systems

Article

Green Independent Innovation or Green Imitation Innovation? Supply Chain Decision-Making in the Operation Stage of Construction and Demolition Waste Recycling Public-Private Partnership Projects

Chuyue Zhou, Jinrong He, Yuejia Li, Weihong Chen, Yu Zhang, Hao Zhang, Shiqi Xu and Xingwei Li *

College of Architecture and Urban-Rural Planning, Sichuan Agricultural University, Chengdu 611830, China
* Correspondence: xwl@sicau.edu.cn

Abstract: Inefficiencies in the construction and demolition waste (CDW) recycling supply chain constrain green innovation in the construction industry. However, existing studies have not analyzed the innovation behavior of recyclers in CDW recycling public-private partnership (PPP) projects from the perspective of innovation diffusion theory. To reveal the mechanism of recyclers' innovation behavior in CDW recycling PPP projects in which recyclers and remanufacturers jointly participate in the operation stage, this study uses a Stackelberg game to analyze the optimal innovation strategy choice and total profit of the CDW recycling supply chain among the two innovation paths of green independent innovation and green imitation innovation under the combined effects of technology spillover, consumer green sensitivity, and government price subsidies to consumers. The main conclusions are as follows. (1) Remanufacturers and recyclers can improve their own innovation level and profit through technology spillover. (2) The total profit of the CDW recycling supply chain changes dynamically with the level of spillover. (3) The government price subsidy to consumers does not always improve the total profit of the CDW recycling supply chain. (4) The effect of consumers' green sensitivity on the total profit of the CDW recycling supply chain shows heterogeneity with the innovation path of recyclers and the level of technological spillover. This study not only enriches the theoretical study of the green supply chain but also provides a basis for decision-making for recyclers and governments in practice.

Keywords: construction and demolition waste; public-private partnership; innovation diffusion theory; Stackelberg game; spillover effect; supply chain management

check for updates

Citation: Zhou, C.; He, J.; Li, Y.; Chen, W.; Zhang, Y.; Zhang, H.; Xu, S.; Li, X. Green Independent Innovation or Green Imitation Innovation? Supply Chain Decision-Making in the Operation Stage of Construction and Demolition Waste Recycling Public-Private Partnership Projects. *Systems* **2023**, *11*, 94. https://doi.org/10.3390/systems11020094

Academic Editor: William T. Scherer

Received: 16 January 2023
Revised: 1 February 2023
Accepted: 7 February 2023
Published: 9 February 2023

1. Introduction

As an important part of the green economy standard system, the construction industry affects the sustainable development of the economy [1]. However, with the improvement in global economic development and the acceleration of urbanization, frequent construction, renovation, and demolition activities have led to a sharp increase in the amount of construction and demolition waste (CDW). The total amount of CDW generated globally exceeds 100 billion tons per year [2], and the production of large amounts of CDW has caused serious environmental pollution and led to an increasingly prominent contradiction between the social economy and the ecological environment [3].

Some countries, such as Germany, Belgium, and the Netherlands, have recycling rates of more than 90% of CDW [4]. In contrast, in China, the country with the largest amount of CDW generation [5], the situation of CDW recycling is not optimistic [6]. How to effectively manage CDW has become the focus of many scholars. At present, there are two main ways to address CDW: landfill and recycling [7]. Compared with landfill treatment, CDW recycling can improve the utilization rate of renewable resources and save limited landfill space [8,9]. The disposal of CDW recycling follows the green growth model and helps to maintain the value of materials and resources in the economy for as long as possible [10]. However, whether companies choose to participate in CDW resource treatment is related to the economic viability of the project [11]. At present, CDW recycling technology is not mature enough, and CDW recycling requires a large investment and a long payback period, so people prefer to choose landfill disposal [6]. At the same time, the government will individually face large financial pressure to invest in CDW recycling projects [12]. Public-private partnerships (PPPs), as a mode of cooperation between the government and private enterprises, mobilize a combination of public and private resources to achieve specific goals [13]. The use of PPPs for infrastructure development is an effective way to reduce the associated costs and risks, promote technological innovation in enterprises [14], and reduce budget deficits [15]. PPPs are now widely used in infrastructure development and public services, such as water pollution, roads, and environmental protection [16–18]. Therefore, the application of the public-private partnership (PPP) project model in CDW recycling projects can give full play to its advantages of risk sharing and benefit sharing and solve the difficulties faced by the government or enterprises in dealing with CDW alone.

Green technology innovation is an effective way to solve environmental pollution and can balance the contradiction between economic growth and the ecological environment [19,20]. On the one hand, green technology innovation can influence economic growth through innovation diffusion [21]. On the other hand, the technology spillover effect is a specific form of innovation diffusion. Therefore, strengthening relevant technological innovation in the field of CDW recycling is an important way to alleviate the environmental pressure caused by CDW. In the process of CDW recycling, recyclers use the recyclable part of CDW as raw materials for remanufacturers, and recyclers and remanufacturers form a closely cooperative supply chain through material and information flows [22]. In the supply chain of CDW recycling, upstream and downstream enterprises can take advantage of the technology spillover caused by the diffusion and application of green innovation technology in the supply chain to obtain heterogeneous innovation technology, thus enhancing the green technology innovation capability [23]. Both imitation innovation and independent innovation strategies can promote technology upgrading [24]. Green independent innovation is difficult, costly, and has a low success rate but a high return on innovation. The opposite is true for green imitation innovation [25]. However, research and development of green innovation products requires significant capital investment, resulting in higher pricing for the sale of green products [26]. Consumers, as the buyers of green products, are the last link in the green supply chain. Therefore, consumers' attitudes toward green products cannot be ignored. Consumers' perceptions and preferences of green products influence their consumption behavior and market demand [27], and although the vast majority of consumers express their willingness to support green consumption behavior [28], the premium price of green products still makes consumers hesitant [29]. Therefore, consumers' perceptions and preferences for green products will influence the motivation of enterprises related to the CDW recycling supply chain to participate in green innovation. In addition, government policies are important drivers for enterprises to participate in green innovation [30] and will stimulate consumers to voluntarily pay extra for green products [31]. Many studies have identified government subsidies as an influencing factor in the CDW recycling process, which is crucial to promote CDW recycling and stakeholder decision-making [32–34]. Particularly, in PPP projects, appropriate government subsidies play a positive role in motivating recyclers to participate in CDW recycling PPP projects [35]. Therefore, it is the responsibility of the government to try to achieve the maximum benefits of PPP projects [35]. In summary, consumers' incentive to purchase green products and promote green innovation in CDW recycling PPP projects can be increased by subsidizing consumer prices.

Unfortunately, existing studies have not yet analyzed the innovation behavior of recyclers in CDW recycling PPP projects from the perspective of innovation diffusion theory. Then, this study will attempt to fill this gap. The purpose of this paper is to reveal the mechanism of the role of the technology spillover effect, consumer green sensitivity, and government subsidies on the innovation behavior of recyclers in CDW recycling PPP projects through the perspective of innovation diffusion theory. How does the technology spillover between recyclers and remanufacturers affect the level of innovation and profits of both parties in a CDW recycling PPP project? How does the total profit of the CDW recycling supply chain vary with the level of technology spillover when recyclers choose different innovation paths? How does the government price subsidy to consumers affect the total profit of the CDW recycling supply chain? When recyclers choose different innovation paths and the technology spillover is at different levels, how does the green sensitivity of consumers affect the total profit of the CDW recycling supply chain? To address the above scientific questions, the main elements of the study are as follows. First, in the context of innovation diffusion, this study constructs a Stackelberg game model in which the remanufacturer leads and the recycler follows and in which the technology spillover effect among game players, the consumers' green sensitivity, and the government price subsidy to consumers are considered simultaneously. Second, through propositional calculations, the impact of the technology spillover effect on the innovation level of the recycler and remanufacturer and the total profit of the CDW recycling supply chain is revealed. Third, MATLAB is used to simulate the changes in the total profits of the CDW recycling supply chain under different levels of technology spillover, consumer green sensitivity, and government price subsidies to consumers. Finally, research conclusions are drawn, and corresponding management implications are proposed.

On the one hand, this study introduces innovation diffusion theory into the research of the CDW recycling supply chain, which not only enriches the relevant research in the field of green supply chain management but also provides a theoretical basis for other countries or regions to promote green innovation in CDW recycling; on the other hand, this study provides an idea of choosing the optimal green innovation strategy for recyclers in CDW recycling PPP projects in different contexts and the decision-making for the government to formulate a reasonable price subsidy for CDW recycling PPP projects.

The rest of the paper is structured as follows. Section 2 is the related literature review. Section 3 constructs the Stackelberg game model between recyclers and remanufacturers. Section 4 analyses the impact of the technology spillover level on the innovation level, profit, and total profit of CDW recycling through proposition calculation. Section 5 carries out numerical simulations on relevant factors to explore the trend of the total profit of the CDW recycling supply chain under different values of the technology spillover level, consumer green sensitivity, and government price subsidies to consumers. Section 6 draws conclusions and proposes corresponding management recommendations.

2. Literature Review

This section reviews the relevant literature in terms of both innovation diffusion theory and supply chain decision-making in CDW recycling PPP projects (Table 1).

Table 1. Research on supply chain decision-making related to innovation diffusion theory and CDW recycling PPP projects.

Research Topics	Dimensions	Source Papers
Innovation diffusion theory	Basic concepts of innovation diffusion	[36,37]
	The relationship between innovation diffusion and technology spillover	[38–41]
	The relationship between innovation diffusion and innovation or imitation behavior	[42–44]
Supply chain decision-making in CDW recycling PPP project	Government subsidies and consumer environmental awareness have an impact on supply chain decision-making in PPP projects for CDW recycling	[45–50]
	Technology spillover effect has an impact on supply chain decision-making in CDW recycling PPP projects	[51–53]

2.1. Innovation Diffusion Theory

Innovation diffusion refers to a process in which potential adopters imitate the behavior of adopters [36]. This process has a great impact on the economy [54] and has been widely studied in economics, sociology, ecology, and other disciplines [37].

Innovation diffusion is closely related to technology spillover. First, technology spillover is included in the process of innovation diffusion. The innovation diffusion phenomenon consists of two subprocesses, namely, the spillover effect of technological innovation [38] and the diffusion of technology spillover along the industrial chain [39]. Second, the innovation diffusion effect can be reflected by measuring the spillover effect of research and development (R&D) activities [40]. Finally, innovation diffusion theory can explain the related problems of the spillover effect. For example, Nie et al. [41] explored the impact of knowledge spillover channels on the green innovation activities of enterprises based on innovation diffusion theory. In summary, the level of technology spillover can reflect the degree of innovation diffusion, which provides an opportunity to study the impact of technology spillover on enterprise innovation behavior in the process of innovation diffusion.

