systems

MDPI

Article

Enhancing Greenness and Performance of Agricultural Supply Chains with Nash Bargaining Contract Under Consumer Environmental Awareness

Guangxing Wei [1,2], Xinyue Zhang [1,*] and Binta Bary [3]

[1] School of Economics and Management, Chongqing Jiaotong University, Chongqing 400074, China; wgx777@126.com
[2] Chongqing Key Research Base of Port Logistics and Maritime Development, Chongqing 400074, China
[3] West African Oil Pipeline (Benin) Company S.A., Cotonou P.O. Box 458, Benin; bintabary.ir@gmail.com
* Correspondence: yuexiaoyue426@163.com

Abstract: To enhance product greenness and operational performance, this study designs a Nash bargaining contract incorporating consumer environmental awareness in an agricultural supply chain consisting of one manufacturer and one retailer. The manufacturer invests in green technologies and the retailer shares partial green costs to improve greenness and efficiency. Using game theory, theoretical models for competitive scenario without Nash bargaining, local cooperative scenario with given ratio, and global cooperative scenario with Nash bargaining are constructed. Through comparison and sensitivity analysis, the enhancements from Nash bargaining are explored, and the effects of consumer environmental awareness on these enhancements are examined. The findings reveal several key insights. First, the process of bargaining determines the optimal contract ratio, which also depends on the magnitude of price sensitivity, marginal green costs, and consumer environmental awareness. Second, the Nash bargaining contract significantly improves product greenness, increases retail prices, and boosts profits for both the manufacturer and the retailer. Finally, consumer environmental awareness amplifies the effectiveness of the Nash bargaining contract, leading to greener products, higher prices, and greater overall supply chain profits. This research contributes to agricultural supply chain management by providing a theoretically rigorous Nash bargaining mechanism alongside a real-world case study, which harmonizes environmental stewardship and economic viability in agricultural supply chains. The findings offer actionable insights for supply chain managers and policymakers seeking to promote green innovation while maintaining profitability.

Keywords: agricultural supply chains; consumer environmental awareness; Nash bargaining contract; product greenness

check for updates

Academic Editor: Wen-Chyuan Chiang

Received: 18 March 2025
Revised: 21 April 2025
Accepted: 29 April 2025
Published: 1 May 2025

Citation: Wei, G.; Zhang, X.; Bary, B. Enhancing Greenness and Performance of Agricultural Supply Chains with Nash Bargaining Contract Under Consumer Environmental Awareness. *Systems* **2025**, *13*, 337. https://doi.org/10.3390/systems13050337

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Agricultural supply chains are key enablers of food security, rural development, and sustainable agriculture because they orchestrate the movement of agricultural products from farms to consumers. However, they have become the most significant greenhouse gas emitting sector, generating nearly one-quarter of the overall greenhouse gas emissions. To support the United Nations 2030 Agenda for Sustainable Development; that is, to control pollutant emissions, agricultural supply chains should improve greenness by substituting chemical substances such as fertilizers and additives with decomposable and recyclable materials in producing, distributing, and selling agricultural products. As a large

agricultural country, China proposed the green transformation strategy of development mode at the 20th National Congress of the Communist Party of China and introduced the Comprehensive Revitalization of Rural Areas in January 2025. Green agricultural supply chains, conducive to low carbon, high quality, and safety [1,2], are essential components of national strategies for rural revitalization and green transformation in China [3].

At the consumer level, environmental awareness has been spreading widely and rapidly. Evidence from 39 countries shows that environmental awareness results in more eco-friendly actions [4]. For example, consumers want to buy green furniture [5] and electric vehicles [6,7], which emit less pollution. Consumer environmental awareness is especially strong in agricultural supply chains, as consumers are concerned about greener agricultural products in daily meals. As governments are increasingly emphasizing consumer requirement satisfaction in national strategies, it is important to enhance product greenness and the operational performance of agricultural supply chains under consumer environmental awareness.

Investing in eco-friendly technologies is the basic requirement of enhancing product greenness [8]. If the upstream manufacturer burdens all the green costs, he will not carry out enough green investments because of the intrinsic double marginalization. When the downstream retailer proactively shares a portion of the green costs, more investments in eco-friendly technologies will be carried out and the product greenness will be enhanced to a higher level [9]. There is a conflict over the contract ratio. The manufacturer prefers that the retailer covers most of the green investment, whereas the retailer wants a smaller proportion [10]. They have to bargain on the specific contract ratio [11]. In view of agricultural supply chains, this paper designs the optimal green cost-sharing contract with Nash bargaining to enhance agricultural product greenness and supply chain performance.

While the previous literature has proposed similar solutions, there are three overlooked limitations. First, the previous literature omitted consumer environmental awareness. Existing contracts such as cost-sharing contract [12], benefit-sharing contract [13], and smart contract [14] do not incorporate consumer environmental awareness which incentivize consumers to pay more for green products. Second, the previous literature gave little attention to the process of bargaining on contract parameters. The cost-sharing ratios are often treated as given in the way of local equilibria [15,16], and the question of who and how the contract ratios are determined has rarely been examined. Third, the previous literature lacks real-life data from case studies. Numerical analysis such as in [11,17] is widely adopted, but it is insufficient to validate the analytical results of the game theoretical model.

This paper addresses these three limitations of existing research by incorporating widespread consumer environmental awareness and designing a Nash bargaining contract to enhance the greenness and performance of agricultural supply chains. It aims to answer the following important questions.

(1) What is the optimal Nash bargaining contract that incorporates the process of negotiating on green cost-sharing ratios within agricultural supply chains?
(2) How does the Nash bargaining contract impact the greenness and performance of agricultural supply chains?
(3) How does consumer environmental awareness change the impact of the Nash bargaining contract?

To characterize and answer those three questions, this paper develops a game theory model around a supply chain that includes a manufacturer investing in eco-friendly technologies to improve agricultural product greenness, and a retailer sharing part of the green costs to promote green investments. However, there is a conflict over the sharing ratio. The manufacturer hopes the retailer will bear most of the investment, while the retailer prefers to contribute minimally. To answer the first question, this paper adopts the way

of global equilibria, explores and attains the specific negotiated green cost-sharing ratio, which actually determines the optimal bargaining contract. To answer the second question, this paper compares the greenness and performance levels with and without the Nash bargaining contract. To answer the third question, this paper conducts a sensitivity analysis to describe how the impact of the Nash bargaining contract changes with the strength of consumer environmental awareness. The main contributions in this study are concluded as follows.

First, it offers a globally optimal green cost-sharing contract incorporating consumer environmental awareness. By adopting Nash bargaining theory, the specific negotiated green cost-sharing ratio is obtained, which expands the common local equilibria in the previous literature to global equilibria. By incorporating consumer environmental awareness, the interaction between external contract incentive and internal intrinsic willingness to pay for green products is examined.

Second, it systematically analyzes the dual impacts of bargaining on both product greenness and supply chain performance. Through a comparative analysis between scenarios with and without bargaining, this study reveals the dynamic relationship between negotiation outcomes and supply chain efficiency, which was previously unaddressed due to the absence of bargaining assumptions in the prior literature.

Third, it conducts a comprehensive sensitivity analysis on consumer environmental awareness initiatively, manifesting how this internal factor moderates the contract's effectiveness. By examining the interaction between external contract parameters and internal behavioral preferences, this study extends existing research which primarily focused on a single factor.

Fourth, it constructs a validation with a real-life case study. Using real-world data from Guizhou Province's green hot pepper supply chain, the case study validates the model's practicality by demonstrating how the proposed bargaining mechanism enhances greenness and performance in actual agricultural supply chain management, providing valuable insights for industry practitioners.

The remainder of this paper is as follows. Section 2 provides a literature review, and Section 3 describes the target problem. Section 4 constructs and solves models in the competitive scenario without the Nash bargaining contract, the local cooperative scenario with ratio-given contract, and the global cooperative scenario with the Nash bargaining contract. Section 5 discusses the impact of the Nash bargaining and its sensitivity to consumer environmental awareness. Section 6 concludes.

2. Literature Review

Previous related research focused on three main directions: consumer environmental awareness (CEA) in supply chains, greenness-improving supply chain contracts with CEA, and greenness-improving contracts for agricultural supply chains.

2.1. Consumer Environmental Awareness (CEA) in Supply Chains

The influence of consumer environmental awareness (CEA) has been growing rapidly. A study of 39 countries concluded that CEA leads to pro-environmental behaviors [4]. For example, environmentally conscious consumers are more willing to pay for green furniture [5], second-hand clothes [18], and electric vehicles [6,7]. CEA has been extensively discussed in general supply chains from the following two perspectives.

On the one hand, it has been proven that CEA promotes product greenness and improves the overall performance of supply chains. For example, in supply chains with two competing substitutable non-green products and green products, CEA raises the number of orders for eco-friendly products and the retailer's profit [19]. It also increases the

profitability of environmentally friendly manufacturers under low competition intensity and decreases under highly intensive competition [20,21]. Similar to green subsidies, CEA promotes green products but may result in more profits for manufacturers even if they face more fierce competition, which is different from subsidies [22,23]. In dual-channel supply chains with green and regular products, CEA is advantageous in developing green products but disadvantageous in producing regular products [24]. In sustainable supply chains with manufacturers competing in an uncertain market, CEA improves product greenness and manufacturers' profits [21]. In platform supply chains, CEA positively influences product greenness and simultaneously increases the profits of the manufacturer, platform, and retailer [25]. A consumer environmental mindset, which covers CEA and expectation of greenness, raises product greenness and profits of supply chains in sustainable development [26].

On the other hand, studies of the influences of CEA on environmental quality found that CEA promotes supply chain emission reduction and energy efficiency. In supply chains with carbon emission caps, CEA pushes carbon emission reduction directly and indirectly, expanding governmental subsidy policies' positive effects on carbon emission reduction [27,28]. In supply chains with retailer fairness concerns, CEA raises the environmental quality of supply chains, which interacts positively with retailer's fairness concerns in case of favorable disutility [29,30]. In energy-saving supply chains with energy-intensive manufacturers and energy service companies, CEA simultaneously improves energy efficiency and profits of the manufacturer and the energy service company [31,32]. In a green supply chain with regulatory pressure and retailer responsibility, CEA can effectively curb pollution, complementing and expanding the environmental pressure of governmental regulation [33,34]. In e-commerce supply chains, CEA strengthens the manufacturer's preference for collaborators' selling habits and improves operational energy efficiency [23,35].

2.2. Greenness-Improving Supply Chain Contracts with CEA

Supply chain contracts aimed at improving greenness have been widely studied to address the market demand for consumer environmental awareness, and they can be classified into two sub-groups: individual contracts and hybrid contracts.

First, a group of researchers have focused on various individual supply chain contracts, such as revenue-sharing, cost-sharing, and cross-shareholding contracts. Both revenue-sharing contracts and cost-sharing contracts incentivize carbon emission reduction and coordinate marine green fuel supply chains [16]. The profit-sharing contracts can, but the cost-sharing contracts cannot coordinate green dual-channel supply chains [17]. Revenue-sharing contracts can realize the Pareto improvement of members in competitive dual-channel supply chains [36], and promote green investment interacting with fairness concerns [30]. Cost-sharing contracts urge technological innovation of green intelligent home appliance supply chain [37], improve the greenness and overall supply chain profits [11], and enhance carbon emission reduction in green supply chains [13]. CEA can amplify the improvement from cost-sharing contracts [38]. Two-part tariff contracts can screen the asymmetric information of green investment cost in retailer-dominated supply chains [8] and reach the coordinated level of centralized decision-making for prefabricated construction supply chains [39]. Three-echelon manufacturer–transporter–retailer supply chains are another example where CEA supports carbon tax policy in enabling cross-shareholding contracts to achieve coordination and cooperation in carbon emission reduction and pricing decisions [40]. Agency contracts motivate a higher technological level than resale contracts do in green supply chains [41].

Second, relatively little research currently focuses on hybrid supply chain contracts that combine the aforementioned independent contracts. For example, hybrid green costs and revenue-sharing contracts in green supply chains can enhance green innovation and thus product greenness [42], reduce the retail price, expand market demand, promote operational sustainability, achieve coordination [43], and provide individual members with more profits than their decentralized profits [44]. Furthermore, combining consignment and zero wholesale price contracts in supply chains with customized cap-and-trade and CEA can improve efficiency, promote carbon emission reduction, and enhance operational sustainability [28].

