Investment Decision of Blockchain-based Traceability Service Input in a Competitive Agri-food Supply Chain

Pan Liu (✉ hnycliupan@163.com)

Henan Agricultural University

Zhang Ziran

Henan Agricultural University

Li Ye

Henan Agricultural University

Research Article

Keywords: high-quality agri-food supply chain, blockchain-based traceability service, perceived quality and safety, investment decision

Posted Date: December 20th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1060130/v1>

License: This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Applications of the blockchain-based traceability service (hereafter, BBTS) will not only help members of high-quality agri-food supply chain (hereafter, FPSC) improve consumers' perception on product quality and safety, but also increase their extra expenditure. Competitive AFSC as an important component of AFSC, its investment and coordination laws after using the BBTS obtain more attentions. To explore these laws, we constructed two competitive AFSCs, and each of them includes a supplier and a retailer. Considering the new changes of consumers' perception on product quality and safety after using the BBTS, the demand function was modified. Then, considering the BBTS costs and the new changes of consumers perceived on quality and safety, we built the income functions of chain members under the proposed three situations, i.e., 1) neither of the two supply chains invests in the BBTS, and 2) one supply chain invests in the BBTS, and 3) both supply chains invest in the BBTS. The research finds that: 1) if both of the two supply chains invest in the BBTS, supply chain members will gain a bigger threshold value sum of the BBTS costs, moreover, supply chain members will gain more benefits compared with them no investment BBTS. Thus, governments need to guide more enterprises to adopt BBTS. 2) The competitor's perceived quality is negative with the threshold value sum of the BBTS costs. When the competitor's perceived quality is high, investors should reduce investment costs. 3) If investors or decision makers about BBTS want to get a big the threshold value sum of the BBTS costs, they should reduce the cost optimization coefficient and avoid fierce price competition as much as possible. Results can offer a theoretical guidance of adopting BBTS for FPSC.

1. Introduction

With the dramatic development of China's economy and the improvement of people's living standards, consumers' demands for agricultural products are developing in a greener and safer direction. However, a number of produce scandals have occurred in the past decades. Such as, the horse meat was found in several ground beef products in Europe in 2013, and 100000 tons expired meat was confiscated by Chinese authorities in 2015. In 2018, 44% of Canadian seafood products were mislabeled (Köhler and Pizzol 2020). These quality and safety accidents about agricultural products had seriously dampened consumers' confidence to the quality of agricultural products (Zhang, Xu et al. 2016). At the same time, it also stimulates consumers' demand for quality traceability of agricultural products from farm to table, and consumers have a huge demand for safe agricultural products (Kendall, Kuznesof et al. 2019, Riccioli, Moruzzo et al. 2020).

To reduce these harmful food safety accidents, the European Union, the United States, Australia, Canada, Japan, China and other countries have issued laws and regulations to require the agri-food industry to build traceability service systems (Charlebois, Sterling et al. 2014). However, traditional traceability systems mainly collect data through RFID technology, and then share data on networked devices. Consumers and supply chain members could query products' data on intelligent devices (Lehmann, Reiche et al. 2012). However, the information collected by service is not safe in the storage process. Because the data managers are also members of the supply chain, when they found these data are

adverse, these data may be modified. So, the credibility of the traditional traceability service is not high. As a distributed data structure, blockchain technology can share data on peer-to-peer network (Pearson, May et al. 2019, Sunny, Undralla et al. 2020). In the blockchain environment, the data were converted into digital code and stored in a shared database with higher transparency and limited risk of deletion and modification. So the blockchain cannot be usurped (Esmaeilian, Sarkis et al. 2020). Blockchain technology has received extensive attention in the agricultural product traceability area (Niknejad, Ismail et al. 2021).

In fact, some supply chain enterprises have adopted blockchain technology. For example, Wal-Mart put the blockchain-based traceability service (hereafter, BBTS) into the mango supply chain, and it took only 2.2 seconds to track the mango (Yiannas 2021). JD, Procter & Gamble, Amazon and other companies also used blockchain. According to the measurement of consumption data from JD Zhizhen chain, we found that applications of the BBTS could effectively improve the repurchase rate and sales volume. Therefore, more and more supply chain enterprises want to use the BBTS, but this will also increase their extra expenditure. Thus, investment rules of the BBTS obtain more attention from supply chain members, particularly, the competitive AFSC become an important component of AFSC, its investment laws of using the BBTS are very important. Therefore, the study will discuss the two competitive AFSCs' investment strategies of the BBTS.

Although, some literatures have discussed the investment problems about the traceability system, they are in the traditional environment, in the blockchain environment, considering the BBTS cost as a variable, studying the BBTS investment decision rules are few in a competitive AFSC. For instance, product traceability could increase the value of products, and enhanced consumers' confidence in agricultural products, and had a higher willingness to pay for such products (Charlebois and Haratifar 2015, Riccioli, Moruzzo et al. 2020, Zhang, Mankad et al. 2020). At the same time, the research showed that the main cost of the investment blockchain technology for the supply chain is the variable cost, and the fixed cost of the investment has little influence on the supply chain (De Giovanni 2020). The research of Chen, Tian et al. (2018) showed that consumers were sensitive to price, and agricultural products' sales price was low. If the price of agricultural products increases significantly because of the increase of the BBTS costs, it will decline the agricultural products' sales volume, which is not conducive to the profits of the supply chain. The existing researches mainly focuses on the technology and significance of blockchain, but there is little research on how the supply chain should invest blockchain, especially in the current competitive business environment. The research on blockchain investment in competitive AFSC is even less.

Aims of our study are to research the investment decision strategies of the BBTS in a competitive high-quality AFSC. Based on the above considerations, we firstly constructed two competitive AFSCs, which including a supplier and a retailer respectively to study the investment decision of chain members about the BBTS. Based on the new changes of consumers' perception to product quality and safety after using the BBTS, the demand function model was modified. Then, considering the BBTS costs and the new

changes of consumers perceived on quality and safety, we built the income functions of chain members under the proposed three situations.

There were three innovations in this paper: (1) a competitive demand function model was established based on consumers' price sensitivity and consumers' perception to product quality and safety. (2) We consider two competing supply chains, each supply chain has two investment options, thus there are four situations. Due to the symmetry of two supply chains, we only need to study three situations, when the two supply chains do not invest blockchain technology was N situation, only one supply chain invests blockchain technology was I situation, and both the two supply chains invest blockchain technology was M situation. (3) Chain members profit models were established under the proposed three kinds of investment situations considering the BBTS costs.

