Contract Design for Enhancing Green Food Material Production Effort with Asymmetric Supply Cost Information

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Abstract: In order to improve green performance and achieve sustainability goals, food companies see the need to adopt green supply chain management. However, ensuring a green supply is a tough task since food companies do not always have full information of their suppliers' efforts in improving their green performance. This information asymmetry issue will lead the food producers to make poor decisions and cause a profit loss. Therefore, to fill this research gap, this study investigates a two-stage supply chain, which consists of one dominated food producer and a food supplier who has private knowledge of its green food material producing (GFMP) cost. To figure out how green performance is the major parameter that influences the decision-making of supply chain members under information asymmetry, this study first expands demand functions for both a food supplier and a producer, considering their influence on the green degree of the food products and associated consumer acceptance. It is found that under certain conditions, information sharing will improve the supplier's green performance and increase the food producer's profit. This study then presents the prerequisite of green cost information sharing by the food supplier. Furthermore, a newly designed menu of contracts, which combine the wholesale price contract and cost sharing contract, is proposed for the asymmetric information case to incentivize the food supplier to disclose the green effort information and improve the environmental and economic performance of the food supply chain. Numerical experiments are conducted through a case analysis to illustrate and validate the proposed models.

Keywords: green supply chain; information asymmetry; contract design; cost sharing contract; food supply chain

1. Introduction

The food industry is a critical industry that promotes pollution free products [1]. Sustainable nutrition and food safety are key themes within the United Nations Sustainable Development Goals [2]. Meanwhile, on the market side, increasing environmental awareness of consumers improves green product demand [3–6]. Due to the increasing pressures from stakeholders and potential opportunities for green marketing, food companies are driven to adopt green supply chain management (GSCM) to improve their green performance and realize sustainable development [7]. However, ensuring a green supply is a tough task due to the cost and information asymmetry in food supply chains [8]. On one hand, the perishable nature and fragmented supply of the food materials always gives rise to problems of coordination and quality control, which increases transaction costs [9]. On the other hand, information asymmetry leads to uncertainties in transactions in the whole supply chain [10,11].

Basically, in a food supply chain, green efforts include processes for food safety guarantees, energy saving, reduction of pesticide residues and solid wastes, and decrease of air pollution and water consumption [12,13]. Therefore, environmental performance is contributed to not only by food producers that commit themselves to green food production, but also suppliers who provide green materials [14–16]. However, food companies do not always have direct control of their suppliers, therefore, many downstream companies have lost their profits in food safety events due to their supplier's (upstream) irresponsibility, e.g., TESCO in the horse meat scandal [17], the 2008 Peanut Corporation of America salmonella outbreak, and the 2008 Chinese infant milk powder contaminated by melamine (a chemical used in plastic) [8]. At the same time, upstream suppliers, especially in emerging economies, can suffer a lot as well due to green collaboration without additional benefits [18]. In this sense, since food suppliers have their own private information of input costs in green practice, in order to maximize their own profits, they may exaggerate the information of their efforts in improving their green performance, which will lead the food producers to make poor decisions and cause a loss in their profits [19,20].

Some studies claim that organic labels and certification have the potential to improve the traceability and reduce information asymmetry among food supply chain members [11,21,22], but only if they are credible and have a significant effect on changing production processes towards more sustainable methods [10]. However, ensuring and promoting traceability for food supply chains is still hard work due to the cost and asymmetric information [23]. The supplier may cut corners when facing high implementation costs of obtaining organic labels and certification which will improve traceability in the food supply chain [22]. Coordination is viewed as a solution to reduce governance costs and improve private incentives [21,24]. Therefore, it is critical for food firms to develop an effective coordination mechanism to incentivize their suppliers to share information of green costs and integrate both sides' green effort to improve the economic and the environmental performance of the whole supply chain. This paper hence tries to fill this research gap and aims to explore the following three questions. (i) How will the magnitude of asymmetry of the supplier's green cost information affect the profit and the green performance of both the food supplier and the food producer? (ii) What effect has green cost information sharing on the food supplier's decision under information asymmetry? (iii) What can the food producer do to incentivize the supplier to disclose green cost information and improve its green effort?

To address these issues, we propose a coordination mechanism in a two-stage food supply chain consisting of a food producer who is a Stackelberg leader and a contract food supplier who has private information about its green costs. We first develop demand functions for the two-stage food supply chain, considering both the food supplier's and the food producer's influence on the green degree of the food and associated consumer acceptance. Then, we derive the influence of the magnitude of green material production cost information asymmetry on the economic and environmental performance of both sides based on the wholesale contract. Next, the study further looks into the prerequisite of green cost information sharing by the food supplier. Finally, for the purpose of motivating the supplier to share its green material production cost information and improve its green material producing effort, we develop a newly designed menu of contracts, which combine the wholesale price contract and the cost sharing contract under the green material cost information asymmetry situation.

2. Literature Review

This study focuses on establishing an effective mechanism to incentivize the food supplier to share its green cost information and improve its green performance. Therefore, two streams of literature pertinent to this research were reviewed. One part of the studies pertains to contract coordination in the supply chain under cost information asymmetry, and the other part pertains to contract coordination in the green supply chain under a green cost information asymmetry situation.

2.1. Contract Coordination in the Supply Chain under Cost Information Asymmetry

Buyers motivate suppliers to provide qualified products by designing contracts and strategies scientifically to reduce their opportunistic behavior [25–30]. Some studies used different sorts of single contracts and strategies to address the incentive issue in a two-stage supply chain considering information asymmetry of the seller's cost type, such as a strategy of expected margin commitment [17,20], an optimal wholesale price contract model [31], and a strategy of sharing marketing expenditure [28,32]. There are quite a few studies as well that have designed a menu of contracts for motivating channel members to share their cost information. Corbett et al. [33] analyzed six contract scenarios with the buyer's cost information being asymmetric. The study derived the supplier's optimal contracts and profits for all six scenarios and examined the value of information. Wang and He [34] presented two contract formats, namely, volume discounting on markup and volume discounting on the slotting fee, as channel-coordinating for the dominant supplier. Wang et al. [35] looked into a contract that includes the order quantity and transfer payment. Nosoohi and Nookabadi [36] proposed a menu of call option contracts including three variables: a supply order, an option, and an exercise price. Chen et al. [37] devised a menu of option contracts within a one-period two-echelon supply chain for the retailer to incentivize the supplier to reveal asymmetric production cost information. As per the literature reviewed above, some studies have focused on how to motivate supply chain members to share information through different contracts. However, these studies did not address the issues arising out of green cost information asymmetry in green supply chain management where green performance of the supply chain becomes the major factor influencing the decision-making of supply chain members.

2.2. Contract Coordination in the Green Supply Chain under Green Cost Information Asymmetry

A few studies in the recent past have investigated sustainable supply chain problems pertaining to contract coordination under an asymmetric green cost scenario. Zheng et al. [38] introduced a two-part tariff contract in a reverse supply chain for the remanufacturer to motivate the collector to disclose its private information about the base supply of the used product and the collection effort cost scale. Yang et al. [39] investigated a supply chain of waste cooking oil recycling in which the unit recycling cost of the recycler was private. The study compared two possible contracting mechanisms for improving information sharing and stimulating the recycler's recycling investment. Wang and He [40] derived incentive strategies for motivating the manufacturer to reveal their true private information of carbon-reduction efficiency to the product designer in a low-carbon supply chain with asymmetric information of carbon reduction efficiency. Liu et al. [41] inquired into a corporate social responsibility-sensitive supply chain and devised a coordination mechanism for motivating the supplier to disclose the true corporate social responsibility cost information and realizing the supply chain coordination. Zhou et al. [42] proposed a contract design which can achieve the channel coordination and information sharing under uncertain demand situations in a fresh agri-food supply chain. Different from the previous studies, this study focuses on a green food supply chain consisting of a food producer and food supplier and investigates the coordination mechanism for incentivizing the food supplier to share the green cost information and improve its green performance.

The contributions of this research are as follows. To figure out how green performance as the major parameter influencing the decision-making of supply chain members under information asymmetry, the study expands the previous demand functions for a food supplier and a producer by considering both of their influences on the green degree of the food and associated consumer acceptance. The study further investigates the impact of the information difference of the supplier's green food material producing (GFMP) cost on the green performance and profits of the food producer and the food supplier. In order to fill the research gap on incentivizing the food supplier to share its green cost information and improve its green effort, the study first explores the prerequisite of cost information sharing by the food supplier, then a newly designed menu of contracts which combine the wholesale

price contract and cost sharing contract is proposed. The study extends and enriches the research of application of contracts into practical green food supply chain management.

To realize the research goals, the remainder of the paper is structured as follows. Section 2 contributes to the delineation of parameters and decision variables, and then proposes basic models. Section 3 discusses decision-making in the case of wholesale contracts under information symmetric situations, which provides a benchmark for the following coordination results. Section 4 discusses wholesale contracts and wholesale contracts combined with cost sharing contracts, respectively, for motivating the food supplier to disclose the green materials production cost under an information asymmetric scenario. Section 5 focuses on a case study using developed contracts. Section 6 concludes the whole research and proposes some suggestions for further research. All the proofs are presented in the Appendix.