However, most of the above literature examined greenness-improving supply chain contracts through the lens of local equilibria, which treat contract ratios as given parameters and thus fail to address the question of who determines the contract ratios and how they are established. Only a few studies, such as [11,30], explored the process through which the upstream and downstream entities bargained over contract ratios, ultimately reaching negotiated terms and thereby achieving global equilibria.

2.3. Greenness-Improving Contracts for Agricultural Supply Chains

Existing work mainly studied three types of contracts for agricultural supply chains to improve greenness: revenue-sharing, cost-sharing, and flexible contracts.

First, revenue-sharing contracts. In fresh agricultural product supply chains considering spatial-temporal costs, profit-sharing contracts based on the principal-agent theory elevate freshness and operational efficiency [45]. Similarly, in green agricultural supply chains with the uncertainty of output and demand, profit-sharing contracts lead to optimal product greenness and coordination [15]. In low-carbon agricultural supply chains with product traceability, a profit-distribution mechanism adopting improved Raiffa value is conducive to improving sustainable development [1]. Ref. [46] designed a profit-sharing contract to raise the freshness and greenness of agricultural product supply chains under community group purchasing, but only reached the local equilibria where the profit-sharing ratio and freshness preservation efforts were exogenous variables. The combination of freshness preservation cost-sharing and revenue-sharing contracts enhances efficiency of fresh mixed dual-channel supply chains [47].

Second, cost-sharing contracts. Green investment cost-sharing contracts strengthen the efforts in agricultural product greenness and improve individual and overall profitability, particularly in two-echelon agricultural product supply chains with freshness and greenness concerns [48]. In the supply chain of fresh agricultural products with two-period prices, cost-sharing contracts can raise the greenness and selling quantity through complete coordination [49]. In three-tier fresh agricultural product supply chains, freshness-keeping cost-sharing contracts motivate freshness-keeping efforts and realize individual and system-wide profit improvements [12]. In fresh agricultural product supply chains, cost-sharing contracts can promote the freshness of agricultural products, and increase sales [50].

Third, flexible contracts. For example, a smart contract based on blockchain technology can raise credibility and traceability by recording the data flow of agricultural supply chains automatically and thereby improve product greenness [14,51]. Moreover, option contracts can decrease retail prices while increasing the order quantity for green agricultural products and improving the overall profits of agricultural supply chains [52]. Similarly, the minimum commitment supply contract can coordinate the community group buying fresh food supply chain and enhance the green efforts [53]. Specifically, scan-based-trading agreements can achieve food waste reduction and coordination in perishable product supply chains [54].

However, CEA has rarely been incorporated into greenness-improving contracts for agricultural supply chains. This is inconsistent with the fact that CEA incentivizes consumers to purchase green organic foods [55] and prompts farmers to conserve land towards sustainable agriculture [56].

2.4. Research Gap

In summary, the extant literature has widely recognized the importance of consumer environmental awareness in supply chains and explored the greenness-improving contracts for both general supply chains and agricultural supply chains. However, there are three-fold gaps as follows. To highlight the contribution of this paper, the main differences between this paper and previous typical highly related literature are listed in Table 1.

Table 1. Main differences between this paper and previous typical highly related literature.

Literature	CEA	Nash Bargaining	Greenness Improving	Agricultural Product
[7,32]	√			
[8,38]	√		√	
[11,30]	√	√	√	
[15,54]	√		√	√
This paper	√	√	√	√

First, there is little research on the bargaining over contract ratios. Although existing work introduced diverse contracts to improve product greenness, they overlooked the process of bargaining on consistent contract parameters. The contract ratios were assumed to be given, and hereby the results belonged to local equilibria.

Second, there is little research on the interaction of consumer environmental awareness and contract design. The widespread consumer environmental awareness may interact with and change the impact of supply chain contracts on the greenness and performance of agricultural supply chains. But existing contracts for agricultural supply chains rarely incorporate consumer environmental awareness.

Third, there is little research on practical evidence supporting analytical findings. Previous contract designs usually adopt mathematic models, especially the game theory, and lack validation from real-life case studies.

To fill the above gaps, this paper incorporates the widespread consumer environmental awareness into agricultural supply chains, designs a Nash bargaining contract meeting global equilibria, examines the enhancement of greenness and supply chain performance, and illustrates the interaction of consumer environmental awareness and Nash bargaining in a theoretical analytical approach with a real-life case study.

3. Problem Description

3.1. Framework

The agricultural supply chain is composed of an upstream manufacturer denoted as he, a downstream retailer denoted as she, and many consumers in the market. Consumers endowed with environmental awareness are willing to pay more for greener products. Green agricultural products can sell at higher prices and larger volumes, resulting in more profits. To achieve such a target, both the manufacturer and the retailer must improve product greenness together. Investing in eco-friendly technologies is an approach to enhance agricultural product greenness, but it leads to green costs. If the manufacturer covers all costs, he will not make enough green investments because of the intrinsic double marginalization. Consequently, cooperation between the manufacturer and retailer is required. A

cost-sharing contract where the downstream retailer proactively shares a portion of the green costs promotes cooperation in green investment to enhance agricultural product greenness. However, sharing green costs introduces a conflict over the contract ratio. The manufacturer prefers that the retailer covers most of the green investment, whereas the retailer wants a smaller proportion. Competition arises in which the manufacturer and the retailer compete to share a smaller proportion of green investments. In practice, they often determine the optimal contract ratio through Nash bargaining. We explore the process and result of reaching the mutually agreed equilibrium ratio. Figure 1 illustrates the basic framework.

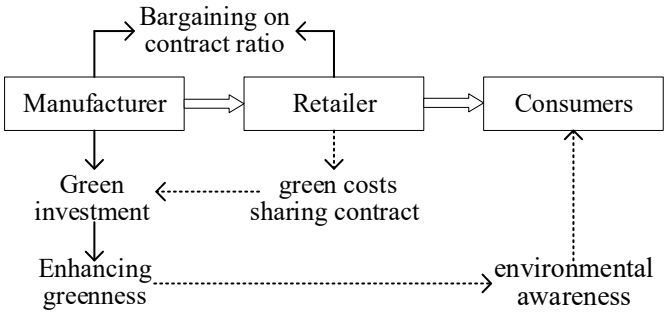


Figure 1. Framework of Nash bargaining contract in agricultural supply chains.

In the following, we describe the design of a Nash bargaining contract, probe how it enhances the product greenness and operational performance of agricultural supply chains, and explore the effect of consumer environmental awareness on the enhancement.

3.2. Methods

In the agricultural supply chain, the retailer interacts with the manufacturer through cooperation coexisting with competition. The moving timeline between the manufacturer and the retailer unfolds in two stages. The first stage involves making decisions on the contract ratio at the cooperative strategic level. The second stage involves making decisions on the greenness and price at the competitive operational level.

Nash bargaining theory is applied at the first cooperation stage. The manufacturer and retailer bargain to reach a mutually agreed contract ratio, which governs their collaboration in sharing the green costs to promote green investment and thus enhance product greenness. Some supply chain literature such as [11,30] has applied Nash bargaining theory to describe the process of negotiating between the manufacturer and retailer.

Stackelberg game, as a research approach commonly adopted in most theoretical model-based supply chain literature such as [8,12], is applied at the second competition stage to describe the leader–follower relationship. The manufacturer as the leader sets the product greenness level and wholesale price to maximize his profit. Then, the retailer as the follower considers the greenness level and wholesale price established by the manufacturer, and thereby determines the retail price to optimize her profit.

Moreover, Stackelberg game is also used to describe the above two-level configuration with backward reduction. First, we derive the optimal product greenness, wholesale price, and retail price in the low operational competitive level, which are all the reaction functions of the given contract ratio and are hereby defined as local scenario. Second, we solve the optimal contract ratio by substituting the above reactions into the objective function of the Nash bargaining problem in the high cooperative strategic level. Third, we substitute the solved contract ratio into the reactions derived in the first step to obtain the optimal values for product greenness, wholesale price, and retail price, which are defined as global equilibria.

Additionally, several other methods are employed. Comparison analysis is used to analyze the impacts of bargaining on the product greenness and operational performance of the agricultural supply chain. Sensitivity analysis is adopted to show how consumer environmental awareness affects the enhancement resulting from bargaining. Case study is applied to validate the theoretical propositions with data from green hot pepper supply chains in Guizhou Province of China. The methods of comparison and sensitivity analysis are popular in theoretical model-based supply chain literature such as [36,46], while few such as [57] incorporated case study into theoretical models to attain practical validation.

3.3. Assumptions

The market demand is described as $D(p, e) = a - \alpha p + \beta e$ employed by [8] wherein parameter a represents the maximized demand, p and α stand for the retail price and price sensitivity coefficient, respectively, e denotes agricultural product greenness, and β indicates consumer environmental awareness. The agricultural product greenness is defined as the pollution level from environmental pollutants such as poly-brominated biphenyls and asbestos during various processes, e.g., planting, processing, and packaging. For example, using an integrated planting and breeding model, the ZHENGDA Group reduces chemical fertilizer use by 50% and cuts emissions of pollutants such as carbon dioxide and sulfides by 99%. This model ensures that manure is fully recycled and returned to the fields as fertilizer. Consumer environmental awareness captures the sensitivity to product greenness, by which consumers will pay more for greener agricultural products. For example, a questionnaire survey in Shanghai 2024 shows that 96.51% of consumers prefer green, eco-friendly products even at higher prices.

The agricultural supply chain is made up of an upstream manufacturer and a downstream retailer. Upstream manufacturers refer to agricultural companies such as New Hope Group and BEIDAHUANG Group, which produce agricultural products with unit costs denoted as c. The manufacturer sells agricultural products of greenness denoted as e to the downstream retailer at the wholesale price w. Downstream retailers, such as Wal-Mart, Carrefour, CR Vanguard, and YONGHUI Superstores, process, package, and retail agricultural products at a retail price p. The following model does not incorporate processing and packaging costs.

The agricultural product greenness depends on investments in eco-friendly technologies made by the manufacturer, who construct pollutant treatment facilities and use organic fertilizers and easily degradable films. The costs of green investment are denoted as $f(e) = \frac{1}{2}ke^2$, where the marginal green cost k is usually assumed to be sufficiently large compared with other parameters and variables, which is popular in the previous literature such as [8,9]. Similar to but different from the above convention, this paper restricts it to $k > \frac{11\beta^2}{8\alpha}$.

3.4. Notations

The notations classified into four categories of symbols, parameters, variables, and superscripts are, respectively, listed in the following Table 2.

Table 2. Notations and their meanings used in the model.

Classifications	Notations	Meanings
Symbols	m	Manufacturer of the agricultural supply chain, the upstream agricultural company, he.
	r	Retailer of the agricultural supply chain, the downstream sales firm, she.
	t	Entire agricultural supply chain system.

Table 2. *Cont.*

Classifications	Notations	Meanings
Parameters	d	Demand for agricultural products.
	a	Utmost potential demand.
	α	Price sensitivity coefficient.
	β	Consumer environmental awareness.
	c	Unit production cost.
	k	Marginal green cost.
	π_m	Profit of the manufacturer.
	π_r	Profit of the retailer.
	π_t	Profit the supply chain system.
	π_A	Social welfare defined in Nash bargaining theory.
	f	Costs of green investment on eco-friendly technologies.
Variables	e	Greenness of agricultural products, established by the manufacturer's green investment.
	w	Wholesale price established by the manufacturer.
	p	Retail price established by the retailer.
	λ	Ratio of green costs shared by the retailer reached through Nash bargaining between the manufacturer and the retailer.
Superscripts	$*$	Optimal results.
	D	Scenario without Nash bargaining contract.
	F	Local scenario with ratio-given contract.
	B	Global scenario with Nash bargaining contract.

4. Model Construction and Solution

4.1. Competitive Scenario Without Nash Bargaining

4.1.1. Optimization Model

In the competitive scenario without Nash bargaining denoted as D, the manufacturer and the retailer maximize their profits independently. First, the manufacturer as the leader sets the product greenness level and wholesale price. Then, the retailer as the follower determines the retail price by considering the greenness level and wholesale price established by the manufacturer.

According to the Stackelberg game, the optimization model is as follows:

$$\begin{aligned} &\max_{w,e} \pi_m^D = (w-c)(a-\alpha p+\beta e) - \tfrac{1}{2}ke^2 \\ &s.t. \quad \max_{p} \pi_r^D = (p-w)(a-\alpha p+\beta e) \end{aligned}$$

4.1.2. Optimal Solution

The solutions of the above model reveal optimal greenness and profitability in the scenario without Nash bargaining contract, which are listed in the following Theorem 1. The proofs of all Theorems, Corollaries, and Propositions can be found in Appendix A.