The significances of this study are as follows: (1) considering the new changes of consumers' perception to product quality and safety under the new background, we modified the demand function of agricultural products, and it will enrich the research perspective of demand function in AFSCs. (2) Considering the BBTS costs, we constructed chain members' benefits functions under the three competitive supply chain models (N, I, M). This will expand the theory research on investment decision-making of competitive AFSC under the new background. Meanwhile, the results will provide theoretical support for competitive AFSC to invest the BBTS.

The article structure is shown in Figure 1.

2. Literature Review

The research of this study mainly involved the following three aspects: first, the application of blockchain technology in AFSC; second, the application of traceability service in AFSC; third, AFSC decision-making.

2.1. Application of Blockchain Technology in AFSCs

Because of its traceability, digitalization and security, many scholars studied how the supply chain uses blockchain technology. (Cole, Stevenson et al. 2019, Chang, Iakovou et al. 2020, Esmailian, Sarkis et al. 2020, Fosso Wamba, Queiroz et al. 2020, Wong, Tan et al. 2020, Kouhizadeh, Saberi et al. 2021, Park and Li 2021). Blockchain technology has been widely concerned in the research of AFSC because of its traceability. Griffin, Harris et al. (2021) used distributed ledger technology to detect cotton quality, track cotton data and coordinate supply chain management. Stranieri, Riccardi et al. (2021) studied how blockchain technology affects the performance of high-quality AFSCs, they believed that using blockchain technology can improve their management and enhance products' quality to increase the income. By investigating the actual case, Shew, Snell et al. (2021) find that consumer trust could be increased while application both of USDA combined certification and blockchain technology. At the same time, Wal-Mart, an American retail company, studied the change of traceability when the mango supply chain has been invested the blockchain technology (Yiannas 2021). Salah, Nizamuddin et al. (2019) designed a traceability system for soybeans using blockchain and intelligent contracts. Through a survey

of the wine supply chain, Saurabh and Dey (2021) studied the factors that decision makers were most concerned about the adoption of blockchain technology. Zhao, Liu et al. (2019) believed that the application of blockchain in high-quality AFSC can improve traceability and quality safety. Niknejad, Ismail et al. (2021) used bibliometric analysis to study the research and development of blockchain technology in high-quality AFSC in recent years.

Through the above analyses, more and more scholars were interested in this field. The research also showed that the research of blockchain in the field of agricultural products was mainly divided into traceability system, blockchain technology and blockchain benefits. To sum up, it can be found that there were few studies on the effect of blockchain on the decision-making of high-quality AFSC, and the research of this paper can make up for the deficiency in this aspect.

2.2. Application of traceability service in AFSCs

In recent years, with the promotion of national policy and consumers, traceability service has gradually become an important part of AFSC management (Bosona and Gebresenbet 2013). Badia-Melis, Mishra et al. (2015) summarized the technological development of traditional traceability service, such as RFID, NFC, isotope analysis and DNA barcode, but did not show the development of blockchain technology in this study. Yang, Li et al. (2021) used blockchain technology to design the supply chain traceability system of fresh agricultural products, which improved the transparency and credibility of supply chain information and made up for the shortcomings of traditional traceability service in transparency and credibility. Sun and Wang (2019) studied the purchasing decisions of supply chain buyers considering traceability and found that buyers were more likely to purchase suppliers with high traceability. Collart and Canales (2021) believed that future research should focus on traceable economic sustainability data and the economic feasibility of blockchain technology based on a case study of high-quality AFSC. Casino, Kanakaris et al. (2020) designed a traceability system of agricultural products based on blockchain, and evaluated the feasibility of the model through a specific study of a real dairy enterprise.

Through the above researches, we can find that the current traceability researches are mainly focused on the significance of traceability service and the technical level of traceability system. There are few studies on the economic profits and the decision-making impact of the traceability service for the competitive supply chain.

2.3. Investment decision of competitive AFSCs

This research is also participant with the investment decision of competitive AFSC. Dai, Nu et al. (2021) studied the coordination and pricing of competitive supply chain. They divided the competition of supply chain into three models: upstream competition, downstream competition and a mixed supply chain model with both upstream and downstream competition, and designed a mixed competition mode to study the effect of traceability and product recall in the supply chain. Based on this mode, Dai believed that traceability investment is always beneficial to manufacturers, and the impact on retailers depends on the cost of traceability. Niu, Mu et al. (2021) designed a co-opetitive supply chain model composed of an multinational firm located in high tax region and an e-tailer, the e-tailer purchased and resold the

multinational firm's products. Choi, Feng et al. (2020) designed a game mode of duopoly competition, and studied the effect of product information disclosure based on blockchain technology on the supply chain of rental service platforms. This study indicated that risk attitude is an important factor to accurately describe the impacts brought by the blockchain technology. In the field of AFSC, Wang and Chen (2016) studied the decision-making problem of portfolio contracts in fresh supply chain and designed a model concluding suppliers and retailers. They found that option prices have diverse impressions for supply chain members' income. Wang and Zhao (2018) also studied the investment decision about the cold chain invested in the fresh supply chain. Results suggested that cooperative cold chain investment and collaborative pricing are the dominant strategies of the supply chain. Wu, Fan et al. (2021) studied the coordinated pricing of investment blockchain technology in fresh supply chain, and designed a three-level supply chain model concluding suppliers, third-party logistics and retailers. Their research found that the investment of blockchain technology is related to consumer acceptance, cost sharing ratio and deterioration rate of the fresh product. Considering freshness and greenness, Liu, Long et al. (2020) designed an AFSC composed of a manufacturer and a retailer, and studied integrating blockchain with big data. The research indicated that when the investment cost changed in a certain range, it is beneficial to supply chains' profits. The above researches do not involve the competitive decision-making of dual-channel AFSC. In view of this, this study designed a dual-channel supply chain, each of which concluding a supplier and a retailer, which enriched the research of competitive supply chain decision-making.

Based on the aforementioned analyses, the existing researches have the following shortcomings: (1) the current research is mainly focused on blockchain technology, and there are few studies on the decision-making impact of blockchain in high-quality AFSC. (2) At present, the traceability research is primarily focused on the meaning of traceability service and the technical level of traceability system, but there are few studies on the economic profits of traceability service and how the competitive supply chain making decisions about traceability service. (3) The above researches do not involve the competitive decision-making of dual-channel AFSC. In order to solve the deficiency of the above researches, considering the new changes of consumer price sensitivity and consumer perception of product quality and safety, this paper discussed the investment decision-making of the BBTS in competitive AFSC under different investment situations.

