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The Effects of Fairness Concern and Corporate Social Responsibility on Bilateral Quality Efforts of Agricultural Products Supply Chain

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The Effects of Fairness Concern and Corporate Social Responsibility on Bilateral Quality Efforts of Agricultural Products Supply Chain

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Abstract: This study takes a two-echelon agricultural products supply chain (APSC) composed of an agricultural product processor (processor) and an agricultural product supermarket (supermarket) as the research object. In order to ensure the stable supply of high-quality agricultural products, this paper considers both fairness concern and corporate social responsibility (CSR), and establishes four Stackelberg game models with or without considering fairness concern and CSR, and obtains the influence mechanism of fairness concern and CSR on bilateral quality efforts in APSC through comparative analysis and numerical analysis. Research shows that the supermarket's fairness concern can take the role of "profit distribution mechanism", but it is not conducive to improving bilateral quality efforts resulting in the inability to improve market demand, and it is not conducive to improving the utility of the supply chain system and consumer surplus; both members of APSC sharing CSR can not only improve the quality of agricultural products and promote the expansion of market demand, but also can achieve Pareto improvement of both profit of all members and supply chain system. Besides, The CSR shared by both members has a greater impact on bilateral quality efforts decision than the supermarket's fairness concern, and thus the positive effect of CSR can overcome the negative effect of supermarket's fairness concern.

Keywords: fairness concern; corporate social responsibility (CSR); bilateral quality efforts; agricultural products supply chain

1. Introduction

In order to strengthen the supervision of the quality and safety of agricultural products and ensure the "tip of the tongue safety" of consumers, the Law of the People's Republic of China on the quality and safety of agricultural products, which was reviewed and passed in 2022, emphasized the importance of ensuring the stable supply of high-quality agricultural products. In 2023, the No. 1 central document of the Central Committee of the People's Republic of China was repeatedly proposed to ensure the supply safety of agricultural products, further highlighting the importance of improving the supply quality of agricultural products. However, in recent years, there have been frequent quality and safety incidents of agricultural products, such as excessive aflatoxin in milk and overnight dead crabs impersonating live crabs, which have attracted widespread attention to quality and safety issues on agricultural products and corporate social responsibility (CSR).

On the one hand, the fundamental reason for the quality and safety issues of agricultural products lies in the lack of CSR in APSC and inadequate quality control. It is necessary for supply chain members to actively undertake CSR to improve the quality of agricultural products, thereby promoting high-quality and sustainable development of agricultural products. On the other hand, an important reason for the quality issues of agricultural products is that some supply chain members perceive the unfair distribution of channel profits and make decisions that are detrimental to the quality of agricultural products, leading to the occurrence of quality and safety incidents, such as the "Sanlu Poison Milk Powder" incident caused by the imbalance of profit distribution in the milk powder industry chain. The cause of the "Sanlu Poisoned Milk Powder" incident was that dairy farmers added melamine to raw milk, and the milk powder industry chain had a serious imbalance in income distribution due to being squeezed by manufacturers. Poisoned milk powder posed a threat to life, leading to the breakdown of supply chain cooperation and bankruptcy. Therefore, considering CSR and fairness concern to study bilateral quality efforts decision-making optimization in APSC is of great significance for improving the quality of agricultural products.

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This study will take a two-echelon APSC composed of single processor and single supermarket as the research object. We will establish four Stackelberg game models with or without considering fairness concern and CSR, i.e. In Model I: both fairness concern and CSR are not considered, Model II: Only CSR is considered; Model III: Only fairness concern is considered; Model IV: both fairness concern and CSR are considered, respectively. Then, the backward induction method is applied to solve each model, and the influence mechanism of fairness concern and CSR on bilateral quality efforts in APSC through comparative analysis, sensitivity analysis and numerical analysis, so as to ensure the high-quality supply of agricultural products and improve the operational efficiency of APSC.

The reminder of this paper is organized as follows. Section2 presents related literature, discusses the gap of exiting research and illustrates uniqueness of our research. Section 3 introduces the two-echelon APSC including single processer and single supermarket, including problem description and assumptions. Section 4 develops the four decision models under four scenarios, i.e. Model I: both fairness concern and CSR are not considered, Model II: only CSR is considered; Model III: only fairness concern is considered; Model IV: both fairness concern and CSR are considered, respectively, and compute the optimal solution. Section 5 compares the equilibrium solution in each scenario, and analyzes the effect of fairness concern and CSR on the bilateral quality efforts and APSC. Section 6 conducts the numerical simulation to verify our conclusions. Section 7 concludes our research and propose certain future directions.

2. Literature Review

To analyze the effects of fairness concern and CSR on bilateral quality efforts in APSC, we will review the literatures from three aspects: the quality management of APSC, the effect of CSR on APSC and the effect of fairness concern on APSC.

(1) The quality management of APSC

This article studies the quality management of the two-echelon APSC, and therefore sorts out the research on APSC quality management from both upstream and downstream perspectives.

Firstly, some scholars focus on the unilateral quality management of agricultural products by upstream enterprises in APSC. Henson et al. (2005) believe that controlling producers is the top priority in ensuring the quality and safety of agricultural products, as the production process of agricultural products directly affects food safety. Liang et al. (2019) proposed that manufacturer's production efforts can effectively ensure high standards of initial quality of agricultural products, which can help improve the overall quality of the supply chain and thereby increase overall profits. Wang et al. (2015) designed a "wholesale price + preservation cost sharing" contract to incentivize suppliers to improve their preservation efforts while considering consumer utility. Seo et al. (2017) analyzed the impact of supplier preservation effort on the freshness of fresh agricultural products. Fei (2016) pointed out that upstream enterprise will make efforts to strictly control the quality and safety of agricultural products. Yang et al. (2018) demonstrated that the revenue sharing contract based on effort cost sharing can effectively incentivize agricultural producer to invest in quality efforts and achieve supply chain coordination. Hu et al. (2019) established a four-echelon APSC, demonstrating that revenue sharing contract can affect the quality effort of agricultural producers.

Secondly, some scholars focus on the unilateral quality management of agricultural products by downstream enterprises in APSC. Hsu et al. (2010) and Lee et al. (2012) studied the optimal investment in preservation technology and retailer replenishment strategies based on retailer's effort to reduce the spoilage of fresh agricultural products through preservation technology investment. Pu et al. (2014) and Ding Ning (2015) demonstrated that quality testing and control of agricultural products in the retail process can effectively improve the quality and safety of agricultural products. Zhong et al. (2016) pointed out that the quality effort of agricultural supermarket has a positive impact on the quality and safety control effectiveness of agricultural products. Wen et al. (2017) considered the quality control of agricultural products by agricultural supermarket, and improved the quality of agricultural products through income sharing contract with retained earnings. Shi et al. (2019) studied the quality and safety of fresh agricultural products in the internet environment and proposed strategies and suggestions to improve the unilateral quality effort of agricultural products seller. Liu et al. (2018) believe that it is necessary to strengthen the sale process of agricultural products to solve the quality problems of agricultural products, and propose that

supermarket should develop quality testing standard of agricultural products, responsible for cold chain distribution to ensure the supply quality of agricultural products. Chen (2020) constructed a game model for grading the quality of agricultural products, proving that retailer can achieve maximum profit in the supply chain system by grading quality.

Finally, only few literatures involve bilateral quality management in APSC. Yoo et al. (2018) studied the impact of bilateral quality efforts between supplier and retailer of agricultural products on the APSC performance and proposed quality improvement mechanism for retailer to supervise supplier. Huo et al. (2019) established bilateral quality decision-making and coordination model for APSC based on the concept of "company + farmer", and demonstrated that when both company and farmer jointly bear the loss of agricultural product quality, both the APSC coordination and high-quality supply of agricultural products can be achieved. Yang et al. (2019) studied the bilateral quality and safety investment between supplier and producer of agricultural products, and proposed that when the government's punishment reaches a certain threshold, it can encourage supplier and producer to simultaneously invest in quality and safety.

However, the above research has studied the quality management of upstream and downstream in APSC, with less research on bilateral quality management in APSC and without considering fairness concern and CSR. For agricultural products have characteristics such as perishability, difficulty in preservation, and strict transportation conditions, and the quality of agricultural products is jointly influenced by bilateral quality efforts. Besides, ignoring the fairness concern of members will lead to making decisions that are detrimental to the quality of agricultural products due to unfair distribution of supply chain benefits, leading to the agricultural products with low quality flowing into the market, and the quality safety of agricultural products are related to social security. In APSC, considering CSR requires members to not only focus on their own profit but also on social benefit, thus CSR affects the quality decisions of both parties. Therefore, it is necessary to simultaneously study the impact of fairness concern and CSR on the quality management of APSC.

(2) The effect of CSR on APSC

At present, most of the literature focuses on the impact of CSR on relevant decisions in general supply chain, while there are few literatures considering CSR to study APSC. Given the unique nature of APSC, i.e., perishability, difficulty in preservation, etc., the research findings on the impact of CSR on general supply chain can help better study the impact of CSR on APSC. Therefore, this section of literature review is divided into two parts: effect of CSR on supply chain and effect of CSR on APSC.

① Effect of CSR on supply chain. Firstly, some scholars consider the CSR of upstream enterprises in the supply chain to conduct research. Chen et al. (2016) analyzed the impact of CSR input from upstream enterprises on market equilibrium results under different pricing rules. Hsueh (2014) validated that revenue sharing contract can motivate manufacturer to fulfill CSR under uncertain market demand. Nematollahi et al. (2017) considered supplier's CSR in the coordination model and pointed out that supplier's investment in CSR activities can improve product awareness and market demand. Li et al. (2018) considered upstream enterprises in the supply chain to undertake CSR and establish a quality signal transmission game model to improve product quality. Liang et al. (2020) demonstrated that the assumption of CSR by original manufacturers helps to improve product greenness and consumer welfare, and adopts a two-part pricing contract to achieve Pareto improvement in the supply chain. Yao et al. (2020) pointed out that manufacturer undertaking CSR can enhance social welfare and improve other members of the supply chain. Secondly, some scholars considered the CSR of downstream enterprises in the supply chain to conduct research. Seyyed et al. (2020) studied sustainability issues in closed-loop supply chain and pointed out that retailer's increasing CSR investment will increase market demand. Liang et al. (2013) studied the impact of CSR in a dual channel competition model, demonstrating that as consumers' recognition of retailer CSR behavior increases, the profits of each enterprise in the supply chain increase, and CSR behavior can help to reduce market competition. Liu et al. (2019) demonstrated that improving the retailer's CSR is beneficial for achieving balance between corporate interest and social welfare. Lin et al. (2020) demonstrated that increasing the retailer's CSR can improve social welfare, manufacturer's emission reduction, and profit. Jin et al. (2018) studied an online retail supply chain composed of manufacturer and online retailer, and they demonstrated that retailer's CSR can effectively improve the overall utility of the supply chain system. Tang et al. (2020) used CSR attention to characterize the retailer's CSR, and pointed out that increasing the retailer's CSR attention can benefit both manufacturer and

retailer. Finally, only few research considered the sharing of CSR by both parties in the supply chain. Gao et al. (2014) proved that when both members bear CSR in supply chain, the profit of the supply chain is positively correlated with the degree of CSR burden, and they design two-part pricing contract and revenue sharing contract to achieve coordination of closed-loop supply chain. Fan et al. (2019) demonstrated that sharing CSR between manufacturer and retailer can help improve the quality of supply chain products and the profitability of supply chain enterprises. Nie et al. (2020) considered the sharing CSR between manufacturer and retailer under nonlinear cost, and pointed out that regardless of whether manufacturer has scale economy or scale economy, both manufacturer and retailer are always willing to share CSR.