Theorem 1. *In the scenario without the Nash bargaining contract, the optimal agricultural product greenness is* $e^{D^*} = \frac{(a-\alpha c)\beta}{4\alpha k-\beta^2}$ *, the wholesale price is* $w^{D^*} = \frac{2k(a+\alpha c)-\beta^2 c}{4\alpha k-\beta^2}$ *, the retail price is* $p^{D^*} = \frac{(3a+\alpha c)k-\beta^2 c}{4\alpha k-\beta^2}$ *, the profits of the manufacturer, retailer, and overall system are* $\pi_m^{D^*} = \frac{(-c\alpha+a)^2 k}{8\alpha k-2\beta^2}$ *,* $\pi_r^{D^*} = \frac{\alpha k^2(-c\alpha+a)^2}{(4\alpha k-\beta^2)^2}$ *, and* $\pi_t^{D^*} = \frac{(6\alpha k-\beta^2)(a-\alpha c)^2 k}{2(4\alpha k-\beta^2)^2}$ *, respectively.*

Furthermore, from the above Theorem 1, it is clear that $\frac{\partial e^{D^*}}{\partial \beta} = \frac{(a-\alpha c)(4k\alpha+\beta^2)}{(4k\alpha-\beta^2)^2} > 0$, $\frac{\partial p^{D^*}}{\partial \beta} = \frac{6k\beta(a-\alpha c)}{(4k\alpha-\beta^2)^2} > 0$, and $\frac{\partial \pi_r^{D^*}}{\partial \beta} = \frac{4k^2\alpha\beta(a-\alpha c)^2}{(4k\alpha-\beta^2)^3} > 0$ because of $k > \frac{11\beta^2}{8\alpha}$, $a > \alpha p$, and $p > c$.

Therefore, consumer environmental awareness simultaneously heightens the product greenness, retail price, and profits of the manufacturer and retailer. The manufacturer will invest more in eco-friendly technologies and attain greener agricultural products when consumer environmental awareness strengthens this trend. Although bearing more green costs, the manufacturer gains more profits. The retailer can also profit more because environmentally conscious consumers will purchase greener products at higher prices. Consumer environmental awareness incentivizes the manufacturer and the retailer to interact in a win-win situation by increasing their profits concurrently.

4.2. Local Cooperative Scenario with Given Ratio

4.2.1. Optimization Model

In the local cooperative scenario under the ratio-given contract denoted as F, the ratio of green costs shared by the retailer is given and thus fixed, and the results are all the reactions of the given ratio and hereby actually fall into local equilibria. Although such a scenario has not obtained the optimal contract ratio, it is widely adopted in literature such as in [12,17,36].

Under the given ratio denoted as λ, the manufacturer chooses the product greenness and wholesale price before the retailer decides the retail price to maximize the manufacturer's profit. The intrinsic problem of double marginalization leads to their competition, reflected in the following optimization model:

$$\begin{aligned} &\max_{w,e} \pi_m^F = (w-c)(a-\alpha p+\beta e) - \tfrac{1}{2}(1-\lambda)ke^2 \\ &s.t. \quad \max_{p} \pi_r^F = (p-w)(a-\alpha p+\beta e) - \tfrac{1}{2}\lambda ke^2 \end{aligned}$$

There is a leader–follower relationship of the Stackelberg game. Given the contract ratio λ, the manufacturer decides the product greenness and wholesale price to maximize his profit, followed by the retailer's choice of the retail price to maximize her profit.

4.2.2. Optimal Solution

The solutions to the above model yield optimal decisions for greenness and profitability, as shown in Theorem 2.

Theorem 2. *Given the fixed contract ratio, the optimal agricultural product greenness is modeled as* $e^{F^*}(\lambda) = \frac{(-\alpha c+a)\beta}{4k(1-\lambda)\alpha-\beta^2}$ *while the optimal wholesale and retail prices, respectively are* $w^{F^*}(\lambda) = \frac{2(1-\lambda)(\alpha c+a)k-c\beta^2}{4k(1-\lambda)\alpha-\beta^2}$ *and* $p^{F^*}(\lambda) = \frac{(1-\lambda)(\alpha c+3a)k-c\beta^2}{4k(1-\lambda)\alpha-\beta^2}$. *The optimal profits of the manufacturer, retailer, and supply chain system are* $\pi_m^{F^*}(\lambda) = \frac{k(-c\alpha+a)^2(1-\lambda)}{8k(1-\lambda)\alpha-2\beta^2}$, $\pi_r^{F^*}(\lambda) = \frac{k(-c\alpha+a)^2(2(1-\lambda)^2k\alpha-\lambda\beta^2)}{2(4k(1-\lambda)\alpha-\beta^2)^2}$, *and* $\pi_t^{F^*}(\lambda) = \frac{k(6k(1-\lambda)^2\alpha-\beta^2)(-c\alpha+a)^2}{2(4k(1-\lambda)\alpha-\beta^2)^2}$, *respectively.*

The optimal greenness, wholesale and retail prices, and the profits of the manufacturer, retailer, and supply chain system are all the reaction functions of the given fixed ratio of the local equilibria.

The following corollary 1 can be concluded by integrating Theorems 1 and 2 above.

Corollary 1. *Within the threshold of the contract ratio, the Nash bargaining contract improves the overall agricultural supply chain profits such that* $\pi_t^{D^*}(\lambda) < \pi_t^{F^*}(\lambda)$ *only if* $0 < \lambda < \frac{2(4k\alpha-\beta^2)}{16k\alpha-3\beta^2}$.

Therefore, when the ratio falls within the threshold, the contract for sharing green costs will improve the system profits compared with the scenario without Nash bargaining contract.

The contract enhances the total profit of the agricultural supply chain, creating opportunities for cooperation in green investment. However, the overall system profit must first increase for the manufacturer and retailer to benefit. The retailer is willing to share part of the green costs but remains constrained by a ratio threshold, preventing it from bearing an excessive share.

4.3. Global Cooperative Scenario with Nash Bargaining

4.3.1. Optimization Model

In the global cooperative scenario with Nash bargaining, denoted as B, the manufacturer and retailer jointly determine the contract ratio under a green cost-sharing agreement by negotiating with each other. Because it attains the optimal contract ratio, some literature such as [11,30] applies it to explore the final optimal product greenness.

With the restriction displayed in Corollary 1, the optimization model for global scenario is formulated by applying Nash bargaining theory [58,59].

$$\max_{\lambda} \pi_A = [\pi_m^{F^*}(\lambda) - \pi_m^{D^*}][\pi_r^{F^*}(\lambda) - \pi_r^{D^*}]$$
$$s.t. \begin{cases} 0 < \lambda < \frac{2(4k\alpha-\beta^2)}{16k\alpha-3\beta^2} \\ \pi_m^{F^*}(\lambda) > \pi_m^{D^*}, \pi_r^{F^*}(\lambda) > \pi_r^{D^*} \end{cases}$$

As defined in Nash bargaining theory, social welfare is represented by π_A. The manufacturer's profit $\pi_m^{D^*}$ and the retailer's profit $\pi_r^{D^*}$ in the absence of a Nash bargaining contract are given in Theorem 1. The optimal profits of the manufacturer $\pi_m^{F^*}(\lambda)$ and the retailer $\pi_r^{F^*}(\lambda)$ under the given contract ratio λ are provided in Theorem 2.

Then, substituting them into the optimization model, it is extended accordingly as follows.

$$\max_{\lambda} \pi_A = \left[\frac{k(-c\alpha+a)^2(1-\lambda)}{8k(1-\lambda)\alpha-2\beta^2} - \frac{(-c\alpha+a)^2k}{8\alpha k-2\beta^2}\right]\left[\frac{k(-c\alpha+a)^2(2k\alpha(1-\lambda)^2-\lambda\beta^2)}{2(4k(1-\lambda)\alpha-\beta^2)^2} - \frac{\alpha k^2(-c\alpha+a)^2}{(4\alpha k-\beta^2)^2}\right]$$
$$s.t. \begin{cases} 0 < \lambda < \frac{2(4k\alpha-\beta^2)}{16k\alpha-3\beta^2} \\ \frac{k(-c\alpha+a)^2(1-\lambda)}{8k(1-\lambda)\alpha-2\beta^2} > \frac{(-c\alpha+a)^2k}{8\alpha k-2\beta^2} \\ \frac{k(-c\alpha+a)^2(2k\alpha(1-\lambda)^2-\lambda\beta^2)}{2(4k(1-\lambda)\alpha-\beta^2)^2} > \frac{\alpha k^2(-c\alpha+a)^2}{(4\alpha k-\beta^2)^2} \end{cases}$$

4.3.2. Optimal Solution

- Optimal Negotiated Contract Ratio

Solving the optimization model in global scenario with Nash bargaining contract leads to the optimal negotiated contract ratio, as illustrated in the following Theorem 3.

Theorem 3. *The optimal contract ratio is* $\lambda^{B^*} = \frac{\beta^2(4\alpha k-\beta^2)}{\alpha k(24\alpha k-5\beta^2)}$, *which represents the portion* λ^{B^*} *that the retailer will share of the green costs for eco-friendly technologies.*

The optimal contract ratio $\lambda^{B^*} = \frac{\beta^2(4\alpha k-\beta^2)}{\alpha k(24\alpha k-5\beta^2)}$ is influenced by three key factors: the price sensitivity coefficient, marginal green costs, and the intensity of consumer environmental awareness. This ratio is refined to a precise value through mutual negotiation between the manufacturer and the retailer, making it more operationally effective than the range described in Corollary 1, $0 < \lambda < \frac{2(4k\alpha-\beta^2)}{16k\alpha-3\beta^2}$. This refinement enhances the practicality of implementing the contract in real-world agricultural supply chains.

On the one hand, the direct effect of consumer environmental awareness on the contract ratio is captured in Corollary 2.

Corollary 2. *Consumer environmental awareness positively influences the retailer's willingness to share a more significant portion of the green investment costs, namely* $\frac{\partial \lambda^{B^*}}{\partial \beta} > 0$.

As consumer environmental awareness increases, the retailer is incentivized to contribute more towards green costs, strengthening cooperation within the agricultural supply chain. This reduces the green investment burden on the manufacturer and drives additional investments in eco-friendly technologies, further improving product greenness. Thereby, consumer environmental awareness influences both the structure of the green cost-sharing contract and the overall greenness of the agricultural supply chain. Specifically, using the case study data in the following Section 5.1, Figure 2 illustrates how the negotiated contract ratio evolves in response to increasing consumer environmental awareness. It is clear that, as consumers pay more attention to environmental issues, the retailer becomes more willing to share green costs.

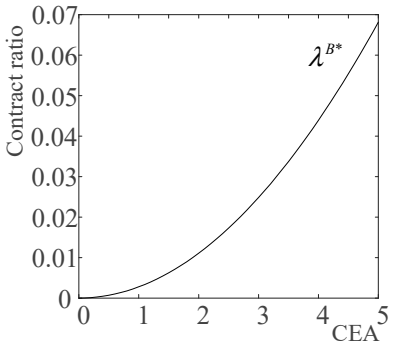


Figure 2. Trend of contract ratio changing with CEA.

On the other hand, the indirect effects of consumer environmental awareness on the contract ratio, which captures the mediation through the marginal green cost and price sensitivity, are shown in Corollary 3.

Corollary 3. *Both the marginal green cost and the price sensitivity factors negatively influence the retailer's willingness to share more green costs; that is,* $\frac{\partial \lambda^{B^*}}{\partial k} < 0$, $\frac{\partial \lambda^{B^*}}{\partial \alpha} < 0$.

From Corollary 3, the following two points can be found.

First, the marginal green cost negatively affects the contract ratio. As marginal green costs increase, the retailer becomes less inclined to share a larger portion of green costs. Conversely, as marginal green costs decrease, the retailer is more willing to bear a larger portion of green costs. Therefore, technological progress driven by sustainable research and development programs can help reduce marginal green costs, thereby enhancing the greenness of agricultural supply chains.

Second, price sensitivity also negatively affects the contract ratio. The more consumers are sensitive to price, the less willing the retailer is to absorb additional green costs. As consumer willingness to pay a higher price for green agricultural products diminishes due to price sensitivity, the retailer's profits reduce, lowering the retailer's share of green costs.

- Optimal Agricultural Product Greenness

Building on the contract ratio from Theorem 3 and on the base of the reactive choices of the manufacturer for a given ratio from Theorem 2, the optimal product greenness under the Nash bargaining contract is determined and shown in Theorem 4.