3. Model Description And Hypothesis

3.1. Model description

In order to study the effect of BBTS investment strategy on FPSCs' profits, we constructed a Stackelberg game model constructed two competitive AFSCs, and each of them includes a supplier and a retailer, as shown in Figures 2. Investing in BBTS can improve consumers' quality perception of fresh agricultural products. The demand of each supply chain is linear with its own retail price, product perceived quality and the retail price and perceived quality of competitors' products. In general, supply chain has two choices in decision-making, i.e. investment and non-investment. We consider two competing supply chains, each supply chain has two investment options, thus there are four situations as follow: 1) both

supply chains do not invest in BBTS; 2) supply chain 1 invests in BBTS, supply chain 2 does not invest in BBTS; 3) supply chain 1 does not invest in BBTS, supply chain 2 invests in BBTS; 4) both supply chains invest in BBTS. Due to the symmetry of two supply chains, we only need to study three situations:(1) neither of the two AFSCs invests the BBTS, namely, N situation; (2) only one AFSC invests the BBTS, namely, I situation; (3) both AFSCs invest the BBTS, namely, M situation.

The relevant parameters involved in the construction of the model and their descriptions are shown in Table 1.

Table 1
Variable description

Variable	Explanation
	Three different investment situations, Namely, $x = \{N, I, M\}$.
	Two kinds of substitutable agricultural products, $i=\{1,2\}$.
	When $i = 1, j = 2$; when $i = 2, j = 1$.
Π_{ri}^x	Revenues of the retailer in the situation.
Π_{mi}^x	Revenues of the supplier in the situation.
D_i^x	The demand of in the situation.
w_i^x	The wholesale price of the kind of agricultural products in the situation.
p_i^x	The retail price of the kind of agricultural products in the situation.
λ_i^x	The perceived quality safety factor of the kind of agricultural products in the situation.
	The quality and safety level of agricultural products, this paper assumes that the quality and safety level of two kinds of agricultural products are equal.
a_i	The potential demand for the kind of agricultural products in the market
β	The sensitivity coefficient of market demand to the price of substitutes, the greater the β , the higher the sensitivity, and the stronger the competitiveness of the supply chain.
κ	The sensitivity coefficient of market demand to the quality of substitutes, the greater the κ , the higher the sensitivity, and the stronger the competitiveness of the supply chain.
c_r	The retailer's cost of sales, this paper presumed that sales' cost of the two products is the same.
c_m	The supplier's cost of sales, this paper presumed that sales' cost of the two products is the same.
c_{or}	The retailers' capitalized cost of BBTS
c_{om}	The suppliers' capitalized cost of BBTS
θ	Cost optimization coefficient of sales industry based on the BBTS. Through the integration of information and the BBTS from within the enterprise, suppliers and sellers can effectively optimize the sales process and reduce the sales cost.
*	Equilibrium solution

3.2. Hypothesis

- (1) The quality of the two alternative agricultural products are satisfy the national quality and safety of agricultural products or agricultural industry standards. Therefore, it is assumed that the quality of the two agricultural products is the same. The supply chain invested in the blockchain technology can improve customers quality perception. Consumers prefer to buy fresh agricultural products with complete information because they think such products' quality are higher (Patelli and Mandrioli 2020).
- (2) In the face of two kinds of alternative products, it is assumed that consumers decide whether to buy the product mainly according to the retail price and the degree of quality and safety of the product. There is no difference in the quality and safety level of the same product under the three investment situations. In addition, consumers' perceived quality and safety of products is expected to be improved, through the investment of the BBTS, for example, $\lambda_i^N \text{cript} > .$ The members of the supply chain make decisions with the goal of maximizing their own incomes.
- (3) BBTS can increase the credibility among supply chain members. By eliminating intermediaries, we can improve audit efficiency and reduce communication and financial costs (Gurtu and Johny 2019). We assumed the optimization coefficient of cost is θ .
- (4) The supplier has sufficient production capacity to ensure that the products are not out of stock. The members of the supply chain are risk-neutral and completely rational.
- (5) Suppose the market demand is definite, and it is equal to the retails' order amount. Therefore, the market demand of product 1 is $D_1^x = a_1 - p_1^x + \beta p_2^x + \lambda_1^x q_1 - \kappa q_2$. The market demand of product 2 is $D_2^x = a_2 - p_2^x + \beta p_1^x + \lambda_2^x q_2 - \kappa q_1$, $a_1 > 0$, $a_2 > 0$. Suppose $1 > \beta \geq 0$, demand is more sensitive to its own price. $\lambda^x \geq 0$, $\kappa \geq 0$, the greater the β and κ , the stronger the competition between the two products. Suppose $\lambda^x \geq \kappa$, the demand is more sensitive to its own quality level than to the substitute quality level.
- (6) In order to facilitate the research, it is presumed that the production costs of the suppliers in the two supply chains is zero. In order to enhance the competitiveness of the whole supply chain and obtain more revenue, both suppliers and retailers have the inherent motivation to invest the BBTS. It is assumed that suppliers and retailers bear their own the BBTS costs, and indirectly share the BBTS costs of each other by adjusting wholesale prices and ordering quantities.

4. Supply Chain Revenue Model In Different Investment Situations

4.1. Revenue model of supply chain members in the N situation

In the N situation, suppliers and retailers in both supply chains do not invest the BBTS. The wholesale price w_i^N will sell by the supplier of product to its exclusive retailer. The demand of the retailer is D_i^N , and

the retail price of the product is p_i^N . Then the expected returns of supply chain members π_{ri}^N and π_{mi}^N are as follows:

$$\pi_{mi}^N = (w_i^N - c_m) D_i^N$$

1

$$\pi_{ri}^N = (p_i^N - w_i^N - c_r) D_i^N$$

2

The retailer determines the retail price and the product's order demand according to the supplier's wholesale price. Therefore, using backward induction to solve the retail price, we can get the retail price p_i^N of agricultural products. Then, putting the p_i^N into (1) to get the supplier's equilibrium wholesale price w_i^{N*} . According to the equilibrium wholesale price w_i^{N*} , we can get the equilibrium retail price p_i^{N*} . Putting the equilibrium retail price p_i^{N*} into the demand function D_i^N to get the equilibrium order quantity D_i^{N*} . Base on the equilibrium wholesale price w_i^{N*} , the equilibrium retail price p_i^{N*} and the equilibrium order quantity D_i^{N*} , we can derive the equilibrium incomes of the supplier and the retailer in Lemma 1.