Innovation diffusion and innovation or imitation behavior are closely linked. On the one hand, enterprise innovation or imitation behavior affects innovation diffusion. For example, Nikolaeva et al. [42] have shown that the organization's cognitive framework for imitation decision-making affects the speed of innovation diffusion. On the other hand, innovation diffusion affects enterprises' independent innovation or imitation behavior, as Collins et al. [43] show that technology diffusion can facilitate the transition from imitative to independent innovation in developing countries. However, the existence of innovation diffusion may lead to an increase in the profits of enterprises that imitate innovation, while the profits of enterprises with successful independent innovation decrease, thus adversely affecting the first innovators [44].

Existing research has explained the relationship between innovation diffusion, technology spillover, and enterprise innovation behavior. Unfortunately, the above three elements have not been considered simultaneously in the relevant research on the CDW recycling supply chain. Therefore, in the process of considering the cooperative operation of PPP projects between CDW recyclers and remanufacturers, this study uses innovation diffusion theory to analyze the impact of technology spillovers on the innovation behavior of recyclers.

2.2. Supply Chain Decision-Making in CDW Recycling PPP Projects

2.2.1. Government Subsidies and Consumer Awareness of Environmental Protection

Technological innovation, as an important intangible resource in CDW recycling units, plays a crucial role in improving the CDW recycling rate [34]. In CDW recycling PPP projects, recyclers, and remanufacturers are the main operators of the projects, and their green innovation behaviors are supported by the government [55]. Government intervention is crucial to address the market imperfections, free-rider problems, and spillover effects faced by enterprises' green technology innovation [45]. As one of the ways of government intervention in enterprises' green behavior [46], green product subsidies not only give consumers a price advantage in purchasing green products and stimulate consumers' green consumption demand [47] but also promote consumers' environmental awareness and green consumption concepts [48]. The significant increase in consumers' environmental awareness helps stimulate increasing green demand in the market [49], which in turn motivates enterprises to strive to improve the innovative performance of green products to meet market demand [50]. Therefore, the combined effect of government subsidies and consumer environmental awareness on enterprises' green technology innovation decisions cannot be ignored.

2.2.2. Technology Spillover Effect

In addition, technology spillover effects can influence enterprises' green technology innovation decisions. Spillovers from other green innovators in the same industry can promote green innovation [51], but they can also induce imitation [52]. It can be seen that spillover effects play an important role in both types of innovation activities, namely, independent innovation and imitation innovation. Specifically, technology spillovers can reduce R&D costs for imitation innovation compared to independent innovation [52]. However, as the level of spillovers increases, the cost of identifying and imitating existing knowledge increases, and the relationship between spillovers and innovation becomes negative [53]. Therefore, enterprises need to make innovation decisions based on the level of spillover.

Although these studies have shown the important effects of government subsidies, consumer environmental awareness, and technology spillovers on enterprises' green technology innovation decisions, none of them have considered the combined effects of all three from the perspective of the CDW resource-based supply chain. Moreover, although scholars have revealed the influence of government subsidies and consumer environmental awareness on CDW recycling supply chain decisions, the existing studies neither discuss the background of CDW recycling PPP projects nor consider the technology spillover effects between recyclers and remanufacturers in the supply chain and the innovation decisions of CDW recyclers. To the best of our knowledge, this paper considers government subsidies and consumers' environmental awareness and introduces the technology spillover effect into the background of CDW recycling PPP projects for the first time, aiming to bridge the gap in existing studies and reveal the mechanism of CDW recyclers' innovation behavior.

3. Problem Description and Model Assumption

3.1. Problem Description and Model Building

The local government needs to build a new CDW recycling project, which will be implemented through a PPP model, with the participation of a CDW recycler and a remanufacturer. This study focuses on a green supply chain of CDW recycling consisting of a recycler and a remanufacturer by constructing a Stackelberg game model. The recycler recycles the usable part of CDW generated in the production activities of the construction industry at a cost c and sells it to the remanufacturer at a wholesale price ω. The remanufacturer processes the CDW to form green recycled building materials (hereinafter referred to as green products) and sells them to consumers at the selling price p. At this time, the government will subsidize the price of green recycled building materials for the smooth implementation of the CDW recycling PPP project, and the amount of the subsidy is S . The formed game model is shown in Figure 1.

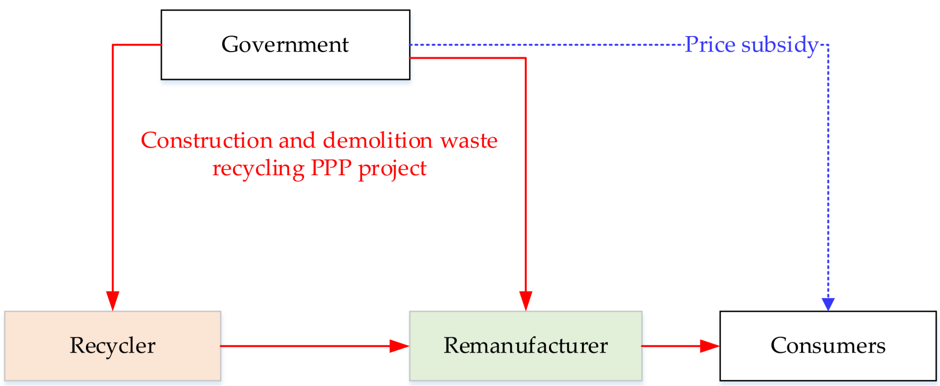

Figure 1. Game model.

3.2. Model Assumptions

(1) Assuming that the final green product meets the demand characteristics of the general product in economics, it is easy to know what the market demand for the green product is $Q = a - p$, where a is the market capacity of the product [56,57].

(2) With the increasing awareness of environmental protection among consumers, they have the characteristic of $\beta(0 < \beta < 1)$ green preference for products and will be more inclined to buy green products with environmental attributes, which indicates the green sensitivity of consumers [58].

(3) In the CDW recycling supply chain, the remanufacturer, as the party closer to the market, is more aware of the green preferences of consumers [59], so it will certainly carry out green independent innovation. The remanufacturers will continue to improve their technology and put forward higher requirements for raw materials, forcing recyclers to carry out green technology. As a follower, the recycler can choose between green independent innovation and green imitation innovation. Among them, green independent innovation is more helpful for the recycler to achieve technological breakthroughs but requires higher costs; green imitation innovation can only meet the technical needs of the recycler when recycling, and the R&D investment is also less [25].

(4) Under the condition of bounded rationality, the performance of the R&D innovation of recyclers is better than that of green imitation innovation. The R&D investment costs of the two green innovation paths are different, and the cost of green independent innovation is greater than the cost of green imitation innovation. Let the R&D investment cost of green independent innovation be $\frac{1}{2}\rho_i\varepsilon_i^2$ and the R&D investment cost of green imitation innovation be $\frac{1}{2}\rho_r{\theta_r}^2$, where $i \in \{m, r\}$, ρ_i and ρ_r are the innovation cost coefficients. To simplify the model, the innovation cost coefficient is assumed to be 1 [60].

(5) Due to the high product-relatedness of enterprises in the same CDW recycling supply chain, remanufacturers and recyclers have certain correlations in terms of technology. Therefore, the innovation behavior of remanufacturers and recyclers often has vertical technology spillover effects [61]. Different innovation paths correspond to different levels of technology spillover. Let $\mu(0 < \mu < 1)$, the spillover coefficient, reflect the degree of innovation diffusion among the CDW recycling supply chains; then, the spillover coefficient under green independent innovation of the recycler and remanufacturer is μ_1, and the spillover coefficient under the green imitation innovation of the recycler is μ_2.

(5) According to the research of Gao Peng et al. [62], the unit cost of remanufacturing will not affect the results, so it is ignored in the model. Relevant participation and specific meanings are shown in Table 2.

Table 2. Symbol Description.

Symbols	Unit	Meaning Description
ε_i	USD/t	The performance of R&D innovation under green independent innovation of remanufacturers and recyclers, $i \in \{m, r\}$
θ_r	USD/t	The performance of R&D innovation under green imitation innovation of recyclers
a	1	The market capacity of the product
c	1	CDW recycling costs
ω	USD/t	The unit wholesale price of CDW provided by recyclers to remanufacturers
p	USD/t	The selling price of green products
s	USD/t	Government's price subsidies for consumers
β	1	Consumer green sensitivity
μ_1	1	Spillover coefficient under green independent innovation
μ_2	1	Spillover coefficient of recyclers under green imitation innovation

3.3. Model Calculation

3.3.1. Recyclers Choose Non-Innovation (RNI)

The profits of remanufacturers and recyclers are shown in (1) and (2), respectively.

$$\pi_m = (p - \omega + \varepsilon_m)(a - (p - s) + \beta\varepsilon_m) - \frac{1}{2}{\varepsilon_m}^2 \tag{1}$$

$$\pi_{\mathrm{r}} = (\omega - c)(a - (p - s) + \beta\varepsilon_m) \tag{2}$$

We solved the optimal p, ω, ε_m, π_m, and π_r in the case that the recycler chooses non-innovative as follows:

$$p = \frac{(1+\beta)(a+s+c\beta) - 2(3a+c+3s)}{(1+\beta)^2 - 8} \tag{3}$$

$$w = \frac{c(1+\beta)^2 - 4(a+c+s)}{(1+\beta)^2 - 8} \tag{4}$$

$$\varepsilon_m = -\frac{(a-c+s)(1+\beta)}{(1+\beta)^2 - 8} \tag{5}$$

$$\pi_m = -\frac{(a-c+s)^2}{2((1+\beta)^2 - 8)} \tag{6}$$

$$\pi_r = \frac{8(a-c+s)^2}{((1+\beta)^2 - 8)^2} \tag{7}$$

3.3.2. Recyclers Choose Green Independent Innovation (RII)

The profits of remanufacturers and recyclers are shown in (8) and (9), respectively.

$$\pi_m = (p - \omega + \varepsilon_m + \mu_1\varepsilon_r)(a - (p - s) + \beta(\varepsilon_m + \varepsilon_r)) - \frac{1}{2}{\varepsilon_m}^2 \tag{8}$$

$$\pi_r = (\omega - c + \varepsilon_r + \mu_1\varepsilon_m)(a - (p - s) + \beta(\varepsilon_m + \varepsilon_r)) - \frac{1}{2}{\varepsilon_r}^2 \tag{9}$$