Theorem 4. *In the global cooperative scenario with the Nash bargaining contract, the optimal agricultural product greenness is* $e^{B^*} = \frac{\beta(a-\alpha c)(24\alpha k - 5\beta^2)}{12\alpha k(8\alpha k - 5\beta^2) + 9\beta^4}$.

This optimal greenness results from the combined effects of several factors, including consumer environmental awareness, marginal green costs, and price sensitivity.

On the one hand, the direct effect of consumer environmental awareness on optimal product greenness is illustrated in Corollary 4.

Corollary 4. *Consumer environmental awareness enhances the agricultural product greenness, namely* $\frac{\partial e^{B^*}}{\partial \beta} > 0$.

Consumers with stronger environmental awareness are more inclined to pay a premium for greener products. As their environmental consciousness increases, the retailer, according to Corollary 2, is more willing to share a larger portion of the green investment costs. As a result, the manufacturer is incentivized to increase his investments in eco-friendly technologies, leading to higher product greenness.

On the other hand, the indirect effect of consumer environmental awareness on the product greenness via the marginal green cost and the price sensitivity is reflected in Corollary 5.

Corollary 5. *The marginal green cost and price sensitivity negatively affect the agricultural product greenness; that is,* $\frac{\partial e^{B^*}}{\partial k} < 0$, $\frac{\partial e^{B^*}}{\partial \alpha} < 0$.

From Corollary 5, the following two points can be found.

First, as the marginal green cost rises, product greenness decreases. Although consumers with high environmental awareness are willing to pay more for greener products, higher marginal green costs force the agricultural supply chain to shoulder more significant green investment costs. Therefore, advancements in technology that reduce marginal green costs are essential for improving the greenness of the agricultural supply chain.

Second, price sensitivity also diminishes product greenness. Consumers' willingness to pay for green products weakens as they become more sensitive to the price. This trade-off between the cost of a product and its greenness reduces the likelihood of consumers paying a premium for eco-friendly products. Consequently, as price sensitivity increases, the marginal revenue from green investments declines, lowering product greenness.

- Optimal Supply Chain Profitability

Building on the contract ratio from Theorem 3 and on the base of the reactive choices of the manufacturer, retailer, and system for a given ratio from Theorem 2, the optimal profits for the manufacturer, the retailer, and the overall system under the Nash bargaining contract can be determined as the following Theorem 5.

Theorem 5. *In the global cooperative scenario with the Nash bargaining contract, the optimal wholesale price and retail price are* $w^{B^*} = \frac{6k\alpha(\alpha c(8k\alpha-7\beta^2)+a(8k\alpha-3\beta^2))+\beta^4(7\alpha c+2a)}{3\alpha(4k(8\alpha k-5\beta^2)+3\beta^4)}$ *and* $p^{B^*} = \frac{\alpha^2 ck(8\alpha k-11\beta^2)+3ak\alpha(8\alpha k-3\beta^2)+\beta^4(2\alpha c+a)}{\alpha(4k\alpha(8\alpha k-5\beta^2)+3\beta^4)}$, *respectively, while the optimal profits of the manufacturer, the retailer, and the system are* $\pi_m^{B^*} = \frac{(3\alpha k(8\alpha k-3\beta^2))(a-\alpha c)^2}{24\alpha^2 k(8\alpha k-5\beta^2)+18\alpha\beta^4}$, $\pi_r^{B^*} = \frac{(18\alpha^2k^2(8\alpha k-3\beta^2)+\beta^6)(a-\alpha c)^2}{18\alpha(4\alpha k-\beta^2)^2(8\alpha k-3\beta^2)}$, $\pi_t^{B^*} = \frac{(6\alpha k-\beta^2)(9\alpha k(8\alpha k-3\beta^2)+2\beta^4)(a-\alpha c)^2}{18\alpha(4\alpha k-\beta^2)^2(8\alpha k-3\beta^2)}$, *respectively.*

Once the contract ratio is determined through bargaining, as shown in Theorem 3, product prices and the overall profitability of the supply chain become clearly defined.

Furthermore, it holds that $\frac{\partial w^{B^*}}{\partial \beta} = \frac{4k\beta(8k\alpha-\beta^2)(24k\alpha-7\beta^2)(a-\alpha c)}{3(4k\alpha(8k\alpha-5\beta^2)+3\beta^4)^2} > 0$, $\frac{\partial p^{B^*}}{\partial \beta} = \frac{2k\beta(8k\alpha-\beta^2)(24k\alpha-7\beta^2)(a-\alpha c)}{(4k\alpha(8k\alpha-5\beta^2)+3\beta^4)^2} > 0$, $\frac{\partial \pi_m^{B^*}}{\partial \beta} = \frac{k\beta(8k\alpha-\beta^2)(24k\alpha-7\beta^2)(a-\alpha c)^2}{3(4k\alpha(8k\alpha-5\beta^2)+3\beta^4)^2} > 0$,

$\frac{\partial \pi_r^{B^*}}{\partial \beta} = \frac{4k\beta(144k^2\alpha^2(4k\alpha-3\beta^2)+\beta^4(105k\alpha-8\beta^2))(a-\alpha c)^2}{9(4k\alpha-\beta^2)^3(8k\alpha-3\beta^2)^2} > 0$, and $\frac{\partial \pi_t^{B^*}}{\partial \beta} = \frac{4k\beta(8k^2\alpha^2(576k\alpha-408\beta^2)+\beta^4(744k\alpha-53\beta^2))(a-\alpha c)^2}{9(4k\alpha-\beta^2)^3(8k\alpha-3\beta^2)^2} > 0$ from $k > \frac{11\beta^2}{8\alpha}$, $a > \alpha p$, and $p > c$. These observations indicate that consumer environmental awareness positively influences product pricing and supply chain profitability. More environmentally conscious consumers are willing to pay higher prices for greener agricultural products. As a result, the manufacturer will invest more in eco-friendly technologies, leading to greener products. Although manufacturers bear higher green investment costs, they ultimately gain greater profits. Similarly, while retailers contribute a larger share of these costs, as shown in Corollary 2, they also experience increased profitability. This cost–profit correlation creates a reinforcing positive cycle. The effect of consumer willingness to purchase greener products at higher prices outweighs the burden of increased green investment costs. Consequently, consumer environmental awareness fosters stronger collaboration between manufacturers and retailers, driving them to engage more actively in the market. This dynamic interaction leads to a win-win outcome where both parties experience concurrent profit growth.

5. Comparisons and Sensitivity Analysis

5.1. Case Study: Data from Green Hot Pepper Supply Chains in Guizhou Province of China

Guizhou Province has developed China's largest hot pepper industry, a key pillar of the region's agricultural economy. With a stable planting area of 5 million acres and an annual yield of 7 million tons, the industry generates 28 billion yuan in primary output and 18 billion yuan in processing output. As the industry scales, sustainability has become an essential focus, driving leading manufacturers to adopt greener agricultural practices.

ZH Food, a major player in Guizhou's hot pepper supply chain, has taken the lead in integrating high-quality seeds, advanced techniques, and sustainable farming methods to enhance the environmental friendliness of hot pepper cultivation. The company cultivates locally renowned, high-yield varieties, achieving an intensive seedling cultivation rate of over 90% on large-scale, standardized bases and ensuring 100% coverage of top-tier varieties. ZH Food promotes innovative farming techniques to improve efficiency and sustainability, including floating seedling raising, mechanical ridging and film covering, mechanical drilling and transplanting, and targeted irrigation and fertilization. Additionally, the company has advanced ecological green cultivation by developing scientifically validated fertilizers and implementing water reservation management, mechanized harvesting, optimized planting density, and timely irrigation, leveraging modern agricultural machinery for land preparation and ridge planting. ZH Food has established over 100 ecological cultivation demonstration sites through these initiatives, significantly improving product sustainability. A testament to this progress is the ZUNJIAO 222 variety, which delivers double the usual yield—1500 kg per acre compared to the standard 750 kg—while maintaining high environmental standards.

As a leading hot pepper supply chain manufacturer, ZH Food distributes Guizhou hot peppers nationwide and globally through offline and online channels. The China Hot Pepper City, the country's largest hot pepper trading hub, and MaiLa.com, a specialized e-commerce platform, serve as critical distribution channels. Beyond facilitating trade, these platforms are vital in promoting green agriculture. Recognizing the costs associated with sustainability, downstream retailers such as China Hot Pepper City and MaiLa.com have actively supported investments in eco-friendly technologies. By sharing part of the green costs incurred by upstream manufacturers, they create a more equitable and sustainable supply chain that incentivizes environmental responsibility while maintaining profitability.

In order to protect business secrets and be consistent with the setting of the above theoretical model, we standardize ZH Food's operational data, and denote the utmost

potential demand as $a = 5000$, price sensitivity coefficient as $\alpha = 3$, marginal green cost as $k = 20$, and unit production cost as $c = 1$. Additionally, to illustrate the effect of consumer environmental awareness, let its degree change in the interval $0 \leq \beta \leq 5$ freely. The standardized data are illustrated in Table 3.

Table 3. Standardized numerical values of some key parameters in the case study.

Parameters	Meanings	Standardized Values
a	Utmost potential demand.	5000
α	Price sensitivity coefficient.	3
c	Unit production cost.	1
k	Marginal green cost.	20
β	Consumer environmental awareness.	[0, 5]

Following the analytical framework of [60], we illustrate the theoretical findings about the impact of Nash bargaining on product greenness and supply chain performance numerically and visually.

5.2. Comparisons: Enhancements from Nash Bargaining

By comparing the outcomes with and without Nash bargaining contract, we can explore how Nash bargaining improves product greenness and operational performance of agricultural supply chains.

5.2.1. Enhancement of Product Greenness

From Theorems 1 and 4, the impact of the Nash bargaining contract on the product greenness is demonstrated as the following Proposition 1.

Proposition 1. *The Nash bargaining contract enhances the agricultural product greenness, namely* $e^{D^*} < e^{B^*}$.

Without the Nash bargaining contract, the manufacturer and the retailer maximize their profits individually, with the manufacturer bearing all green investments, leading to the inherent issue of double marginalization. However, under Nash bargaining, the retailer shares a portion of the green investment costs through mutual bargaining, incentivizing the manufacturer to increase green investments, thereby improving product greenness. As a result, the Nash bargaining contract not only meets the growing market demand for green products but also strengthens the sustainability of agricultural supply chains.

5.2.2. Enhancement of Product Price

From Theorems 1 and 2, the impact of the Nash bargaining contract on the agricultural product pricing is outlined as the following Proposition 2.

Proposition 2. *The Nash bargaining contract increases the product price, namely* $p^{D^*} < p^{B^*}$.

The price of agricultural products under the Nash bargaining contract is higher than that in the scenario without it.

Compared to the scenario without Nash bargaining contract, the retailer encourages the manufacturer to increase green investments by sharing part of the green costs. Although the manufacturer bears only a fraction of these costs instead of all, the total green investment increases, requiring the manufacturer to allocate more resources. To compensate for these additional costs, the manufacturer raises the wholesale price. In turn, the retailer adjusts her marginal price, reflecting both the partial burden of green costs and the higher wholesale

price set by the manufacturer. As a result, the retailer has to raise the final retail price. Through this mechanism, the Nash bargaining contract mitigates the issue of double marginalization to a certain extent.

5.2.3. Enhancement of Supply Chain Profitability

From Theorems 1 and 4, the impact of the Nash bargaining contract on the profitability of the agricultural supply chain is demonstrated as the following Proposition 3.

Proposition 3. *The Nash bargaining contract enhances the overall profitability of the agricultural supply chain, benefiting the manufacturer, the retailer, and the entire system; that is,* $\pi_m^{B^*} > \pi_m^{D^*}$, $\pi_r^{B^*} > \pi_r^{D^*}$, $\pi_t^{B^*} > \pi_t^{D^*}$.

The Nash bargaining contract fosters a win-win situation where the overall system profitability increases, and both the manufacturer and the retailer achieve higher individual profits. First, the Nash bargaining contract strengthens cooperation between the manufacturer and the retailer by facilitating mutual bargaining. This partially alleviates the issue of double marginalization, leading to greater overall system profitability. Second, the contract enhances product greenness by requiring the retailer to share some green costs. Consequently, the manufacturer is incentivized to invest further in green initiatives, as outlined in Theorem 1. Since consumers are sensitive to product greenness, the market demand is likely to expand. Third, the Nash bargaining contract leads to higher product prices. Environmentally conscious consumers are willing to pay a premium for greener agricultural products. As a result, both the manufacturer and the retailer can sell more products at higher prices, with the additional revenue surpassing the increased green investment costs.