Lemma 1

when the two supply chains do not invest in BBTS, the equilibrium demand are given by:

$$D_i^N = - \frac{(\beta^2 - 2) (A + C_1 + C_2 + S_1^N + S_2^N)}{F}$$

3

and the value function of supply chain is given by:

$$\pi_{mi}^{N*} = \frac{(\beta^2 - 2) (A + C_1 + C_2 + S_1^N + S_2^N)^2}{BF}$$

4

$$\pi_{ri}^{N*} = \frac{(\beta^2 - 2)^2 (A + C_1 + C_2 + S_1^N + S_2^N)^2}{F^2}$$

5

Furthermore, the profit of whole FPSC is given by:

$$\Pi_{sci}^{N*} = \frac{2 \left(\beta^4 - 5\beta^2 + 6 \right) \left(A + C_1 + C_2 + S_1^N + S_2^N \right)^2}{F^2}$$

6

where

$$A = -8a_i - 6a_j\beta + 3a_i\beta^2 + 2a_j\beta^3$$

7

$$C_1 = +8c_m - 9\beta^2c_m + 2\beta^4c_m + 8c_r - 9\beta^2c_r + 2\beta^4c_r$$

8

$$C_2 = -2\beta c_m + \beta^3c_m - 2\beta c_r + \beta^3c_r$$

9

$$S_1^x = -8\lambda_i^x q_i - 6\beta\lambda_j^x q_j + 3\beta^2\lambda_i^x q_i + 2\beta^3\lambda_j^x q_j$$

10

$$S_2^x = +8kq_j + 6\beta kq_i - 3\beta^2kq_j - 2\beta^3kq_i$$

11

$$B = 4\beta^4 - 17\beta^2 + 16$$

12

$$F = 4\beta^6 - 33\beta^4 + 84\beta^2 - 64$$

13

Proposition 1

With the raise of λ_i^N , the profit of supplier, retailer and whole FPSC will increase. In addition, with the raise of κ , the profit of whole FPSC will reduce.

Proof

Base on function (4) and (5), we can get

$$\begin{aligned}\frac{\partial \Pi_{ri}^{N*}}{\partial \lambda_i^N} &= - \frac{2 \left(\beta^2 - 2 \right)^2 \left(-2q_j\beta^3 - 3q_i\beta^2 + 6q_j\beta + 8q_i \right) \left(A + C_1 + C_2 + S_1^N + S_2^N \right)}{F^2} \\ \frac{\partial \Pi_{mi}^{N*}}{\partial \lambda_i^N} &= - \frac{2 \left(\beta^2 - 2 \right) \left(-2q_j\beta^3 - 3q_i\beta^2 + 6q_j\beta + 8q_i \right) \left(A + C_1 + C_2 + S_1^N + S_2^N \right)}{\left(\beta^2 - 4 \right) B^2} \text{ and} \\ \frac{\partial \Pi_{ri}^{N*}}{\partial K} &= \frac{2 \left(\beta^2 - 2 \right)^2 \left(-2q_i\beta^3 - 3q_j\beta^2 + 6q_i\beta + 8q_j \right) \left(A + C_1 + C_2 + S_1^N + S_2^N \right)}{F^2}\end{aligned}$$

Due to $D_i^{N*} = -\frac{\left(\beta^2 - 2 \right) \left(-2q_j\beta^3 - 3q_i\beta^2 + 6q_j\beta + 8q_i \right) \left(A + C_1 + C_2 + S_1^N + S_2^N \right)}{\left(\beta^2 - 4 \right) B^2} > 0$, we can get $\frac{\partial \Pi_{ri}^{N*}}{\partial \lambda_i^N} > 0$, $\frac{\partial \Pi_{mi}^{N*}}{\partial \lambda_i^N} > 0$, $\frac{\partial \Pi_{ri}^{N*}}{\partial K} > 0$, $\frac{\partial \Pi_{mi}^{N*}}{\partial K} > 0$, $\frac{\partial \Pi_{ri}^{N*}}{\partial \lambda_i^N} > 0$, $\frac{\partial \Pi_{mi}^{N*}}{\partial \lambda_i^N} > 0$, $\frac{\partial \Pi_{ri}^{N*}}{\partial K} > 0$, $\frac{\partial \Pi_{mi}^{N*}}{\partial K} > 0$.

According to Proposition 1, we find that price competition coefficient will increase the profits of FPSC member when the two supply chains does not invest in BBTS. In addition, quality competition will reduce the profits of FPSC members.

4.2. Revenue model of supply chain members in the I situation

In the I situation, in order not to lose generality, only the retailer and supplier in one supply chain are investing in the BBTS. By adopting the BBTS, consumers' perception of product safety is improved, and the supplier and retailers can effectively optimize the sales process and reduce sales cost (i.e., θ_{c_m} , θ_{c_r}) by the integration of enterprise information and the BBTS. Suppose that supply chain 1 invests in the BBTS, while supply chain 2 does not invest the BBTS. The perceived quality safety factor

of agricultural products in supply chain 1 is λ_1^I , while that of agricultural products in supply chain 2 is λ_2^I , and $\lambda_1^I > \lambda_2^I$. Revenues of supplier 1 and supplier 2 can be expressed as functions (12) and (13), respectively.

$$\pi_{m1}^I = (w_1^I - \theta_{cm} - c_{or})D_1^I$$

14

$$\pi_{m2}^I = (w_2^I - c_m)D_2^I$$

15

Revenues of retailer 1 and retailer 2 can be expressed as functions (14) and (15), respectively.

$$\pi_{r1}^I = (p_1^I - w_1^I - \theta_{cr} - c_{or})D_1^I$$

16

$$\pi_{r2}^I = (p_2^I - w_2^I - c_r)D_2^I$$

17

The demand D_i^I in the I situation is given by

$$D_1^I = a_1 - p_1^I + \beta p_2^I + \lambda_1^I q_1 - \kappa q_2$$

18

$$D_2^I = a_2 - p_2^I + \beta p_1^I + \lambda_2^I q_2 - \kappa q_1$$

19

We solve the problem of agricultural products' retail prices by backward induction, and we can get the retail prices p_1^I and p_2^I of agricultural products. Then, putting the p_1^I and p_2^I into (12) and (13) to get the suppliers' equilibrium wholesale prices w_1^{I*} and w_2^{I*} . Based on the equilibrium wholesale prices w_1^{I*} and w_2^{I*} , we can get the equilibrium retail prices p_1^{I*} and p_2^{I*} . Then putting the equilibrium retail prices p_1^{I*} and p_2^{I*} into the demand functions (16) and (17) to get the equilibrium order quantities D_1^{I*} and D_2^{I*} . Based on the equilibrium wholesale prices w_1^{I*} and w_2^{I*} , the equilibrium retail prices p_1^{I*} and p_2^{I*} , and the equilibrium order quantities D_1^{I*} and D_2^{I*} , we can derive the equilibrium incomes of the supplier and the retailer in the Lemma 2.