3. Model Descriptions

We studied a two-stage food supply chain and considered the coordination for green production and marketing between a supplier and a food producer who is a Stackelberg leader. The food industry provides plenty examples of food producers acting as the channel leaders who will offer supply contracts to the suppliers. Supply chains with those giant companies, such as Coca-Cola, McDonald's, and Nestle Kraft Foods, belong to this model. These companies have great market power and many measures are driven by these food producers and the suppliers become followers. In order to provide a benchmark case to compare with the two contract models, a wholesale contract under a full information situation was introduced firstly.

The food supplier has private information about its green cost and provides green materials at a unit wholesale price of w to the food producer. The food producer produces and sells food products to consumers at price of $p(k)$. We assumed that the supplier processes ordinary food materials at a unit cost of c_s, While it processes green materials, the supplier needs to make additional efforts to improve the green degree of its materials according to the required standard from the food producer. The comprehensive green degree of food materials was measured by their safety and environmentally friendly level. For example, there are different green levels of food materials in the Chinese market, such as pollution-free, green, and organic. To improve the green degree of food, suppliers need to make efforts to promote green production, train employees, and supervise green standards. The total increased cost depends on the unit green materials prodution cost (k) and the effort (g_1) that the supplier makes for improving the green level of materials, expressed as kg_1^2 [43,44]. The supplier has its own private information of the unit green material production cost, which is not fully known to the food producer. We assume that the unit green material cost k is uniformly distributed on the interval $[\delta_k - \sigma, \delta_k + \sigma]$, with a probability density function and cumulative distribution function $u(k)$, and δ_k is the mean of the k. Where $u(k) = \frac{1}{2\sigma}$. $u(k) = \frac{k - k_{min}}{2\sigma}$. $k_{min} = \delta_K - \sigma$, $k_{max} = \delta_K + \sigma$. $0 < \sigma < \delta_K$. σ measures the magnitude of asymmetry of green material cost information. The larger the value of σ is, the bigger the difference between the real green cost of the supplier and that being anticipated by the food producer will be. We named it in this paper as the information difference of the GFMP cost.

The food producer produces and sells ordinary food products at a unit cost of c. Similar to their supplier, when they produce and sell green food products, the total green cost depends on the unit green processing cost v and the level of green processing effort by the food producer g_2, expressed as $vg_2^2(k)$. According to the existing research [44–47], the demand of green products can be expressed as follows.

$$D = \alpha - \beta p + (1 + \eta)\phi\gamma g_1 + (1 + \eta)\phi\mu g_2 \tag{1}$$

The green degree of product (g) can be expressed as $g = \gamma g_1 + \mu g_2$. γ denotes the contribution rate of the supplier's green material production effort to the green degree of the product. μ enotes the contribution rate of the producer's green processing effort to the green degree of the product. We assumed that the parameter of ϕ measures the consumer's sensitivity to the green degree of products

(green product sensitivity). η denotes the increased rate of green product sensitivity due to sale efforts by the food producer. The sale efforts by the food producer cannot improve the green degree of food products, but it can change consumers' perception of greenness of the products and thus improve their preference to greener products [46,47]. Finally, it will increase the demand of the green product. According to previous research [48,49], the unit variable green sale cost that will vary with the increased green demand by a food producer is c_g, while the fixed green sale cost by a food producer is c_{gf}.

Several assumptions were made throughout this study and are listed as follows.

1. The food supplier has the full information of the food producer's green processing and green sale cost.
2. Consumers' green product demand can be completely met during the sale period.
3. There is no overstock after completely meeting the consumers' green product demands.
4. Both the food producer and the food supplier are risk-neutral and aim to maximize their expected profits.

4. Wholesale Price Contract under Information Symmetry

In this model, the food producer acts as the Stackelberg leader and the channel members have complete information about each other's cost and price. The food producer first sets a profit-maximizing sales margin (m, $m = p\text{-}w$), green production effort (g_2), and marketing effort (c_g). Based on which, the supplier determines its wholesale price (w) and green material processing efforts (g_1) to maximize their profit.

$$\pi_R = Max_A^R\left\{(p - w - c - c_g)[\alpha - \beta p + (1+\eta)\phi\gamma g_1 + (1+\eta)\phi\mu k g_2] - v g_2^2 - c_{gf}\right\} \tag{2}$$

$$\pi_s = Max_A^R\left\{(w - c_s)[\alpha - \beta m - \beta w + (1+\eta)\phi\gamma g_1 + (1+\eta)\phi\mu k g_2] - k g_1^2\right\} \tag{3}$$

With the above model, we can derive the following equations.

$$m = \frac{(\alpha - \beta c_s - \beta c - \beta c_g)[4\beta kv - (1+\eta)^2\phi^2\gamma^2 v]}{[8\beta kv - 2(1+\eta)^2\phi^2\gamma^2 v - (1+\eta)^2\phi^2\mu^2 k]\beta} + c \tag{4}$$

$$g_2 = \frac{(\alpha - \beta c_s - \beta c - \beta c_g)(1+\eta)\phi\mu k}{8\beta kv - 2(1+\eta)^2\phi^2\gamma^2 v - (1+\eta)^2\phi^2\mu^2 k} \tag{5}$$

$$g_1 = \frac{(\alpha - \beta c_s - \beta c - \beta c_g)(1+\eta)\phi\gamma v}{8\beta kv - 2(1+\eta)^2\phi^2\gamma^2 v - (1+\eta)^2\phi^2\mu^2 k} \tag{6}$$

$$\pi_s^{DR*} = \frac{(\alpha - \beta c_s - \beta c - \beta c_g)^2[4\beta k - (1+\eta)^2\phi^2\gamma^2]kv^2}{[8\beta kv - 2(1+\eta)^2\phi^2\gamma^2 v - (1+\eta)^2\phi^2\mu^2 k]^2} \tag{7}$$

$$\pi_R^{DR*} = \frac{(\alpha - \beta c_s - \beta c - \beta c_g)^2 kv}{8\beta kv - 2(1+\eta)^2\phi^2\gamma^2 v - (1+\eta)^2\phi^2\mu^2 k} - c_{gf} \tag{8}$$

5. Contract under Information Asymmetry

5.1. Wholesale Price Contract under Information Asymmetry

In this model, the green material production cost information is not held by the food producer. Therefore, first, the food producer determines the sale margin (m) and green production effort $g_2(k)$ based on the anticipated information of the supplier's green cost. Second, the supplier determines the

wholesale price (w) and the green material processing effort (g_2). The profit function of the supplier and the food producer is given in the following equation.

$$E[\pi_S]^{A-R} = (W - C_S)[\alpha - \beta P(K) + (1+\eta)\phi\gamma g_1 + (1+\eta)\phi\mu g_2(k)] - kg_1^2 \tag{9}$$

$$E[\pi_R]^{A-R} = \int_{\delta_k-\sigma}^{\delta_k+\sigma}\{(p(k) - w - c - c_g)[\alpha - \beta P(K) + (1+\eta)\phi\gamma g_1 + (1+\eta)\phi\mu g_2(k)] - vg_2^2(k) - c_{gf}\}U(k)dk \tag{10}$$

Take the first order derivatives of Equation (9) with respect to w and g_1, and let them be zero. If $4\beta k - (1+\eta)^2\phi^2\gamma^2 > 0$, according to results from the Hessian matrix of $\pi(w, (k), m, g_1)$, we can derive w^{A-R} and g_1^{A-R}. Subtitling w^{A-R} and g_1^{A-R} to Equation (10), we can obtain

$$E[\pi_R]^{A-R} = \int_{\delta_k-\sigma}^{\delta_k+\sigma}\left\{\frac{2\beta m[k\mu g_2(k) - k\beta m + k\alpha + 2k\beta c_s - (1+\eta)^2\phi^2\gamma^2 c_s]}{4\beta k - (1+\eta)^2\phi^2\gamma^2} - vg_2^2(k) - c_{gf}\right\}U(k)dk[\frac{1}{2} + \frac{\gamma^2}{16\beta\sigma}\ln\frac{4\beta(\delta_k+\sigma) - \gamma(1+\eta)^2\phi^2}{4\beta(\delta_k-\sigma) - (1+\eta)^2\phi^2\gamma^2}] =$$
$$[\mu g_2 - \beta m + \alpha + \beta c_s - (1+\eta)^2\phi^2\gamma^2 c_s] - vg^2 - c_{gf} \tag{11}$$

Let

$$[\frac{1}{2} + \frac{\gamma^2}{16\beta\sigma}\ln\frac{4\beta(\delta_k+\sigma) - \gamma(1+\eta)^2\phi^2}{4\beta(\delta_k-\sigma) - (1+\eta)^2\phi^2\gamma^2}] = Z(\sigma) \tag{12}$$

Taking the first order derivatives with respect to w and g_1, we can obtain

$$m^{A-R} = \frac{\mu(\alpha - \beta c_s - \beta c - \beta c_g)}{[4\beta kv - (1+\eta)^2\phi^2\mu^2 z(\sigma)]} \tag{13}$$

$$g_2(k)^{A-R} = \frac{\mu z(\sigma)(\alpha - \beta c_s - \beta c - \beta c_g)}{[4\beta kv - (1+\eta)^2\phi^2\mu^2 vz(\sigma)]} \tag{14}$$

According to Equation (12), (14), and (15), we can derive

$$P(K)^{A-R} = \frac{3\beta KV[4\beta v - (1+\eta)^2\phi^2\mu^2 z(\sigma)] - \gamma^2 v(\alpha - \beta c_s - \beta c - \beta c_g)}{[4\beta v - (1+\eta)^2\phi^2\mu^2 z(\sigma)][4\beta k - (1+\eta)^2\phi^2\gamma^2]} \tag{15}$$

$$g_1^{A-R} = \frac{\gamma v(\alpha - \beta c_s - \beta c - \beta c_g)}{[4\beta v - (1+\eta)^2\phi^2\mu^2 z(\sigma)][4\beta k - (1+\eta)^2\phi^2\gamma^2]} \tag{16}$$

Substituting Equation (14)–Equation (17) to Equation (9)–Equation (10), respectively, we can have

$$E[\pi_R]^{A-R} = \frac{z(\sigma)[8\beta^2 kv^2 - 8\beta k(1+\eta)^2\phi^2\gamma^2\mu^2 z(\sigma)](\alpha - \beta c_s - \beta c - \beta c_g)}{[4\beta v - (1+\eta)^2\phi^2\mu^2 z(\sigma)]^2[4\beta k - (1+\eta)^2\phi^2\gamma^2]} \tag{17}$$

$$E[\pi_S]^{A-R} = \frac{\beta^2(1+\eta)^2\phi^2\gamma^2\mu^2 k(\alpha - \beta c_s - \beta c - \beta c_g)^2}{[4\beta v - (1+\eta)^2\phi^2\mu^2 z(\sigma)]^2[4\beta k - (1+\eta)^2\phi^2\gamma^2]} \tag{18}$$

With the above models, we can derive the following theorem.