In summary, Propositions 1, 2, and 3 highlight that the Nash bargaining contract requires more green investments, higher product greenness, higher product prices, and improves supply chain profitability. The contract drives a larger sales volume and prices at the supply chain level, providing strong economic incentives for further green investments. At the societal level, it enhances product greenness, aligning with the growing trend of green consumption while contributing to sustainable and balanced economic and environmental development.

5.3. Sensitivity Analysis: Effect of CEA on the Enhancements

Consumer environmental awareness tends to amplify the enhancement impacts of the Nash bargaining contract. Specifically, it often strengthens the degree to which the Nash bargaining contract enhances product greenness and supply chain profitability.

5.3.1. Amplifying the Enhancement of Product Greenness

From Theorems 1 and 4, the effect of consumer environmental awareness on the extent to which the Nash bargaining contract enhances product greenness can be summarized as the following Proposition 4:

Proposition 4. *Consumer environmental awareness strengthens the ability of the Nash bargaining contract to enhance product greenness, namely* $\frac{\partial(e^{B^*}-e^{D^*})}{\partial\beta} > 0$.

The extent to which the Nash bargaining contract enhances product greenness, denoted as $e^{B^*} - e^{D^*}$ in Theorems 1 and 4, increases with the degree of consumer environmental awareness, denoted as β. The stronger the consumer environmental awareness, the greater the positive impact of the Nash bargaining contract on product greenness.

The impact of the Nash bargaining contract on product greenness can be categorized into two aspects: the aspect of direction, which determines whether product greenness improves or declines, and the aspect of magnitude, which measures the extent of this change. As established in Proposition 1, the Nash bargaining contract improves, rather than reduces, product greenness. Meanwhile, Proposition 4 demonstrates that the magnitude of this improvement increases with the intensity of consumer environmental awareness. Thus, while the Nash bargaining contract solely determines the direction, the magnitude results from the interaction between the Nash bargaining contract and consumer environmental awareness.

The effect of consumer environmental awareness on product greenness enhancement reflects the synergy between these two factors. Accordingly, fostering environmental awareness among consumers can improve agricultural product greenness in two ways: by strengthening the market's green orientation and by amplifying the greenness enhancement achieved through the Nash bargaining contract.

On the basis of data from green hot pepper supply chains in Guizhou Province of China, Figure 3 illustrates how the increment of product greenness resulting from Nash bargaining changes with the varying degree of consumer environmental awareness.

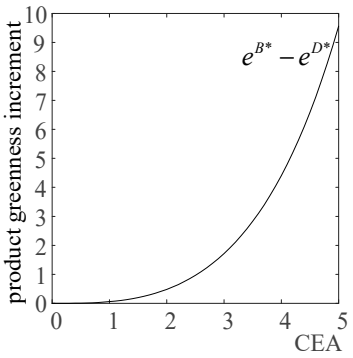


Figure 3. Trend of product greenness increment changing with CEA.

Figure 3 shows that product greenness enhancement remains consistently positive, regardless of consumer environmental awareness levels. This trend confirms that Nash bargaining always promotes product greenness, a conclusion supported by Proposition 1. Additionally, when consumer environmental awareness falls between 0 and 2, its effect on the degree of product greenness enhancement is minimal. However, within the range of 2–5, its effect becomes significant, verifying Theorem 4 and Corollary 4. Lastly, as consumer environmental awareness increases, product greenness enhancement continues to rise. This reflects the synergistic interaction between Nash bargaining and consumer awareness, further supporting Propositions 1 and 4.

5.3.2. Amplifying the Enhancement of Product Price

From Theorems 1 and 5, the effect of consumer environmental awareness on the extent to which the Nash bargaining contract influences agricultural product prices is summarized as the following Proposition 5:

Proposition 5. *Consumer environmental awareness strengthens the ability of the Nash bargaining contract to enhance product prices; that is,* $\frac{\partial(p^{B^*} - p^{D^*})}{\partial \beta} > 0$.

The extent to which the Nash bargaining contract raises product prices, denoted as $p^{B^*} - p^{D^*}$ in Theorems 1 and 5, increases with the level of consumer environmental

awareness, denoted as β. The stronger the consumer environmental awareness, the more significantly the Nash bargaining contract enhances product prices.

Similar to its impact on product greenness, the Nash bargaining contract's impact on product price can be analyzed in terms of direction and magnitude. As established in Proposition 2, the Nash bargaining contract increases, rather than decreases, product prices. Proposition 5 further indicates that the magnitude of this price increase grows as consumer environmental awareness strengthens. While the direction is determined solely by the Nash bargaining contract, the magnitude is jointly influenced by the Nash bargaining contract and consumer environmental awareness. Moreover, the amplification of product price enhancement due to consumer environmental awareness directly results from the amplified greenness enhancement. Since environmentally conscious consumers are willing to pay higher prices for greener agricultural products, their awareness reinforces the impact of the Nash bargaining contract.

5.3.3. Amplifying the Enhancement of Supply Chain Profitability

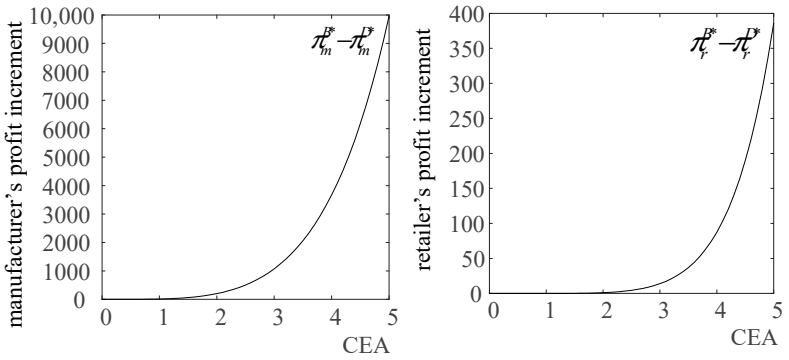
From Theorems 1 and 5, the effect of consumer environmental awareness on the extent to which the Nash bargaining contract enhances supply chain profitability is summarized as the following Proposition 6:

Proposition 6. *Consumer environmental awareness strengthens the Nash bargaining contract's ability to enhance overall agricultural supply chain profitability, including the profits of the manufacturer, the retailer, and the entire system; that is,* $\frac{\partial(\pi_m^{B^*}-\pi_m^{D^*})}{\partial\beta} > 0$, $\frac{\partial(\pi_r^{B^*}-\pi_r^{D^*})}{\partial\beta} > 0$, $\frac{\partial(\pi_t^{B^*}-\pi_t^{D^*})}{\partial\beta} > 0$.

The extent to which the Nash bargaining contract enhances system-wide, manufacturer, and retailer profits, denoted as $\pi_t^{B^*} - \pi_t^{D^*}$, $\pi_m^{B^*} - \pi_m^{D^*}$, $\pi_r^{B^*} - \pi_r^{D^*}$ in Propositions 1 and 5, increases with the level of consumer environmental awareness, denoted as β. The stronger the consumer environmental awareness, the more significantly the Nash bargaining contract improves supply chain profitability. In other words, consumer environmental awareness leads to an improvement in the agricultural supply chain's profitability.

Similar to those with product greenness and price, the impact of the Nash bargaining contract on supply chain profitability consists of two aspects: the direction aspect, which determines whether profitability increases or decreases, and the magnitude aspect, which measures the extent of the change. Proposition 3 establishes that the Nash bargaining contract enhances, rather than reduces, supply chain profitability. Proposition 6 further indicates that the magnitude of this enhancement increases with consumer environmental awareness. While the direction is determined solely by the Nash bargaining contract, the magnitude results from the interaction between the Nash bargaining contract and consumer environmental awareness. The effect of consumer environmental awareness on amplifying product price enhancement dominates its impact on greenness enhancement. Consequently, the overall performance of the agricultural supply chain experiences a Pareto improvement.

The relationship between consumer environmental awareness and the manufacturer's profit and retailer's profit increments from Nash bargaining is illustrated in Figure 4a (manufacturer's profit) and Figure 4b (retailer's profit).



(**a**) (**b**)

Figure 4. Trend of system profit increment changing with CEA. (**a**) Manufacturer's profit increment; (**b**) Retailer's profit increment.

Figure 4 highlights three important findings. First, both the manufacturer's profit and retailer's profit increments remain consistently positive, regardless of the level of consumer environmental awareness. This confirms that Nash bargaining effectively enhances supply chain profitability, aligning with Proposition 3. Second, when the level of consumer environmental awareness is between 0 and 3, its effect on profit increments is negligible. However, in the range of 3–5, its effect becomes significant, further validating Propositions 3 and 6. Finally, although increased consumer environmental awareness boosts the profits of both the manufacturer and the retailer, the manufacturer's profit grows at a significantly higher rate than the retailer's. This not only supports Propositions 1 and 6 but also underscores the manufacturer's dominant position in agricultural supply chains, extending the conclusions of Propositions 3 and 6.

Summarizing Propositions 4–6, consumer environmental awareness strengthens the impacts of the Nash bargaining contract, thereby amplifying the enhancements in agricultural product greenness and supply chain profitability. Consequently, fostering environmental awareness among consumers improves the operational performance of agricultural supply chains and promotes the economic and environmental balance necessary for sustainable agricultural development.

6. Conclusions

6.1. Main Findings

This paper integrates the widespread consumer environmental awareness into agricultural supply chains. It explores a Nash bargaining contract to enhance product greenness and operational performance, aligning with evolving development strategies and consumer expectations. The pivotal points of this research endeavor are encapsulated as follows.

First, bargaining between the manufacturer and the retailer determines the optimal contract ratio. The green cost-sharing ratio defines the optimal Nash bargaining contract and each participant's burden of green investment. Factors such as price sensitivity coefficient, marginal green cost, and consumer environmental awareness influence this ratio. Especially as consumer environmental awareness increases, the retailer is willing to share more green costs. This upgrades the local equilibria adopted widely in the previous literature such as in [36,41] to the global equilibria, and the given sharing ratio is replaced by obtaining the optimal value of the sharing ratio. According to the conflict that both the manufacturer and the retailer prefer a smaller proportion, it is more reasonable and practical to assume that the contract ratio is determined through Nash bargaining than to assume that it is given by others.

Second, the Nash bargaining contract enhances product greenness, improves operational performance, and raises the retail price of agricultural products. The all-round enhancement and Pareto improvement from Nash bargaining makes it possible for the manufacturer and the retailer to negotiate mutually on the sharing ratio, and creates conditions for resolving the conflict that both the manufacturer and the retailer prefer bearing a smaller portion of green costs. By comparing scenarios with and without bargaining, we reveal the dynamic relationship between negotiation outcomes and supply chain efficiency, which was previously unaddressed due to ignoring the process of bargaining in the prior literature.

Third, consumer environmental awareness amplifies the benefits of Nash bargaining. Environmentally conscious consumers are willing to pay a premium for greener products, prompting retailers to share a portion of green investment costs. As a result, manufacturers are incentivized to invest more in eco-friendly technologies. Interestingly, despite bearing some green costs, retailers still achieve higher profits due to increased unit revenue and higher sales volumes. The interaction between internal consumer preferences and external contract design leads to greener products, higher retail prices, and improved supply chain profitability. This underscores the importance of incorporating consumer environmental awareness into agricultural supply chain strategies, and hereby fills the gap that consumer environmental awareness has rarely been incorporated into greenness-improving contracts for agricultural supply chains.

6.2. Managerial Implications

Based on these findings, several managerial and policy recommendations for supply chain managers and policymakers in the agricultural sector are proposed.

First, supply chain managers should prioritize investments in eco-friendly technologies. Manufacturers should embrace green strategies by substituting chemical-based substances, including pesticides, fertilizers, and herbicides, with biodegradable and recyclable alternatives. Meanwhile, retailers should actively share green investment costs through mutual bargaining. This approach creates a win-win situation where manufacturers and retailers achieve higher profits while consumers benefit from greener products and greater value.

Second, supply chain managers should implement advanced smart information management systems. From a business perspective, manufacturers and retailers can accurately assess key factors such as price sensitivity, marginal green costs, and consumer environmental awareness, enabling them to negotiate more effectively. From a consumer perspective, having access to transparent product greenness information empowers them to make well-informed purchasing decisions, which in turn enhances market efficiency and boosts the overall performance of the supply chain.