Lemma 2

When supply chain 1 invests in the BBTS and supply chain 2 does not invest in the BBTS, the demand of supplier and retailer are given by, respectively.

$$D_1^{I*} = -\frac{(\beta^2 - 2)\left(A + \theta_{C_1} + C_2 + O_1 + S_1^I + S_2^I\right)}{(F)}$$

20

$$D_2^{I*} = -\frac{(\beta^2 - 2)\left(A + C_1 + \theta_{C_2} + O_2 + S_1^I + S_2^I\right)}{(F)}$$

21

The equilibrium revenues of suppliers are given by

$$\pi_{m1}^{I*} = \frac{(\beta^2 - 2) \left(A + \theta C_1 + C_2 + O_1 + S_1^I + S_2^I \right)}{(BF)^2}$$

22

$$\pi_{m2}^{I*} = \frac{(\beta^2 - 2) \left(A + C_1 + \theta C_2 + O_2 + S_1^I + S_2^I \right)}{(BF)^2}$$

23

and the equilibrium revenues of retailers are given by

$$\pi_{r1}^{I*} = \frac{(\beta^2 - 2)^2 \left(A + \theta C_1 + C_2 + O_1 + S_1^I + S_2^I \right)}{(F^2)^2}$$

24

$$\pi_{r2}^{I*} = \frac{(\beta^2 - 2)^2 \left(A + C_1 + \theta C_2 + O_2 + S_1^I + S_2^I \right)}{(F^2)^2}$$

25

Furthermore, the profit of whole FPSC is given by:

$$\pi_{sc1}^{I*} = \frac{2\mu \left(\beta^4 - 5\mu \beta^2 + 6 \right) \left(A + \theta C_1 + C_2 + O_1 + S_1^I + S_2^I \right)}{(F^2)^2}$$

26

$$\pi_{sc2}^{I*} = \frac{2\mu \left(\beta^4 - 5\mu \beta^2 + 6 \right) \left(A + C_1 + \theta C_2 + O_2 + S_1^I + S_2^I \right)}{(F^2)^2}$$

27

where

$$O_1 = 8c_{om} - 9\beta^2 c_{om} + 2\beta^4 c_{om} + 8c_{or} - 9\beta^2 c_{or} + 2\beta^4 c_{or}$$

28

$$O_2 = -2\beta c_{om} + \beta^3 c_{om} - 2\beta c_{or} + \beta^3 c_{or}$$

29

Base on the equilibrium profits of FPSC members, we can get Proposition 2.

Proposition 2

With the raise of λ_1^I , the profits of supplier, retailer and the whole FPSC will increase.

Proof

Base on the function (22), (23), (24) and (25), we can get $\frac{\partial \pi_{r1}^{(I*)}}{\partial \lambda_1} \bigg|_{\lambda_1=1} > 0$, $\frac{\partial \pi_{m1}^{(I*)}}{\partial \lambda_1} \bigg|_{\lambda_1=1} > 0$, $\frac{\partial \pi_{r2}^{(I*)}}{\partial \lambda_1} \bigg|_{\lambda_1=1} > 0$ and $\frac{\partial \pi_{m2}^{(I*)}}{\partial \lambda_1} \bigg|_{\lambda_1=1} > 0$. Due to $D_1^{(I*)} = -\frac{\partial \pi_{r1}^{(I*)}}{\partial \lambda_1} \bigg|_{\lambda_1=1} > 0$ and $D_2^{(I*)} = -\frac{\partial \pi_{r2}^{(I*)}}{\partial \lambda_1} \bigg|_{\lambda_1=1} > 0$, we can get $\frac{\partial \pi_{r1}^{(I*)}}{\partial \lambda_1} \bigg|_{\lambda_1=1} > 0$, $\frac{\partial \pi_{m1}^{(I*)}}{\partial \lambda_1} \bigg|_{\lambda_1=1} > 0$, $\frac{\partial \pi_{r2}^{(I*)}}{\partial \lambda_1} \bigg|_{\lambda_1=1} > 0$ and $\frac{\partial \pi_{m2}^{(I*)}}{\partial \lambda_1} \bigg|_{\lambda_1=1} > 0$.

According to Proposition 2, we find that improving consumers' perceived quality will increase the profits of supplier, retailer and the whole FPSC members.

4.3. Revenue model of supply chain members in the M situation

In the M situation, retailers and suppliers in both supply chains invest the BBTS. The wholesale price sold by the supplier of product to its exclusive retailer is w_i^M . The demand of the retailer is D_i^M , and

the retail price of the product is p_i^M . Then the expected returns of supply chain members π_{ri}^M and π_{mi}^M are as follows:

$$\pi_{mi}^M = (w_i^M - \theta_{c_m} - c_{om})D_i^M$$

30

$$\pi_{ri}^M = (p_i^M - w_i^M - \theta_{c_r} - c_{or})D_i^M$$

31

The retailer identified the retail price and order demand of the product according to the supplier's wholesale price. Therefore, using backward induction to solve the retail price, and we can get the retail price p_i^M of agricultural products. Then, putting the p_i^M into (24) to get the supplier's equilibrium wholesale price w_i^{M*} . Based on the equilibrium wholesale price w_i^{M*} , we can get the equilibrium retail price p_i^{M*} and then put the equilibrium retail price p_i^{M*} into the demand function D_i^M to get the equilibrium order quantity D_i^{M*} . Based on the equilibrium wholesale price w_i^{M*} , the equilibrium retail price p_i^{M*} and the equilibrium order quantity D_i^{M*} , we can derive the equilibrium incomes of the supplier and the retailer in the Lemma 3.