We solved the optimal p, ω, ε_m, ε_r, π_m, and π_r in the case that the recycler chooses green independent innovation as follows:

$$p = \frac{3a+c+3s - \frac{(1-3\beta+\mu_1)(1+\beta+\mu_1)\left(-a+c-s-\frac{128(a-c+s)}{-16(1+\beta+\mu_1)^2+\left((1+\beta+\mu_1)^2-8\right)^2}\right)}{(1+\beta+\mu_1)^2-8}}{4} \tag{10}$$

$$w = \frac{a+c+s+\frac{16(a-c+s)(-1+\beta+\mu_1)(1+\beta+\mu_1)}{-16(1+\beta+\mu_1)^2+\left((1+\beta+\mu_1)^2-8\right)^2} - \frac{(1+\beta-\mu_1)(1+\beta+\mu_1)\left(a-c+s+\frac{16(a-c+s)(1+\beta+\mu_1)^2}{-16(1+\beta+\mu_1)^2+\left((1+\beta+\mu_1)^2-8\right)^2}\right)}{(1+\beta+\mu_1)^2-8}}{2} \tag{11}$$

$$\varepsilon_m = -\frac{(1+\beta+\mu_1)\left(a-c+s+\frac{16(a-c+s)(1+\beta+\mu_1)^2}{-16(1+\beta+\mu_1)^2+\left((1+\beta+\mu_1)^2-8\right)^2}\right)}{(1+\beta+\mu_1)^2-8} \tag{12}$$

$$\varepsilon_r = \frac{16(a-c+s)(1+\beta+\mu_1)}{-16(1+\beta+\mu_1)^2 + \left((1+\beta+\mu_1)^2 - 8\right)^2} \tag{13}$$

$$\pi_m = -\frac{(a-c+s)^2\left((1+\beta+\mu_1)^2-8\right)^3}{2\left(-16(1+\beta+\mu_1)^2+\left((1+\beta+\mu_1)^2-8\right)^2\right)^2} \tag{14}$$

$$\pi_r = \frac{8(a-c+s)^2}{-16b(1+\beta+\mu_1)^2+\left((1+\beta+\mu_1)^2-8\right)^2} \tag{15}$$

3.3.3. Recyclers Choose Green Imitation Innovation (RIMI)

The profits of remanufacturers and recyclers are shown in (16) and (17), respectively.

$$\pi_m = (p-\omega+\varepsilon_m+\mu_2\theta_r)(a-(p-s)+\beta(\varepsilon_m+\theta_r)) - \frac{1}{2}{\varepsilon_m}^2 \tag{16}$$

$$\pi_r = (\omega-c+\theta_r+\mu_1\varepsilon_m)(a-(p-s)+\beta(\varepsilon_m+\theta_r)) - \frac{1}{2}{\theta_r}^2 \tag{17}$$

We solved the optimal p, ω, ε_m, θ_r, π_m, and π_r in the case that the recycler chooses green imitation innovation as follows:

$$p = \frac{3a+c+3s-\frac{16(a-c+s)(1-3\beta+\mu_2)(1+\beta+\mu_2)}{-16(1+\beta+\mu_2)^2+\left((1+\beta+\mu_1)^2-8\right)^2}+\frac{(1-3\beta+\mu_1)(1+\beta+\mu_1)\left(a-c+s+\frac{16(a-c+s)(1+\beta+\mu_2)^2}{-16(1+\beta+\mu_2)^2+\left((1+\beta+\mu_1)^2-8\right)^2}\right)}{(1+\beta+\mu_1)^2-8}}{4} \tag{18}$$

$$w = \frac{a+c+s+\frac{16(a-c+s)(-1+\beta+\mu_2)(1+\beta+\mu_2)}{-16(1+\beta+\mu_2)^2+\left((1+\beta+\mu_1)^2-8\right)^2}-\frac{(1+\beta-\mu_1)(1+\beta+\mu_1)\left(a-c+s+\frac{16(a-c+s)(1+\beta+\mu_2)^2}{-16(1+\beta+\mu_2)^2+\left((1+\beta+\mu_1)^2-8\right)^2}\right)}{(1+\beta+\mu_1)^2-8}}{2} \tag{19}$$

$$\varepsilon_m = -\frac{(1+\beta+\mu_1)\left(a-c+s+\frac{16(a-c+s)(1+\beta+\mu_2)^2}{-16(1+\beta+\mu_2)^2+\left((1+\beta+\mu_1)^2-8\right)^2}\right)}{(1+\beta+\mu_1)^2-8} \tag{20}$$

$$\theta_r = \frac{16(a-c+s)(1+\beta+\mu_2)}{-16(1+\beta+\mu_2)^2+\left((1+\beta+\mu_1)^2-8\right)^2} \tag{21}$$

$$\pi_m = -\frac{(a-c+s)^2\left((1+\beta+\mu_1)^2-8\right)^3}{2\left(-16(1+\beta+\mu_2)^2+\left((1+\beta+\mu_1)^2-8\right)^2\right)^2} \tag{22}$$

$$\pi_r = \frac{8b(a-c+s)^2}{-16(1+\beta+\mu_2)^2+\left((1+\beta+\mu_1)^2-8\right)^2} \tag{23}$$

4. Model Analysis

Proposition 1. *Impact of the spillover coefficient on the innovation level of the remanufacturer.*

In the RII mode, the level of remanufacturer innovation is positively correlated with μ_1.

In the RIMI mode, when $0 < \mu_1 < 2\sqrt{2}-1-\beta$, the level of remanufacturer innovation is positively correlated with the recycler spillover coefficient at μ_2; when $2\sqrt{2}-1-\beta < \mu_1 < 1$, the level of remanufacturer innovation is negatively correlated with the recycler spillover coefficient at μ_2.

Proposition 1 shows that when the recycler chooses green independent innovation, the innovation level of the remanufacturer will increase with an increase in the spillover coefficient between the remanufacturer and recycler. When the recycler chooses green imitation innovation, if the remanufacturer's spillover coefficient is satisfied $0 < \mu_1 < 2\sqrt{2} - 1 - \beta$, the remanufacturer's innovation level increases first with the increase of the recycler's spillover coefficient μ_2. If the remanufacturer's spillover coefficient exceeds this range, the remanufacturer's innovation level begins to decrease with the increase in the recycler's spillover coefficient μ_2, and the interval length of the decrease is very small. Thus, to a certain extent, regardless of the innovation path chosen by the recycler, the existence of the technology spillover effect is conducive to promoting the innovation level of the remanufacturer in the same construction waste reuse supply chain.

Proposition 2. *Impact of the spillover coefficient on the innovation level of the recycler.*

In the RII mode, the level of innovation of the recycler is positively correlated with the spillover coefficient μ_1.

In the RIMI mode, when $0 < \mu_1 < 2\sqrt{2} - 1 - \beta$, the level of innovation of the recycler is positively correlated with the remanufacturer's spillover coefficient μ_1; when $2\sqrt{2} - 1 - \beta < \mu_1 < 1$, the level of innovation of the recycler is negatively correlated with the remanufacturer's spillover coefficient μ_1.

Proposition 2 shows that when the recycler chooses green independent innovation, the innovation level of the recycler increases with an increase in the spillover coefficient between the remanufacturer and the recycler. When the recycler chooses green imitation innovation, if the remanufacturer's spillover coefficient is satisfied $0 < \mu_1 < 2\sqrt{2} - 1 - \beta$, the recycler's innovation level increases with the increase of the remanufacturer's spillover coefficient μ_1. If the remanufacturer's spillover coefficient exceeds this range, the remanufacturer's innovation level begins to decrease with the increase in the recycler's spillover coefficient μ_1, and the length of the decreasing part is very small. Regardless of which innovation path the recycler chooses, the change rule of the innovation level of the recycler with the spillover coefficient is basically the same as that of the remanufacturer. When the spillover coefficient continues to increase within a certain range, the innovation level of the recycler also increases. This shows that the stronger the technological spillover effect generated by the upstream remanufacturer's innovation in the CDW recycling supply chain, the more technical knowledge the downstream recycler can absorb as a follower, which will be more conducive to improving the innovation level of the recycler.

Proposition 3. *Impact of the spillover coefficient on the profit of the remanufacturer.*

In the RII mode, when $0 < \mu_1 < 2\sqrt{3} - 3 - \beta$, the remanufacturer's profit is positively correlated with μ_1; when $2\sqrt{3} - 3 - \beta < \mu_1 < 1$, the remanufacturer's profit is negatively correlated with μ_1.

In the RIMI model, when $0 < \mu_1 < 1 - \beta$ and $0 < \mu_2 < 1 - \frac{(1+\beta+\mu_1)^2}{4} - \beta$ or $2\sqrt{2} - 1 - \beta < \mu_1 < 1$ are satisfied, the profit of the remanufacturer is positively correlated with μ_2; when $0 < \mu_1 < 1 - \beta$ and$1 - \frac{(1+\beta+\mu_1)^2}{4} - \beta < \mu_2 < 1$ or $1 - \beta < \mu_1 < 2\sqrt{2} - 1 - \beta$ are satisfied, the profit of the remanufacturer is negatively correlated with μ_2.

Proposition 3 shows that when the recycler chooses green independent innovation, the profit of the remanufacturer increases first with an increase in the spillover coefficient between itself and the recycler μ_1 and starts to decrease after reaching $2\sqrt{3} - 3 - \beta$. In the case that the recycler chooses green imitation innovation, the profit of the remanufacturer changes with the spillover coefficient of the recycler μ_2 in a more complex way. However, regardless of which innovation path is chosen by the recycler, the existence of the spillover effect makes it difficult for the remanufacturer to achieve a profit increase. However, compared with green imitation innovation, recyclers are more conducive to improving their own profits when carrying out green independent innovation.

Proposition 4. *The impact of the spillover coefficient on the profit of the recycler.*

In the RII mode, the recycler's profits are positively correlated with μ_1.

In RIMI mode, when $0 < \mu_1 < 2\sqrt{2} - 1 - \beta$, the recycler's profit is positively correlated with μ_1; when $2\sqrt{2} - 1 - \beta < \mu_1 < 1$, the recycler's profit is negatively correlated with μ_1.