Third, government policymakers should actively promote and cultivate consumer environmental awareness. As our findings have shown, stronger consumer awareness magnifies the benefits of Nash bargaining, driving greater product greenness and higher profitability across the supply chain. Notably, this enhancement is automatic and cost-free, making it a highly effective long-term strategy. Encouraging consumer environmental awareness will bring about extensive and enduring benefits for sustainability and economic growth.

6.3. Future Directions

In practice, agricultural supply chains often are endowed with an unbalanced power structure. For example, NEW HOPE GROUP as an upstream agribusiness dominates its fresh pork supply chains, while JD FRESH as a downstream retailer dominates its

retail supply chains. However, this study assumes that manufacturers and retailers have equal bargaining power in negotiations. Consequently, future research should explore asymmetric bargaining models to better capture the diverse influences of manufacturers and retailers on contract ratios within agricultural supply chains.

Author Contributions: Writing—original draft preparation, G.W.; writing—review and editing, X.Z.; validation, B.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Humanities and Social Science Foundation of Chongqing Education Commission (Grant No. 24SKJD094) and the National Social Science Foundation of China (Grant No. 24FGLB076).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: Gratitude is expressed to the Chongqing Education Commission for its support.

Conflicts of Interest: Author Binta Bary was employed by the company West African Oil Pipeline (Benin) Company S.A. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix A

Appendix A.1. Proof of Theorem 1

Firstly, the first-order and second-order partial derivatives of π_r^D on p are, respectively, $\frac{\partial \pi_r^D}{\partial p} = (w-2p)\alpha + \beta e + a$ and $\frac{\partial^2 \pi_r^D}{\partial p^2} = -2\alpha$. From $\frac{\partial^2 \pi_r^D}{\partial p^2} = -2\alpha < 0$ and $\frac{\partial \pi_r^D}{\partial p} = (w-2p)\alpha + \beta e + a = 0$, the optimal reaction of p with respective to w and e is denoted as $\overline{p}^D(w,e) = \frac{\alpha w + \beta e + a}{2\alpha}$. Secondly, substituting $\overline{p}^D(w,e)$ into $\pi_m^D = (w-c)(a-\alpha p+\beta e) - \frac{1}{2}ke^2$, yield $\pi_m^D = (w-c)(\frac{a-\alpha w+\beta e}{2}) - \frac{ke^2}{2}$. The first-order partial derivatives of π_m^D about w and e are $\frac{\partial \pi_m^D}{\partial w} = \frac{a+\beta e+\alpha(c-2w)}{2}$ and $\frac{\partial \pi_m^D}{\partial e} = \frac{(w-c)\beta}{2} - ke$, respectively. Then, the Hessian matrix of π_m^D on w and e is $H_1 = \begin{bmatrix} -\alpha & \frac{\beta}{2} \\ \frac{\beta}{2} & -k \end{bmatrix}$, which is negative because $-\alpha < 0$ and $\alpha k - \frac{\beta^2}{4} > 0$. Combining the first-order conditions $\frac{\partial \pi_m^D}{\partial e} = \frac{(w-c)\beta}{2} - ke = 0$ and $\frac{\partial \pi_m^D}{\partial w} = \frac{a+\beta e+\alpha(c-2w)}{2} = 0$, the optimal product greenness and retail price can be solved as $e^{D*} = \frac{(a-\alpha c)\beta}{4\alpha k-\beta^2}$ and $w^{D*} = \frac{2k(a+\alpha c)-\beta^2 c}{4\alpha k-\beta^2}$. Thirdly, substituting e^{D*} and p^{D*} into π_m^D, π_r^D, and $\pi_t^D = \pi_m^D + \pi_r^D$, respectively, yield the max profits $\pi_m^{D*} = \frac{(-c\alpha+a)^2 k}{8\alpha k-2\beta^2}$, $\pi_r^{D*} = \frac{\alpha k^2(-c\alpha+a)^2}{(4\alpha k-\beta^2)^2}$, and $\pi_t^{D*} = \frac{(6\alpha k-\beta^2)(a-\alpha c)^2 k}{2(4\alpha k-\beta^2)^2}$. ***Q. E. D.***

Appendix A.2. Proof of Theorem 2

Firstly, the first-order and second-order partial derivatives of π_r^F on p are, respectively, $\frac{\partial \pi_r^F}{\partial p} = (-2p+w)\alpha + \beta e + a$ and $\frac{\partial^2 \pi_r^F}{\partial p^2} = -2\alpha$. From $\frac{\partial^2 \pi_r^F}{\partial p^2} = -2\alpha < 0$ and $\frac{\partial \pi_r^F}{\partial p} = (-2p+w)\alpha + \beta e + a = 0$, the optimal reaction of p with respective to w and e is denoted as $\overline{p}^S(w,e) = \frac{a+\beta e+\alpha w}{2\alpha}$. Secondly, substituting $\overline{p}^S(w,e)$ into $\pi_m^F = (w-c)(a-\alpha p+\beta e) - \frac{1}{2}(1-\lambda)ke^2$, yield $\pi_m^F = (w-c)(\frac{a-\alpha w+\beta e}{2}) - \frac{1}{2}(1-\lambda)ke^2$. The first-order partial derivatives of π_r^F about e and w, respectively, are $\frac{\partial \pi_m^F}{\partial e} = \frac{(w-c)\beta}{2} - (1-\lambda)ke$ and $\frac{\partial \pi_m^F}{\partial w} = \frac{\alpha(c-2w)+\beta e+a}{2}$. Then, the Hessian matrix of π_r^F on e and w is $H_2 = \begin{bmatrix} -(1-\lambda)k & \frac{\beta}{2} \\ \frac{\beta}{2} & -\alpha \end{bmatrix}$, which is negative because $-\alpha < 0$ and $\alpha(1-\lambda)k - \frac{\beta^2}{4} > 0$. Combining the first-order conditions $\frac{\partial \pi_m^F}{\partial e} = \frac{(w-c)\beta}{2} - (1-\lambda)ke = 0$ and $\frac{\partial \pi_m^F}{\partial w} = \frac{\alpha(c-2w)+\beta e+a}{2}$, the

optimal product greenness and retail price can be solved as $e^{F^*}(\lambda) = \frac{(-\alpha c+a)\beta}{4k(1-\lambda)\alpha-\beta^2}$ and $w^{F^*}(\lambda) = \frac{2(1-\lambda)(\alpha c+a)k-c\beta^2}{4k(1-\lambda)\alpha-\beta^2}$. Thirdly, substituting e^{F^*} and p^{F^*} into π_m^F, π_r^F, and $\pi_t^F = \pi_m^F + \pi_r^F$, respectively, yields the max profits $\pi_m^{F^*}(\lambda) = \frac{k(-c\alpha+a)^2(1-\lambda)}{8k(1-\lambda)\alpha-2\beta^2}$, $\pi_r^{F^*}(\lambda) = \frac{k(-c\alpha+a)^2((1-\lambda)^2k\alpha-\frac{1}{2}\lambda\beta^2)}{(4k(1-\lambda)\alpha-\beta^2)^2}$, and $\pi_t^{F^*}(\lambda) = \frac{k(6k(1-\lambda)^2\alpha-\beta^2)(-c\alpha+a)^2}{2(4k(1-\lambda)\alpha-\beta^2)^2}$. ***Q. E. D.***

Appendix A.3. Proof of Corollary 1

By $\pi_t^{D^*} = \frac{(6\alpha k-\beta^2)(a-\alpha c)^2k}{2(4\alpha k-\beta^2)^2}$ and $\pi_t^{F^*}(\lambda) = \frac{k(6k(1-\lambda)^2\alpha-\beta^2)(-c\alpha+a)^2}{2(4k(1-\lambda)\alpha-\beta^2)^2}$, it is clear that $\pi_t^{D^*}(\lambda) < \pi_t^{F^*}(\lambda)$ equals $\frac{k(6k(1-\lambda)^2\alpha-\beta^2)(-c\alpha+a)^2}{2(4k(1-\lambda)\alpha-\beta^2)^2} > \frac{(6\alpha k-\beta^2)(a-\alpha c)^2k}{2(4\alpha k-\beta^2)^2}$, whose optimal solution is $0 < \lambda < \frac{2(4k\alpha-\beta^2)}{16k\alpha-3\beta^2}$. ***Q. E. D.***

Appendix A.4. Proof of Theorem 3

First, all constraints are assumed to be relaxation conditions. Then, regarding the objective function, the first-order partial derivatives and second-order partial derivatives of π_A with respect to λ are $\frac{\partial\pi_A}{\partial\lambda} = \frac{(-24\alpha^2k^2\lambda+\alpha\beta^2k(\lambda+4)-\beta^4)k^2\lambda(a-c\alpha)^4\beta^4}{128(4\alpha k-\beta^2)^2(4k(1-\lambda)\alpha+\beta^2)^4}$ and $\frac{\partial^2\pi_A}{\partial\lambda^2} = \frac{8(8\alpha^2k^2(\lambda(1+\lambda)\alpha k-(5\lambda^2+17\lambda+2)\beta^2)+\beta^4(2(11\lambda+4)\alpha k-\beta^2))k^2(a-\alpha c)^4\beta^4}{8(4\alpha k-\beta^2)^2(\beta^2-4k(1-\lambda)\alpha)^5}$, respectively. From $k > \frac{11\beta^2}{8\alpha}$ and $0 < \lambda < 1$, yield $\frac{\partial^2\pi_A}{\partial\lambda^2} < 0$. Then, from the first-order condition $\frac{\partial\pi_A}{\partial\lambda} = \frac{(-24\alpha^2k^2\lambda+\alpha\beta^2k(\lambda+4)-\beta^4)k^2\lambda(a-c\alpha)^4\beta^4}{128(4\alpha k-\beta^2)^2(4k(1-\lambda)\alpha+\beta^2)^4} = 0$, yield $\lambda^{B^*} = \frac{\beta^2(4\alpha k-\beta^2)}{\alpha k(24\alpha k-5\beta^2)}$, which proves the first constraint is relaxed really. The second and third constraints are proven to be slack in the following Proposition 3.

Q. E. D.

Appendix A.5. Proof of Corollary 2

By $\lambda^{B^*} = \frac{\beta^2(4\alpha k-\beta^2)}{\alpha k(24\alpha k-5\beta^2)}$ in Theorem 3, yield $\frac{\partial\lambda^{B^*}}{\partial\beta} = \frac{96k\alpha\beta(2k\alpha-\beta^2)+10\beta^5}{k\alpha(24k\alpha-5\beta^2)^2}$. From $k > \frac{11\beta^2}{8\alpha}$, yield $\frac{96k\alpha\beta(2k\alpha-\beta^2)+10\beta^5}{k\alpha(24k\alpha-5\beta^2)^2} > 0$. ***Q. E. D.***

Appendix A.6. Proof of Corollary 3

By $\lambda^{B^*} = \frac{\beta^2(4\alpha k-\beta^2)}{\alpha k(24\alpha k-5\beta^2)}$ in Theorem 3, yield $\frac{\partial\lambda^{B^*}}{\partial k} = \frac{-48k\alpha\beta^2(2k\alpha-\beta^2)-5\beta^6}{k^2\alpha(24k\alpha-5\beta^2)^2}$ and $\frac{\partial\lambda^{B^*}}{\partial\alpha} = \frac{-48k\alpha\beta^2(2k\alpha-\beta^2)-5\beta^6}{k\alpha^2(24k\alpha-5\beta^2)^2}$. From $k > \frac{11\beta^2}{8\alpha}$, yield $\frac{-48k\alpha\beta^2(2k\alpha-\beta^2)-5\beta^6}{k^2\alpha(24k\alpha-5\beta^2)^2} < 0$ and $\frac{-48k\alpha\beta^2(2k\alpha-\beta^2)-5\beta^6}{k\alpha^2(24k\alpha-5\beta^2)^2} < 0$. ***Q. E. D.***

Appendix A.7. Proof of Theorem 4

Substituting the sharing ratio $\lambda^{B^*} = \frac{\beta^2(4\alpha k-\beta^2)}{\alpha k(24\alpha k-5\beta^2)}$ into the reaction function of greenness on given ratio $e^{F^*}(\lambda) = \frac{(-\alpha c+a)\beta}{4k(1-\lambda)\alpha-\beta^2}$, yield $e^{B^*} = \frac{\beta(a-\alpha c)(24\alpha k-5\beta^2)}{12\alpha k(8\alpha k-5\beta^2)+9\beta^4}$. ***Q. E. D.***