Lemma 3

When two supply chains invest in the BBTS, the demand is given by

$$D_i^{M*} = -\frac{(\beta^2 - 2)\left(A + \theta(C_1 + C_2) + O_1 + O_2 + S_1^M + S_2^M\right)}{F}$$

32

and the value function of supply chain is given by

$$\pi_{mi}^{M*} = \frac{(\beta^2 - 2)\left(A + \theta(C_1 + C_2) + O_1 + O_2 + S_1^M + S_2^M\right)}{(BF)^2}$$

33

$$\pi_{ri}^{M*} = \frac{(\beta^2 - 2)^2\left(A + \theta(C_1 + C_2) + O_1 + O_2 + S_1^M + S_2^M\right)}{(F^2)^2}$$

34

Furthermore, the profit of whole FPSC is given by:

$$\pi_{sci}^{M*} = \frac{2\mu(\beta^4 - 5\mu\beta^2 + 6)\left(A + \theta(C_1 + C_2) + O_1 + O_2 + S_1^M + S_2^M\right)}{(F^2)^2}$$

35

Proposition 3

With λ_i^M increases, the profits of FPSC invested in BBTS will increase.

Proof

Base on function (33) and (34), we can get $\frac{\partial \pi_{ri}^{M*}}{\partial \lambda_i^M} \frac{\partial \lambda_i^M}{\partial \beta} = -\frac{2(\mu_1 - 2\mu_2)(\beta^2 - 2)}{(\mu_1 - 2\mu_2)(\beta^3 - 3\mu_1\mu_2 + 6\mu_2\beta + 8\mu_1)} \left((A + \theta(C_1 + C_2) + O_1 + O_2 + S_1^M + S_2^M) \right) \{BF\}$

$\frac{\partial \pi_{ri}^{M*}}{\partial \lambda_i^M} \frac{\partial \lambda_i^M}{\partial \beta} = -\frac{2(\mu_1 - 2\mu_2)(\beta^2 - 2)}{(\mu_1 - 2\mu_2)(\beta^3 - 3\mu_1\mu_2 + 6\mu_2\beta + 8\mu_1)} \left((A + \theta(C_1 + C_2) + O_1 + O_2 + S_1^M + S_2^M) \right) \{F^2\}$. Due to $D_i^{M*} = -\frac{(\beta^2 - 2)}{(A + \theta(C_1 + C_2) + O_1 + O_2 + S_1^M + S_2^M)} \{F\} > 0$, we can get $\frac{\partial \pi_{mi}^{M*}}{\partial \lambda_i^M} \frac{\partial \lambda_i^M}{\partial \beta} > 0$,

$\frac{\partial \pi_{ri}^{M*}}{\partial \lambda_i^M} \frac{\partial \lambda_i^M}{\partial \beta} > 0$.

5. Analysis Of Equilibrium Investment Strategy Of Bbts

Base on the above hypothesis and analysis, we can easy to find that each profit of two FPSC in N situation is same. In order to further study the equilibrium investment strategy of BBTS, we analysis the change of profits after investment the BBTS by comparing the profits of supplier and retailer before and after investing in BBTS (i.e. situation, N, I and M).

Proposition 4

When $c_{om} + c_{or} \leq \frac{\lambda_1^I(q_1 - q_2)}{\lambda_2^I(1 + \beta)} + (c_m + c_r)(1 - \theta)$, two supply chains will invest in BBTS.

Proof

When neither FPSC invests in BBTS (i.e. situation N), if decision maker of supply chain 1 want to invest in BBTS, they should consider that the profits' change of supply chain 1 $\Delta \pi_1 = \pi_1^I - \pi_1^N$ and their profits is higher than competitor. Thus $\Delta \pi_1 > 0$ and $\pi_1^I \geq \pi_2^I$, due to $D_1^{I*} > 0$, $D_2^{I*} > 0$ and $D_1^{N*} > 0$, we can get $H_1: \left(8(\mu_1 - 9\mu_2)(\beta^2 + 2\mu_2\beta + 4\mu_1) \right) \left((c_{om} + c_{or}) + (c_m + c_r)(1 - \theta) \right) + (3(\mu_1 - 8\mu_2) \left(\lambda_1^I - \right.$

safety factor of the supply chain have been improved $\lambda_i^M=0.8$ after investing in BBTS. In addition, assume that the optimization coefficient of the sales cost of agricultural products $\theta=0.75$.

Figure 4, 5 and 6 show the change of retail prices, wholesale prices and demand with respect to parameters. We can get the following observations.

1. Figure 4 indicates, with price competition coefficient β raise, retail price, wholesale price and demand will increase in three situations (i.e. N, I and M). This is because the price competition will expand market demand. Then the retailer will raise the retail price and the supplier also will raise wholesale price following the retailer.
2. Figure 5 indicates, with λ^M raise, retail price, wholesale price and demand will increase in three situations (i.e. N, I and M). It can be explained as follow. With λ^M increases, fresh agricultural products' quality is more reliable. And Consumers prefer products with reliable quality. In addition, supply chain 1 in I situation and two supply chains in M situation increase faster. That indicates, it is benefits to increase price and expand demand by investing in BBTS.

Figure 6

Then, we will use numerical examples to discuss the investment strategy of BBTS. In general, we set price competition coefficient β is 0.5. Using above parameter value, the Figure 7a shown the change of profits after investing in BBTS with different investment cost $\{c_{om}\}+\{c_{or}\}$. We can see that if FPSC want to invest in BBTS, the investment cost should be less than 0.3833 when the price competition coefficient β is 0.5. In addition, the Figure 7b shown the threshold value sum of BBTS costs $\{c_{om}\}+\{c_{or}\}$ following the change of price competition coefficient β . We can find that condition H_2 contains condition H_7 as **Proposition 4**, and the minimum threshold value sum of BBTS costs is 0.35.

Thus, we assumed $\{c_{\{\text{om}\}}\}=0.15$, $\{c_{\{\text{or}\}}\}=0.15$. Meanwhile assumed $\{c_{om}\}=0.22$, $\{c_{or}\}=0.22$ and $\{c_{om}\}=0.29$, $\{c_{or}\}=0.29$ to contrast with $\{c_{om}\}=0.15$, $\{c_{or}\}=0.15$.