Theorem 1. *If $0 < \sigma < \delta_k$, under information asymmetry, the green production effort by the food producer (g_2) will increase with the increase of the information difference of the GFMP cost, as shown in Appendix A.*

Theorem 1 shows that due to the information asymmetry of the supplier's GFMP cost, with the increase of the difference between the real green cost of the supplier and that being anticipated by the food producer, the food producer will improve the green level of food production to reduce the negative effect of the information asymmetry on the green degree of food products.

Theorem 2. *Under an information asymmetry situation, the green level of material by the supplier will increase with the increase of the information difference of the GFMP cost, but the green level of materials will always be lower than of that under information symmetry, as shown in Appendix B.*

Theorem 3. *When $\frac{1}{2} < z(\sigma) < min\left\{ \frac{4\beta^2 kv}{[3\beta kv - (1+\eta)^2\phi^2\gamma^2](1+\eta)^2\phi^2\mu^2} , \frac{(1+\eta)^2\phi^2\gamma^2}{4\beta k} \right\}$, the expected profit of the food producer will increase with the increase of the information difference of the GFMP cost (σ).*

When $\frac{4\beta^2 kv}{[3\beta kv - (1+\eta)^2\phi^2\gamma^2](1+\eta)^2\phi^2\mu^2} < z(\sigma) < \frac{(1+\eta)^2\phi^2\gamma^2}{4\beta k}$, the expected profit of the food producer will decrease with the increase of the information difference of the GFMP cost (σ), as shown in Appendix C.

Theorem 3 shows that when the information difference of the GFMP cost (σ) is low, the food producer's expected profit will increase with the information difference of the GFMP cost. However, when the information difference of the GFMP cost (σ) increases to a certain value, the food producer's expected profit will decrease with the information difference of the GFMP cost (σ).When the difference between the real green material processing cost of the supplier and that being anticipated by the food producer increases to a certain value, information asymmetry has a great negative effect on the decision of the food producer and causes a loss to their profits.

Theorem 4. *When $\frac{1}{2} < z(\sigma) < \frac{(1+\eta)^2\phi^2\gamma^2}{4\beta\kappa}$, the supplier's expected profits will increase with the increase of the information difference of the GFMP cost (σ), as shown in Appendix D.*

Theorem 4 shows that the supplier will benefit from the information asymmetry of their own green cost. A supplier will take advantage of its private information and exaggerate its green cost, which will eventually lead to the food producer's loss of profit for the wrong decision made without the full information of the supplier's GFMP cost. Thus, the food producer always needs to motivate the supplier to share their green cost information through designing a more flexible contract besides the wholesale price contract.

5.2. Impact of Information Sharing on Supplier's Decision under Information Asymmetry

Whether the supplier will share the green cost information with the food producer or not depends on to what extent the supplier can benefit from such behavior. Improving the profit of the supplier is the main incentive for the supplier to share information with the food producer. Therefore, in the subsequent analysis, supplier's profit generated under information symmetry and asymmetry will be compared to clear the prerequisite of sharing information by the supplier.

Let $E[\pi_S]^{A-R} - E[\pi_S^{DR*}]$, so that we can derive Theorem 5.

Theorem 5. *(1) When $k > k_2$ or $k < k_1$, $E[\pi_S^{DR*}] < E[\pi_S]^{A-R}$, the supplier sharing green cost information will decrease its expected profits.*
(2) When $k = k_1$ or $k = k_2$, $E[\pi_S^{DR*}] = E[\pi_S]^{A-R}$.
(3) When $k_1 < k < k_2$, the supplier sharing green cost information will increase its expected profits, as shown in Appendix E.

Theorem 5 shows that when the supplier's GFMP cost is very low or very high, they will not share their information of green material cost with the food producer since the supplier will not benefit from such behavior. However, under a wholesale price contract situation, w is the only available parameter that can be used as a negotiation condition. Thus, in order to further incentivize the supplier to share green cost information, the food producer needs to design more flexible coordination contracts. Only when a contract will bring no less benefit for the supplier under an information asymmetry situation than of that under information symmetry can such a contract motivate the supplier to share green cost information.

5.3. Combining a Wholesale Price Contract and a Green Cost Sharing Contract under an Information Asymmetry Situation

In this section, we will coordinate the food producer and the supplier through a cost sharing contract based on the wholesale price contract under information asymmetry. The supplier in this scenario needs to share a certain proportion of the food producer's green production cost. We denote this contract as (p^{A-CR}, θ), where θ is the proportion of the food producer's green production cost that the supplier needs to assume in the contract. The food producer assumes the remaining $(1 - \theta)$ proportion of the cost. Meanwhile, the supplier is not willing to disclose its unit green material processing cost (k) unless the contract provided by the food producer can bring them more profits. The food producer can only predict that the supplier's unit green cost is varied in the range of $[\delta_k - \sigma, \delta_k + \sigma]$. The food producer will determine the fraction of (θ) and the price (p^{A-CR}) to incentivize the supplier to accept the contract and disclose information of the GFMP cost. The profit functions of the supplier and the food producer are as follows:

$$\pi_s^{A-CR}(w, p(k), m, g) = (w - c_s)[\alpha - \beta p(k) + (1 + \eta)\phi\gamma g_1 + (1 + \eta)\phi\mu g_2(k)] - kg_1^2 - (1 - \theta)vg_2^2(k) \quad (19)$$

$$\pi_R^{A-CR} = \int_{\delta_K - \sigma}^{\delta_K + \sigma} \left\{[p(k) - w - c - c_g][\alpha - \beta p(k) + (1 + \eta)\phi\gamma g_1 + (1 + \eta)\phi\mu g_2(k)] - \theta vg_2^2(k) - c_{gf}\right\}U(k)dk \quad (20)$$

Take the first order derivatives of Equation (19) with respect to w and g_1, when $4\beta k - (1 + \eta)^2\varphi^2\gamma^2 > 0$ and $[8\beta k - 2(1 + \eta)^2\varphi^2\mu^2 k](1 - \theta) - (1 + \eta)^2\varphi^2\gamma^2 v > 0$, for any w, g_1, $H(w, g_1, g_2, \theta)$ that are a negative definite, let the first order derivatives equal zero and substitute the results into Equation (21), then we can derive that the food producer faces the following objectives and constraints. *Max*

$$Max E\pi_R^{A-CR} = [\tfrac{1}{2} + \tfrac{\gamma^2}{16\beta\sigma} \ln \tfrac{4\beta(\delta_k + \sigma) - \gamma(1 + \eta)^2\phi^2}{4\beta(\delta_k - \sigma) - (1 + \eta)^2\phi^2\gamma^2}](w - c - c_g)[\mu g_2 - \beta w + \alpha + \beta c_s - \gamma(1 + \eta)^2\phi^2 c_s - \theta vg_2^2(k) - c_{gf} \quad (21)$$

St:

$$\pi_s^{A-CR}(w, p(k), m, g) = \frac{2k[\mu g_2(k) - \beta m + \beta c_s]}{4\beta k - (1 + \eta)^2\phi^2\gamma^2}\left\{\alpha - \beta m - \frac{[2\beta k + (1 + \eta)^2\phi^2\gamma^2[\mu g_2(k) - \beta m + \beta c_s]}{4\beta k - (1 + \eta)^2\phi^2\gamma^2} + (1 + \eta)^2\phi^2\gamma^2\right\}$$
$$+ \frac{k[(1 + \eta)^2\phi^2\gamma^2][\mu g_2(k) - \beta w + \alpha + \beta c_s]^2}{[4\beta k - (1 + \eta)^2\phi^2\gamma^2]^2} - (1 - \theta)vg_2^2(k) \geq \pi_s^{A-R}$$

$$(22)$$

The following theorem offers the optimal fraction of (θ) when facing asymmetric information based on Equation (22) and Equation (23).