Appendix A.8. Proof of Corollary 4

By $e^{B^*} = \frac{\beta(a-\alpha c)(24\alpha k-5\beta^2)}{12\alpha k(8\alpha k-5\beta^2)+9\beta^4}$, yield $\frac{\partial e^{B^*}}{\partial\beta} = \frac{(4k\alpha(192k^2\alpha^2-29\beta^4)+15\beta^6)(a-\alpha c)}{3(4k\alpha(8k\alpha-5\beta^2)+3\beta^4)^2}$, which is greater than zero because $k > \frac{11\beta^2}{8\alpha}$ and $a > \alpha c$. ***Q. E. D.***

Appendix A.9. Proof of Corollary 5

By $e^{B^*} = \frac{\beta(a-\alpha c)(24\alpha k-5\beta^2)}{12\alpha k(8\alpha k-5\beta^2)+9\beta^4}$, yield $\frac{\partial e^{B^*}}{\partial k} = -\frac{4\beta\alpha(a-\alpha c)(192k^2\alpha^2-80\beta^2\alpha k+7\beta^4)}{3(4k\alpha(8k\alpha-5\beta^2)+3\beta^4)^2}$ and $\frac{\partial e^{B^*}}{\partial \alpha} = -\frac{\beta(768a\alpha^2k^3+320\alpha\beta^2(a-\alpha c)k^2+4\beta^4(36\alpha c+7a)k-15\beta^6 c)}{3(4k\alpha(8k\alpha-5\beta^2)+3\beta^4)^2}$. Furthermore, from $k > \frac{11\beta^2}{8\alpha}$ and $a > \alpha c$, it is clear that $-\frac{4\beta\alpha(a-\alpha c)(192k^2\alpha^2-80\beta^2\alpha k+7\beta^4)}{3(4k\alpha(8k\alpha-5\beta^2)+3\beta^4)^2} < 0$ and $-\frac{\beta(768a\alpha^2k^3+320\alpha\beta^2(a-\alpha c)k^2+4\beta^4(36\alpha c+7a)k-15\beta^6 c)}{3(4k\alpha(8k\alpha-5\beta^2)+3\beta^4)^2} < 0$. ***Q. E. D.***

Appendix A.10. Proof of Theorem 5

Substituting the sharing ratio $\lambda^{B^*} = \frac{\beta^2(4\alpha k-\beta^2)}{\alpha k(24\alpha k-5\beta^2)}$ into the reactions function on given ratio, respectively, $w^{F^*}(\lambda) = \frac{2(1-\lambda)(\alpha c+a)k-c\beta^2}{4k(1-\lambda)\alpha-\beta^2}$, $p^{F^*}(\lambda) = \frac{(1-\lambda)(\alpha c+3a)k-c\beta^2}{4k(1-\lambda)\alpha-\beta^2}$, $\pi_m^{F^*}(\lambda) = \frac{k(-c\alpha+a)^2(1-\lambda)}{8k(1-\lambda)\alpha-2\beta^2}$, $\pi_r^{F^*}(\lambda) = \frac{k(-c\alpha+a)^2(2(1-\lambda)^2k\alpha-\lambda\beta^2)}{2(4k(1-\lambda)\alpha-\beta^2)^2}$, and $\pi_t^{F^*}(\lambda) = \frac{k(6k(1-\lambda)^2\alpha-\beta^2)(-c\alpha+a)^2}{2(4k(1-\lambda)\alpha-\beta^2)^2}$, yield the corresponding final optimal wholesale price, retail price, profit of system $w^{B^*} = \frac{6k\alpha(\alpha c(8k\alpha-7\beta^2)+a(8k\alpha-3\beta^2))+\beta^4(7\alpha c+2a)}{3\alpha(4k(8\alpha k-5\beta^2)+3\beta^4)}$, $p^{B^*} = \frac{\alpha^2ck(8\alpha k-11\beta^2)+3a\alpha k(8\alpha k-3\beta^2)+\beta^4(2\alpha c+a)}{\alpha(4k\alpha(8\alpha k-5\beta^2)+3\beta^4)}$, $\pi_m^{B^*} = \frac{(3\alpha k(8\alpha k-3\beta^2))(a-\alpha c)^2}{24\alpha^2k(8\alpha k-5\beta^2)+18\alpha\beta^4}$, $\pi_r^{B^*} = \frac{(18\alpha^2k^2(8\alpha k-3\beta^2)+\beta^6)(a-\alpha c)^2}{18\alpha(4\alpha k-\beta^2)^2(8\alpha k-3\beta^2)}$, and $\pi_t^{B^*} = \frac{(6\alpha k-\beta^2)(9\alpha k(8\alpha k-3\beta^2)+2\beta^4)(a-\alpha c)^2}{18\alpha(4\alpha k-\beta^2)^2(8\alpha k-3\beta^2)}$. ***Q. E. D.***

Appendix A.11. Proof of Proposition 1

By Theorem 1 and 5, yield $e^{B^*} - e^{D^*} = \frac{4(a-\alpha c)\beta^3}{12\alpha k(8\alpha k-5\beta^2)+9\beta^4}$. From $a > \alpha c$ and $k > \frac{11\beta^2}{8\alpha}$, yield $e^{B^*} > e^{D^*}$. ***Q. E. D.***

Appendix A.12. Proof of Proposition 2

By Theorem 1 and 5, yield $p^{B^*} - p^{D^*} = \frac{(a-\alpha c)\beta^4}{\alpha(4k\alpha-\beta^2)(8k\alpha-3\beta^2)}$. From $a > \alpha c$ and $k > \frac{11\beta^2}{8\alpha}$, yield $p^{B^*} > p^{D^*}$. ***Q. E. D.***

Appendix A.13. Proof of Proposition 3

According to $\pi_t^{D^*}$ given in Theorem 1 and $\pi_t^{B^*}$ given in Theorem 5, it is clear that $\pi_t^{B^*} - \pi_t^{D^*} = \frac{(6k\alpha-\beta^2)(a-\alpha c)^2(288\alpha^3k^3-36\alpha^2(5\beta^2+2)k^2+\alpha\beta^2(35\beta^2+27)k-2\beta^6)}{18\alpha(4\alpha k-\beta^2)^2(8\alpha k-3\beta^2)}$. From $k > \frac{11\beta^2}{8\alpha}$, yield $\pi_t^{B^*} > \pi_t^{D^*}$. Similarly, $\pi_m^{B^*} - \pi_m^{D^*} = \frac{\beta^4(a-\alpha c)^2}{24\alpha^2k(8\alpha k-5\beta^2)+18\alpha\beta^4} > 0$, and thereby $\pi_m^{B^*} > \pi_m^{D^*}$; $\pi_r^{B^*} - \pi_r^{D^*} = \frac{(a-\alpha c)^2\beta^6}{18\alpha(4k\alpha-\beta^2)^2(8k\alpha-3\beta^2)} > 0$, and thereby $\pi_r^{B^*} > \pi_r^{D^*}$. ***Q. E. D.***

Appendix A.14. Proof of Proposition 4

According to e^{D^*} given in Theorem 1 and e^{B^*} in Theorem 4, it can be found that $\frac{\partial(e^{B^*}-e^{D^*})}{\partial\beta} = \frac{4(a-\alpha c)^2\beta^2(4\alpha k(24\alpha k-5\beta^2)-3\beta^4)}{3(4\alpha k(8\alpha k-5\beta^2)+3\beta^4)^2}$. From $k > \frac{11\beta^2}{8\alpha}$, yield $e^{B^*} > e^{D^*}$. ***Q. E. D.***

Appendix A.15. Proof of Proposition 5

According to p^{D^*} given in Theorem 1 and p^{B^*} in Theorem 5, it can be found that $\frac{\partial(p^{B^*}-p^{D^*})}{\partial\beta} = \frac{8\beta^3k(a-\alpha c)(16\alpha k-5\beta^2)}{3(4\alpha k(8\alpha k-5\beta^2)+3\beta^4)^2}$. From $a > \alpha p, p > c$ and $k > \frac{11\beta^2}{8\alpha}$, yield $e^{B^*} > e^{D^*}$. ***Q. E. D.***

Appendix A.16. Proof of Proposition 6

According to $\pi_t^{D^*}$ given in Theorem 1 and $\pi_t^{B^*}$ given in Theorem 5, it is clear $\frac{\partial(\pi_t^{B^*}-\pi_t^{D^*})}{\partial\beta} = \frac{2\beta(a-\alpha c)^2(192k^3\alpha^3-16k^2\alpha^2\beta^2-24k\alpha\beta^4+3\beta^5)}{9\alpha(4k\alpha-\beta^2)^3(8k\alpha-3\beta^2)^2}$. From $k > \frac{11\beta^2}{8\alpha}$, yield $\frac{\partial(\pi_t^{B^*}-\pi_t^{D^*})}{\partial\beta} > 0$. Similarly, $\frac{\partial(\pi_m^{B^*}-\pi_m^{D^*})}{\partial\beta} = \frac{4\beta^3k(a-\alpha c)^2(16\alpha c-5\beta^2)}{3(4\alpha k(8\alpha k-5\beta^2)+3\beta^4)^2}$, and thereby $\frac{\partial(\pi_m^{B^*}-\pi_m^{D^*})}{\partial\beta} > 0$; $\frac{\partial(\pi_r^{B^*}-\pi_r^{D^*})}{\partial\beta} = \frac{32k\beta^5(3k\alpha-\beta^2)(a-\alpha c)^2}{9(4k\alpha-\beta^2)^3(8k\alpha-3\beta^2)^2}$, and thereby $\frac{\partial(\pi_r^{B^*}-\pi_r^{D^*})}{\partial\beta} > 0$. **Q. E. D.**

References

1. Jiang, J.D.; Jiang, S.H.; Xu, G.Y.; Li, J. Research on pricing strategy and profit-distribution mechanism of green and low-carbon agricultural products' traceability supply chain. *Sustainability* **2024**, *16*, 2087. [CrossRef]
2. Li, F.C.; Du, Y.D.; Gui, Y.T.; Wen, J. Research on the optimization of supply chain decisions for green agricultural products based on farmers' risk preferences and disaster year subsidies. *Int. J. Ind. Eng. Comput.* **2025**, *16*, 275–294. [CrossRef]
3. Wang, W.K.; Cao, Q.L.; Liu, Y.; Zhou, C.; Jiao, Q.H.; Mangla, S.K. Risk management of green supply chains for agricultural products based on social network evaluation framework. *Bus. Strat. Environ.* **2024**, *33*, 4913–4934. [CrossRef]
4. Yang, M.X.; Tang, X.; Cheung, M.L.; Zhang, Y. An institutional perspective on consumers' environmental awareness and pro–environmental behavioral intention: Evidence from 39 countries. *Bus. Strat. Environ.* **2021**, *30*, 566–575. [CrossRef]
5. Xu, X.P.; Wang, S.Y.; Yu, Y.G. Consumer's intention to purchase green furniture: Do health consciousness and environmental awareness matter? *Sci. Total Environ.* **2020**, *704*, 135275. [CrossRef] [PubMed]
6. He, X.H.; Hu, Y.Y.; Hong, Z.Y. Consumers' intention to purchase electric vehicles: The moderating role of environmental awareness. *J. Environ. Plann. Manag.* **2025**, *68*, 935–956. [CrossRef]
7. Wang, Y.Z.; Witlox, F. Global trends in electric vehicle adoption and the impact of environmental awareness, user attributes, and barriers. *Energy Rep.* **2025**, *13*, 1125–1137. [CrossRef]
8. Yu, N.; Xiong, M.N.; Zhou, P.; Bai, Q.G. Contract design for a retailer-dominated supply chain under asymmetric green investment cost information. *Oper. Res.* **2025**, *25*, 15. [CrossRef]
9. Liao, C.H.; Lu, Q.H.; Ghamat, S.; Cai, H.H. Blockchain adoption and coordination strategies for green supply chains considering consumer privacy concern. *Eur. J. Oper. Res.* **2025**, *323*, 525–539. [CrossRef]
10. Ghosh, D.; Shah, J. Supply chain analysis under green sensitive consumer demand and cost sharing contract. *Int. J. Prod. Econ.* **2015**, *164*, 319–329. [CrossRef]
11. Shen, J.Y.; Yan, H.Y.; Sheng, L.X.; Zhang, B.; Shi, Y.J.; Shen, S.S. Pricing decision in an uncertain green product supply chain under cost sharing contract. *Expert Syst. Appl.* **2024**, *250*, 123899. [CrossRef]
12. Wang, X.F.; Xiong, M.F.; Yang, F.; Shi, W.Q. Decision-making and coordination of a three-tier fresh agricultural product supply chain considering dynamic freshness-keeping effort. *Int. Trans. Oper. Res.* 2025, early access. [CrossRef]
13. Wang, Y.Y.; Fang, L.; Jiang, M.C. Optimal contract design for carbon emission reduction in a green supply chain: Monetary incentive vs. symbolic incentive. *Manag. Decis. Econ.* **2024**, *45*, 3152–3162. [CrossRef]
14. Daraghmi, E.Y.; Jayousi, S.; Daraghmi, Y.A.; Daraghma, R.S.M.; Fouchal, H. Smart contracts for managing the agricultural supply chain: A practical case study. *IEEE Access* **2024**, *12*, 125462–125479. [CrossRef]
15. Wang, Q.Y.; Ni, M.H.; Wen, W.; Qi, R.J.; Zhang, Q.W. Study on sustainable operation mechanism of green agricultural supply chain based on uncertainty of output and demand. *Sustainability* **2024**, *16*, 5460. [CrossRef]
16. Xu, C.Y.; Wang, Y.Q.; Yao, D.L.; Qiu, S.Y.; Li, H. Research on the coordination of a marine green fuel supply chain considering a cost-sharing contract and a revenue-sharing contract. *Front. Mar. Sci.* **2025**, *12*, 1552136. [CrossRef]
17. Das, R.; Barman, A.; Roy, B.; De, P.K. Pricing and greening strategies in a dual-channel supply chain with cost and profit-sharing contracts. *Environ. Dev. Sustain.* **2023**, *25*, 5053–5086. [CrossRef]
18. Chen, X.Q.; Tabata, T. Circular economy in fashion: Consumer awareness and life-style, and environmental impact on second-hand clothes. *J. Mater. Cycles Waste Manag.* **2024**, *26*, 3876–3892. [CrossRef]
19. Li, Z.T.; Zhang, C.H.; Kong, W.; Lyu, R.X. The optimal product-line design and incentive mechanism in a supply chain with customer environmental awareness. *J. Ind. Manag. Optim.* **2023**, *19*, 730–759. [CrossRef]
20. Liu, Z.G.; Anderson, T.D.; Cruz, J.M. Consumer environmental awareness and competition in two-stage supply chains. *Eur. J. Oper. Res.* **2012**, *218*, 602–613. [CrossRef]
21. Han, X.Y.; Zhou, Y.Y. Responding to consumer environmental awareness: A variational inequality approach to green manufacturing optimization. *Comput. Ind. Eng.* **2024**, *191*, 110174. [CrossRef]
22. Yu, Y.G.; Han, X.Y.; Hu, G.P. Optimal production for manufactures considering consumer environmental awareness and green subsidies. *Int. J. Prod. Econ.* **2016**, *182*, 397–408. [CrossRef]