② Effect of CSR on APSC. Liu et al. (2019) demonstrated that fulfilling CSR is beneficial for improving the performance of APSC. Ji (2021) constructed a CSR decision-making model for fresh product supplier and e-commerce platform under random demand, and proved that members fulfilling CSR can effectively improve the performance level of enterprises at each node. Li et al. (2020) demonstrated that in the process of transforming the agricultural product processing trade model to the agricultural technology transfer model, agricultural product processing enterprises attach importance to CSR and adopt new agricultural technologies and equipment, which is beneficial for improving the quality level of agricultural products and improving the utilization rate of agricultural resources. Wei et al. (2016) pointed out that chain supermarket enterprises, as the end of the supply chain, should first bear CSR, form a scale advantage through centralized procurement, and ensure the timely listing of high-quality agricultural products through logistics network advantages.

The above literatures have studied the impact of CSR on relevant decisions by single member of general supply chain, while there is less research on the impact of CSR shared by members and CSR on agricultural product quality. The quality and safety of agricultural products are related to social stability, and sharing CSR among members of the APSC will affect bilateral quality decisions and further ensure the quality of agricultural products. Therefore, it is necessary to study the impact of CSR shared by both members of APSC on the quality of agricultural products.

(3) The effect of fairness on APSC

Hendrickson et al. (2018) pointed out that the unfair performance in APSC is more complex. Moon et al. (2018) pointed out that retailer's fairness concern can affect investment decision of members in fresh APSC. Hong et al. (2014) demonstrated that both profit and order quantity of fresh APSC members strictly decrease with retailer's fairness concern. Kang et al. (2021) found that the fairness concern of APSC enterprises exacerbates the double marginalization of the supply chain, reduces the profits of both members, and leads to a decrease in the efficiency of APSC. Zhang et al. (2017a, 2017b) established a supplier led secondary fresh APSC model and proved that the stronger the retailer's fairness concern, the more profit the supplier transfers, and they proposed an improved side payment automatic execution contract to achieve supply chain coordination and Pareto improve both parties' profits. Liu et al. (2019) established a three-level APSC model and demonstrated that retailer's fairness concern has a significant impact on the coordination of revenue sharing contract. Cao et al. (2014) introduced fairness concern into the dual channel supply chain of fresh agricultural products, and proved that supplier's fairness concern has the function of automatically coordinating the supply chain. Xiong et al. (2017) studied the impact of supplier's fairness concern on the quality input and pricing of fresh agricultural products by retailers. Yan et al. (2020) demonstrated that fairness concern between manufacturer and retailer lead to a decrease in the overall effectiveness of the fresh APSC, and proposed revenue sharing contract to improve both parties' profit and motivate manufacturer to implement preservation work.

The above literatures proved that the fairness concern of members in APSC can affect order quantity, profit of each member, and coordination of the supply chain. Only Xiong et al. (2017) and Yan et al. (2020) studied the impact of fairness concern on quality decision in APSC. The supply of high-quality agricultural products is key to the stable operation of APSC, and the fairness concern will also affect the quality investment of both members. Therefore, it is necessary to consider fairness concern in studying the quality management of APSC.

To sum up, the above research has studied quality control of agricultural product and some have considered the impact of CSR or fairness concern on decision-making of APSC, but there are still the following shortcomings. Firstly, these researches only studied unilateral quality management in APSC, with few referred to bilateral quality management in APSC, and none consider both fairness

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concern and CSR simultaneously. Secondly, some literature have studied the impact of CSR on relevant decisions by single member in general supply chain, while there are few studies on the impact of CSR shared by members and CSR on quality of agricultural products. Finally, the above literature proves that the fairness concern of members can affect order quantity, profits of each member, and coordination of the supply chain. There is relatively few research on the impact of member's fairness concern on quality decision-making in APSC.

In reality, the quality of agricultural products is jointly influenced by bilateral quality efforts in APSC, and the fulfillment of CSR by both parties and the fairness concern of members in APSC will affect bilateral quality efforts. Therefore, this article will consider both fairness concern and CSR, and establishes four Stackelberg game models with or without fairness concern and CSR, and obtains the influence mechanism of fairness concern and CSR on bilateral quality efforts in the agricultural products supply chain through comparative analysis and numerical analysis.

3. Problem Description and Assumptions

We focus on two-echelon APSC composed of a processor and a supermarket. The processor is in a dominant position to take action first due to unique processing technology and other advantages, while supermarket is in a subordinate position to take action later. In order to study the impact of CSR on bilateral quality efforts, there are two scenarios:

(1) When CSR is not considered

Assumption 1: The processor first determines wholesale price w, and then the supermarket determines the order quantity q.

Assumption 2: Market demand is only affected by retail price, denoted as $q = a - \alpha p$, where a ($a > 0$) represents the scale of market demand, and α represents the sensitivity coefficient of market demand to the retail price of agricultural products.

Assumption 3: according to Panda (2016), the consumer surplus CS can be used to measure the fulfillment of CSR in APSC. According to the demand function in Assumption 2, it is easy to know $p \in (\frac{a-q}{\alpha}, \frac{a}{\alpha})$, and thus the CS can be computed as $CS = \int_{p_{\min}}^{p_{\max}} q dp = \int_{\frac{a-q}{\alpha}}^{\frac{a}{\alpha}} (a - \alpha p) dp = \frac{q^2}{2\alpha}$.

(1) When CSR is considered

Assumption 4: The processor makes decision on wholesale price w and quality effort e_s in the first place, and then the supermarket makes decision on order quantity q and quality effort e_r. In order to highlight the importance of CSR, bilateral quality efforts only represent additional quality efforts made by both processor and supermarket to fulfill CSR, and do not include general quality efforts made by them to ensure the quality of agricultural products.

Assumption 5: The processor's CSR awareness can be denoted as θ , and supermarket's CSR awareness is $1-\theta$, while $\theta \in [\frac{1}{2}, \frac{2}{3})$ denotes the processor should bear the majority of CSR as the leader, and ensure that both parties are willing to jointly bear CSR.

Assumption 6: Based on the research of Wen et al. (2017), the processer's cost and supermarket's cost function can be denoted as $c_s = \frac{1}{2} e_s^2$ and $c_r = \frac{1}{2} e_r^2$ respectively. The quality effort cost function indicates that the higher the quality effort paid by APSC members to fulfill CSR, the higher the cost incurred.

Assumption 7: The market demand for agricultural products is jointly influenced by retail price and quality, and the market demand function is $q = a - \alpha p + \beta(e_s + e_r)$, where β represents the sensitivity coefficient of market demand to the quality of agricultural products. To ensure that the supermarket's order quantity is positive under any circumstances, we assume $2\beta^2 < \alpha < \frac{8}{3}\beta^2$ and $2\alpha\theta > \beta^2$.

Assumption 8: similar to assumption 3, according to the market demand function under CSR, we can get $p \in (\frac{a + \beta e_s + \beta e_r - q}{\alpha}, \frac{a + \beta e_s + \beta e_r}{\alpha})$, and then the consumer surplus is below:

$$CS = \int_{p_{\min}}^{p_{\max}} q dp = \int_{\frac{a+\beta(e_s+e_r)-q}{\alpha}}^{\frac{a+\beta(e_s+e_r)}{\alpha}} [a - \alpha p + \beta(e_s + e_r)] dp = \frac{q^2}{2\alpha}$$

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To simplify the calculation, it is assumed that the order quantity of agricultural supermarkets is equal to the market demand, without considering stockout cost and surplus cost. Use the subscripts "S", "r", and "SC" to represent processor, supermarket, and supply chain system, respectively.

The superscript "n" to indicate decision without fairness concern or CSR, "$n-CSR$" indicates the condition only considering CSR without fairness concern, "f" indicates the condition only considering fairness concern without CSR, and "$f-CSR$" indicates the condition only considering both fairness concern and CSR. The superscript "$*$" denotes the solution in equilibrium. "π" denotes profit, and "$\prod$" denotes utility.

4. Models and Solutions under Four Scenarios

In order to study the impact mechanism of fairness concern and CSR on bilateral quality efforts decision-making in APSC, this section will develop the four decision models under four scenarios, i.e. Model I: both fairness concern and CSR are not considered, Model II: only CSR is considered; Model III: only fairness concern is considered; Model IV: both fairness concern and CSR are considered, respectively, and compute the optimal solution.

Model I: Both fairness concern and CSR are not considered

When both fairness concern and CSR are not considered, the processor's profit refers to the reduction of sales revenue and procurement cost, while utility refers to the utility obtained through direct income, i.e. $\pi_s^n = (w - c_0)q$, $\prod_s^n = (w - c_0)q$ .Similarly, the supermarket's profit and utility can be denoted as $\pi_r^n = (p - w)q = (\frac{a-q}{\alpha} - w)q$ and $\prod_r^n = (p - w)q = (\frac{a-q}{\alpha} - w)q$ .So the utility of supply chain is equal to the sum of processor's utility and supermarket's utility, i.e. $\prod_{sc}^n = \prod_s^n + \prod_r^n = (\frac{a-q}{\alpha} - c_0)q$.

Both processor and supermarket make decision based on maximizing profit. The decision-making model for APSC can be denoted as:

$$\underset{w}{Max}\, \pi_s^n = (w - c_0)q$$

s.t $\underset{q}{Max}\, \pi_r^n = (p - w)q = (\frac{a-q}{\alpha} - w)q$

For π_r^n is strictly concave in q, and π_s^n is strictly concave in w, so both π_r^n and π_s^n has unique optimal solution, and the backward induction method can be applied to compute equilibrium solution, which is shown in Table 1.