Proposition 4 shows that when the recycler chooses green independent innovation, the profit of the recycler increases with the increase in the spillover coefficient between itself and the remanufacturer μ_1. In the case that the recycler chooses green imitation innovation, the profit of the remanufacturer increases with the increase in the spillover coefficient of the recycler μ_1 and starts to decrease after reaching $2\sqrt{2} - 1 - \beta$. It can be seen from proposition 2 that regardless of which innovation path the recycler chooses, the change rule of the recycler's profit with the spillover coefficient is the same as that of the innovation level with the spillover coefficient. When the recycler chooses green imitation innovation, as the spillover coefficient μ_1 increases, the recycler's innovation level and profit both increase to the same threshold and then start to decrease. This shows that when the spillover level is low, the increase in the spillover coefficient is conducive to the innovation and profit of the recycler; in contrast, when the spillover level is high, the increase in the spillover coefficient will have a negative impact on the recycler's innovation and profit.

Proposition 5. *Impact of the spillover coefficient on the total profit of the CDW recycling supply chain.*

In the RII mode, when $0 < \mu_1 < -3 + 2\sqrt{3} - \beta$ or $m_0 - \beta - 1 < \mu_1 < 1$, the total profit of the CDW recycling supply chain is positively correlated with μ_1, and when $-3 + 2\sqrt{3} - \beta < \mu_1 < m_0 - \beta - 1$, the total profit of the CDW recycling supply chain is negatively correlated with μ_1. Note: $1.7 < m_0 < 1.71$.

In the RIMI mode, when $0 < \mu_2 < \mu_a$, the total profit of the CDW recycling supply chain is negatively correlated with μ_2; when $\mu_a < \mu_2 < 1$, the total profit of the CDW recycling supply chain is positively correlated with μ_2. Among them $\mu_a = \frac{\sqrt{-(-16+(1+\beta+\mu_1)^2)(-8+(1+\beta+\mu_1)^2)^2}}{8\sqrt{2}} - 1 - \beta$.

Proposition 5 shows that in the case that the recycler chooses green independent innovation, the total profit of the CDW recycling supply chain shows a dynamic change of increasing, then decreasing, and finally increasing with the increase in the mutual spillover coefficient between the remanufacturer and recycler, and the length of the decreasing interval is small. This shows that on the whole, in the CDW recycling supply chain, if both remanufacturer and recycler carry out independent innovation, the sharing and exchange of relevant technical knowledge between the two parties in the innovation process will be conducive to the improvement of the total profit of this supply chain. In the case that the recycler chooses green imitation innovation, the total profit of the CDW recycling supply chain first decreases with the increase in the remanufacturer's spillover coefficient μ_2 and then starts to increase after reaching μ_a.

5. Numerical Simulation

In this section, numerical simulations are used to verify the correctness of the proposition conclusion and to analyze the impact of the level of technology spillover between the recycler and remanufacturer, the level of consumer green sensitivity, and government price subsidies to consumers on the total profit of the CDW recycling supply chain in different situations. By consulting the literature and discussing with experts [63–67], the initial parameters of the study were set as shown in Table 3.

Table 3. Initial parameter settings.

a	c	β	μ_1	μ_2	s
10	3	0.4	0.7	0.3	0.6

5.1. RNI

Figure 2 shows that in the CDW recycling supply chain, the impact of government subsidies and consumer green sensitivity on the total profit of the CDW recycling supply chain under the non-innovation path of recyclers are as follows: (1) the higher the consumer green sensitivity under the same subsidy is, the greater the total profit of the CDW recycling supply chain is; consumers with green preference prefer innovative products with a high green degree, and the total profit of the CDW recycling supply chain increases with increasing consumer demand. (2) Under the same consumer green sensitivity, the greater the subsidy is, the greater the total profit of the supply chain; an increase in the government subsidy reduces the R&D investment cost of green independent innovation of the remanufacturer. In addition, the total profit of the supply chain of CDW recycling is positively correlated with the subsidy and the green sensitivity of consumers, and the total profit of the supply chain reaches its highest value when the subsidy and the green sensitivity of consumers are the highest. Thus, it can be seen that an increase in the subsidy and an increase in the green sensitivity of consumers are conducive to an increase in the total profit of the supply chain. Government subsidies can promote remanufacturers and recyclers to recycle CDW, while the existence of consumer green sensitivity provides a good opportunity for the development of CDW remanufacturers and recyclers in the supply chain. The results of this study are consistent with the findings of Mu et al. [68].

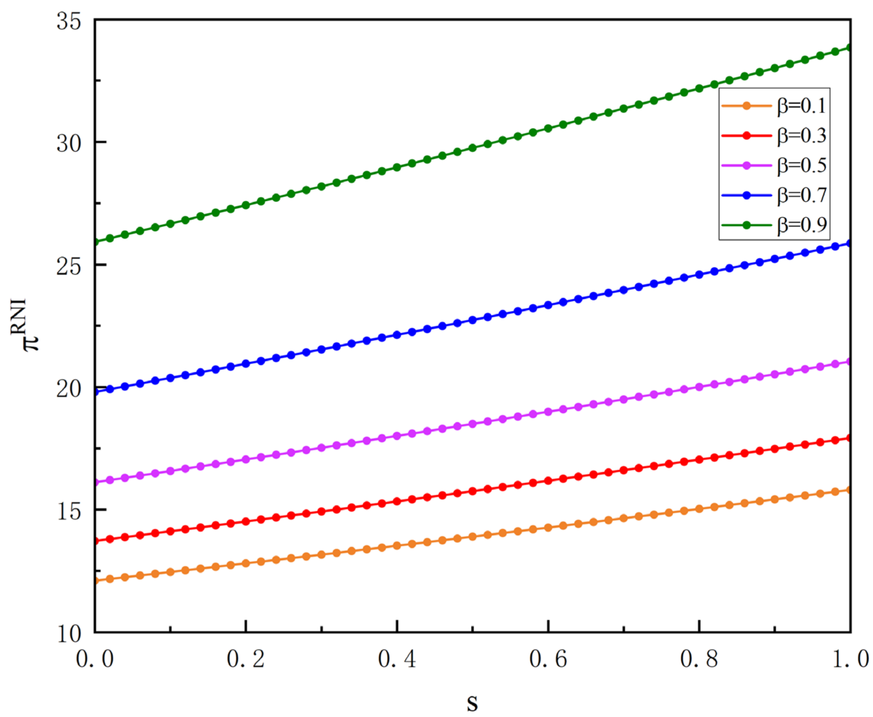

Figure 2. Impact of government subsidies and consumer green sensitivities on the total profit of the CDW recycling supply chain.

5.2. RII

Figure 3 shows that when the spillover coefficient satisfies $\mu_1 \in [0, \mu_1^1]$, the total profit of the CDW recycling supply chain increases slightly with an increase in the spillover coefficient. When the spillover coefficient is satisfied $\mu_1 \in [\mu_1^2, 1]$, the total profit of the supply chain first decreases and then tends to stabilize with the increase of the spillover coefficient. Therefore, too low or too high of a spillover coefficient at different subsidies is not conducive to the total profit of the CDW recycling supply chain. When the spillover coefficient is satisfied $\mu_1 \in [\mu_1^1, \mu_1^2]$, the total profit of the CDW recycling supply chain under different subsidies is far greater than the total profit of the CDW recycling supply chain under the conditions of RNI mode and RIMI mode. In this region, the greater the subsidy is, the greater the total profit of the supply chain. When the subsidy s= 0.9 and the spillover coefficient is satisfied $\mu_1 \in [\mu_1^1, \mu_1^2]$, the total profit of the CDW recycling supply chain reaches the optimal value, and the remanufacturer's green independent innovation technology appropriately overflows to the recycler who also carries out green independent innovation, which plays a positive role in the total profit of the supply chain. The results of this study are consistent with those of Li et al. [69]. Therefore, the government can set a higher subsidy to promote green independent innovation among CDW remanufacturers and recyclers.

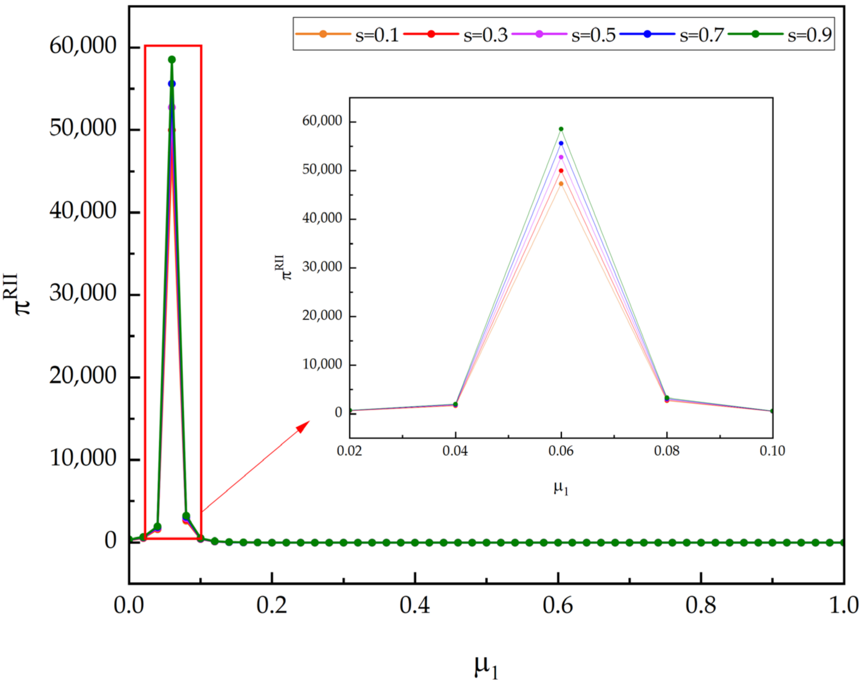

Figure 3. Impact of the spillover coefficient μ_1 on the total profit of the CDW recycling supply chain under different subsidies in RII mode.

Figure 4 shows that when the green sensitivity of consumers is low, with an increase in the spillover coefficient, the total profit of the CDW recycling supply chain increases first, then decreases, and finally approaches 0. If the green sensitivity of consumers increases at this time, this phenomenon will lag behind. This shows that when both parties innovate independently, consumer sensitivity to green products is low, so a small spillover effect can bring about the integration of heterogeneous knowledge between the two parties and increase the total profit of the CDW recycling supply chain by promoting the green technology innovation of both parties. This is consistent with the findings of Bi and Shen [70]. However, as the green sensitivity of consumers increases, consumers' requirements for green products have increased. At this time, CDW recyclers and remanufacturers need to further promote the integration of heterogeneous knowledge between them through the spillover effect.