Theorem 6. $0 < \theta < \frac{[4\beta k - (1 + \eta)^2\varphi^2\mu^2 k - (1 + \eta)^2\varphi^2\gamma^2 v]z(\sigma)}{4\beta k - (1 + \eta)^2\varphi^2\mu^2 z(\sigma)}$, $E[\pi_S]^{A-CR} > \pi_S^{A-R}$. *Under information asymmetry, the supplier will accept the optimal cost sharing contract, as shown in Appendix E.*

Theorem 6 shows that under information asymmetry, for the sake of motivating the supplier to share information and improve its green material processing effort, based on the wholesale price contract, a green production cost sharing contract in which the supplier needs to assume a proportion (θ) of green production cost is proposed. Under such a combined contract, the food producer wants to realize their profit objective, while being constricted by the supplier's participating prerequisite. Therefore, the food producer needs to optimize and determine the parameter of (p^{A-CR}, θ). When the supplier can gain more profit than it generates from the wholesale price contract under an information symmetry situation, the supplier will accept the contract. Thus, in this case, when the sharing proportion (θ) satisfies $0 < \theta < \frac{[4\beta k - (1 + \eta)^2\varphi^2\mu^2 k - (1 + \eta)^2\varphi^2\gamma^2 v]z(\sigma)}{4\beta k - (1 + \eta)^2\varphi^2\mu^2 z(\sigma)}$, the supplier can benefit more from the contract by sharing information with the food producer, which motivates the supplier to accept the contract.

5.4. Numerical Analysis

　　The data for numerical analysis are from a famous Chinese food producer, Beijing DongLaiShun (DLS) restaurant group company. DLS mainly focus on the business of Muslim catering. It owns its century-old brand and provides natural and green products to its customers. In recent years, DLS has made great efforts to realize green supply chain management. Therefore, it has established a long-term cooperative relationship with major suppliers, such as Inner Mongolia YeHeNaLa (YHNL) Co., Ltd.

　　Supplier YHTL is the largest animal husbandry enterprise in Hulunbuir, Inner Mongolia. It has passed certification of ISO22000, National Green Food Certification, and Organic Food Certification. The company has been recognized by DLS as its main mutton supplying base. Supplier YHTL was officially listed on the new third board in August 2016. According to its annual report and the field survey of producer DLS, the relevant data is listed as follows.

　　Supplier YHTL's sales revenue of mutton to producer DSL in 2015 was 20,143,692.37 ¥, where the operating cost was 15,254,800 ¥ and the sales cost was 1,095,900 ¥. The average wholesale price of mutton was about 45 ¥/kg. The cost was about 35 ¥/kg.

　　The mutton supplied by the supplier YHTL to food producer DLS has passed the Muslim Food Certification and the National Green Food Certification. Therefore, the average wholesale price of mutton was about 65 ¥/kg, p_s = 6.5. The cost of raw materials was about 45 ¥/kg, C_s = 45.

　　The food producer DLS sells the mutton at 150 ¥/kg, p = 150.

　　Assuming $g_1 \in (0,100)$ and the green material degree is from 0% to 100%, we consider $g_1 \in \{45,55,65\}$. Based on investigation, obtaining the certification of 'National Green Food' improved the material cost by about 10 ¥/kg. Then, here, under an information symmetry situation, $k \in \{0.91,1.01,1.09\}$. Under an information asymmetry situation, the mean of the value δ_k = 1.

　　Assuming $g_2 \in (0,100)$ and the green production effort level from 0% to 100%, we consider $g_2\{40,50,60\}$, and then $v \in \{0.71,0.60,0.52\}$. Based on investigation, we consider γ = 0.55 and μ = 0.45.

　　Based on analysis of the sales data from the food producer DLS, it is estimated that α = 310,000 kg, β = 5, ϕ = 2, η = 0.65, and c_{gs} = 80, c_g = 10. All the collected data are shown in Table 1.

Table 1. Baseline parameters.

Parameter	v	a	β	γ	μ	c_s	c	η	ϕ	c_{gs}	σ_k
Value	0.71	310,000	5	0.55	0.45	45	35	0.65	2	80	1
Value	0.60	310,000	5	0.55	0.45	45	35	0.65	2	80	1
Value	0.52	310,000	5	0.55	0.45	45	35	0.65	2	80	1

　　Based on the data from the case, we looked into the effect of the information difference of the GFMP cost on the environmental performance and profits of the food supply chain under information asymmetry. Therefore, the research results will further test the theorems proposed above.

　　1. The effect of the information difference of the GFMP cost on the green processing level by the food producer.

　　Figure 1 shows that under information asymmetry, the optimal green processing level of the food producer will increase with the information difference of the GFMP cost, as does the optimal green material level of the food supplier. However, the optimal green material level of the food supplier under information asymmetry will never exceed that under information symmetry. Due to the information asymmetry, the food producer improves the green processing effort and green performance in order to reduce the negative effect caused by information asymmetry. This further proved Theorem 1.
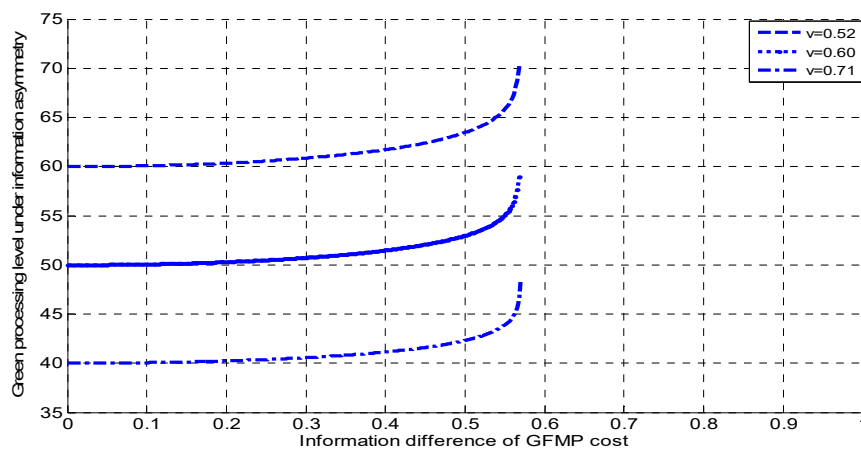
Figure 1. The effect of information difference of the green food material producing (GFMP) cost on green processing level by DongLaiShun (DLS).

Figure 2 shows that the food supplier will increase its green level of food materials with the increase of the information difference of the GFMP cost as it can benefit from concealing information of its green cost. However, in order to ensure the benefits from the concealing behavior, the green level of the food material by the food supplier will never exceed of that under information symmetry, which further tests Theorem 2. This result implies that the effective contract design by the food producer for motivating the food supplier to disclose the green effort information will improve the green performance of the whole food supply chain.
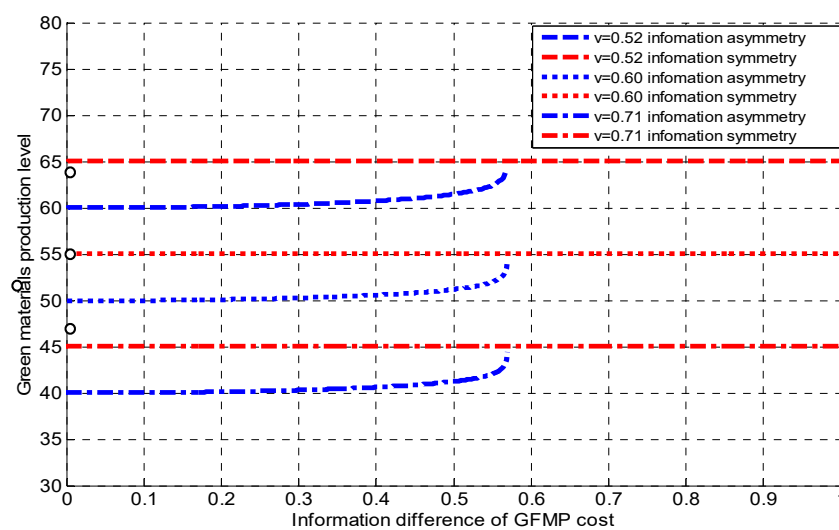

Figure 2. The effect of information difference of the GFMP cost on green materials level by YeHeNaLa (YHNL).

2. The impact of information difference of the GFMP cost (σ) on the expected profits of the food producer and food supplier.