Model II: only CSR is considered

In the real business process, more and more enterprises have actively undertaken CSR and believe that improving the interests of stakeholders is beneficial for long-term stable cooperation and obtaining more economic benefits. The Model II only considers that both APSC members make quality efforts so as to jointly undertake CSR, and thus both them make decisions to maximize the total utility including profit and consumer surplus. Under CSR, the processor's profit is the reduction of their sale revenue, procurement cost, and quality effort cost, i.e. $\pi_s^{n-CSR} = (w - c_0)q - \frac{1}{2}e_s^2$, and utility function is $\prod_s^{n-CSR} = \pi_s + \theta CS$, i.e. $\prod_s^{n-CSR} = \pi_s + \theta CS = (w - c_0)q - \frac{1}{2}e_s^2 + \theta\frac{q^2}{2\alpha}$. Similarly, the supermarket's profit and utility function is below:

$$\pi_r^{n-CSR} = (p - w)q - \frac{1}{2}e_r^2 = [\frac{a + \beta(e_s + e_r) - q}{\alpha} - w]q - \frac{1}{2}e_r^2$$

$$\prod_r^{n-CSR} = \pi_r + (1 - \theta)CS = [\frac{a + \beta(e_s + e_r) - q}{\alpha} - w]q - \frac{1}{2}e_r^2 + (1 - \theta)\frac{q^2}{2\alpha}$$

The APSC's utility is

$$\prod_{sc}^{n-CSR} = \prod_s^{n-CSR} + \prod_r^{n-CSR} = [\frac{a + \beta(e_s + e_r) - q}{\alpha} - c_0]q - \frac{1}{2}e_s^2 - \frac{1}{2}e_r^2 + \frac{q^2}{2\alpha}$$

The APSC decision model can be denoted as below:

$$\underset{w,e_s}{Max}\, \prod_s^{n-CSR} = (w - c_0)q - \frac{1}{2}e_s^2 + \theta\frac{q^2}{2\alpha}$$

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$$\underset{q,e_r}{Max}\Pi_r^{n-CSR}=[\frac{a+\beta(e_s+e_r)-q}{\alpha}-w]q-\frac{1}{2}e_r^2+(1-\theta)\frac{q^2}{2\alpha}$$

s.t.

For Π_r^{n-CSR} is strictly concave in q and e_r, and Π_s^{n-CSR} is strictly concave in w and e, so both Π_r^{n-CSR} and Π_s^{n-CSR} has unique optimal solution, and the backward induction method can be applied to compute equilibrium solution, which is shown in Table 1.

Table 1. Equilibrium results with and without CSR under non-fairness concern.

Variable	Model I	Model II
w	$\frac{a+\alpha c_0}{2\alpha}$	$\frac{\alpha c_0[(1+\theta)\alpha-2\beta^2]+a(\alpha-\beta^2)}{\alpha[(2+\theta)\alpha-3\beta^2]}$
q	$\frac{a-\alpha c_0}{4}$	$\frac{\alpha(a-\alpha c_0)}{(2+\theta)\alpha-3\beta^2}$
e_s	0	$\frac{\beta(a-\alpha c_0)}{(2+\theta)\alpha-3\beta^2}$
e_r	0	$\frac{\beta(a-\alpha c_0)}{(2+\theta)\alpha-3\beta^2}$
π_s	$\frac{(a-\alpha c_0)^2}{8\alpha}$	$\frac{(a-\alpha c_0)^2(2\alpha-3\beta^2)}{2[(2+\theta)\alpha-3\beta^2]^2}$
π_r	$\frac{(a-\alpha c_0)^2}{16\alpha}$	$\frac{(a-\alpha c_0)^2(2\alpha\theta-\beta^2)}{2[(2+\theta)\alpha-3\beta^2]^2}$
Π_s	$\frac{(a-\alpha c_0)^2}{8\alpha}$	$\frac{(a-\alpha c_0)^2}{2[(2+\theta)\alpha-3\beta^2]}$
Π_r	$\frac{(a-\alpha c_0)^2}{16\alpha}$	$\frac{(a-\alpha c_0)^2[(1+\theta)\alpha-\beta^2]}{2[(2+\theta)\alpha-3\beta^2]^2}$
Π_{sc}	$\frac{3(a-\alpha c_0)^2}{16\alpha}$	$\frac{(a-\alpha c_0)^2[(3+2\theta)\alpha-4\beta^2]}{2[(2+\theta)\alpha-3\beta^2]^2}$
CS	$\frac{(a-\alpha c_0)^2}{32\alpha}$	$\frac{\alpha(a-\alpha c_0)^2}{2[(2+\theta)\alpha-3\beta^2]^2}$

Model III: only fairness concern is considered

From Model I, we can find that the supermarket's profit is always lower than processor ($\pi_r^{n*}<\pi_s^{n*}$), and supermarket may perceive the unfair distribution of benefit in supply chain and then cares about fairness. Therefore, according to Zhang et al. (2017a), the fairness concern coefficient λ ($0<\lambda<1$) is introduced. At this time, the supermarket's utility includes the utility obtained from direct income and the negative unfair utility $\prod_r=\pi_r-\lambda(\pi_s-\pi_r)$, and the supermarket's profit is the same as Model I, so the supermarket's profit and utility can be denoted as: $\pi_r^f=(p-w)q=(\frac{a-q}{\alpha}-w)q$ and $\Pi_r^f=\pi_r-\lambda(\pi_s-\pi_r)=(1+\lambda)(\frac{a-q}{\alpha}-w)q-\lambda(w-c_0)q$. While the processor's profit and utility is same as Model I, i.e. $\pi_s^f=(w-c_0)q$ and $\Pi_s^f=(w-c_0)q$. Then, the utility of supply chain is $\Pi_{sc}^f=\Pi_s^f+\Pi_r^f=(1+\lambda)(\frac{a-q}{\alpha}-w)q+(1-\lambda)(w-c_0)q$.

The APSC decision model can be denoted as below:

$$\underset{w}{Max}\,\pi_s^f=(w-c_0)q$$

s.t. $$\underset{q}{Max}\,\Pi_r^f=(1+\lambda)(\frac{a-q}{\alpha}-w)q-\lambda(w-c_0)q$$

For Π_r^f is strictly concave in q, and π_s^f is strictly concave in w, so both Π_r^f and π_s^n has unique optimal solution, and the backward induction method can be applied to compute equilibrium solution, which is shown in Table 2.

Model IV: both fairness concern and CSR are considered

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According to Model II, we can find that the supermarket's profit is always lower than processor ($\pi_r^{n-CSR*} < \pi_s^{n-CSR*}$). Therefore, Model III considers supermarket's fairness concern. At this time, the supermarket's utility includes the utility obtained from direct income, negative unfair utility, and the utility obtained from creating consumer surplus. The supermarket's utility function is $\prod_r = \pi_r - \lambda(\pi_s - \pi_r) + (1-\theta)CS$, while the profit is the same as Model II. The supermarket's profit and utility is as following:

$$\pi_r^{f-CSR} = (\frac{a+\beta(e_s+e_r)-q}{\alpha} - w)q - \frac{1}{2}e_r^2$$

$$\prod_r^{f-CSR} = (1+\lambda)[(\frac{a+\beta(e_s+e_r)-q}{\alpha} - w)q - \frac{1}{2}e_r^2] - \lambda[(w-c_0)q - \frac{1}{2}e_s^2] + (1-\theta)\frac{q^2}{2\alpha}$$

The processor's profit and utility is same with Model II, i.e. $\pi_s^{f-CSR} = (w-c_0)q - \frac{1}{2}e_s^2$ and $\prod_s^{f-CSR} = (w-c_0)q - \frac{1}{2}e_s^2 + \theta\frac{q^2}{2\alpha}$. Then, the utility of supply chain is

$$\prod_{sc}^{f-CSR} = \prod_s^{f-CSR} + \prod_r^{f-CSR} = (1+\lambda)[(\frac{a+\beta(e_s+e_r)-q}{\alpha} - w)q - \frac{1}{2}e_r^2] + (1-\lambda)[(w-c_0)q - \frac{1}{2}e_s^2] + \frac{q^2}{2\alpha}$$

The APSC decision model can be denoted as below:

$$\underset{q,e_s}{Max}\prod_s^{f-CSR} = (w-c_0)q - \frac{1}{2}e_s^2 + \theta\frac{q^2}{2\alpha}$$

$$s.t \quad \underset{q,e_r}{Max}\prod_r^{f-CSR} = (1+\lambda)[(\frac{a+\beta e_s+\beta e_r-q}{\alpha} - w)q - \frac{1}{2}e_r^2] - \lambda[(w-c_0)q - \frac{1}{2}e_s^2] + (1-\theta)\frac{q^2}{2\alpha}$$

For $\prod_r^{f-CSR}$ is strictly concave in q, and $\prod_s^{f-CSR}$ is strictly concave in w, so both $\prod_r^{f-CSR}$ and $\prod_s^{f-CSR}$ has unique optimal solution, and the backward induction method can be applied to compute equilibrium solution, which is shown in Table 2.

Table 2. Equilibrium results with and without CSR under fairness concern.