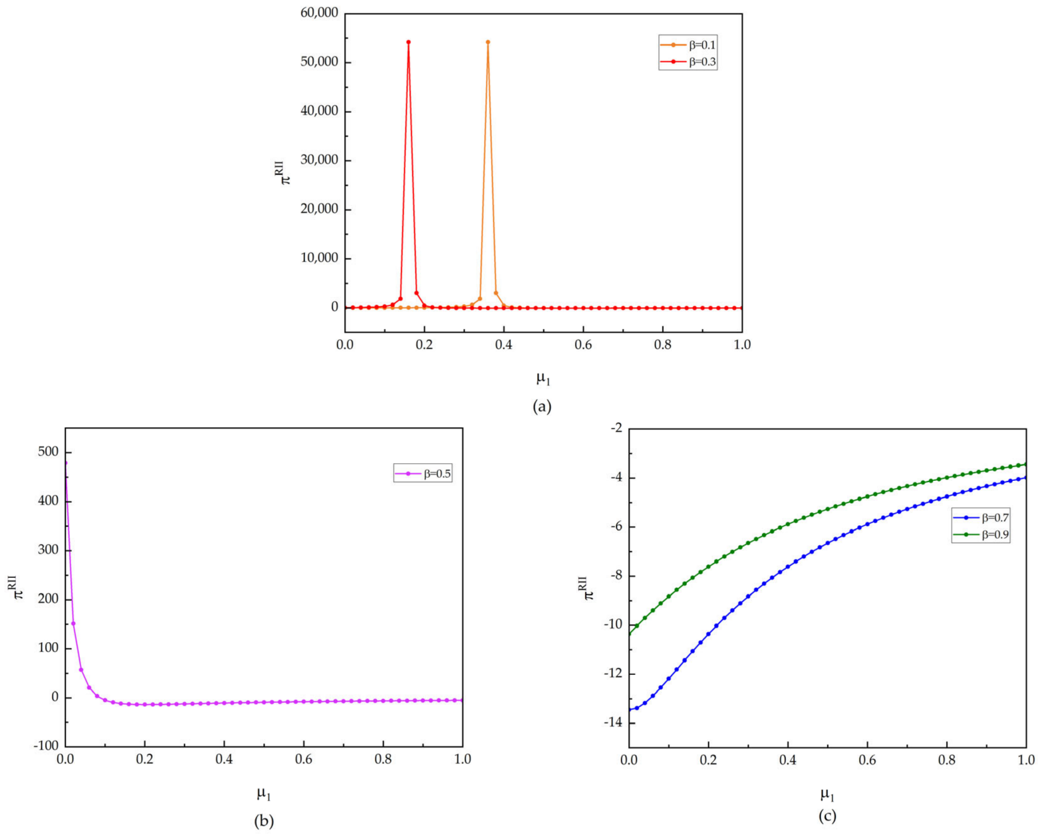

Figure 4. Impact of the spillover coefficient μ_1 on the total profit of the CDW recycling supply chain under different consumer green sensitivities in RII mode.**Note:** The subfigure (**a**) in Figure 4 shows the total profit of the CDW recycling supply chain at $\beta = 0.1$ and $\beta = 0.3$; the subfigure (**b**) in Figure 4 shows the total profit of the CDW recycling supply chain at $\beta = 0.5$; the subfigure (**c**) in Figure 4 shows the total profit of the CDW recycling supply chain at $\beta = 0.7$ and $\beta = 0.9$.

As consumer green sensitivity continues to increase to a moderate level, the total profit of the CDW recycling supply chain decreases as the spillover coefficient increases and then slowly increases and approaches 0. The higher green sensitivity of consumers implies higher requirements for green products, for which construction waste recyclers and remanufacturers need to make more green innovation efforts to improve the greenness of their products. However, due to the dual externalities (spillover effect and external environmental cost) of the green innovation effort, the technical difficulty of green innovation becomes more difficult, and the input cost increases over time, which leads to a continuous decline in the total profit of the CDW recycling supply chain [71]. This result is contrary to the findings of Wang et al. [72]. Wang et al. show that as consumers become more sensitive to green innovation, both remanufacturers and retailers benefit from it, resulting in an increase in total supply chain profits. However, Wang et al. do not consider the role of spillover effects in the supply chain, and in fact, the presence of spillover effects can have a negative impact on total supply chain profits.

When consumer green sensitivity is high, the total profit of the CDW recycling supply chain is consistently negative. At this time, the total profit of the CDW recycling supply chain is no longer affected by the spillover coefficient. However, to meet the high level of consumer green sensitivity, CDW recyclers and remanufacturers will increase their investment to meet consumer expectations, which leads to an increase in costs and a further decline in profit and utility [73], and the total supply chain profit always tends to 0.

5.3. RIMI

Figure 5 shows that under the same subsidy, with the increase in the spillover coefficient μ_1, the total profit of the CDW recycling supply chain first decreases rapidly to the lowest profit point and then increases slowly. Under different subsidies, the effect of the spillover coefficient μ_1 has the same impact on the total profit of the CDW recycling supply chain. In addition, when there is no spillover of green innovation technology, the higher the government subsidy is, the greater the total profit of the CDW recycling supply chain; when there is a complete spillover of green innovation from the remanufacturer, the higher the government subsidy is, the lower the total profit of the CDW recycling supply chain. Therefore, when the spillover situation is serious, the government should reduce the intervention in the green innovation of remanufacturers and recyclers to formulate a reasonable subsidy. The results of this study are contrary to the results of Zhang et al. [74] because this study considers both upstream and downstream firms in the CDW recycling supply chain, remanufacturers, and recyclers are actively engaged in green innovation, and the spillover effect has a significant impact on the total profit of the CDW recycling supply chain. However, the research of Zhang et al. shows that the spillover effect has little impact on the change in the best decision. It is based on the fact that when considering the spillover effect, the upstream supplier will transfer the pressure of innovation to the remanufacturing industry, and its own innovation efforts will be reduced. The main body participation in the green innovation supply chain considered by the two is different, so the research results are opposite.

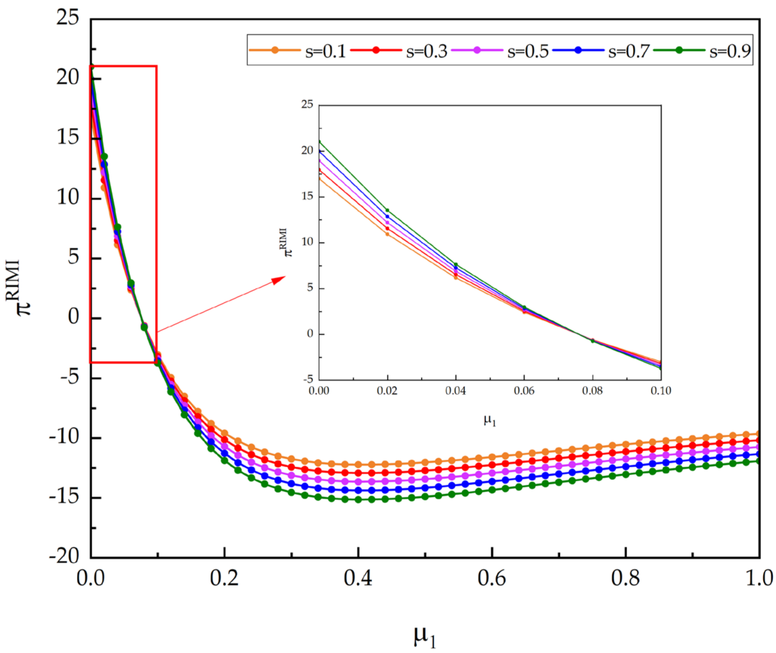

Figure 5. Impact of the spillover coefficient μ_1 on the total profit of the CDW recycling supply chain under different subsidies in RIMI mode.

Figure 6 shows that the total profit of the CDW recycling supply chain is always negative under different subsidies. However, the resulting loss gradually decreases as the spillover coefficient μ_2 increases, and the total profit of the CDW recycling supply chain is positively correlated with the spillover coefficient μ_2. Both remanufacturers and recyclers have to bear high costs for green innovation or green imitative innovation research and development, and new technologies cannot provide high benefits for the supply chain composed of remanufacturers and recyclers in the early years when the initial consumer scale of green innovation products is small. The results of this study are consistent with those of Farrell et al. [75,76]. However, with the continuous spillover of green imitation innovation technology from recyclers, remanufacturers are able to obtain heterogeneous innovation technology from the technology spillover to produce green products with higher innovation levels, attracting more consumers with green preferences to purchase them, and the total profit of the supply chain increases as a result. In addition, the higher the subsidy under the same spillover coefficient μ_2, the lower the total profit of the supply chain, the total profit of the supply chain is negatively correlated with the subsidy, and the increase in government subsidy investment has no positive impact on the total profit of the CDW recycling supply chain.

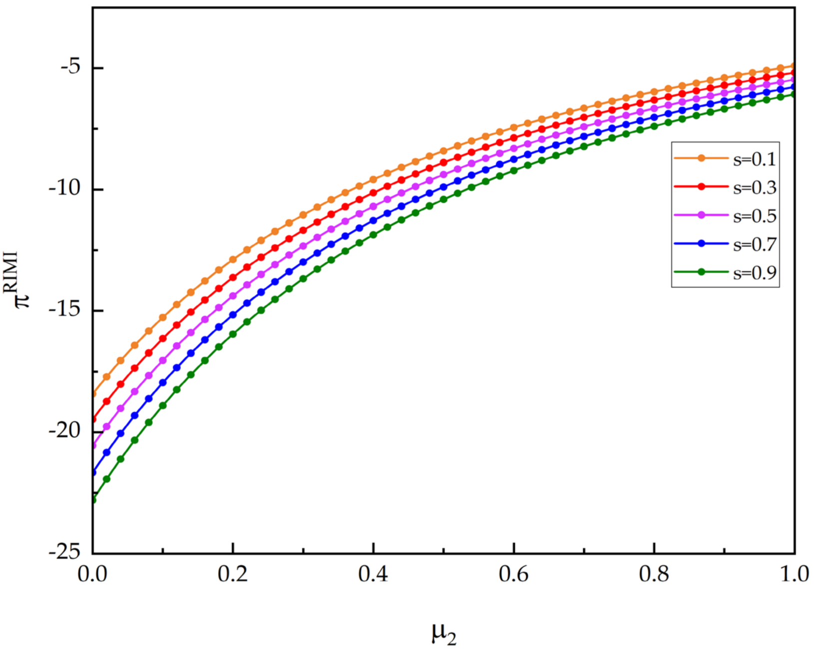

Figure 6. Impact of the spillover coefficient μ_2 on the total profit of the CDW recycling supply chain under different subsidies in RIMI mode.