Figure 3 shows that when $\sigma < 0.301$ ($v = 0.52$), $\sigma < 0.40\ 7$ ($v = 0.60$), $\sigma < 0.433$ ($v = 0.71$), the expected profit of the food producer will slowly increase with the increase of the information difference of the GFMP cost. When $\sigma > 0.301$ ($v = 0.52$), $\sigma > 0.407$ ($v = 0.60$), $\sigma > 0.433$ ($v = 0.71$), the expected profits of food producer DLS will decrease with the information difference of the GFMP cost. The result further proves Theorem 3. Figure 3 also shows that the expected profits of the food supplier will increase with the increase of the information difference of the GFMP cost. It denotes that the food supplier's behavior of concealing its green material cost will improve its profits, which tests Theorem 3. These

results imply that information asymmetry benefits the food supplier but that the food producer may be worse off without the food supplier's full GFMP cost information. Therefore, the food producer is always incentivized to tempt the food producer to disclosing its GFMP cost information.
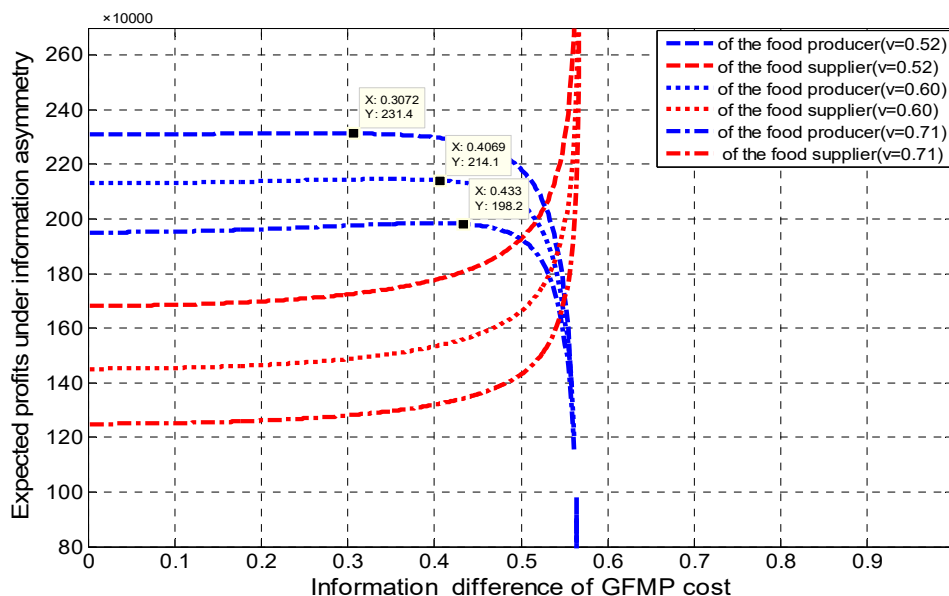

Figure 3. The impact of information difference of GFMP cost σ on the optimal profit of YHNL and DLS.

3. The impact of information difference of the GFMP cost (σ) and the sharing proportion (θ) on the profit of YHNL

Figure 4 shows that when the portion of food processing costs assumed by the food supplier (θ) $0.3 > \theta > 0.1(v = 0.52)$, $0.2 > \theta > 0.1$ ($v = 0.6$), $0.3 > \theta > 0.1$ ($v = 0.71$), and meanwhile, the information difference of the GFMP cost (σ) $0.5 > \sigma > 0.05$ ($v = 0.52$), $0.45 > \sigma > 0.05$ ($v = 0.60$), $0.45 > \sigma > 0$ ($v = 0.71$), the expected profits of the supplier will be no less than its reservation profits. The supplier will accept the contract. This result is in line with common sense. From one side, since the supplier shared the green production cost with the food producer, in order to compensate its increased investment, the supplier will have to make a higher effort to improve the green degree of materials to gain greater payoff. Therefore, this contract can incentivize the supplier to improve the green material processing effort. From the other side, the study proved that under certain conditions, information sharing will improve the supplier's green performance and increase the food producer's profit. Therefore, the cost sharing contract based on the wholesale price contract under information asymmetry can optimally coordinate the benefit of the food supplier and the food producer.
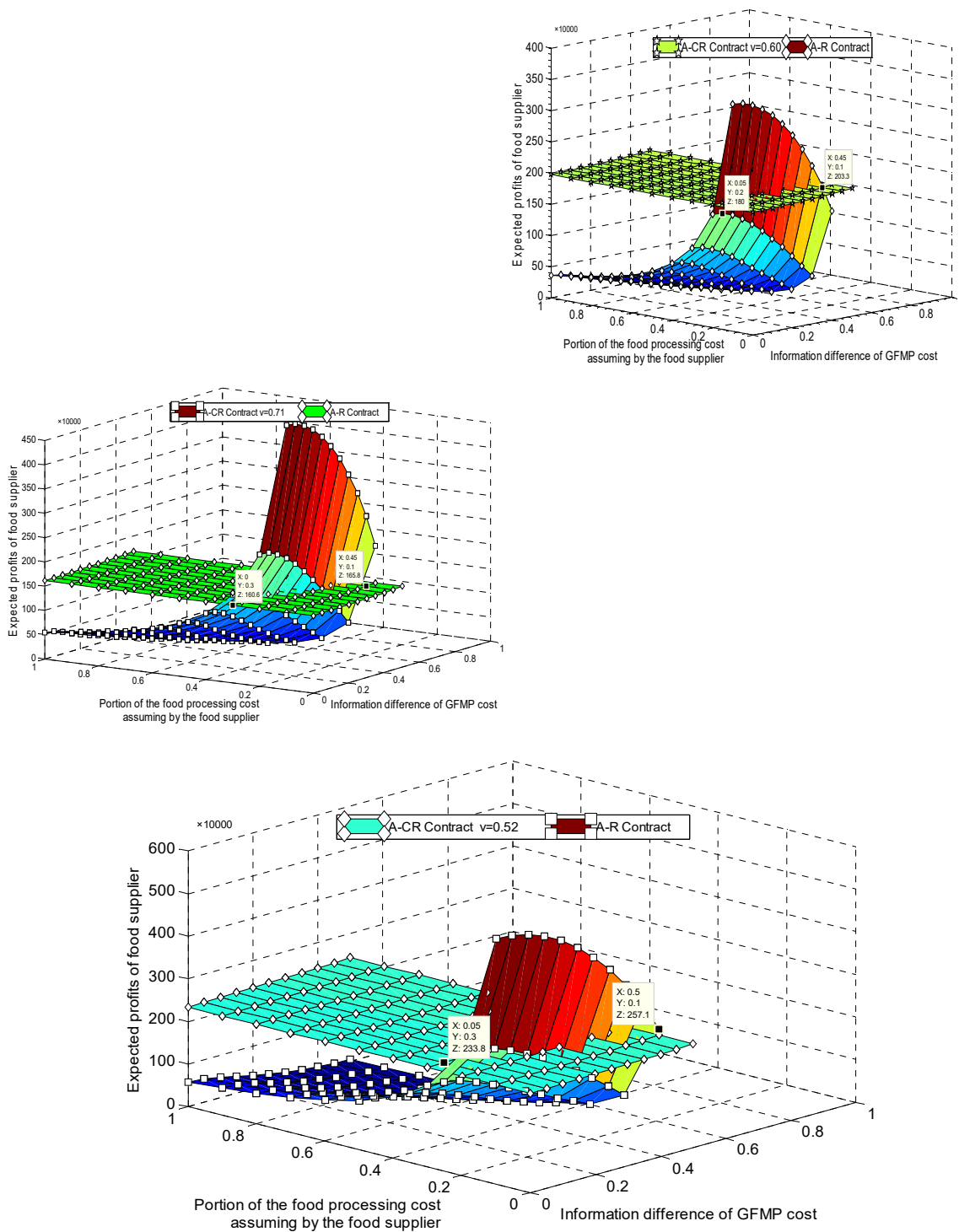
Figure 4. The impact of parameter σ and θ on the profit of YHNL.

6. Conclusions

Due to the increasing pressures from stakeholders and potential opportunities for green marketing, food companies are driven to cooperate with their suppliers to improve their green performance and realize sustainable development. However, food companies do not always have full information of their suppliers' green practice input costs, which will lead them to make poor decisions and cause a loss to their profits. Therefore, for the purpose of incentivizing food suppliers to share information of green costs and to integrate both sides' green effort to improve the economic and the environmental

performance of the whole supply chain, this study proposed a contract coordination mechanism in a two-stage supply chain, which consisted of one dominated food producer and a food supplier who withholds private knowledge of its green material producing cost (GFMP cost).

The wholesale price contract was developed as the base model for examining the impact of the information difference of the GFMP cost on the profits and decision of chain members. The results show that the green material production effort by the food supplier and the green processing effort by the food producer will both increase with the increase of the information difference of the GFMP cost, while the supplier's green material production effort under asymmetric information will never exceed that under symmetric information. Therefore, it is necessary for the food producer to design an effective contract to motivate the food supplier to share green material production effort information, which will improve the green performance of the whole food supply chain. Moreover, information asymmetry always benefits the food supplier, but the food producer may be worse off without the food supplier's full GFMP cost information. Therefore, the food producer is always incentivized to tempt the food supplier to disclosing its GFMP cost information. This study then investigated how information sharing influences the supplier's profit. The research results show that the supplier is unwilling to disclose its own green cost information when the information difference of the GFMP cost is very high or very low, because disclosing information will decrease their profit under that situation. Thus, based on the wholesale contract, this study proposed a cost sharing contract for the asymmetric case. Since the supplier shared the green production cost with the food producer, in order to compensate for their increased investment, the food supplier has to make greater effort to improve the green degree of materials to gain more payoffs. Therefore, the menu of the contract can motivate the supplier to share their cost information, which eventually improves the environmental and economic performance of the food supply chain, as well as promoting the sustainable development of the food supply chain. These results serve to provide practical managerial implications for the members of the food supply chain.

This study investigated a two-stage food supply chain consisting of a food supplier and a food producer who is a Stackelberg leader. Although such a Stackelberg game model is a standard setting in previous research, it can be extended to study the issues on contract designing under the scenario of existing competition among suppliers. Furthermore, this paper assumed that the demand information of food producers is fully available to the supplier, however, in practice, the demand information is always uncertain for the supplier. Therefore, considering such a situation should be another extension in this field. Moreover, the risk attitude of the food producer and the food supplier may be risk-averse or risk-seeking, so the future research direction can focus on contract designing under different risk attitudes.