Variable	Model III	Model IV
w	$\frac{(1+\lambda)a+(1+3\lambda)\alpha c_0}{(1+2\lambda)\alpha}$	$\frac{\alpha^2 c_0[(6-2\theta)\lambda^2+(5+2\theta)\lambda+1+\theta] + (1+\lambda)\alpha[a-\beta^2 c_0+\lambda[(1-\theta)a-2\beta^2 c_0]+(1+\lambda)^2 a\beta^2}{\alpha\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]}$
q	$\frac{a-\alpha c_0}{4}$	$\frac{\alpha(1+\lambda)(1+2\lambda)(a-\alpha c_0)}{\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2}$
e_s	0	$\frac{\beta(1+\lambda)^2(a-\alpha c_0)}{\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2}$
e_r	0	$\frac{\beta(1+\lambda)(1+2\lambda)(a-\alpha c_0)}{\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2}$
π_s	$\frac{(1+\lambda)(a-\alpha c_0)^2}{8\alpha(1+2\lambda)}$	$\frac{(1+\lambda)^2(a-\alpha c_0)^2\left[(1+2\lambda)[(4-4\theta)-2]\alpha-(1+\lambda)(3+5\lambda)\beta^2\right]}{2\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}$
π_r	$\frac{(1+4\lambda)(a-\alpha c_0)^2}{16\alpha(1+2\lambda)}$	$\frac{(1+\lambda)(1+2\lambda)(a-\alpha c_0)^2\left[[(8-4\theta)\lambda^2+(4+4\theta)\lambda-2\theta]\alpha-(1+\lambda)(1+4\lambda)\beta^2\right]}{2\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}$
$\prod_s$	$\frac{(1+\lambda)(a-\alpha c_0)^2}{8\alpha(1+2\lambda)}$	$\frac{(1+\lambda)^2(a-\alpha c_0)^2}{2\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]}$
$\prod_r$	$\frac{(1+\lambda)(a-\alpha c_0)^2}{16\alpha}$	$\frac{(1+\lambda)^2(a-\alpha c_0)^2\left[(1+2\lambda+\theta)(1+2\lambda)^2\alpha-(1+\lambda)(3\lambda^2+3\lambda+1)\beta^2\right]}{2\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}$
$\prod_{sc}$	$\frac{(1+\lambda)(3+2\lambda)(a-\alpha c_0}{16\alpha(1+2\lambda)}$	$\frac{(1+\lambda)^2(a-\alpha c_0)^2\left[(4\lambda^2+8\lambda+2\theta+3)(1+2\lambda)\alpha-(1+\lambda)(2+\lambda)(2+3\lambda)\beta^2\right]}{2\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}$
CS	$\frac{(a-\alpha c_0)^2}{32\alpha}$	$\frac{\alpha(1+\lambda)^2(1+2\lambda)^2(a-\alpha c_0)^2}{2\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}$

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5. The Impact Mechanism of Fairness Concern and CSR

(1) The effect of fairness concern

When the CSR is not considered, we can compare Model I and Model III so as to analyze whether supermarket's fairness concern affects the operation of APSC.

Proposition 1 $w^{f*} < w^{n*}$, $q^{f*} = q^{n*}$.

For $w^{n*} - w^{f*} = \frac{\lambda(a-\alpha c_0)}{2\alpha(1+2\lambda)} > 0$, it is easy to get $w^{f*} < w^{n*}$.

Proposition 1 indicates that the supermarket's fairness concern leads to decrease in wholesale price, but does not reduce order quantity. It can be seen that processor has reduced wholesale price to alleviate the negative unfair utility of supermarket, but the quality of agricultural products remains unchanged, so market demand remains unchanged.

Proposition 2 ① $\pi_s^{f*} < \pi_s^{n*}$, $\pi_r^{f*} > \pi_r^{n*}$. If $0 < \lambda < \frac{1}{2}$, then $\pi_s^{f*} > \pi_r^{f*}$, and if $\frac{1}{2} < \lambda < 1$, then $\pi_s^{f*} < \pi_r^{f*}$.

② $\Pi_s^{f*} < \Pi_s^{n*}$, $\Pi_r^{f*} > \Pi_r^{n*}$. If $0 < \lambda < \frac{1}{2}$, $\Pi_{sc}^{n*} > \Pi_{sc}^{f*}$, and if $\frac{1}{2} < \lambda < 1$, $\Pi_{sc}^{n*} < \Pi_{sc}^{f*}$.

③ $CS^{f*} = CS^{n*}$.

For $\pi_s^{n*} - \pi_s^{f*} = \frac{\lambda(a-\alpha c_0)^2}{8\alpha(1+2\lambda)} > 0$, it is easy to get $\pi_s^{f*} < \pi_s^{n*}$, and $\pi_r^{n*} - \pi_r^{f*} = -\frac{\lambda(a-\alpha c_0)^2}{8\alpha(1+2\lambda)} < 0$, so $\pi_r^{f*} > \pi_r^{n*}$. For $\pi_s^{f*} - \pi_r^{f*} = -\frac{(2\lambda-1)(a-\alpha c_0)^2}{16\alpha(1+2\lambda)}$, if $0 < \lambda < \frac{1}{2}$, then $\pi_s^{f*} > \pi_r^{f*}$, and if $\frac{1}{2} < \lambda < 1$, then $\pi_s^{f*} < \pi_r^{f*}$. For $\Pi_s^{n*} - \Pi_s^{f*} = \frac{\lambda(a-\alpha c_0)^2}{8\alpha(1+2\lambda)} > 0$, and thus $\Pi_s^{f*} < \Pi_s^{n*}$. Similarly, for $\Pi_r^{n*} - \Pi_r^{f*} = -\frac{\lambda(a-\alpha c_0)^2}{16\alpha} < 0$, and then $\Pi_r^{f*} > \Pi_r^{n*}$. For $\Pi_{sc}^{n*} - \Pi_{sc}^{f*} = -\frac{\lambda(a-\alpha c_0)^2(2\lambda-1)}{16\alpha(1+2\lambda)}$, if $0 < \lambda < \frac{1}{2}$, then $\Pi_{sc}^{n*} > \Pi_{sc}^{f*}$, and if $\frac{1}{2} < \lambda < 1$, then $\Pi_{sc}^{n*} < \Pi_{sc}^{f*}$.

Proposition 2 indicates that when supermarket's fairness concern is weak, the supermarket's profit increases with fairness concern, but supermarket's profit is still lower than processor, while supermarket's utility increases. When the supermarket's fairness concern is strong, processor transfers most of the profit to supermarket, resulting in decrease in processor's profit and lower than supermarket. This indicates that the supermarket's fairness concern plays a role in the "profit distribution mechanism". Secondly, although strong fairness concern increases the utility of APSC, it does not mean that supermarket's strong fairness concern is beneficial to the supply chain system, as the unfair distribution of profit in the supply chain system may lead to more complex decision-making problem by both parties and hinder the supply chain operation. Finally, combined with Proposition 1, regardless of whether supermarket has fairness concern or not, the demand and quality of the agricultural product market remain unchanged, and consumer surplus remains unchanged.

Furthermore, when the CSR is considered, we can compare Model II and Model IV so as to analyze whether supermarket's fairness concern affects the operation of APSC.

Proposition 3 $e_s^{n-CSR*} = e_r^{n-CSR*} > e_r^{f-CSR*} > e_s^{f-CSR*}$, $q^{f-CSR*} < q^{n-CSR*}$, $w^{f-CSR*} < w^{n-CSR*}$.

For $\frac{1}{2} \le \theta < \frac{2}{3}$ and $2\beta^2 < \theta < \frac{8}{3}\beta^2$, we can get $e_r^{n-CSR*} - e_r^{f-CSR*} = \frac{\lambda\beta(a-\alpha c_0)\left[[(4-6\theta)\lambda + 2 - 3\theta]\alpha + (1+\lambda)\beta^2\right]}{[(2+\theta)\alpha - 3\beta^2]y_1} > 0$. For $e_r^{f-CSR*} - e_s^{f-CSR*} = \frac{\lambda\beta(a-\alpha c_0)(1+\lambda)}{\left[\lambda^2[(8-4\theta)\alpha - 5\beta^2] + 8\lambda(\alpha-\beta^2) + (2+\theta)\alpha - 3\beta^2\right]} > 0$, i.e. $e_r^{f-CSR*} > e_s^{f-CSR*}$, and thus $e_s^{n-CSR*} = e_r^{n-CSR*} > e_r^{f-CSR*} > e_s^{f-CSR*}$. For

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$q^{n-CSR*}-q^{f-CSR*}=\frac{\lambda\alpha(a-\alpha c_0)\left[[(4-6\theta)\lambda+2-3\theta]\alpha+(1+\lambda)\beta^2\right]}{[(2+\theta)\alpha-3\beta^2]y_1}>0$, i.e. $q^{f-CSR*}<q^{n-CSR*}$, and $w^{n-CSR*}-w^{f-CSR*}=\frac{\lambda(a-\alpha c_0)\left[\begin{matrix}[(2\theta^2-2\theta+4)\lambda+2\theta^2+\theta+2]\alpha^2\\-[(5+\theta)\lambda+3+4\theta]\alpha\beta^2+2(1+\lambda)\beta^4\end{matrix}\right]}{\alpha[(2+\theta)\alpha-3\beta^2]y_1}>0$, i.e. $w^{f-CSR*}<w^{n-CSR*}$.

($y_1=[(4-2\theta)\lambda+2+\theta](1+2\lambda)\alpha-(1+\lambda)(3+5\lambda)\beta^2$)

Combining Proposition 1 and Proposition 3, regardless of whether CSR is considered or not, the supermarket's fairness concern will always lead to decrease in wholesale price, while processor will reduce the cost of quality effort to reduce operational risk. In the face of lower quality agricultural products, supermarket will lack the motivation to invest in higher quality effort due to the inability to improve the quality of agricultural products from the supplier source. However, in order to further reduce loss and ensure consumer safety, supermarket will pay higher quality effort than processor. However, low-quality agricultural products cannot meet the needs of consumers, resulting in decrease in market demand.

Proposition 4 ① $\pi_r^{f-CSR*}>\pi_r^{n-CSR*}$, $\pi_s^{f-CSR*}<\pi_s^{n-CSR*}$. If $0<\lambda<\lambda_1$, then $\pi_s^{f-CSR*}>\pi_r^{f-CSR*}$, and if $\lambda_1<\lambda<1$, $\pi_s^{f-CSR*}<\pi_r^{f-CSR*}$.($\lambda_1\in(0,1)$).

② $\Pi_s^{f-CSR*}<\Pi_s^{n-CSR*}$, $\Pi_r^{f-CSR*}>\Pi_r^{n-CSR*}$, $\Pi_{sc}^{f-CSR*}<\Pi_{sc}^{n-CSR*}$.

③ $CS^{f-CSR*}<CS^{n-CSR*}$.

The Proof is shown in appendix 1.

Proposition 4 indicates that the supermarket's fairness concern plays a role as a "profit distribution mechanism". At the same time, combined with Proposition 3, the decrease in quality and quantity of agricultural products is not conducive to the improvement of consumer welfare, resulting in a decrease in consumer surplus.

Conclusion 1 The supermarket's fairness concern only serves as a "profit distribution mechanism" and cannot improve consumer surplus.

On the one hand, the supermarket's fairness concern can lead to decrease in wholesale price, leading to increase in profit and decrease in the processor's profit. Therefore, the supermarket's fairness concern plays a role as a "profit distribution mechanism", but is not conducive to the stable operation of APSC. On the other hand, the supermarket's fairness concern is not conducive to the improvement of agricultural product quality and the expansion of market demand, so both the effectiveness of the supply chain system and consumer surplus cannot be improved.

(1) The effect of CSR

When the fairness concern is not considered, we can compare Model I and Model II so as to analyze whether CSR affects the operation of APSC.