Figure 7 shows that when consumer green sensitivity is low, the total profit of the CDW recycling supply chain increases, then decreases, and eventually approaches 0 as the spillover coefficient μ_1 increases. However, if consumer green sensitivity increases slightly, the total profit of the CDW recycling supply chain decreases and eventually tends to 0 as the spillover coefficient μ_1 increases. This situation shows that under the independent innovation of the remanufacturer and the imitative innovation of the recycler, the spillover effect has a positive impact on the total profit of the supply chain only when the consumer's green sensitivity is extremely low. When the green sensitivity of consumers gradually increases, the total profit of the CDW recycling supply chain shows irregular changes and remains negative overall. Therefore, the presence of consumer green sensitivity is not always beneficial for the total profit of the CDW recycling supply chain, which is the same result as the research of Han et al. [67]. Although this adverse situation is weakened with increasing consumer green sensitivity, it seems that the spillover effect always has a negative impact on the total profit of the CDW recycling supply chain at higher consumer green sensitivity.

Figure 8 shows that when the green sensitivity of consumers is 0.1, the total profit of the CDW recycling supply chain increases, then decreases, and finally tends to 0 as the spillover coefficient μ_2 increases. When the green sensitivity of consumers is higher than 0.1, the total profit of the CDW recycling supply chain will always be negative. However, with the increase in the spillover coefficient μ_2, the adverse situation of negative total profit of the supply chain will be weakened. Therefore, CDW recyclers and remanufacturers can maximize the total profit of the CDW recycling supply chain by moderate technology spillover. Technology spillovers can increase the innovative productivity of enterprises and enhance their market competitiveness, in line with the phenomenon that increased product output translates into higher profits [77].

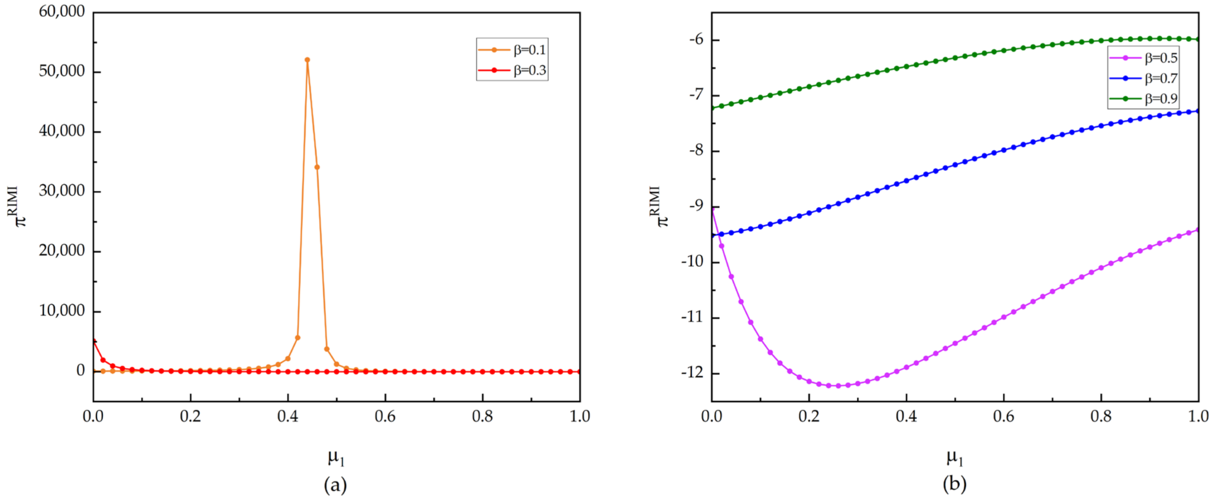

Figure 7. Impact of the spillover coefficient μ_1 on the total profit of the CDW recycling supply chain under different consumer green sensitivities in RIMI mode. **Note:** The subfigure (**a**) in Figure 7 shows the total profit of the CDW recycling supply chain at $\beta = 0.1$ and $\beta = 0.3$; the subfigure (**b**) in Figure 7 shows the total profit of the CDW recycling supply chain at $\beta = 0.5$,$\beta = 0.7$ and $\beta = 0.9$.

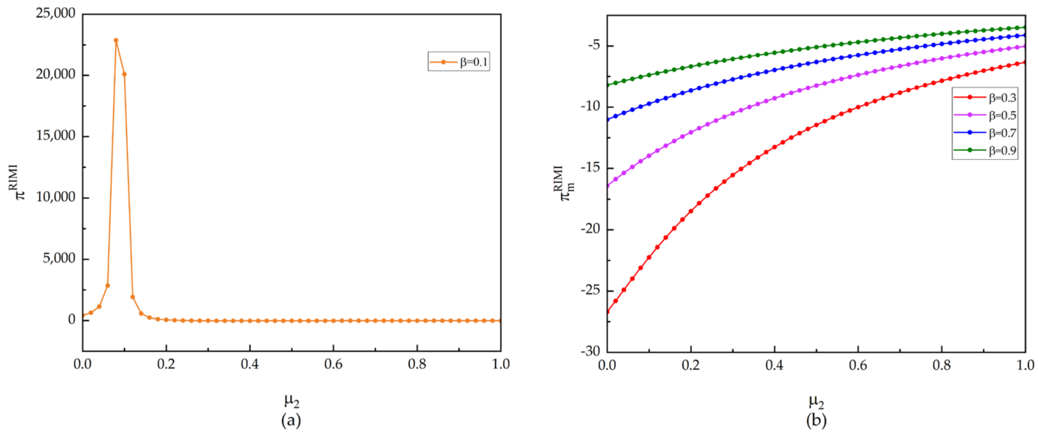

Figure 8. Impact of the spillover coefficient μ_2 on the total profit of the CDW recycling supply chain under different consumer green sensitivities in RIMI mode. **Note:** The subfigure (**a**) in Figure 8 shows the total profit of the CDW recycling supply chain at $\beta = 0.1$; the subfigure (**b**) in Figure 8 shows the total profit of the CDW recycling supply chain at $\beta = 0.3$,$\beta = 0.5$,$\beta = 0.7$ and $\beta = 0.9$.

6. Conclusions and Implications

In the context of innovation diffusion, this paper studies the optimal innovation strategies of game subjects in a CDW recycling PPP project operated by a remanufacturer and a recycler by constructing a Stackelberg game model. At the same time, numerical simulation using MATLAB is used to analyze the impact of spillover coefficients on the total profit of the CDW recycling supply chain under the three innovation paths of non-innovation, independent innovation, and imitation innovation chosen by the remanufacturer and the recycler. The main research conclusions are as follows:

(1) In the CDW recycling PPP project, the two main operators, the remanufacturer and recycler, can achieve their own innovation level as well as profit improvement through technology spillover. When the recycler carries out green independent innovation, the innovation level of the remanufacturer and the recycler and the profit of the recycler

are positively correlated with the spillover level of both parties, but the profit of the remanufacturer increases only when the spillover level is small. When the recycler carries out green imitation innovation, the innovation level of the remanufacturer and recycler and the profits of the recycler only decrease with the technology spillover of each other when the spillover level of the remanufacturer is high. The change in the profit of the remanufacturer is more complex, and only when the level of their own spillovers is very high can it help to improve the profits.

(2) In the CDW recycling PPP project, when the recycler chooses different innovation paths, the total profit of the CDW recycling supply chain changes dynamically with the overflow level. When the recycler engages in green independent innovation, the total profit of the CDW recycling supply chain increases with the mutual spillover level of both the remanufacturer and the recycler, then decreases and finally increases, and the length of the decreasing interval is small; when the recycler engages in green imitation innovation, the total profit of the CDW recycling supply chain decreases and then increases with the spillover level of the recycler.

(3) In the CDW recycling PPP project, the government price subsidy to consumers does not always improve the total profit of the CDW recycling supply chain. In the case of non-innovation of the recycler, green independent innovation, and an appropriate spillover level between the recycler and remanufacturer, an increase in government subsidies can improve the total profit of the CDW recycling supply chain. However, when recyclers carry out green imitation innovation, increasing government subsidies will reduce the total profit of the CDW recycling supply chain.

(4) In the CDW recycling PPP project, when the recycler chooses different innovation paths and technology spillovers, the impact of consumer green sensitivity on the total profit of the CDW recycling supply chain is heterogeneous. When the recycler does not innovate, the total profit of the CDW recycling supply chain is positively correlated with the green sensitivity of consumers. The total profit of the CDW recycling supply chain increases only when the recycler carries out green independent innovation, green imitation innovation with a small amount of technology spillover, and when the consumer's green sensitivity is low. When the green sensitivity of consumers is high, the total profit of the CDW recycling supply chain decreases with the mutual technology spillover under the green independent innovation of the recycler; however, when the recycler imitates green innovation, the increase in the recycler's spillover level can weaken the negative impact of the remanufacturer's technology spillover on the total profit of the supply chain.

In addition, this paper obtains the following management implications:

(1) In the process of recycling CDW, technology spillover has become an important driving force for recyclers and remanufacturers to improve their innovation level. Recyclers and remanufacturers should seize the opportunity of collaborative innovation, make full use of technology spillover to integrate innovation resources, and absorb more heterogeneous knowledge. For example, the China Shandong Electric Construction Company mentioned in the 2021 National Solid Waste Resource Utilization Technology Conference that CDW can be "turned into treasure" and reused by technical means, and there have been successful cases in Shanghai, Wuhan, Zhengzhou, and other cities; meanwhile, Shandong Ming Ran Recycling Resources Co. Ltd. has also had some successful experiences in the comprehensive treatment and recycling of CDW. In addition, remanufacturers and recyclers should reasonably control the degree of technology spillover in the innovation process to maximize their own profits. The government and relevant departments should strive to build a platform for green innovation technology exchange and cooperation to promote innovation cooperation between the two major operators of CDW, recyclers and remanufacturers.

(2) It is suggested that the government and relevant departments should further improve the technology innovation guidance mechanism and form a good technological innovation diffusion mechanism between CDW recyclers and remanufacturers to play

the driving role of technology innovation in driving the development of the overall CDW recycling industry. For example, the China Construction Waste Resourcefulness Industry Technology Innovation Strategy Alliance promotes the rapid development of the CDW recycling industry through extensive and in-depth dialogue and cooperation with politicians, entrepreneurs, international organizations, regional governments, etc. It has developed the world's first carbon methodology to produce recycled concrete mainly from CDW and applied it to several projects in Beijing. However, at the same time, the government and relevant departments should also be aware of the adverse impact of technology spillover on the total profit of the CDW recycling supply chain and should attach great importance to optimizing the allocation of innovation resources and creating a good technological innovation environment.