23. Zhou, H.; Duan, Y.R. Online channel structures for green products with reference greenness effect and consumer environmental awareness (CEA). *Comput. Ind. Eng.* **2022**, *170*, 108350. [CrossRef]
24. Ge, G.H.; Wang, D.P.; Epede, M.B. Pricing policies of green dual-channel supply chain with fairness concerns and altruistic preferences based on consumers' environmental awareness and channel preference. *Int. J. Environ. Res. Public Health* **2022**, *19*, 13564. [CrossRef] [PubMed]
25. Tao, F.; Zhou, Y.; Bian, J.S.; Lai, K.K. Agency selling or reselling? Channel selection of green products with consumer environmental awareness. *Int. J. Logist. Res. Appl.* **2024**, *27*, 326–345. [CrossRef]
26. Cao, X.G.; Hu, M.T.; Wen, H.; Huang, K. Green supply chain decision-making and coordination considering consumer's environmental mindset and fairness concerns in the context of sustainable development. *Environ. Dev. Sustain.* **2024**, *26*, 28485–28517. [CrossRef]
27. Xu, L.; Wang, C.X.; Miao, Z.; Chen, J.H. Governmental subsidy policies and supply chain decisions with carbon emission limit and consumer's environmental awareness. *RAIRO-Oper. Res.* **2019**, *53*, 1675–1689. [CrossRef]
28. Tat, R.; Heydari, J.; Mlinar, T. Supply chain coordination: The application of consignment and zero wholesale price contracts under customized cap-and-trade and consumers' environmental awareness. *Int. J. Retail Distrib. Manag.* **2023**, *51*, 1388–1412. [CrossRef]
29. Zhang, L.H.; Zhou, H.; Liu, Y.Y.; Lu, R. Optimal environmental quality and price with consumer environmental awareness and retailer's fairness concerns in supply chain. *J. Clean. Prod.* **2019**, *213*, 1063–1079. [CrossRef]
30. Chen, L.; Shen, H.; Liu, Q.R.; Rao, C.J.; Li, J.; Goh, M. Joint optimization on green investment and contract design for sustainable supply chains with fairness concern. *Ann. Oper. Res.* 2025, early access. [CrossRef]
31. Ouyang, J.J.; Fu, J. Optimal strategies of improving energy efficiency for an energy-intensive manufacturer considering consumer environmental awareness. *Int. J. Prod. Res.* **2020**, *58*, 1017–1033. [CrossRef]
32. Sun, H.X.; Li, H. Pricing strategies for end-of-life vehicle regarding reward-penalty mechanism and customers' environmental awareness. *RAIRO-Oper. Res.* **2024**, *58*, 397–421. [CrossRef]
33. Cheng, S.S.; Zhang, F. Regulatory pressure and consumer environmental awareness in a green supply chain with retailer responsibility: A dynamic analysis. *Manag. Decis. Econ.* **2022**, *43*, 1133–1151. [CrossRef]
34. Dai, Y.; Wu, H.L.; Pan, H.L.; Luo, L.J. The manufacturers' strategy selection of carbon emission reduction and pricing under carbon trading policy and consumer environmental awareness. *Front. Environ. Sci.* **2023**, *11*, 1120165. [CrossRef]
35. Li, J.; Wang, H.Y.; Shi, V.; Sun, Q. Manufacturer's choice of online selling format in a dual-channel supply chain with green products. *Eur. J. Oper. Res.* **2024**, *318*, 131–142. [CrossRef]
36. Barman, A.; Das, R.; De, K.P.; Sana, S.S. Pricing policies for a competitive dual-channel supply chain with green investment and sales effort under revenue-sharing contract. *RAIRO-Oper. Res.* **2024**, *58*, 3985–4012. [CrossRef]
37. Che, C.; Li, Q.; Yin, Q.; Li, S.H.; Zheng, H.X.; Geng, X. Research on technological innovation and marketing publicity decision of green intelligent home appliance supply chain considering consumer subsidy and cost-sharing contract. *Front. Energy Res.* **2023**, *11*, 1259566. [CrossRef]
38. Ghosh, S.K.; Goswami, P. Green initiative in a two-echelon supply chain with coordination and contract. *RAIRO-Oper. Res.* **2024**, *58*, 1147–1161. [CrossRef]
39. Jiang, W.; Yuan, M. Coordination of prefabricated construction supply chain under cap-and-trade policy considering consumer environmental awareness. *Sustainability* **2022**, *14*, 5724. [CrossRef]
40. Zhang, Y.F.; Qin, Y. Carbon emission reductions, pricing and social welfare of three-echelon supply chain considering consumer environmental awareness under carbon tax policy. *Front. Environ. Sci.* **2022**, *10*, 969613. [CrossRef]
41. Li, B.; Wen, S.N.; Li, X.F.; Cheng, Y.P. Contract adoption of motivating green technological innovation in a supply chain. *Int. Trans. Oper. Res.* 2025, early access. [CrossRef]
42. Zhang, G.M.; Jin, H.; Xu, S.S. A study on green innovation behavior of eldercare products supply chain based on the perspective of cost-sharing-revenue-sharing contract. *Environ. Eng. Manag. J.* **2024**, *23*, 2607–2615. [CrossRef]
43. Heydari, J.; Govindan, K.; Basiri, Z. Balancing price and green quality in presence of consumer environmental awareness: A green supply chain coordination approach. *Int. J. Prod. Res.* **2021**, *59*, 1957–1975. [CrossRef]
44. Samanta, B.; Giri, B.C.; Chaudhuri, K. A supply chain model with two competitive buyers under a hybrid greening cost and revenue-sharing contract. *J. Manag. Anal.* **2023**, *10*, 270–307. [CrossRef]
45. Li, M.; He, L.N.; Yang, G.C.; Lian, Z. Profit-sharing contracts for fresh agricultural products supply chain considering spatio-temporal costs. *Sustainability* **2022**, *14*, 2315. [CrossRef]
46. Li, M.; Lian, Z.; Yang, G.C.; Li, L.N. Profit-sharing contract of the fresh agricultural products supply chain under community group purchase mode considering freshness preservation efforts. *Sustainability* **2023**, *15*, 7572. [CrossRef]
47. Xiao, Q.; Zhang, Q.Y.; Gao, Z.Y. A quantum gaming study on the pricing of fresh mixed dual-channel supply chains considering the level of preservation effort. *J. Ind. Manag. Optim.* **2025**, *21*, 79–102. [CrossRef]

48. Tan, M.Y.; Tu, M.L.; Wang, B.; Zou, T.Y.; Cheng, H. A two-echelon agricultural product supply chain with freshness and greenness concerns: A cost-sharing contract perspective. *Complexity* **2020**, *2020*, 8560102. [CrossRef]
49. Yan, B.; Liu, G.D.; Wu, X.H.; Wu, J.W. Decision-making on the supply chain of fresh agricultural products with two-period price and option contract. *Asia-Pac. J. Oper. Res.* **2021**, *38*, 2050038. [CrossRef]
50. Xi, J.; Lai, L.L.; Li, Y.; Yang, D.T. The coordination mechanism of fresh agricultural products supply chain: A game-theoretic approach considering retailer's fairness concern and price competition. *Econ. Comput. Econ. Cybern. Stud. Res.* **2025**, *59*, 120–137.
51. Wang, L.; Xu, L.Q.; Zheng, Z.Y.; Liu, S.Y.; Li, X.T.; Cao, L.; Li, J.B.; Sun, C.H. Smart contract-based agricultural food supply chain traceability. *IEEE Access* **2021**, *9*, 9296–9307. [CrossRef]
52. Zhao, Z.; Cheng, Y. Two-stage decision model of fresh agricultural products supply chain based on option contract. *IEEE Access* **2022**, *10*, 119777–119795. [CrossRef]
53. Wang, X.J.; He, T.R. The community group buying models and strategic management for fresh food under supply uncertainty. *Comput. Ind. Eng.* **2025**, *204*, 111083. [CrossRef]
54. Mohamadi, N.; Transchel, S.; Fransoo, J.C. Coordinate or collaborate? Reducing food waste in perishable-product supply chains. *Eur. J. Oper. Res.* **2025**, *323*, 795–809. [CrossRef]
55. Li, Y.; Shan, B. Exploring the role of health consciousness and environmental awareness in purchase intentions for green-packaged organic foods: An extended TPB model. *Front. Nutr.* **2025**, *12*, 1528016. [CrossRef] [PubMed]
56. Khan, F.; Abbass, K.; Qun, W.; Grebinevych, O. Moderating role of digital media on environmental awareness and environmental beliefs to shape farmers' behavioral intentions towards sustainable agricultural land conservation. *J. Environ. Manag.* **2025**, *373*, 123745. [CrossRef]
57. Shi, L.G.; Pang, T.; Peng, H.J.; Feng, X. Green technology outsourcing for agricultural supply chains with government subsidies. *J. Clean. Prod.* **2024**, *436*, 140674. [CrossRef]
58. Xia, L.L.; Li, K.; Xiong, Y. The influence of distributional fairness concern on quality co-creation mobile application supply chain: Exogenous and endogenous revenue-retaining mechanisms. *Transp. Res. Part E-Logist. Transp. Rev.* **2025**, *195*, 103966. [CrossRef]
59. Li, H.M.; Zhang, Z.Y.; Wang, W.; Liao, F.N. Optimal relation-specific investment, financing, and the supply chain capital structure under uncertainty. *Int. Rev. Financ. Anal.* **2025**, *97*, 103854. [CrossRef]
60. Li, Z.P.; Wang, J.J.; Perera, S.; Shi, J. Coordination of a supply chain with Nash bargaining fairness concerns. *Transp. Res. Part E-Logist. Transp. Rev.* **2022**, *159*, 102627. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.