Proposition 5 $q^{n-CSR*}>q^{n*}$, $w^{n-CSR*}<w^{n*}$.

Proof. For $q^{n-CSR*}-q^{n*}=\frac{(a-\alpha c_0)[(2-\theta)\alpha+3\beta^2]}{[(8+4\theta)\alpha-12\beta^2]}>0$, it is easy to get $q^{n-CSR*}>q^{n*}$. let $y_2=w^{n*}-w^{n-CSR*}=\frac{(a-\alpha c_0)(\alpha\theta-\beta^2)}{\alpha[(4+2\theta)\alpha-6\beta^2]}$, for $\frac{\partial y_2}{\partial\theta}=\frac{(a-\alpha c_0)(\alpha-\beta^2)}{[(2+\theta)\alpha-3\beta^2]^2}>0$, which indicates that y_2 is strictly increasing in θ, and $y_2(\theta=\frac{1}{2})=\frac{(\alpha-2\beta^2)(a-\alpha c_0)}{2\alpha(5\alpha-6\beta^2)}>0$, $y_2(\theta=\frac{2}{3})=\frac{(a-\alpha c_0)(2\alpha-3\beta^2)}{2\alpha(8\alpha-9\beta^2)}>0$, so $w^{n-CSR*}<w^{n*}$.

Through Proposition 5, the sharing of CSR among members of APSC leads to a decrease in wholesale price and an increase in market demand. This is because processor with CSR awareness indirectly encourages supermarket to set reasonable retail price to bring benefits to consumers by reducing wholesale price and reducing supermarket cost. At the same time, bilateral quality efforts by members of APSC will improve the quality of agricultural products and promote an increase in market demand.

Proposition 6 ① $\pi_s^{n-CSR*}>\pi_s^{n*}$, $\pi_r^{n-CSR*}>\pi_r^{n*}$.

② $\Pi_s^{n-CSR*}>\Pi_s^{n*}$, $\Pi_r^{n-CSR*}>\Pi_r^{n*}$, $\Pi_{sc}^{n-CSR*}>\Pi_{sc}^{n*}$.

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③ $CS^{n-CSR*} > CS^{n*}$.

The Proof is shown in appendix 2.

Through Proposition 6, sharing CSR among members of APSC can lead to an increase in both members' own profits and utility, supply chain system utility, and consumer surplus. This is because members of APSC invest in bilateral quality efforts to promote the improvement of agricultural product quality, stimulate market demand, and ensure the stable supply of high-quality agricultural products. This not only benefits members themselves and the supply chain system, but also brings welfare to consumers.

Furthermore, when the fairness concern is considered, we can compare Model III and Model IV so as to analyze whether CSR affects the operation of APSC.

Proposition 7 $q^{f-CSR*} > q^{f*}, w^{f-CSR*} < w^{f*}$.

For $q^{f*} - q^{f-CSR*} = -\frac{(a-\alpha c_0)\left[\lambda^2(4\theta\alpha+5\beta^2)+\lambda(4\alpha+8\beta^2)+(2-\theta)\alpha+3\beta^2\right]}{4\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]} < 0$, $q^{f-CSR*} > q^{f*}$ and for $\frac{1}{2} \le \theta < \frac{2}{3}$, so $w^{f*} - w^{f-CSR*} = \frac{(a-\alpha c_0)(1+\lambda)\left[\lambda^2(4\theta\alpha-\beta^2)+\lambda(4\theta\alpha-2\beta^2)+\theta\alpha-\beta^2\right]}{2\alpha(1+2\lambda)\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]} > 0$, i.e. $w^{f-CSR*} < w^{f*}$.

Combining Proposition 7 and Proposition 5, regardless of fairness concern, sharing CSR between supermarket and processor will lower wholesale price and increase market demand, which indicates that APSC members with CSR awareness can be beneficial to the welfare of stakeholders. On the one hand, processor shares the operating pressure of supermarket by reducing wholesale price. On the other hand, both supermarket and processor invest in bilateral quality efforts to stimulate consumer demand for agricultural products and expand market share by improving the quality of agricultural products.

Proposition 8 ① $\pi_s^{f-CSR*} > \pi_s^{f*}, \pi_r^{f-CSR*} > \pi_r^{f*}$.

② $\Pi_s^{f-CSR*} > \Pi_s^{f*}, \Pi_r^{f-CSR*} > \Pi_r^{f*}, \Pi_{sc}^{f-CSR*} > \Pi_{sc}^{f*}$.

③ $CS^{f-CSR*} > CS^{f*}$.

The Proof is shown in appendix 3.

Combining Proposition 8 and Proposition 6, sharing CSR between supermarket and processor can improve the profit and utility of both members, the utility of the supply chain system, and consumer surplus. For both members, sharing CSR can help to enhance the corporate image, and improve profit and utility. For consumers, their needs in terms of quantity and quality of agricultural products can be met. For the APSC system, the increase of member's profit and utility can promote closer cooperation, providing consumers with higher quality agricultural products, expanding consumer groups, and thereby improving the competitiveness of the APSC system. Therefore, sharing CSR among supermarket and processor is conducive to achieving a win-win situation among the three and promoting the good operation of APSC.

Conclusion 2 Sharing CSR between supermarket and processor is beneficial for improving the quality of agricultural products, and Pareto improves the profit and utility of APSC and consumer surplus.

Inference 1 Sharing CSR between supermarket and processor in the APSC can alleviate the negative impact of fairness concern on the supply chain system.

According to Conclusion1 and Conclusion2, supermarket's fairness concern has negative impact on the operation of supply chain, and sharing CSR between supermarket and processor has positive impact. From Proposition 8, the performance under considering both fairness concern and CSR is better that under only consider fairness concern. Therefore, sharing CSR between supermarket and processor can alleviate the negative impact of fairness concern on the supply chain.

(3) Sensitivity analysis

Property 1 ① $\frac{\partial q^{f-CSR*}}{\partial \lambda} < 0$, $\frac{\partial e_r^{f-CSR*}}{\partial \lambda} < 0$, $\frac{\partial e_s^{f-CSR*}}{\partial \lambda} < 0$, $\frac{\partial w^{f-CSR*}}{\partial \lambda} < 0$.

② $\frac{\partial q^{f-CSR*}}{\partial \theta} > 0$, $\frac{\partial e_r^{f-CSR*}}{\partial \theta} > 0$, $\frac{\partial e_s^{f-CSR*}}{\partial \theta} > 0$, $\frac{\partial w^{f-CSR*}}{\partial \theta} < 0$.

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Proof. $\frac{\partial q^{f-CSR*}}{\partial \lambda}=-\frac{\alpha(a-\alpha c_0)\left[(2-3\theta)(1+2\lambda)^2\alpha+(1+\lambda)^2\beta^2\right]}{\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}<0$,

$\frac{\partial e_r^{f-CSR*}}{\partial \lambda}=-\frac{\beta(a-\alpha c_0)\left[(2-3\theta)(1+2\lambda)^2\alpha+(1+\lambda)^2\beta^2\right]}{\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}<0$,

$\frac{\partial e_s^{f-CSR*}}{\partial \lambda}=-\frac{2\beta(a-\alpha c_0)(1+\lambda)\left[[(4-4\theta)\lambda+2-\theta]\alpha-(1+\lambda)\beta^2\right]}{\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}<0$,

$\frac{\partial w^{f-CSR*}}{\partial \lambda}=-\frac{(a-\alpha c_0)\left[\begin{array}{l}[(8\theta^2-12\theta+8)\lambda^2+(4\theta^2-4\theta+8)\lambda+2\theta^2+\theta+2]\alpha^2\\-(1+\lambda)[(7-2\theta)\lambda+4\theta+3]\alpha\beta^2+2(1+\lambda)^2\beta^4\end{array}\right]}{\alpha\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}<0$,

$\frac{\partial q^{f-CSR*}}{\partial \theta}=\frac{\alpha^2(a-\alpha c_0)(1+\lambda)(1+2\lambda)(1+4\lambda^2)}{\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}>0$,

$\frac{\partial e_r^{f-CSR*}}{\partial \theta}=\frac{\alpha\beta(a-\alpha c_0)(1+\lambda)(1+2\lambda)(1+4\lambda^2)}{\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}>0$,

$\frac{\partial e_s^{f-CSR*}}{\partial \theta}=\frac{\alpha\beta(a-\alpha c_0)(1+\lambda)^2(1+4\lambda^2)}{\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}>0$,

$\frac{\partial w^{f-CSR*}}{\partial \theta}=-\frac{(a-\alpha c_0)(1+\lambda)\left[2\lambda^3(4\alpha-3\beta^2)+12\lambda^2(\alpha-\beta^2)+\lambda(6\alpha-7\beta^2)+\alpha-\beta^2\right]}{\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}<0$.

From Property 1, as supermarket's fairness concern increases, all the optimal order quantity, wholesale price, and bilateral quality efforts in APSC will decrease. With the enhancement of processor's CSR awareness, both the optimal order quantity and bilateral quality efforts is increasing, while wholesale price is declining. This is consistent with Propositions 1, 3, 5, and 7.

Property 2 $\frac{\partial q^{f-CSR*}}{\partial \theta}>\left|\frac{\partial q^{f-CSR*}}{\partial \lambda}\right|$, $\frac{\partial e_r^{f-CSR*}}{\partial \theta}>\left|\frac{\partial e_r^{f-CSR*}}{\partial \lambda}\right|$, $\frac{\partial e_s^{f-CSR*}}{\partial \theta}>\left|\frac{\partial e_s^{f-CSR*}}{\partial \lambda}\right|$, $\left|\frac{\partial w^{f-CSR*}}{\partial \theta}\right|>\left|\frac{\partial w^{f-CSR*}}{\partial \lambda}\right|$.

Proof.