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Appendix A. Poof of Theorem 1

$$\frac{\partial g_2^{A-R}}{\partial \sigma} = \frac{4\beta v(1+\eta)\phi\mu z(\sigma)(\alpha - \beta c_s - \beta c - \beta c_g)}{\left[4\beta v - (1+\eta)^2\phi^2\mu^2 z(\sigma)\right]^2} \tag{23}$$

$$z(\sigma)' = \frac{\gamma^2}{16\beta\sigma}\left\{\frac{4\beta(\delta_k+\sigma)-\gamma^2(1+\eta)^2\phi^2}{[4\beta(\delta_k+\sigma)-\gamma^2(1+\eta)^2\phi^2][4\beta(\delta_k-\sigma)-(1+\eta)^2\phi^2\gamma^2]} - \ln\frac{4\beta(\delta_k+\sigma)-\gamma^2(1+\eta)^2\phi^2}{4\beta(\delta_k-\sigma)-(1+\eta)^2\phi^2\gamma^2}\right\} \tag{24}$$

Let

$$p(\sigma) = \frac{4\beta(\delta_k+\sigma)-\gamma^2(1+\eta)^2\phi^2}{[4\beta(\delta_k+\sigma)-\gamma^2(1+\eta)^2\phi^2][4\beta(\delta_k-\sigma)-(1+\eta)^2\phi^2\gamma^2]} - \ln\frac{4\beta(\delta_k+\sigma)-\gamma(1+\eta)^2\phi^2}{4\beta(\delta_k-\sigma)-(1+\eta)^2\phi^2\gamma^2} \tag{25}$$

When $p(\sigma)' = 0$, then

$$p(\sigma)' = \frac{128\beta^3[4\beta\delta_k - \gamma(1+\eta)^2\phi^2)\sigma]}{[4\beta(\delta_k+\sigma)-\gamma^2(1+\eta)^2\phi^2]^2[4\beta(\delta_k-\sigma)-(1+\eta)^2\phi^2\gamma^2]^2} > 0 \tag{26}$$

When $0 < \sigma < \delta_k$, $p(\sigma) > 0$, $z(\sigma)' > 0$. When $0 < \sigma < \delta_k$, $\frac{\partial g_2^{A-R}}{\partial\sigma} > 0$.

Appendix B. Poof of Theorem 2

$$\frac{\partial g_1^{A-R}}{\partial\sigma} = \frac{2(1+\eta)^2\phi^2\mu^2 z(\sigma)'\gamma v(\alpha-\beta c_s-\beta c-\beta c_g)}{[4\beta k-(1+\eta)^2\phi^2\gamma^2][4\beta v-(1+\eta)^2\phi^2\mu^2 z(\sigma)]^2} \tag{27}$$

When $0 < \sigma < \delta_k$, $z(\sigma) > 0$. Then, $\frac{\partial g_1^{A-R}}{\partial\sigma} > 0$.
Then

$$g_1^{A-R} - g_1 = \frac{\beta\gamma v(\alpha-\beta c_s-\beta c-\beta c_g)[4\beta k\mu^2(1+\eta)^2\phi^2-\mu^2\gamma^2(1+\eta)^4\phi^4 z(\sigma)-\beta k\mu^2(1+\eta)^2\phi^2]}{[4\beta k-(1+\eta)^2\phi^2\gamma^2][4\beta v-(1+\eta)^2\phi^2\mu^2 z(\sigma)][8\beta k-2(1+\eta)^2\phi^2\gamma^2-(1+\eta)^2\phi^2\mu^2 K]} \tag{28}$$

Assuming profit and green degree are positive, then $< \frac{(1+\eta)^2\phi^2\gamma^2}{4\beta k}$. Since $0 < \sigma < \delta_k$, then
$z(\sigma) = [\frac{1}{2} + \frac{\gamma^2}{16\beta\sigma}\ln\frac{4\beta(\delta_k+\sigma)-\gamma(1+\eta)^2\phi^2}{4\beta(\delta_k-\sigma)-(1+\eta)^2\phi^2\gamma^2}] > \frac{1}{2}$, namely $\frac{1}{2} < z(\sigma) < \frac{(1+\eta)^2\phi^2\gamma^2}{4\beta k}$.
Since
$\frac{\beta k}{4\beta k-(1+\eta)^2\phi^2\mu^2} > \frac{(1+\eta)^2\phi^2\gamma^2}{4\beta k-\gamma^2}$, when $\frac{(1+\eta)^2\phi^2\gamma^2}{4\beta k-\gamma^2} > z(\sigma) > \frac{1}{2}$, $g_1^{A-R} - g_1^{DR} < 0$.

Appendix C. Poof of Theorem 3

Taking the first order derivatives of $E[\pi_R]^{A-R}$ with respect to σ, we can obtain

$$\frac{\partial E[\pi_R]^{A-R}}{\partial\sigma} = \frac{2\beta z(\sigma)'\{16\beta^2 kv^2 + 2(1+\eta)^2\phi^2\mu^2 V[2(1+\eta)^2\phi^2\gamma^2 - 6\beta kz(\sigma)]\}(\alpha-\beta c_s-\beta c-\beta c_g)}{[4\beta v-(1+\eta)^2\phi^2\mu^2 z(\sigma)]^2[4\beta k-(1+\eta)^2\phi^2\gamma^2]} \tag{29}$$

Here, $z(\sigma)' > 0$.
Since $16\beta^2 kv^2 + 2(1+\eta)^2\phi^2\mu^2 V[2(1+\eta)^2\phi^2\gamma^2 - 6\beta kz(\sigma) > 0$,
When $\frac{1}{2} < z(\sigma) < \min\{\frac{4\beta^2 kv}{[3\beta kv-(1+\eta)^2\phi^2\gamma^2](1+\eta)^2\phi^2\mu^2}, \frac{(1+\eta)^2\phi^2\gamma^2}{4\beta k}\}$, $\frac{\partial E[\pi_R]^{A-R}}{\partial\sigma} > 0$.
Similarly, when $\frac{4\beta^2 kv}{[3\beta kv-(1+\eta)^2\phi^2\gamma^2](1+\eta)^2\phi^2\mu^2} < z(\sigma) < \frac{(1+\eta)^2\phi^2\gamma^2}{4\beta k}$, $\frac{\partial E[\pi_R]^{A-R}}{\partial\sigma} < 0$.

Appendix D. Proof of Theorem 4

Taking the first order derivatives of $E^{[\pi_R]}A - R$ with respect to σ, we can obtain:

$$\frac{\partial E[\pi_S]^{A-R}}{\partial\sigma} = \frac{8kv^2 z(\sigma)'(1+\eta)^2\phi^2\mu^2(\alpha-\beta c_s-\beta c-\beta c_g)}{[4\beta v-(1+\eta)^2\phi^2\mu^2 z(\sigma)][4\beta k-(1+\eta)^2\phi^2\gamma^2]} \tag{30}$$

Thus, when $\frac{1}{2} < z(\sigma) < \frac{(1+\eta)^2\phi^2\gamma^2}{4\beta k}$, $\frac{\partial E[\pi_S]^{A-R}}{\partial\sigma} > 0$.

Appendix E. Proof of Theorem 5

$$E\pi_S^{A-CR} - E[\pi_S^{DR*}] =$$
$$\frac{1}{[4\beta k-(1+\eta)^2\phi^2\gamma^2][4\beta v-(1+\eta)^2\phi^2\mu^2 z(\sigma)][8\beta k-2(1+\eta)^2\phi^2\gamma^2-(1+\eta)^2\phi^2\mu^2 K]} \times$$
$$[-32\beta^3(1+\eta)^2\phi^2\mu^2 vz(\sigma) + 4\beta^2(1+\eta)^4\phi^4\mu^4 + 16\beta^3(1+\eta)^2\phi^2\mu^2 v - \beta^2(1+\eta)^4\phi^4\mu^4]k^2 +$$
$$[-32\beta^2(1+\eta)^4\phi^4\gamma^2\mu^2 v + 4\beta^2(1+\eta)^4\phi^4 z^2(\sigma) + 16\beta^3(1+\eta)^2\phi^2\gamma^2 v - 8\beta^2(1+\eta)^4\gamma^2\mu^2 v]k -$$
$$8\beta^2(1+\eta)^6\phi^6\gamma^4\mu^4 z(\sigma) + (1+\eta)^6\phi^6\gamma^4\mu^4 z^2(\sigma)$$

(31)

When $E[\pi_s]^{A-R} - E[\pi_s^{DR*}] = 0$,

$$I(k) = [-32\beta^3(1+\eta)^2\phi^2\mu^2 vz(\sigma) + 4\beta^2(1+\eta)^4\phi^4\mu^4 + 16\beta^3(1+\eta)^2\phi^2\mu^2 v - \beta^2(1+\eta)^4\phi^4\mu^4]k^2 +$$
$$[-32\beta^2(1+\eta)^4\phi^4\gamma^2\mu^2 v + 4\beta^2(1+\eta)^4\phi^4 z^2(\sigma) + 16\beta^3(1+\eta)^2\phi^2\gamma^2\mu - 8\beta^2(1+\eta)^4\phi^4\gamma^2\mu^2 v]k$$
$$-8\beta^2(1+\eta)^6\phi^6\gamma^4\mu^4 z(\sigma) + (1+\eta)^6\phi^6\gamma^4\mu^4 z^2(\sigma)$$

(32)

The discriminant of I(k) = 0, $\Delta = (1+\eta)^8\phi^8\gamma^4\mu^4[4\beta v - (1+\eta)^2\phi^6\gamma^2 z(\sigma)]^2 > 0$, thus, we obtain two roots of the function as follows.

$$k_1 = \frac{2\beta(1+\eta)^4\phi^4\gamma^4 z^2(\sigma)+8\beta^2(1+\eta)^4\phi^4\gamma^2\mu^2 vz(\sigma)-16\beta^2(1+\eta)^4\phi^4\gamma^2\mu^2 v-\beta(1+\eta)^6\phi^6\gamma^4\mu^2 z(\sigma)]}{-32\beta^3(1+\eta)^2\phi^2\mu^2 vz(\sigma)+4\beta^2(1+\eta)^4\phi^4\mu^4 z^2(\sigma)+16\beta^3(1+\eta)^2\phi^2\mu^2 v-\beta^2(1+\eta)^4\phi^4\mu^4}$$

(33)

Since $\Delta > 0$, so the equation $I(k)$ has two different roots. Namely, $k_1 \neq k_2$.