(3) In CDW recycling PPP projects, the government should adjust the subsidy amount according to the specific situation when subsidizing the price of consumers. When the government subsidy is low, it is more beneficial for recyclers to carry out green imitation innovation; when the government subsidy is high, it is more beneficial for recyclers to carry out green independent innovation. However, even if recyclers do not innovate, the total profit of the CDW recycling supply chain will also increase with an increase in government subsidies. For example, the Housing and Urban-Rural Development Bureau of Yiwu City, Zhejiang Province, has increased its policy support for CDW, and the city's financial support for enterprises that invest in comprehensive utilization facilities for CDW is given a subsidy of 20% of the total investment in the acquisition of production equipment. Therefore, to promote the technological innovation of recyclers, the government should give consumers appropriate price subsidies according to the innovation path of recyclers.

(4) When recyclers have innovative behaviors, higher consumer green sensitivity is not conducive to increasing the total profit of the CDW recycling supply chain. In China, CDW recycling PPP projects have started to operate in cities along the upstream and downstream of the Yangtze River, core cities in Beijing, Tianjin, and Tang, as well as in the southwest transportation stronghold. Therefore, to promote the smooth implementation of more CDW recycling PPP projects, the government should actively publicize the project at the social level to establish the correct awareness of consumers about the green innovative behaviors of recyclers and remanufacturers in the CDW recycling process. Recyclers and remanufacturers should also make full use of each other's technology spillover and strive to improve their innovative technology level to meet market demand.

In summary, to promote the smooth implementation of CDW recycling PPP projects, joint efforts of the government, recyclers, and remanufacturers are needed. This paper reveals the impact of technology spillover effects between remanufacturers and recyclers in the CDW recycling supply chain on the innovation behavior mechanism of recyclers and considers the green sensitivity of consumers and the role of government price subsidies to consumers. However, this paper has not yet considered that the horizontal spillover effect among similar enterprises and different government subsidy models in real-world situations also affects the progress of CDW recycling PPP projects. Therefore, in future research, the horizontal spillover effect of similar enterprises and the impact of different government subsidy models in other countries or regions of the world on CDW recycling PPP projects can be considered to provide more practical suggestions for in-depth research on the impact of different regions and different subjects on the supply chain management of CDW recycling.

Author Contributions: Methodology, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing—Original Draft, Writing—Review and Editing, Visualization, C.Z.; Conceptualization, Methodology, Writing—Original Draft, Supervision, Project Administration, X.L.; Writing—Review and Editing, C.Z., J.H., Y.L., W.C., Y.Z., H.Z. and S.X. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Natural Science Foundation of China (grant number 72204178), Natural Science Foundation of Sichuan, China (grant number 2023NSFSC1053), National College Students Innovation and Entrepreneurship Training Plan (grant number 202210626026), Undergraduate Training Program for Innovation and Entrepreneurship of Sichuan Agricultural University (grant number 202210626026), and Undergraduate Research Interest Cultivation Program of Sichuan Agricultural University (grant numbers 2023030, 2023024).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Vukovic, N.; Pobedinsky, V.; Mityagin, S.; Drozhzhin, A.; Mingaleva, Z. A study on green economy indicators and modeling: Russian context. *Sustainability* **2019**, *11*, 4629. [CrossRef]
2. Wu, H.Y.; Zuo, J.; Zillante, G.; Wang, J.Y.; Yuan, H.P. Status quo and future directions of construction and demolition waste research: A critical review. *J. Clean. Prod.* **2019**, *240*, 118163. [CrossRef]
3. Wang, Q.F.; Yang, Y.; Luan, D.; Qin, S. Current Situation and Comprehensive Treatment of Construction Waste. *Fresenius Environ. Bull.* **2020**, *29*, 8751–8756.
4. Statistics. Eurostat. Available online: https://ec.europa.eu/eurostat/databrowser/view/cei_wm040/default/table?lang=en (accessed on 15 January 2023).
5. Borrachero, M.V.; Payá, J.; Brito, S.; Segura, Y.P.; Soriano, L.; Tashima, M.M.; Monzó, J.M. Reusing construction and demolition waste to prepare alkali-activated cement. *Materials* **2022**, *15*, 3437. [CrossRef]
6. Huang, B.J.; Wang, X.Y.; Kua, H.W.; Geng, Y.; Bleischwitz, R.; Ren, J.Z. Construction and demolition waste management in China through the 3R principle. *Resour. Conserv. Recycl.* **2018**, *129*, 36–44. [CrossRef]
7. Yazdani, M.; Kabirifar, K.; Frimpong, B.E.; Shariati, M.; Mirmozaffari, M.; Boskabadi, A. Improving construction and demolition waste collection service in an urban area using a simheuristic approach: A case study in Sydney, Australia. *J. Clean. Prod.* **2021**, *280*, 124138. [CrossRef]
8. Bai, X.P.; Wang, X.W. A Novel Planning Method of Urban Building Wastes for Environment Protection and Sustainable Development. *SAGE Open* **2020**, *10*, 1–10. [CrossRef]
9. Tam, V.W. Economic comparison of concrete recycling: A case study approach. *Resour. Conserv. Recycl.* **2008**, *52*, 821–828. [CrossRef]
10. Lyytimäki, J.; Antikainen, R.; Hokkanen, J.; Koskela, S.; Kurppa, S.; Känkänen, R.; Seppälä, J. Developing Key Indicators of Green Growth. *Sustain. Dev.* **2017**, *26*, 51–64. [CrossRef]
11. Ramos, M.; Martinho, G. Influence of construction company size on the determining factors for construction and demolition waste management. *Waste Manag.* **2021**, *136*, 295–302. [CrossRef]
12. Liu, J.K.; Hua, Z.W.; Pang, Y.S.; Wang, X.T. Risk sharing for PPP project in construction waste recycling industry in China. *Environ. Sci. Pollut. Res.* **2022**, *29*, 12614–12628. [CrossRef]
13. Hammond, J.; Bailey, S.; Gore, O.; Checkland, K.; Darley, S.; McDonald, R.; Blakeman, T. The problem of success and failure in public-private innovation partnerships. *J. Soc. Policy* **2021**, *51*, 771–791. [CrossRef]
14. Hermans, F.; Geerling-Eiff, F.; Potters, J.; Klerkx, L. Public-private partnerships as systemic agricultural innovation policy instruments-Assessing their contribution to innovation system function dynamics. *NJAS-Wagen J. Life Sci.* **2018**, *88*, 76–95. [CrossRef]
15. Willems, T.; Van Dooren, W. (De)Politicization Dynamics in Public-Private Partnerships: Lessons from a Comparison between UK and Flemish PPP Policy. *Public Manag. Rev.* **2016**, *18*, 199–220. [CrossRef]
16. Wang, L.G.; Shrestha, A.; Zhang, W.; Wang, G.B. Government guarantee decisions in PPP wastewater treatment expansion projects. *Water* **2020**, *12*, 3352. [CrossRef]
17. Rajan, T.A.; Gopinath, G.; Behera, M. PPPs and project overruns: Evidence from road projects in India. *J. Constr. Eng. Manag.* **2014**, *140*, 04013070. [CrossRef]
18. Wang, H.M.; Xiong, W.; Wu, G.D.; Zhu, D.J. Public-private partnership in public administration discipline: A literature review. *Public Manag. Rev.* **2018**, *20*, 293–316. [CrossRef]
19. Feng, S.L.; Chong, Y.; Li, G.X.; Zhang, S.B. Digital finance and innovation inequality: Evidence from green technological innovation in China. *Environ. Sci. Pollut. Res.* **2022**, *29*, 87884–87900. [CrossRef]
20. Hong, M.; Li, Z.H.; Drakeford, B. Do the green credit guidelines affect corporate green technology innovation? Empirical research from China. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1682. [CrossRef]
21. Blaut, J.M. Diffusionism: A uniformitarian critique. *Ann. Assoc. Am. Geogr.* **1987**, *77*, 30–47. [CrossRef]
22. Tan, R.W.; Qing, X.; Yang, J.S.; Zhang, J.; Li, D. Analysis on Recycling Channel Selection of Construction and Demolition Waste in China from the Perspective of Supply Chain. *Int. J. Environ. Res. Public Health* **2022**, *19*, 4975. [CrossRef] [PubMed]