$\left|\frac{\partial q^{f-CSR*}}{\partial \theta}\right|-\left|\frac{\partial q^{f-CSR*}}{\partial \lambda}\right|=\frac{\alpha(a-\alpha c_0)\left[8\lambda^4\alpha+12\lambda^3\alpha+\lambda^2[(10-12\theta)\alpha+\beta^2]+\lambda[(5-4\theta)\alpha+2\beta^2]+(1-\theta)\alpha+\beta^2\right]}{\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}>0$,

$\left|\frac{\partial e_s^{f-CSR*}}{\partial \theta}\right|-\left|\frac{\partial e_s^{f-CSR*}}{\partial \lambda}\right|=\frac{\beta(a-\alpha c_0)(1+\lambda)\left[4\lambda^3\alpha+4\lambda^2\alpha+\lambda[(7-8\theta)\alpha-2\beta^2]+(3-2\theta)\alpha-2\beta^2\right]}{\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}>0$,

$\left|\frac{\partial w^{f-CSR*}}{\partial \theta}\right|-\left|\frac{\partial w^{f-CSR*}}{\partial \lambda}\right|=\frac{(a-\alpha c_0)\left[\begin{array}{l}[(8\lambda^4+20\lambda^3+2\lambda^2(5+6\theta-4\theta^2)+\lambda(2\theta-1)^2\\-2\theta^2-\theta+1]\alpha^2-2(1+\lambda)(3\lambda^3+6\lambda^2+\lambda\theta-2\theta-1)\alpha\beta^2+2(1+\lambda)^2\beta^4\end{array}\right]}{\alpha\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}>0$.

From Property 2, the impact of CSR shared by both parties on bilateral quality efforts is greater than supermarket's fairness concern. At the same time, combining with Property 1, sharing CSR between supermarket and processor can alleviate the negative impact of fairness concern on APSC, further verifying Inference 1.

6. Numerical Analysis

In order to more intuitively compare the effects of supermarket's fairness concern and CSR on the optimal quality efforts, order quantity, profit and utility of APSC, this section conducts numerical analysis. Referring to the research of Zhang et al. (2017) and Yao et al. (2022), the relevant parameters are $a=100$, $\alpha=\beta=0.4$, $c_0=0.5$ and $\theta=0.5$.

(1) Bilateral quality efforts

In Figure 1, the optimal bilateral quality efforts of APSC is highest in Model II, followed by Model IV, and decreases with supermarket's fairness concern. In Figure 2, the optimal order quantity

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is the highest in Model II, followed by Model IV, and the lowest and equal in Model I and Model III. In Figure 3, the wholesale price is the lowest in Model IV and the highest in Model I, and decreases with supermarket's fairness concern. The changes in bilateral quality efforts, order quantity, and wholesale prices in APSC with supermarket's fairness concern are consistent with Proposition 1, Proposition 3, Proposition 5, and Proposition 7. Meanwhile, by comparing four scenarios, we can find that the impact of CSR shared by both parties on bilateral quality effort decision-making is greater than fairness concern, further confirming Property 2.

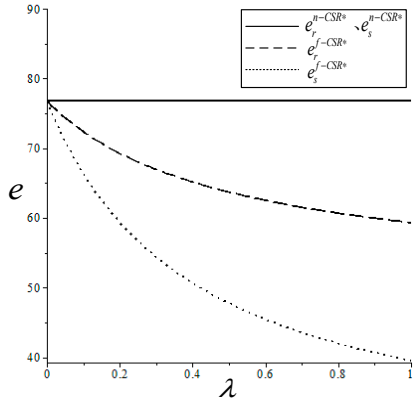

Figure 1. Bilateral quality efforts.

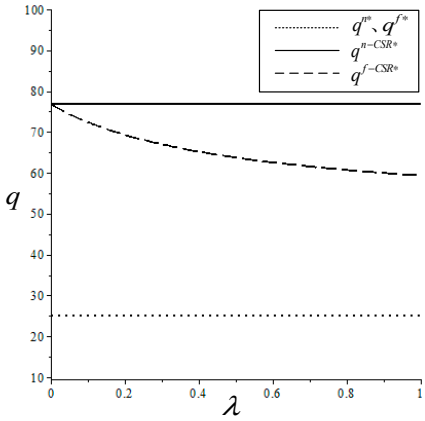

Figure 2. Order quantity.

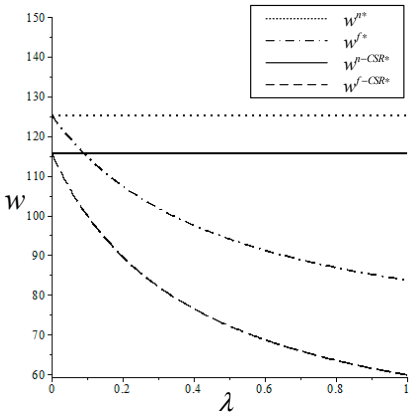

Figure 3. Wholesale price.

From Figures 1–3, the bilateral quality efforts and market demand are the highest in Model II, and it indicates that when members have no fairness concern and both them share CSR, which is most advantageous for stable supply of high-quality agricultural products. Secondly, the supermarket's fairness concern and CSR can significantly reduce wholesale price, which is the most

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unfavorable for processor. Finally, combining Model II and Model IV, it can be concluded that sharing CSR among members of APSC can alleviate the negative impact of fairness concern on APSC.

(2) Profit and utility

In Figure 4, the processor's profit is the highest in Model II and the lowest in Model III, and decreases with the supermarket's fairness concern. In Figure 5, the supermarket's profit is highest in Model IV, followed by Model II, lower in Model III, and lowest in Model I, and increases with fairness concern. The changes in the profits of both members of APSC with the enhanced fairness concern of supermarket is consistent with Proposition 2①, Proposition 4①, Proposition 6①, and Proposition 8①.

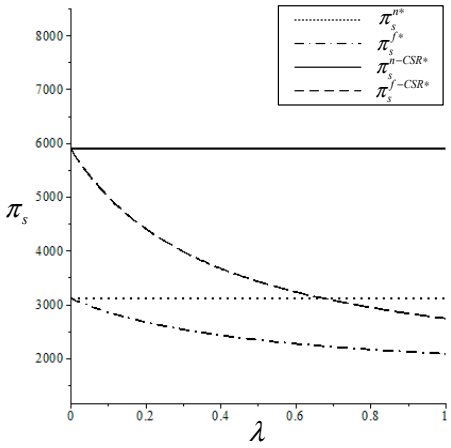

Figure 4. The profit of processor.

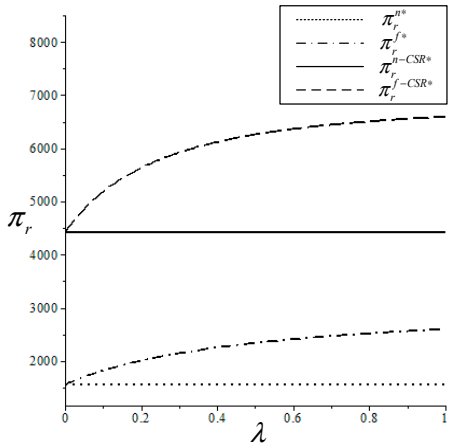

Figure 5. The profit of supermarket.

From Figures 4 and 5, when supermarket has no fairness concern and both them share CSR, it is most advantageous for processor, but when supermarket cares about fairness and none bear CSR is most unfavorable for processor. Therefore, it is necessary for supermarket to judge whether the processor has CSR awareness so as to choose the right partner. For supermarket, once supermarket has fairness concern or both parties share CSR, they can increase their profits. Especially, when both fairness concern and CSR exist, it can increase profit to the most extent. Therefore, the supermarket should also choose the processor with CSR awareness.

In Figure 6, the processor's utility is highest in Model II, followed by Model IV, lower in Model I, and lowest in Model III, and decreases with the supermarket's fairness concern. The utility of agricultural product supermarkets is highest in Model IV, followed by Model II, lower in Model I, and lowest in Model III, and decreases with the supermarket's fairness concern. The utility of APSC is the highest in Model II, followed by Model IV, and the lowest in Models I and III with a small difference between the two scenarios. The above numerical analysis confirms the consistency of Proposition 2②, Proposition 4②, Proposition 6② and Proposition 8②.

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From Figures 6–8, it can be observed that supermarket's fairness concern is always detrimental to the improvement of processor's utility, but sharing CSR between both parties can alleviate the negative impact of fairness concern. The supermarket's fairness concern is beneficial for improving utility, and the joint existence of fairness concern and CSR results in the greatest increase in the supermarket's utility of agricultural product supermarkets. In addition, for agricultural product supply chain systems, sharing CSR among members of both parties can greatly improve system utility, while the fairness preference of agricultural product supermarkets is not always favorable for system utility and the enhancement effect is weak. This indicates that sharing CSR between both parties is beneficial for Pareto improving and alleviating the negative impact of fairness concern, further confirming Conclusion 2.

(3) The consumer surplus

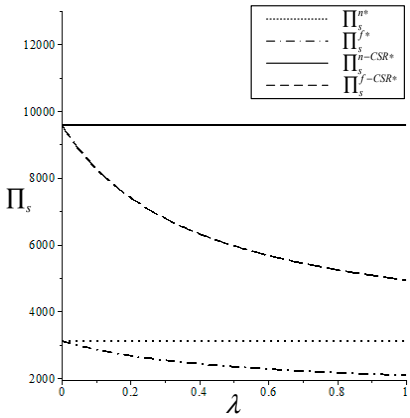

Figure 6. The utility of processor.

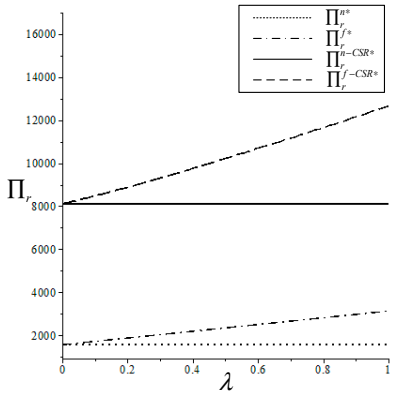

Figure 6. The utility of supermarket.

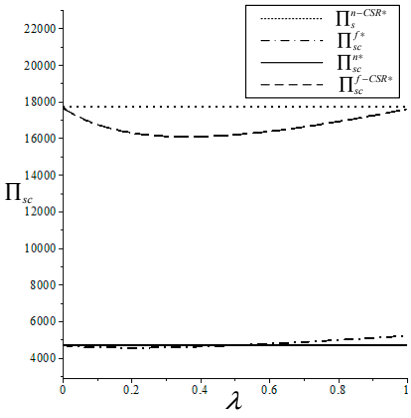

Figure 8. The utility of APSC.

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In Figure 9, consumer surplus is the highest in Model II, followed by Model IV, while Model I and Model III are the lowest and equal, which is consistent with Proposition 2③, Proposition 4③, Proposition 6③, and Proposition 8③. From Figure 9, it can be observed that the sharing CSR by both processor and supermarket can greatly enhance consumer surplus by supplying high-quality agricultural products, while the supermarket's fairness concern cannot improve consumer surplus or even lead to a decrease, further verifying Conclusion 1 and Conclusion 2.