According to Equation (16): $z(\sigma) = [\frac{1}{2} + \frac{\gamma^2}{16\beta\sigma} \ln\frac{4\beta(\delta_k+\sigma)-\gamma(1+\eta)^2\varphi^2}{4\beta(\delta_k-\sigma)-(1+\eta)^2\varphi^2\gamma^2}] > \frac{1}{2}$, we can obtain that:

$-32\beta^3(1+\eta)^2\phi^2\mu^2 vz(\sigma) + 4\beta^2(1+\eta)^4\phi^4\mu^4 + 16\beta^3(1+\eta)^2\phi^2\mu^2 v - \beta^2(1+\eta)^4\phi^4\mu^4 < 0$.

Here, $2\beta(1+\eta)^4\phi^4\gamma^4 z^2(\sigma)+8\beta^2(1+\eta)^4\phi^4\gamma^2\mu^2 vz(\sigma) - 16\beta^2(1+\eta)^4\phi^4\gamma^2\mu^2 v - \beta(1+\eta)^6\phi^6\gamma^4\mu^2 z(\sigma) - 32\beta^3(1+\eta)^2\phi^2\mu^2 vz(\sigma) + 4\beta^2(1+\eta)^4\phi^4\mu^4 + 16\beta^3(1+\eta)^2\phi^2\mu^2 v - \beta^2(1+\eta)^4\phi^4\mu^4 < 0$.

$\frac{1}{2} < z(\sigma) < \min\left\{\frac{4\beta^2 kv}{(1+\eta)^2\phi^2\mu^2[3\beta k-(1+\eta)^2\phi^2\gamma^2]}, \frac{(1+\eta)^2\phi^2\gamma^2}{4\beta k}\right\}$. Therefore, for any given σ, $k_1 > 0$. Similarly, for any given σ, $k_2 > 0$.

Appendix F. Proof of Theorem 6

Taking the first order derivatives of $\pi_s^{A-CR}(w, p(k), m, g_1)$ with respect to w and $g_2(k)$, we can have

$$m^{A-CR} = \frac{(1+\eta)\varphi\mu(\alpha - \beta c_s - \beta c - \beta c_g)}{[4\beta v - (1+\eta)^2\phi^2\gamma^2]}$$

(34)

$$g_2^{A-CR} = \frac{(1+\eta)\phi\mu z(\sigma(\alpha - \beta c_s - \beta c - \beta c_g)}{\theta[4\beta kv - (1+\eta)^2\phi^2\mu^2 z(\sigma)]}$$

(35)

Substituting Equations (34) and (35) into Equation (20). As $4\beta k - (1+\eta)^2\varphi^2\gamma^2 > 0$, $4\beta k - (1+\eta)^2\varphi^2\mu^2 z(\sigma) > 0$, let $\frac{\partial\pi_S^{A-R}}{\partial w} = 0$, $\frac{\partial\pi_S^{A-R}}{\partial g_1} = 0$. We have

$$w^{A-CR} = \frac{2kv(\alpha - \beta c_s - \beta c - \beta c_g)[2\theta\beta v - (1-\theta)(1+\eta)^2\phi^2\mu^2 z(\sigma)]}{\theta[4\beta v - (1+\eta)^2\phi^2\gamma^2][4\beta kv - (1+\eta)^2\phi^2\mu^2 z(\sigma)]} + c_s$$

(36)

$$g_1^{A-CR} = \frac{2v(\alpha - \beta c_s - \beta c - \beta c_g)[2\theta\beta v - (1-\theta)(1+\eta)^2\phi^2\mu^2 z(\sigma)]}{\theta[4\beta v - (1+\eta)^2\phi^2\gamma^2][4\beta kv - (1+\eta)^2\phi^2\mu^2 z(\sigma)]}$$

(37)

Then we have

$$E[\pi_R]^{A-CR} = \frac{2(1+\eta)\phi\mu\beta k(\alpha-\beta c_s-\beta c-\beta c_g)^2[2\theta\beta v-(1-\theta)(1+\eta)^2\phi^2\mu^2 z(\sigma)]}{\theta[4\beta v-(1+\eta)^2\phi^2\gamma^2][4\beta k v-(1+\eta)^2\phi^2\mu^2 z(\sigma)]^2} \times$$
$$\frac{2v(\alpha-\beta c_s-\beta c-\beta c_g)^2(1+\eta)^2\phi^2\mu^2 z(\sigma)^2}{\theta[4\beta k v-(1+\eta)^2\phi^2\mu^2 z(\sigma)]^2} - c_{gf} \tag{38}$$

$$E[\pi_S]^{A-CR} = \frac{(\alpha-\beta c_s-\beta c-\beta c_g)^2\{k\beta^2-(1-\theta)(1+\eta)^2\phi^2\mu^2 v[4\beta v-(1+\eta)^2\phi^2\gamma^2]\}}{\theta^2[4\beta v-(1+\eta)^2\phi^2\gamma^2][4\beta k v-(1+\eta)^2\phi^2\mu^2 z(\sigma)]^2} \tag{39}$$

$$E[\pi_S]^{A-CR} - \pi_S^{A-R} = \frac{(\alpha-\beta c_s-\beta c-\beta c_g)^2\{(1-\theta)^2(1+\eta)^4\phi^4\mu^4 z(\sigma)^2-(1-\theta)(1+\eta)^2\phi^2\mu^2 z(\sigma)^2 v[4\beta v-(1+\eta)^2\phi^2\gamma^2]+4k\beta\theta v(1-\theta)(1+\eta)^2\phi^2\mu^2 z(\sigma)\}}{\theta^2[4\beta v-(1+\eta)^2\phi^2\gamma^2][4\beta k v-(1+\eta)^2\phi^2\mu^2 z(\sigma)]^2} \tag{40}$$

Because
$$\theta^2[4\beta k-(1+\eta)^2\phi^2\gamma^2][4\beta v-(1+\eta)^2\phi^2\mu^2 z(\sigma)]^2 > 0$$
$$4\beta v-(1+\eta)^2\phi^2\mu^2 z(\sigma) > 0$$
$$(1-\theta)(1+\eta)^2 k\phi^2\mu^2 z(\sigma) - vz(\sigma)[4\beta k-(1+\eta)^2\phi^2\gamma^2]+4\beta\theta v(1+\eta)\phi 4\beta v-(1+\eta)^2\phi^2\mu^2 z(\sigma) >$$
0 Then,
$$(1-\theta)^2(1+\eta)^4\phi^4\mu^4 z(\sigma)^2-(1-\theta)(1+\eta)^2\phi^2\mu^2 z(\sigma)^2 v[4\beta v-(1+\eta)^2\phi^2\gamma^2]+$$
$$4k\beta\theta v(1-\theta)(1+\eta)^2\phi^2\mu^2 z(\sigma) > 0$$,
When $0 < \theta < \frac{[4\beta k-(1+\eta)^2\varphi^2\mu^2 k-(1+\eta)^2\varphi^2\gamma^2 v]z(\sigma)}{4\beta k-(1+\eta)^2\varphi^2\mu^2 z(\sigma)}$, $E[\pi_S]^{A-CR} - \pi_S^{A-R} > 0$.

References

1. Wang, Z.; Mathiyazhagan, K.; Xu, L.; Diabat, A. A decision making trial and evaluation laboratory approach to analyze the barriers to Green Supply Chain Management adoption in a food packaging company. *J. Clean. Prod.* **2016**, *117*, 19–28. [CrossRef]

2. Pham, T.P.; Kaushik, R.; Parshetti, G.K.; Mahmood, R.; Balasubramanian, R. Food waste-To-Energy conversion technologies: Current status and future directions. *Waste Manag.* **2015**, *38*, 399–408. [CrossRef] [PubMed]

3. Moser, A.K. Consumers' purchasing decisions regarding environmentally friendly products: An empirical analysis of German consumers. *J. Retail. Consum. Serv.* **2016**, *31*, 389–397. [CrossRef]

4. Peterson, S.B.; Michalek, J.J. Cost-Effectiveness of plug-in hybrid electric vehicle battery capacity and charging infrastructure investment for reducing US gasoline consumption. *Energy Policy* **2013**, *52*, 429–438. [CrossRef]

5. Prakash, G.; Pathak, P. Intention to buy eco-Friendly packaged products among young consumers of India: A study on developing nation. *J. Clean. Prod.* **2017**, *141*, 385–393. [CrossRef]

6. Zhao, S.; Zhu, Q.; Cui, L. A decision-Making model for remanufacturers: Considering both consumers' environmental preference and the government subsidy policy. *Resour. Conserv. Recycl.* **2018**, *128*, 176–186. [CrossRef]