23. Du, Y.P.; Wang, H.H. Green Innovation Sustainability: How Green Market Orientation and Absorptive Capacity Matter? *Sustainability* **2022**, *14*, 8192. [CrossRef]
24. Liu, X.F.; Yu, H.Z.; Lai, G.W.; Wang, S.X.; Xie, Y.Y. Imitation or Innovation? Research on the Path Selection of Enterprise Performance Improvement from the Perspective of Organizational Ecology. *Sustainability* **2022**, *14*, 7223. [CrossRef]
25. Wang, C.B.; Huang, Z.G. Econometric analysis of the impact of financial structure on innovation based on the fixed effects panel model. *Math. Probl. Eng.* **2021**, *2021*, 3022421. [CrossRef]
26. Wang, M.Y.; Li, Y.M.; Li, J.Q.; Wang, Z.T. Green process innovation, green product innovation and its economic performance improvement paths: A survey and structural model. *J. Environ. Manag.* **2021**, *297*, 113282. [CrossRef]
27. Aslani, A.; Heydari, J. Transshipment contract for coordination of a green dual-channel supply chain under channel disruption. *J. Clean. Prod.* **2019**, *223*, 596–609. [CrossRef]
28. Wang, L.; Xu, T.J.; Qin, L.H. A study on supply chain emission-reduction level based on carbon tax and consumers' low-carbon preferences under stochastic demand. *Math. Probl. Eng.* **2019**, *2019*, 1621395. [CrossRef]
29. Chekima, B.; Wafa, S.A.W.S.K.; Igau, O.A.; Chekima, S.; Sondoh, S.L., Jr. Examining green consumerism motivational drivers: Does premium price and demographics matter to green purchasing? *J. Clean. Prod.* **2016**, *112*, 3436–3450. [CrossRef]
30. Fan, R.G.; Wang, Y.T.; Chen, F.Z.; Du, K.; Wang, Y.Y. How do government policies affect the diffusion of green innovation among peer enterprises?—An evolutionary-game model in complex networks. *J. Clean. Prod.* **2022**, *364*, 132711. [CrossRef]
31. Zarnikau, J. Consumer demand for 'green power'and energy efficiency. *Energy Policy* **2003**, *31*, 1661–1672. [CrossRef]
32. Brandao, R.; Hosseini, M.R.; Macedo, A.N.; Melo, A.C.; Martek, I. Public administration strategies that stimulate reverse logistics within the construction industry: A conceptual typology. *Eng. Constr. Arch. Manag.* **2022**, *29*, 2924–2949. [CrossRef]
33. Munaro, M.R.; Tavares, S.F.; Bragança, L. Towards circular and more sustainable buildings: A systematic literature review on the circular economy in the built environment. *J. Clean. Prod.* **2020**, *260*, 121134. [CrossRef]
34. Liu, H.Y.; Long, H.Y.; Li, X.W. Identification of critical factors in construction and demolition waste recycling by the grey-DEMATEL approach: A Chinese perspective. *Environ. Sci. Pollut. Res.* **2020**, *27*, 8507–8525. [CrossRef]
35. Lu, W.; Du, L.; Feng, Y.B. Decision making behaviours and management mechanisms for construction and demolition waste recycling based on public–private partnership. *Environ. Sci. Pollut. Res.* **2022**, *29*, 82078–82097. [CrossRef]
36. Xu, J.; Cao, Y.R. Innovation, the flying geese model, IPR protection, and sustainable economic development in China. *Sustainability* **2019**, *11*, 5707. [CrossRef]
37. Zhang, H.F.; Vorobeychik, Y. Empirically grounded agent-based models of innovation diffusion: A critical review. *Artif. Intell. Rev.* **2019**, *52*, 707–741. [CrossRef]
38. Aldieri, L.; Carlucci, F.; Vinci, C.P.; Yigitcanlar, T. Environmental innovation, knowledge spillovers and policy implications: A systematic review of the economic effects literature. *J. Clean. Prod.* **2019**, *239*, 118051. [CrossRef]
39. Huang, Y.F.; Pei, J.S. Imported intermediates, technology spillover and green development: Evidence from Chinese firms. *Front. Environ. Sci.* **2022**, *10*, 909055. [CrossRef]
40. Ye, T.L.; Li, G.L. Research on the Innovation Diffusion Mechanism and the Diffusion Effect of the Beijing-Tianjin-Hebei Region. *Comp. Econ. Soc. Syst.* **2019**, *35*, 166–177. (In Chinese)
41. Nie, L.B.; Gong, H.; Zhao, D.X.; Lai, X.P.; Chang, M.Y. Heterogeneous knowledge spillover channels in universities and green technology innovation in local firms: Stimulating quantity or quality? *Front. Psychol.* **2022**, *13*, 943655. [CrossRef]
42. Nikolaeva, R. Interorganizational imitation heuristics arising from cognitive frames. *J. Bus. Res.* **2014**, *67*, 1758–1765. [CrossRef]
43. Collins, T. Imitation: A catalyst for innovation and endogenous growth. *Econ. Model* **2015**, *51*, 299–307. [CrossRef]
44. Lee, C.; Kim, J.H.; Lee, D. Intra-industry innovation, spillovers, and industry evolution: Evidence from the Korean ICT industry. *Telemat. Inform.* **2017**, *34*, 1503–1513. [CrossRef]
45. Riehl, K.; Kiesel, F.; Schiereck, D. Political and socioeconomic factors that determine the financial outcome of successful green innovation. *Sustainability* **2022**, *14*, 3651. [CrossRef]
46. Barman, A.; Das, R.; De, P.K.; Sana, S.S. Optimal pricing and greening strategy in a competitive green supply chain: Impact of government subsidy and tax policy. *Sustainability* **2021**, *13*, 9178. [CrossRef]
47. Maniatis, P. Investigating factors influencing consumer decision-making while choosing green products. *J. Clean. Prod.* **2016**, *132*, 215–228. [CrossRef]
48. Zhao, L.M.; Chen, Y.Q. Optimal subsidies for green products: A maximal policy benefit perspective. *Symmetry* **2019**, *11*, 63. [CrossRef]
49. Gong, M.; Dai, A.M. Multiparty evolutionary game strategy for green technology innovation under market orientation and pandemics. *Front. Public Health* **2022**, *9*, 821172. [CrossRef]
50. Lin, R.J.; Tan, K.H.; Geng, Y. Market demand, green product innovation, and firm performance: Evidence from Vietnam motorcycle industry. *J. Clean. Prod.* **2013**, *40*, 101–107. [CrossRef]
51. Siedschlag, I.; Meneto, S.; Koecklin, M.T. Enabling Green Innovations for the Circular Economy: What Factors Matter? *Sustainability* **2022**, *14*, 12314. [CrossRef]
52. Cappelli, R.; Czarnitzki, D.; Kraft, K. Sources of spillovers for imitation and innovation. *Res. Policy* **2014**, *43*, 115–120. [CrossRef]
53. Audretsch, D.B.; Belitski, M. The knowledge spillover of innovation. *Ind. Corp. Change* **2022**, *31*, 1329–1357. [CrossRef]
54. He, M.; Lee, J. Social culture and innovation diffusion: A theoretically founded agent-based model. *J. Evol. Econ.* **2020**, *30*, 1109–1149. [CrossRef]

55. Tsiodra, M.; Chronopoulos, M. A bi-level model for optimal capacity investment and subsidy design under risk aversion and uncertainty. *J. Oper. Res. Soc.* **2022**, *73*, 1787–1799. [CrossRef]
56. Mohsin, A.K.M.; Hossain, S.F.A.; Tushar, H.; Iqbal, M.M.; Hossain, A. Differential game model and coordination model for green supply chain based on green technology research and development. *Heliyon* **2021**, *7*, e07811. [CrossRef]
57. Hong, Z.F.; Guo, X.L. Green product supply chain contracts considering environmental responsibilities. *Omega* **2019**, *83*, 155–166. [CrossRef]
58. Meng, Q.F.; Li, M.W.; Liu, W.Y.; Li, Z.; Zhao, J. Pricing policies of dual-channel green supply chain: Considering government subsidies and consumers' dual preferences. *Sustainability* **2021**, *26*, 1021–1030. [CrossRef]
59. Yan, T.Z. Discussion on the reverse control mechanism and strategy of retailers in commodity supply chain. *Bus. Econ. Res.* **2017**, *724*, 21–23. (In Chinese)
60. EI Ouardighi, F.; Sim, J.; Kim, B. Pollution accumulation and abatement policies in two supply chains under vertical and horizontal competition and strategy types. *Omega* **2021**, *98*, 102108. [CrossRef]
61. Hu, Y.; Fisher-Vanden, K.; Su, B.Z. Technological spillover through industrial and regional linkages: Firm-level evidence from China. *Econ. Model* **2020**, *89*, 523–545. [CrossRef]
62. Gao, P.; Du, J.G.; Nie, J.J.; Zhu, B.X. The Influence of Consumer's Brand Loyalty on Brand Remanufacturing Market Strategy. *China Manag. Sci.* **2021**, *29*, 47–58. (In Chinese)
63. Xu, L.; Wang, C.X.; Li, H. Decision and coordination of low-carbon supply chain considering technological spillover and environmental awareness. *Sci. Rep.* **2017**, *7*, 3107. [CrossRef] [PubMed]
64. Zhang, H.Y.; Xu, H.Y.; Pu, X.J. A cross-channel return policy in a green dual-channel supply chain considering spillover effect. *Sustainability* **2020**, *12*, 2171. [CrossRef]
65. Xie, J.M.; Jiang, M.T.; Qin, Q.; He, Y.; Xie, D.R. Recycling model of low-carbon and closed-loop supply chain considering government subsidies. *Energy Sci. Eng.* **2022**, *10*, 4382–4396. [CrossRef]
66. Su, C.; Liu, X.J.; Du, W.Y. Green supply chain decisions considering consumers' low-carbon awareness under different government subsidies. *Sustainability* **2020**, *12*, 2281. [CrossRef]
67. Han, Y.T.; Zheng, H.X.; Huang, Y.C.; Li, X. Considering consumers' green preferences and government subsidies in the decision making of the construction and demolition waste recycling supply chain: A stackelberg game approach. *Buildings* **2022**, *12*, 832. [CrossRef]
68. Mu, Z.Y.; Li, Q.J.; Dai, G.X.; Li, K.; Zhang, G.M. Government subsidy policy and online selling strategy in a platform supply chain with green RD and DDM activities. *Sustainability* **2022**, *14*, 9658. [CrossRef]
69. Li, L.; Li, W.M. The Promoting Effect of Green Technology Innovations on Sustainable Supply Chain Development: Evidence from China's Transport Sector. *Sustainability* **2022**, *14*, 4673. [CrossRef]
70. Bi, K.X.; Shen, N. Green Innovation System for Manufacturing Industry: Transmission Mechanism of Knowledge Spillover. *Acad. Exch.* **2016**, *32*, 122–128. (In Chinese)
71. He, J.H.; Lei, Y.L.; Fu, X. Do consumer's green preference and the reference price effect improve green innovation? A theoretical model using the food supply chain as a case. *Int. J. Environ. Res. Public Health* **2019**, *16*, 5007. [CrossRef]
72. Wang, W.; Liu, X.J.; Zhang, W.S.; Gao, G.; Zhang, H. Coordination of a green supply chain with one manufacturer and two competing retailers under different power structures. *Discret. Dyn. Nat. Soc.* **2019**, *2019*, 3453850. [CrossRef]
73. Wang, D.P.; Ge, G.; Zhou, Y.; Zhu, M.Y. Pricing-decision analysis of green supply chain with two competitive manufacturers considering horizontal and vertical fairness concerns. *Environ. Sci. Pollut. Res.* **2022**, *29*, 66235–66258. [CrossRef]
74. Zhang, F.F.; Zhang, Z.X.; Xue, Y.W.; Zhang, J.; Che, Y. Dynamic green innovation decision of the supply chain with innovating and free-riding manufacturers: Cooperation and spillover. *Complexity* **2020**, *2020*, 8937847. [CrossRef]
75. Farrell, J.; Saloner, G. Installed base and compatibility: Innovation, product preannouncements, and predation. *Am. Econ. Rev.* **1986**, *76*, 940–955.
76. Jia, L.L.; Nam, E.; Chun, D. Impact of Chinese government subsidies on enterprise innovation: Based on a three-dimensional perspective. *Sustainability* **2021**, *13*, 1288. [CrossRef]
77. Qiu, J.P.; Wan, C. Technology spillovers and corporate cash holdings. *J. Financ. Econ.* **2015**, *115*, 558–573. [CrossRef]