When $\{c_{om}\}=0.15$, $\{c_{or}\}=0.15$, Figure 8 shown the change of FPSCs' profits with price competition coefficient β . We can find that the supply chain's income grows with the increase of the price competition intensity of agricultural products. In addition, no matter what is the value of β , the profits of FPSC will increase when they invest in BBTS (i.e. $\pi_{\{sc\}}^M > \pi_{\{sc1\}}^I > \pi_{\{sc2\}}^I > \pi_{\{sc\}}^N$). The reason perhaps that with the price competition coefficient β increase, the retail price and the demand will also increase, as observed in Figure 4.

When $\{c_{om}\}=0.22$, $\{c_{or}\}=0.22$, the impact of product price competition coefficient on supply chain profits is shown in Figures 9. No matter what is the value of price competition coefficient β , the investment of BBTS will add FPSCs' profits. But the profits of supply chain 2 will higher than supply chain 1 when only supply chain 1 invest in BBTS. Thus when $\{c_{om}\}=0.22$, $\{c_{or}\}=0.22$, FPSC will not invest in BBTS as **Proposition 4**.

only improve their perceived quality λ_1^I , but also should pay attention to the perceived quality of competitor without BBTS λ_2^I . When the competitor's perceived quality λ_2^I is high, investors should reduce their investment costs $c_{om}+c_{or}$.

(3) When the cost of investment satisfies certain conditions, investing in BBTS will increase the profits of FPSC. In addition, the threshold value sum of the BBTS costs $c_{om}+c_{or}$ has a negative correlation with the cost optimization coefficient θ and price competition coefficient β of sales industry based on the BBTS. This demonstrates that if investors or decision makers about BBTS want to get a big the threshold value sum of the BBTS costs $c_{om}+c_{or}$, they should reduce the cost optimization coefficient θ and avoid fierce price competition as much as possible.

(4) When the threshold value sum of the BBTS costs $c_{om}+c_{or}$ is in a certain range, the supply chain invested in the BBTS will obtain more benefits than the competitive supply chain without investing in the BBTS. In addition, if both of the two supply chains invested in the BBTS, supply chain members will gain a bigger threshold value sum of the BBTS costs $c_{om}+c_{or}$, moreover, supply chain members will gain more benefits compared with them no investment BBTS. Thus, governments need to guide more enterprises to adopt blockchain-based traceability platforms.

In this research, we find some Management suggestion. FPSC should know that whether adopt BBTS is mainly related to investment cost and the perceived quality from customers. In addition, FPSC should adopt price competition instead of quality competition.

7.2. Research significance

There are some academic values in this study. (1) Considering the new changes of consumers perceived quality and safety under the new background, we modified the demand function of agricultural products, and it would enrich the research of demand function in an agricultural products supply chain. (2) Considering the investment cost of BBTS, this paper constructed three kinds of profit function models of supply chain members under competitive supply chain (N, I, M). This expands the theory research on investment decision-making of competitive AFSCs under the new background.

There are some practical significances in this study. (1) The modified demand function can provide theoretical guidance for order decisions and production decisions. (2) This paper is helpful for the members of AFSC to formulate the investment strategy about the BBTS. (3) This study can provide theoretical support for competitive AFSC investment blockchain technology under the background of blockchain.

7.3. Future researches

This paper studied a simplified model of two competitive AFSCs, each of them was composed of a supplier and a retailer. AFSC is a complex system. In the future research, third-party logistics and multi-channel supply chain should be added to the model. In addition, the impression of uncertain demand on

the income of the supply chain should be taken into account. Therefore, the next study will establish a multi-node model and consider uncertain requirements to study this problem.

Declarations

Acknowledgements This work was partially supported by National Natural Science Foundation of China (Nos. 61703014), Key scientific research projects of higher education institutions in Henan, China (No.21A630016), General Project of Humanities and Social Sciences in Henan, China(No. 2020-ZDJH-141), Top Talent Project of Henan Agricultural University(No. 30500681), and Creator Talent Support Plan of Henan Agricultural University (No. 30200757).

Conflict of interest The authors declare that there is no conflict of interest regarding the publication of this paper.

Human and animal rights This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Badia-Melis, R., et al. (2015). "Food traceability: New trends and recent advances. A review." Food Control**57**: 393-401.
2. Bosona, T. and G. Gebresenbet (2013). "Food traceability as an integral part of logistics management in food and agricultural supply chain." Food Control**33**(1): 32-48.
3. Casino, F., et al. (2020). "Blockchain-based food supply chain traceability: a case study in the dairy sector." International Journal of Production Research: 1-13.
4. Chang, Y., et al. (2020). "Blockchain in global supply chains and cross border trade: a critical synthesis of the state-of-the-art, challenges and opportunities." International Journal of Production Research**58**(7): 2082-2099.
5. Charlebois, S. and S. Haratifar (2015). "The perceived value of dairy product traceability in modern society: An exploratory study." J Dairy Sci**98**(5): 3514-3525.
6. Charlebois, S., et al. (2014). "Comparison of Global Food Traceability Regulations and Requirements." Comprehensive Reviews in Food Science and Food Safety**13**(5): 1104-1123.
7. Chen, H., et al. (2018). "What are cost changes for produce implementing traceability systems in China? Evidence from enterprise A." Applied Economics**51**(7): 687-697.
8. Choi, T.-M., et al. (2020). "Information disclosure structure in supply chains with rental service platforms in the blockchain technology era." International Journal of Production Economics**221**.
9. Cole, R., et al. (2019). "Blockchain technology: implications for operations and supply chain management." Supply Chain Management: An International Journal**24**(4): 469-483.
10. Collart, A. J. and E. Canales (2021). "How might broad adoption of blockchain-based traceability impact the U.S. fresh produce supply chain?" Applied Economic Perspectives and Policy.