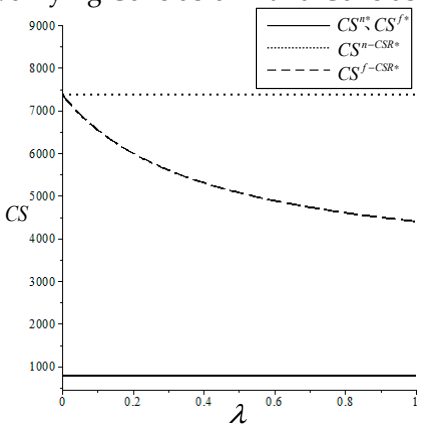

Figure 9. The consumer surplus.

7. Conclusion

This study takes a two-echelon APSC composed of a processor and a supermarket as the research object, and processor dominates the supply chain. We establish four Stackelberg game models with or without fairness concern and CSR, i.e. In Model I: both fairness concern and CSR are not considered, Model II: Only CSR is considered; Model III: Only fairness concern is considered; Model IV: both fairness concern and CSR are considered, respectively. Then, the backward induction method is applied to solve each model, and the influence mechanism of fairness concern and CSR on bilateral quality efforts in the APSC through comparative analysis, sensitivity analysis and numerical analysis, so as to ensure the high-quality supply of agricultural products and improve the operational efficiency of the APSC. Research shows that the fairness concern of agricultural products supermarket can take the role of "profit distribution mechanism", but it is not conducive to improving bilateral quality efforts resulting in the inability to improve market demand, and it is not conducive to improving the utility of the supply chain system and consumer surplus; both members of the APSC sharing CSR can not only improve the quality of agricultural products and promote the expansion of market demand, but also can achieve Pareto improvement of both profit of all members and supply chain system. Besides, The CSR shared by both members has a greater impact on bilateral quality effort decisions than the supermarket's fairness concern, and thus the positive effect of CSR can overcome the negative effect of fairness concern. Based on the above research conclusions, we can suggest the following strategies. The processor can actively share the operating pressure of supermarket, sign flexible contract with agricultural product supermarkets, and increase attention to stakeholder welfare. The supermarket can actively disclose cost information, actively convey fairness concern intensity information, and increase investment in agricultural product quality testing.

In order to obtain intuitive research conclusions, this article only considers a two-echelon APSC structure composed of one processor and one supermarket. In fact, the APSC is a complex network structure composed of multiple agricultural product processors and multiple agricultural product supermarkets. In the future, the "many to many" APSC structure can be studied to make the research more in line with the actual operation of the APSC and improve the explanatory and guiding power of theory to practice.

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Conflict of interest: We all declare that we have no conflict of interest in this paper.

Appendix

Proof of Proposition 4.

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let $y_3 = \pi_r^{n-CSR*} - \pi_r^{f-CSR*}$, $\frac{\partial y_3}{\partial \lambda} = -\frac{(a-\alpha c_0)^2\left[9y_4 + (1+\lambda)(9\lambda+4)\beta^4\right]}{\left[[(4-2\theta)\lambda+2+\theta](1+2\lambda)\alpha-(1+\lambda)(3+5\lambda)\beta^2\right]^3}$,

$$y_4 = -\frac{8}{9}(\lambda+\frac{1}{2})\left[(\theta^2-2\theta)\lambda^3+(-\frac{9}{2}\theta^2+5\theta-4)(\lambda^2+\lambda)-\frac{5}{4}\theta^2+\theta-1\right]\alpha^2+\frac{10}{9}(1+\lambda)\left[(\theta-\frac{12}{5})\lambda^3+(\frac{7}{5}\theta-\frac{26}{5})\lambda^2+(-\frac{1}{5}\theta-\frac{16}{5})\lambda-\frac{3}{10}\theta-\frac{3}{5}\right]\alpha\beta^2$$
$$= (A\alpha - B\beta^2)\alpha$$

For $A-B = \frac{1}{9}\left[\begin{array}{l}(-8\theta^2+6\theta+24)\lambda^4+(32\theta^2-56\theta+108)\lambda^3\\+(54\theta^2-72\theta+132)\lambda^2+(28\theta^2-23\theta+62)\lambda+5\theta^2-\theta+10\end{array}\right] > 0$ and $\alpha > 2\beta^2$, so $y_4 > 0$, i.e. $\frac{\partial y_3}{\partial \lambda} < 0$, which indicates y_3 is strictly decreasing in λ, $y_3(\lambda) < y_3(\lambda=0) = 0$, i.e. $\pi_r^{f-CSR*} > \pi_r^{n-CSR*}$. Similarly, let $y_5 = \pi_s^{n-CSR*} - \pi_s^{f-CSR*}$, and $\frac{\partial y_5}{\partial \lambda} = \frac{(a-\alpha c_0)^2(1+\lambda)\left[y_6 + (1+\lambda)(5\lambda+3)\beta^4\right]}{\left[[(4-2\theta)\lambda+2+\theta](1+2\lambda)\alpha-(1+\lambda)(3+5\lambda)\beta^2\right]^3}$,

$$y_6 = 8(\lambda+\frac{1}{2})\left[(5\theta^2-8\theta+4)\lambda^2+(\frac{5}{2}\theta^2-5\theta+4)\lambda+\frac{1}{2}\theta^2-\frac{1}{2}\theta+1\right]\alpha^2+22(1+\lambda)\left[(\theta-\frac{14}{11})\lambda^2+(\frac{7}{11}\theta-\frac{15}{11})\lambda+\frac{1}{22}\theta-\frac{4}{11}\right]\alpha\beta^2$$

For $\alpha > 2\beta^2$, we can get

$$y_6 > \{8(2\lambda+1)\left[(5\theta^2-8\theta+4)\lambda^2+(\frac{5}{2}\theta^2-5\theta+4)\lambda+\frac{1}{2}\theta^2-\frac{1}{2}\theta+1\right]+22(1+\lambda)\left[(\theta-\frac{14}{11})\lambda^2+(\frac{7}{11}\theta-\frac{15}{11})\lambda+\frac{1}{22}\theta-\frac{4}{11}\right]\}\alpha\beta^2$$
$$= (80\theta^2-106\theta+36)\lambda^3+(80\theta^2-108\theta+38)\lambda^2+(28\theta^2-33\theta+10)\lambda+4\theta^2-3\theta > 0$$

$\frac{\partial y_5}{\partial \lambda} > 0$ indicate that y_5 is strictly increasing in λ, where $y_5(\lambda) > y_5(\lambda=0) = 0$, i.e. $\pi_s^{f-CSR*} < \pi_s^{n-CSR*}$. For $\frac{\partial \pi_s^{f-CSR*}}{\partial \lambda} < 0$ and $\frac{\partial \pi_r^{f-CSR*}}{\partial \lambda} > 0$, $\pi_s^{n-CSR*} > \pi_r^{n-CSR*}$, so $\pi_s^{f-CSR*}(\lambda=0) > \pi_r^{f-CSR*}(\lambda=0)$, $\pi_s^{f-CSR*}(\lambda=1) < \pi_r^{f-CSR*}(\lambda=1)$, and there is only one critical parameter $\lambda_2 \in (0,1)$ subjected to $\pi_s^{f-CSR*} = \pi_r^{f-CSR*}$. When $0 < \lambda < \lambda_2$, $\pi_s^{f-CSR*} > \pi_r^{f-CSR*}$,but when $\lambda_2 < \lambda < 1$, $\pi_s^{f-CSR*} < \pi_r^{f-CSR*}$.

$\Pi_s^{n-CSR*} - \Pi_s^{f-CSR*} = \frac{(a-\alpha c_0)^2\lambda\left[[(3-2.5\theta)\lambda+2-\theta]\alpha-(1+\lambda)\beta^2\right]}{[(2+\theta)\alpha-3\beta^2]\left[[(4-2\theta)\lambda+2+\theta](1+2\lambda)\alpha-(1+\lambda)(3+5\lambda)\beta^2\right]} > 0$, i.e. $\Pi_s^{f-CSR*} < \Pi_s^{n-CSR*}$. For $\frac{\partial \Pi_r^{f-CSR*}}{\partial \lambda} > 0$, $\Pi_r^{f-CSR*}(\lambda) > \Pi_r^{f-CSR*}(\lambda=0) = \frac{(a-\alpha c_0)^2[(1+\theta)-\beta^2]}{[(2+\theta)-3\beta^2]^2} = \Pi_r^{n-CSR*}$, i.e. $\Pi_r^{f-CSR*} > \Pi_r^{n-CSR*}$. for $\frac{\partial \Pi_{sc}^{f-CSR*}}{\partial \lambda} < 0$, we can get $\Pi_{sc}^{f-CSR*}(\lambda) < \Pi_{sc}^{f-CSR*}(\lambda=0) = \Pi_{sc}^{n-CSR*}$, i.e. $\Pi_{sc}^{f-CSR*} < \Pi_{sc}^{n-CSR*}$.

$$CS^{n-CSR*} - CS^{f-CSR*} = \frac{(a-\alpha c_0)^2\alpha\lambda\left[\lambda[(4-6\theta)\alpha+\beta^2]+[(2-3\theta)\alpha+\beta^2]\right]y_7}{2[(2+\theta)\alpha-3\beta^2]\left[[(4-2\theta)\lambda+2+\theta](1+2\lambda)\alpha-(1+\lambda)(3+5\lambda)\beta^2\right]}$$

$$y_7 = (1+2\lambda)[(6-\theta)\lambda+4+2\theta]\alpha-(1+\lambda)(6+11\lambda)\beta^2 > \left[(1+2\lambda)[(6-\theta)\lambda+4+2\theta]\times 2-(1+\lambda)(6+11\lambda)\right]\beta^2$$
$$= \lambda^2(13-4\theta)+\lambda(11+6\theta)+4\theta+2 > 0$$

So we can prove $CS^{f-CSR*} < CS^{n-CSR*}$.

Proof of Proposition 6.

let $y_8 = \pi_s^{n-CSR*} - \pi_s^{n*} = -\frac{(a-\alpha c_0)^2(\alpha^2\theta^2-6\alpha\beta^2\theta+9\beta^4+4\alpha^2\theta-4\alpha^2)}{8\alpha[(2+\theta)\alpha-3\beta^2]^2}$, $\frac{\partial y_8}{\partial \theta} = -\frac{\alpha(a-\alpha c_0)^2(2\alpha-3\beta^2)}{[(2+\theta)\alpha-3\beta^2]^3} < 0$, which indicates y_8 is strictly decreasing in θ, $y_8(\theta=\frac{1}{2}) = \frac{(a-\alpha c_0)^2(7\alpha^2+12\alpha\beta^2-36\beta^4)}{8\alpha(5\alpha-6\beta^2)} > 0$, and $y_8(\theta=\frac{2}{3}) = \frac{(a-\alpha c_0)^2(8\alpha^2+36\alpha\beta^2-81\beta^4)}{8\alpha(8\alpha-9\beta^2)^2} > 0$, i.e. $\pi_s^{n-CSR*} > \pi_s^{n*}$.