7. Zhu, Q.; Sarkis, J.; Lai, K.-H. Institutional-based antecedents and performance outcomes of internal and external green supply chain management practices. *J. Purch. Supply Manag.* **2013**, *19*, 106–117. [CrossRef]

8. Resende-Filho, M.A.; Hurley, T.M. Information asymmetry and traceability incentives for food safety. *Int. J. Prod. Econ.* **2012**, *139*, 596–603. [CrossRef]

9. Royera, A.; Ménard, C.; Gouina, D.-M. Reassessing marketing boards as hybrid arrangements: Evidence from Canadian experiences. *Agric. Econ.* **2016**, *47*, 105–116. [CrossRef]

10. Rousseau, S.; Vranken, L. Green market expansion by reducing information asymmetries: Evidence for labeled organic food products. *Food Policy* **2013**, *40*, 31–43. [CrossRef]

11. Chkanikova, O.; Lehner, M. Private eco-Brands and green market development: Towards new forms of sustainability governance in the food retailing. *J. Clean. Prod.* **2015**, *107*, 74–84. [CrossRef]

12. Grekova, K.; Calantone, R.J.; Bremmers, H.J.; Trienekens, J.H.; Omta, S.W.F. How environmental collaboration with suppliers and customers influences firm performance: Evidence from Dutch food and beverage processors. *J. Clean. Prod.* **2016**, *112*, 1861–1871. [CrossRef]

13. McCarthy, D.; Matopoulos, A.; Davies, P. Life cycle assessment in the food supply chain: A case study. *Int. J. Logist. Res. Appl.* **2015**, *18*, 140–154. [CrossRef]

14. Song, C.; Zhuang, J. Modeling a Government-Manufacturer-Farmer game for food supply chain risk management. *Food Control* **2017**, *78*, 443–455. [CrossRef]

15. Rueda, X.; Garrett, R.D.; Lambin, E.F. Corporate investments in supply chain sustainability: Selecting instruments in the agri-Food industry. *J. Clean. Prod.* **2017**, *142*, 2480–2492. [CrossRef]

16. Rouvière, E.; Royer, A. Public Private Partnerships in food industries: A road to success? *Food Policy* **2017**, *69*, 135–144. [CrossRef]

17. Ringsberg, H. Perspectives on food traceability: A systematic literature review. *Supply Chain Manag. An Int. J.* **2014**, *19*, 558–576. [CrossRef]

18. Gunasekaran, A.; Subramanian, N.; Rahman, S. Green supply chain collaboration and incentives: Current trends and future directions. *Transp. Res. Part E-Logist. Transp. Rev.* **2015**, *74*, 1–10. [CrossRef]

19. Chen, K.; Zhao, H.; Xiao, T. Outsourcing contracts and ordering decisions of a supply chain under multi-dimensional uncertainties. *Comput. Ind. Eng.* **2019**, *130*, 127–141. [CrossRef]

20. Kim, S.-H.; Netessine, S. Collaborative Cost Reduction and Component Procurement Under Information Asymmetry. *Manag. Sci.* **2013**, *59*, 189–206. [CrossRef]

21. Resende-Filho, M.A.; Buhr, B.L. A Principal-Agent Model for Evaluating the Economic Value of a Traceability System: A Case Study with Injection-site Lesion Control in Fed Cattle. *Am. J. Agric. Econ.* **2008**, *90*, 1091–1102. [CrossRef]

22. Sun, S.; Wang, X. Promoting traceability for food supply chain with certification. *J. Clean. Prod.* **2019**, *217*, 658–665. [CrossRef]

23. Stranieri, S.; Cavaliere, A.; Banterle, A. Voluntary traceability standards and the role of economic incentives. *Br. Food J.* **2016**, *118*, 1025–1040. [CrossRef]

24. Zhang, M.; Jin, Y.; Qiao, H.; Zheng, F. Product quality asymmetry and food safety: Investigating the "one farm household, two production systems" of fruit and vegetable farmers in China. *China Econ. Rev.* **2017**, *45*, 232–243. [CrossRef]

25. Wang, W.; Zhou, S.; Zhang, M.; Sun, H.; He, L. A Closed-Loop Supply Chain with Competitive Dual Collection Channel under Asymmetric Information and Reward–Penalty Mechanism. *Sustainability* **2018**, *10*, 2131. [CrossRef]

26. Xu, H.; Yao, N.; Tong, S. Sourcing under cost information asymmetry when facing time-Sensitive customers. *Int. J. Prod. Econ.* **2013**, *144*, 599–609. [CrossRef]

27. Xing, G.; Qian, D.; Guo, J.E. Research on the Participant Behavior Selections of the Energy Performance Contracting Project Based on the Robustness of the Shared Savings Contract. *Sustainability* **2016**, *8*, 730. [CrossRef]

28. Zhang, X.; Zeephongsekul, P. Asymmetric supply chain models implementable with a mechanism design. *Appl. Math. Model.* **2016**, *40*, 10719–10739. [CrossRef]

29. Kerkkamp, R.B.O.; van den Heuvel, W.; Wagelmans, A.P.M. Two-Echelon lot-Sizing with asymmetric information and continuous type space. *Omega* **2019**, *87*, 158–176. [CrossRef]

30. Mahadevan, B.; Hazra, J.; Jain, T. Services outsourcing under asymmetric cost information. *Eur. J. Oper. Res.* **2017**, *257*, 456–467. [CrossRef]

31. Cao, E.; Ma, Y.; Wan, C.; Lai, M. Contracting with asymmetric cost information in a dual-Channel supply chain. *Oper. Res. Lett.* **2013**, *41*, 410–414. [CrossRef]

32. Esmaeili, M.; Zeephongsekul, P. Seller–Buyer models of supply chain management with an asymmetric information structure. *Int. J. Prod. Econ.* **2010**, *123*, 146–154. [CrossRef]

33. Corbett, C.J.; Zhou, D.; Tang, C.S. Designing Supply Contracts: Contract Type and Information Asymmetry. *Manag. Sci.* **2004**, *50*, 550–559. [CrossRef]

34. Wang, Y.Y.; Tao, F.; Wang, J.C. Designing optimal and practical volume discounting contracts for the dominant retailer with information asymmetry. *Int. Trans. Oper. Res.* **2017**, *24*, 1405–1433. [CrossRef]

35. Wang, X.; Guo, H.; Yan, R.; Wang, X. Achieving optimal performance of supply chain under cost information asymmetry. *Appl. Math. Model.* **2018**, *53*, 523–539. [CrossRef]

36. Nosoohi, I.; Nookabadi, A.S. Outsource planning with asymmetric supply cost information through a menu of option contracts. *Int. Trans.Oper. Res.* **2019**, *26*, 1422–1450. [CrossRef]

37. Chen, X.; Li, B.; An, S. Option contract design for supply chains under asymmetric cost information. *Kybernetes.* **2019**, *48*, 835–860. [CrossRef]

38. Zheng, B.; Yang, C.; Yang, J.; Zhang, M. Pricing, collecting and contract design in a reverse supply chain with incomplete information. *Comput. Ind. Eng.* **2017**, *111*, 109–122. [CrossRef]

39. Yang, R.; Tang, W.; Dai, R.; Zhang, J. Contract design in reverse recycling supply chain with waste cooking oil under asymmetric cost information. *J. Clean. Prod.* **2018**, *201*, 61–77. [CrossRef]

40. Wang, Q.; He, L. Incentive Strategies for Low-Carbon Supply Chains with Asymmetric Information of Carbon Reduction Efficiency. *Int. J. Environ. Res. Public Health* **2018**, *15*, 736. [CrossRef]

41. Liu, Y.; Li, J.; Quan, B.T.; Yang, J.B. Decision analysis and coordination of two-Stage supply chain considering cost information asymmetry of corporate social responsibility. *J. Clean. Prod.* **2019**, *228*, 1073–1087. [CrossRef]

42. Zhou, L.; Zhou, G.; Qi, F.; Li, H. Research on coordination mechanism for fresh agri-Food supply chain with option contracts. *Kybernetes* **2019**, *48*, 1134–1156. [CrossRef]

43. Swami, S.; Shah, J. Channel coordination in green supply chain management. *J. Oper. Res. Soc.* **2017**, *64*, 336–351. [CrossRef]

44. Zhu, Q.; Li, X.; Zhao, S. Cost-Sharing models for green product production and marketing in a food supply chain. *Ind. Manag. Data Syst.* **2018**, *118*, 654–682. [CrossRef]

45. Gleim, M.R.; Smith, J.S.; Andrews, D.; Cronin, J.J. Against the Green: A Multi-Method Examination of the Barriers to Green Consumption. *J. Retail.* **2013**, *89*, 44–61. [CrossRef]

46. Lin, P.-C.; Huang, Y.-H. The influence factors on choice behavior regarding green products based on the theory of consumption values. *J. Clean. Prod.* **2012**, *22*, 11–18. [CrossRef]

47. Zhang, L.; Wang, J.; You, J. Consumer environmental awareness and channel coordination with two substitutable products. *Eur. J. Oper. Res.* **2015**, *241*, 63–73. [CrossRef]

48. Hardesty, S.D.; Leff, P. Determining marketing costs and returns in alternative marketing channels. *Renew. Agric. Food Syst.* **2009**, *25*, 24–34. [CrossRef]

49. Foster, G.; Gupta, M. Marketing, cost management and management accounting. *J. Manag. Account.* **1994**, *6*, 36.