11. Dai, B., et al. (2021). "Interactions of traceability and reliability optimization in a competitive supply chain with product recall." European Journal of Operational Research**290**(1): 116-131.
12. De Giovanni, P. (2020). "Blockchain and smart contracts in supply chain management: A game theoretic model." International Journal of Production Economics**228**.
13. Esmaeilian, B., et al. (2020). "Blockchain for the future of sustainable supply chain management in Industry 4.0." Resources, Conservation and Recycling**163**.
14. Fosso Wamba, S., et al. (2020). "Dynamics between blockchain adoption determinants and supply chain performance: An empirical investigation." International Journal of Production Economics**229**.
15. Griffin, T. W., et al. (2021). "Three Digital Agriculture Problems in Cotton Solved by Distributed Ledger Technology." Applied Economic Perspectives and Policy.
16. Gurtu, A. and J. Johny (2019). "Potential of blockchain technology in supply chain management: a literature review." International Journal of Physical Distribution & Logistics Management**49**(9): 881-900.
17. Kendall, H., et al. (2019). "Chinese consumer's attitudes, perceptions and behavioural responses towards food fraud." Food Control**95**: 339-351.
18. Köhler, S. and M. Pizzol (2020). "Technology assessment of blockchain-based technologies in the food supply chain." Journal of Cleaner Production**269**.
19. Kouhizadeh, M., et al. (2021). "Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers." International Journal of Production Economics**231**.
20. Lehmann, R. J., et al. (2012). "Future internet and the agri-food sector: State-of-the-art in literature and research." Computers and Electronics in Agriculture**89**: 158-174.
21. Liu, P., et al. (2020). "Investment decision and coordination of green agri-food supply chain considering information service based on blockchain and big data." Journal of Cleaner Production**277**.
22. Niknejad, N., et al. (2021). "Mapping the research trends on blockchain technology in food and agriculture industry: A bibliometric analysis." Environmental Technology & Innovation**21**.
23. Niu, B., et al. (2021). "Should multinational firms implement blockchain to provide quality verification?" Transportation Research Part E: Logistics and Transportation Review**145**.
24. Park, A. and H. Li (2021). "The Effect of Blockchain Technology on Supply Chain Sustainability Performances." Sustainability**13**(4).
25. Patelli, N. and M. Mandrioli (2020). "Blockchain technology and traceability in the agrifood industry." J Food Sci**85**(11): 3670-3678.
26. Pearson, S., et al. (2019). "Are Distributed Ledger Technologies the panacea for food traceability?" Global Food Security**20**: 145-149.
27. Riccioli, F., et al. (2020). "Willingness to pay in main cities of Zhejiang province (China) for quality and safety in food market." Food Control**108**.

28. Salah, K., et al. (2019). "Blockchain-Based Soybean Traceability in Agricultural Supply Chain." IEEE Access**7**: 73295-73305.
29. Saurabh, S. and K. Dey (2021). "Blockchain technology adoption, architecture, and sustainable agri-food supply chains." Journal of Cleaner Production**284**.
30. Shew, A. M., et al. (2021). "Consumer valuation of blockchain traceability for beef in the United States." Applied Economic Perspectives and Policy.
31. Stranieri, S., et al. (2021). "Exploring the impact of blockchain on the performance of agri-food supply chains." Food Control**119**.
32. Sun, S. and X. Wang (2019). "Promoting traceability for food supply chain with certification." Journal of Cleaner Production**217**: 658-665.
33. Sunny, J., et al. (2020). "Supply chain transparency through blockchain-based traceability: An overview with demonstration." Computers & Industrial Engineering**150**.
34. Wang, C. and X. Chen (2016). "Option pricing and coordination in the fresh produce supply chain with portfolio contracts." Annals of Operations Research**248**(1-2): 471-491.
35. Wang, M. and L. Zhao (2018). "Cold chain investment and pricing decisions in a fresh food supply chain." International Transactions in Operational Research**28**(2): 1074-1097.
36. Wong, L.-W., et al. (2020). "Unearthing the determinants of Blockchain adoption in supply chain management." International Journal of Production Research**58**(7): 2100-2123.
37. Wu, X.-Y., et al. (2021). "An analysis of strategies for adopting blockchain technology in the fresh product supply chain." International Journal of Production Research: 1-18.
38. Yang, X., et al. (2021). "A Trusted Blockchain-Based Traceability System for Fruit and Vegetable Agricultural Products." IEEE Access**9**: 36282-36293.
39. Yiannas, F. (2021). "A NEW ERA OF FOOD TRANSPARENCY POWERED BY BLOCKCHAIN."
40. Zhang, A., et al. (2020). "Establishing confidence in food safety: is traceability a solution in consumers' eyes?" Journal of Consumer Protection and Food Safety**15**(2): 99-107.
41. Zhang, L., et al. (2016). "Consumer trust in different food provisioning schemes: evidence from Beijing, China." Journal of Cleaner Production**134**: 269-279.
42. Zhao, G., et al. (2019). "Blockchain technology in agri-food value chain management: A synthesis of applications, challenges and future research directions." Computers in Industry**109**: 83-99.

Figures

Figure 1

Article structure

Figure 2

Competitive supply chain model

Figure 3

Three Investment situations of the BBTS

Figure 4

Figure 4 indicates, with price competition coefficient β raise, retail price, wholesale price and demand will increase in three situations (i.e. N, I and M). This is because the price competition will expand market demand. Then the retailer will raise the retail price and the supplier also will raise wholesale price following the retailer.

Figure 5

Figure 5 indicates, with λ^M raise, retail price, wholesale price and demand will increase in three situations (i.e. N, I and M). It can be explained as follow. With λ^M increases, fresh agricultural products' quality is

more reliable. And Consumers prefer products with reliable quality. In addition, supply chain 1 in I situation and two supply chains in M situation increase faster. That indicates, it is benefits to increase price and expand demand by investing in BBTS.

Figure 6

Figure 6 indicates, with quality competition coefficient α raise, retail price, wholesale price and demand will reduce in three situations (i.e. N, I and M). The reason is that fierce quality competition will increase cost, reduce the market demand. Then the FPSC member will reduce its retail price and wholesale price.

Figure 7

Figure 7a shown the change of profits after investing in BBTS with different investment cost . We can see that if FPSC want to invest in BBTS, the investment cost $c_{om} + c_{or}$ should be less than 0.3833 when the price competition coefficient β is 0.5. In addition, the Figure 7b shown the threshold value sum of BBTS costs $c_{om} + c_{or}$ following the change of price competition coefficient β . We can find that condition H_2 contains condition H_7 as **Proposition 4**, and the minimum threshold value sum of BBTS costs is 0.35.

Figure 8

Please see the Manuscript PDF file for the complete figure caption.

Figure 9

When $c_{om}=0.22$, $c_{or}=0.22$ the impact of product price competition coefficient on supply chain profits is shown in Figures 9. No matter what is the value of price competition coefficient, the investment of BBTS will add FPSCs' profits. But the profits of supply chain 2 will higher than supply chain 1 when only supply chain 1 invest in BBTS. Thus when $c_{om}=0.22$, $c_{or}=0.22$ FPSC will not invest in BBTS as **Proposition 4**.

Figure 10

Please see the Manuscript PDF file for the complete figure caption.