5302+27i(-589+432i)))))\theta+\\
&8(a^2(-338+36i(56+81(-1+i)i)) + 3ac(242-3i(1181+108i(-37+13i))) + 9c^2(-32+i(927+16i(-481+1179i))))\theta^2+\\
&(3c^2(126+i(-5011+24(1987-5202i)i)) + a^2(1778+27i(-383+48i(7+9i)))+\\
&2ac(-778+9i(1753+36i(-211+192i))))\theta^3 - 16ac(5-18i)^2\theta^4 - 8a^2(5-18i)^2\theta^5)
\end{aligned} \tag{A17}$$

Meanwhile, the profit of the supplier and customer surplus are as follows:

$$\begin{aligned}
&\Pi_{s2} - \Pi_{s1} = \theta(8(-5+18i)(c^2(-116+9(139-498i)i) + 2ac(46+9i(-43+18i)) + 3a^2(8+9i(-11+18i)))\\
&+4(9a^2(-7+18i)(-1+18i(1+3i)) + 6ac(479-27i(183-494i+432i^2)) + c^2(-2237+54i(463+9i(-213+238i))))\\
&\theta + 8(833c^2(1+9i(-1+3i)) + 27a^2(4+i(-5+9i)) - 9ac(149+2i(-584+837i)))\theta^2 + (578ac(7+27i(-2+3i))\\
&-2023c^2(1+9i(-1+3i)) + a^2(-723-729i(-5+9i)))\theta^3)
\end{aligned} \tag{A18}$$

and

$$\begin{aligned}
&CS_2 - CS_1 = \frac{1}{36(5-18i)^2 i(-20+72i+(28-17\theta)\theta)^2}\theta(16(-5+18i)(c(2-3i) + a(-2+9i))\\
&(a(2+9i(-17+18i)) - 3c(-6+i(55+162i))) + 4(3a^2(188+3i(556+243i(-17+12i(1+i))))+\\
&9c^2(196+i(-3228+i(10229+972i(-13+11i)))) - 2ac(1364+27i(-632+i(2645+108i(-41+51i)))))\\
&\theta - 8(a^2(676+9i(-88+9i(-97+18i))) + 6ac(-242+3i(1061+3i(-1163+378i)))\\
&-9c^2(-64+i(1174+i(-2999+1926i))))\theta^2 + (3c^2(252+i(-7132+3(6649-5202i)i))\\
&+a^2(3556-27i(596+9i(-35+6i))) + 2ac(-1556+27i(1112+i(-4945+4914i))))\\
&\theta^3 - 32ac(5-18i)^2\theta^4 - 16a^2(5-18i)^2\theta^5)
\end{aligned} \tag{A19}$$

As a result, it is easy to obtain Figures 3 and 4. It should be noted that our setting in this rectangular coordinate system needs to satisfy

$$\{0 < \theta < 1 \text{ and } \frac{1}{3} < i < 1 \text{ and } 0 < c < \frac{-2a + 6ai + 3a\theta - a\theta^2}{-2 + 10i + \theta}\}.$$

5. Proof of Proposition 4

The difference in the whole system's profit can be expressed as Expression (A20):

$$\begin{aligned}
&\Pi_{f2} + \Pi_{s2} + CS_2 - (\Pi_{f1} + \Pi_{s1} + CS_1) = \frac{1}{36(5-18i)^2 i(-20+72i+(28-17\theta)\theta)^2}\theta(9c^2(-16(-5+18i)\\
&(-8+i(374+i(-3245+10962i))) + 4(392+i(-17274+i(152653+108i(-5129+5247i))))\theta+\\
&8(-128+i(6360+i(-48379+129618i)))\theta^2 + (168+i(-13810+(111269-306918i)i))\theta^3)\\
&+2ac(-16(-5+18i)(32+9i(-122+3i(265+54i))) - 4(2728+27i(-3290+i(25625+108i(-581+531i))))\theta-\\
&24(-484+3i(4924+3i(-9503+10890i)))\theta^2 + (-3112+27i(4978+i(-30817+40734i)))\theta^3 - 32(5-18i)^2\theta^4)\\
&+a^2(640+144i(-466+9i(635+2268(-1+i)i)) + 4512\theta + 36i(374+9i(-923+108i(-1+39i)))\theta\\
&+8(-1352+9i(968+9i(-35+162i)))\theta^2 + (7112-27i(2326-5847i+7938i^2))\theta^3 - 32(5-18i)^2\theta^5))
\end{aligned} \tag{A20}$$

The profit of the whole system will increase when $c \in (0, c_5)$, as shown in Figure A1.

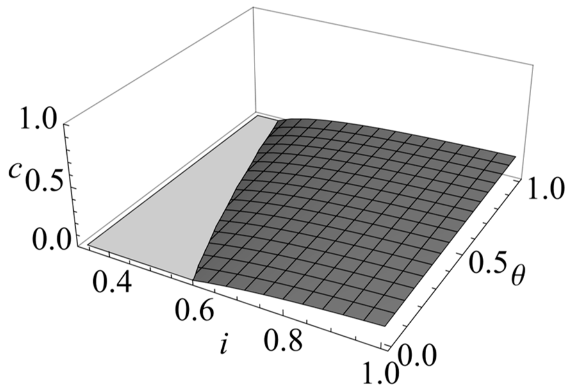

Figure A1. The difference in the whole system's profit between Models N and S (a = 1).

6. Proof of Proposition 5

In order to demonstrate the feasible range for the revenue-sharing contract between the focal company and the upstream supplier, it is necessary to solve for the difference in their profits before and after the spillover occurs. For visualization purposes, values of $a = 1$ and $\theta = 0.5$ are assigned to each for calculation, yielding the following results:

$$\Delta\prod_f = \frac{\begin{array}{l}243i(127+8i(-103+234i))-2112+2c(862+9i(-1745+36i(511+72i(-55+144i))))\\+3c^2(546+i(-26317+72i(5711+18i(-1969+4032i))))\end{array}}{-18(41-288i)^2(5-18i)^2 i}$$

$$\Delta\prod_s = \frac{\begin{array}{l}9(11493+(1812-26185c)c)i-5667-866c+12633c^2\\+4131(-123+c(22+369c))i^2-46656(-15+c(16+71c))i^3\end{array}}{(41-288i)^2(5-18i)^2}$$

Simultaneously, the symmetrical image of the focal company's profits is depicted relative to the X-axis. The purpose of this step is to compare the differences in the absolute values of the profits between the focal company and upstream enterprises, making Figure 6 easy to obtain.

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