Similarly, let $y_9 = \pi_r^{n-CSR*} - \pi_r^{n*} = -\frac{(a-\alpha c_0)^2(\alpha^2\theta^2-6\alpha\beta^2\theta+9\beta^4-12\alpha^2\theta-4\alpha\beta^2+4\alpha^2)}{16\alpha[(2+\theta)\alpha-3\beta^2]^2}$

$\frac{\partial y_9}{\partial \theta} = \frac{(a-\alpha c_0)^2\alpha[(2-\theta)\alpha-\beta^2]}{[(2+\theta)\alpha-3\beta^2]^3} > 0$, y_9 is strictly increasing in θ, $y_9(\theta=\frac{1}{2}) = \frac{(a-\alpha c_0)^2(7\alpha^2+28\alpha\beta^2-36\beta^4)}{16\alpha(5\alpha-6\beta^2)^2} > 0$, and $y_9(\theta=\frac{2}{3}) = \frac{(a-\alpha c_0)^2(32\alpha^2+72\alpha\beta^2-81\beta^4)}{16\alpha(8\alpha-9\beta^2)^2} > 0$, i.e. $\pi_r^{n*} < \pi_r^{n-CSR*}$. $\Pi_s^{n-CSR*} - \Pi_s^{n*} = \frac{(a-\alpha c_0)^2[(2-\theta)\alpha+3\beta^2]}{8\alpha[(2+\theta)\alpha-3\beta^2]} > 0$, $\Pi_s^{n-CSR*} > \Pi_s^{n*}$.

let $y_{10} = \Pi_r^{n-CSR*} - \Pi_r^{n*} = -\frac{(a-\alpha c_0)^2(\alpha^2\theta^2-6\alpha\beta^2\theta+9\beta^4-4\alpha^2\theta-4\alpha\beta^2-4\alpha^2)}{16\alpha[(2+\theta)\alpha-3\beta^2]^2}$, $\frac{\partial y_{10}}{\partial \theta} = -\frac{(a-\alpha c_0)^2\alpha(\alpha\theta+\beta^2)}{2[(2+\theta)\alpha-3\beta^2]^3} < 0$, i.e. y_{10} is strictly decreasing in θ, and $y_{10}(\theta=\frac{1}{2}) = \frac{(a-\alpha c_0)^2(\alpha+2\beta^2)(23\alpha-18\beta^2)}{16\alpha(5\alpha-6\beta^2)^2} > 0$,

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$y_{10}(\theta=\frac{2}{3})=\frac{(a-\alpha c_0)^2(56\alpha^2+72\alpha\beta^2-81\beta^4)}{16\alpha(8\alpha-9\beta^2)^2}>0$, so $y_{10}=\Pi_r^{n-CSR*}-\Pi_r^{n*}>0$, i.e. $\Pi_r^{n-CSR*}>\Pi_r^{n*}$.

$\Pi_{sc}^{c-CSR*}-\Pi_{sc}^{c*}=\frac{(a-\alpha c_0)^2(\alpha+2\beta^2)}{4\alpha(\alpha-2\beta^2)}>0$, i.e. $\Pi_{sc}^{c-CSR*}>\Pi_{sc}^{c*}$.

Let $y_{11}=\Pi_{sc}^{n-CSR*}-\Pi_{sc}^{n*}=-\frac{(a-\alpha c_0)^2(3\alpha^2\theta^2-18\alpha\beta^2\theta+27\beta^4-4\alpha^2\theta-4\alpha\beta^2-12\alpha^2)}{16\alpha[(2+\theta)\alpha-3\beta^2]^2}$,

$\frac{\partial y_{11}}{\partial\theta}=-\frac{\alpha(a-\alpha c_0)^2[(1+\theta)\alpha-\beta^2]}{[(2+\theta)\alpha-3\beta^2]^3}<0$, i.e. y_{11} strictly decreasing in θ ,

$y_{11}(\theta=\frac{1}{2})=\frac{(a-\alpha c_0)^2(\alpha+2\beta^2)(53\alpha-54\beta^2)}{16\alpha(5\alpha-6\beta^2)^2}>0$, $y_{11}(\theta=\frac{2}{3})=\frac{3(a-\alpha c_0)^2(40\alpha^2+48\alpha\beta^2-81\beta^4)}{16\alpha(8\alpha-9\beta^2)^2}>0$, so $y_{11}=\Pi_{sc}^{n-CSR*}-\Pi_{sc}^{n*}>0$, i.e. $\Pi_{sc}^{n-CSR*}>\Pi_{sc}^{n*}$.

Proof of Proposition 8.

$$\pi_s^{f*}-\pi_s^{f-CSR*}=-\frac{(a-\alpha c_0)^2(1+\lambda)\begin{bmatrix}\lambda^4[16\theta^2\alpha^2+40(1-\theta)\alpha\beta^2+25\beta^4]+\lambda^3[(64-32\theta)\alpha^2+(84-64\theta)\alpha\beta^2+80\beta^4]\\+\lambda^2[(8\theta^2-80\theta+48)\alpha^2+14(4-\theta)\alpha\beta^2+96\beta^4]+\lambda[(32-24\theta)\alpha^2-(12-16\theta)\alpha\beta^2\\+48\beta^4+(-\theta^2-4\theta+4)\alpha^2+6\alpha\beta^2+9\beta^4\end{bmatrix}}{8\alpha(1+2\lambda)\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}<0$$

, i.e. $\pi_s^{f-CSR*}>\pi_s^{f*}$.

$$\pi_r^{f*}-\pi_r^{f-CSR*}=-\frac{(a-\alpha c_0)^2\begin{bmatrix}\lambda^5[(128\theta-64\theta^2)\alpha^2+(192-160\theta)\alpha\beta^2-100\beta^4]+\lambda^4[(64-192\theta-16\theta^2)\alpha^2+(496-296\theta)\alpha\beta^2-345\beta^4]\\+\lambda^3[(32\theta^2+224\theta+64)\alpha^2+(480-120\theta)\alpha\beta^2-456\beta^4]+\lambda^2[(8\theta^2+192\theta)\alpha^2+(220+50\theta)\alpha\beta^2-286\beta^4]\\+\lambda[(4\theta^2-80\theta+64)\alpha^2+(48+40\theta)\alpha\beta^2-84\beta^4]+(4+12\theta-\theta^2)\alpha^2+(4+6\theta)\alpha\beta^2-9\beta^4\end{bmatrix}}{16\alpha(1+2\lambda)\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}<0$$

, i.e. $\pi_r^{f-CSR*}>\pi_r^{f*}$. $\Pi_s^{f*}-\Pi_s^{f-CSR*}=-\frac{(a-\alpha c_0)^2(1+\lambda)\begin{bmatrix}\lambda^2[(8+4\theta)\alpha+5\beta^2]+\lambda(4\alpha+8\beta^2)\\+(2-\theta)\alpha+3\beta^2\end{bmatrix}}{8\alpha(1+2\lambda)\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]}<0$, i.e. $\Pi_s^{f-CSR*}>\Pi_s^{f*}$.

$$\Pi_r^{f*}-\Pi_r^{f-CSR*}=-\frac{(a-\alpha c_0)^2(1+\lambda)\left[[(4\theta-\theta^2)\lambda^2+(\theta^2+2\theta+2)\lambda+1+\theta-\frac{1}{4}\theta^2](\lambda+\frac{1}{2})\alpha^2+y_{15}\right]}{16\alpha\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}$$

$y_{12}=40(1+\lambda)\left[(\frac{7}{5}-\theta)\lambda^3+(2-\frac{3}{5}\theta)\lambda^2+(\frac{9}{10}+\frac{1}{4}\theta)\lambda+(\frac{1}{10}+\frac{3}{20}\theta)\right]\alpha\beta^2-(1+\lambda)^2(3+5\lambda)^2\beta^4$, for $\alpha>2\beta^2$, and $\frac{1}{2}\alpha\beta^2>\beta^4$, so

$$y_{12}>40(1+\lambda)\left[(\frac{7}{5}-\theta)\lambda^3+(2-\frac{3}{5}\theta)\lambda^2+(\frac{9}{10}+\frac{1}{4}\theta)\lambda+(\frac{1}{10}+\frac{3}{20}\theta)\right]\alpha\beta^2-(1+\lambda)^2(3+5\lambda)^2\times\frac{1}{2}\alpha\beta^2$$
$$=\frac{1}{2}(1+\lambda)\left[(87-80\theta)\lambda^3+(105-48\theta)\lambda^2+(33+20\theta)\lambda-12\theta-1\right]>0$$

$\Pi_r^{f*}-\Pi_r^{f-CSR*}<0$, i.e. $\Pi_r^{f-CSR*}>\Pi_r^{f*}$. for $\Pi_{sc}^{f-CSR*}=\Pi_s^{f-CSR*}+\Pi_r^{f-CSR*}$, $\Pi_{sc}^{f*}=\Pi_s^{f*}+\Pi_r^{f*}$, $\Pi_s^{f-CSR*}>\Pi_s^{f*}$, and $\Pi_r^{f-CSR*}>\Pi_r^{f*}$, we can get $\Pi_{sc}^{f-CSR*}>\Pi_{sc}^{f*}$,

$$CS^{f*}-CS^{f-CSR*}=-\frac{(a-\alpha c_0)^2\left[(4\lambda^2\theta-\theta+4\lambda+2)\alpha+(1+\lambda)(3+5\lambda)\beta^2\right]y_{13}}{32\alpha\left[\lambda^2[(8-4\theta)\alpha-5\beta^2]+8\lambda(\alpha-\beta^2)+(2+\theta)\alpha-3\beta^2\right]^2}.$$

$y_{13}=(16-4\theta)\lambda^2+20\lambda+\theta+6)\alpha-(1+\lambda)(3+5\lambda)\beta^2>\left[2(16-4\theta)\lambda^2+20\lambda+\theta+6)-(1+\lambda)(3+5\lambda)\right]\beta^2$
$=\left[(27-8\theta)\lambda^2+32\lambda+2\theta+9\right]\beta^2>0$

So $CS^{f*}-CS^{f-CSR*}<0$, i.e. $CS^{f-CSR*}>CS^{f*}$.

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