Blockchain Technology Investment Strategies of Green Agri-food Supply Chain under Government Tax Subsidy Strategy

Pan Liu, Bin Zhao, Qian Liu

***Abstract*—In the context of green development and increasing green demand, consumers' perception of greenness and freshness in agri-food product will affect their purchasing decisions. Blockchain is being looked at as a technology that can build trust between consumers and the greenness and freshness of product. To stimulate the development and application of blockchain technology, the Chinese government has put forward some subsidy strategies, this will have what effect on enterprises' blockchain investment decisions, and what are the investment rules? To study these issues, we chose a green agri-food supply chain (GAFSC) with one producer, one blockchain-based traceability service provider (BBTSP) , and one retailer as the research object. Assume that the government offers a tax subsidy strategy to the organizations of blockchain usage and R&D. Then, considering the perceived credibility of consumers on product greenness and freshness after using the blockchain technology, the demand function was revised. Furthermore, we proposed and analyzed three subsidy models. Findings: 1) When the blockchain technology investment cost of the BBTSP can meet a certain range, the benefits of supply chain stakeholders in the tax subsidy conditions will be higher than those in the no-tax subsidy model. In addition, the BBTSP's blockchain technology investment cost has a negative relationship with the tax discount coefficients of the BBTSP and the producer. 2) All supply chain members getting tax subsidies from the government cannot always increase their incomes, and this is in contact with the tax subsidy rates and the blockchain technology investment cost of the BBTSP.**

***Index Terms*—Subsidy policies, Blockchain, Traceability Service, green agri-food supply chain**

I. INTRODUCTION

IN China, consumers' consumption demands for green agri-foodand the need to meet environmental regulations promote the development of green agricultural products[1]-[3]. Green agri-food means that the production process of products does not cause any harm to the environment, and the products are treated according to the green food regulations of the government[4]. Consumers' perception on the product's greenness will affect their purchasing decisions, and the perception growth on the product greenness will promote the coordinated development of the environment and agricultural production. Recent quality and safety issues in agricultural products have undermined consumer trust[5]. To restore faith in green agricultural markets, researchers have proposed employing product lifecycle traceability methods[3],[6],[7]. Experiments have shown over 90% willingness among participants to purchase products with traceable information[8]. While various traceability technologies aid product quality tracing, they are susceptible to data tampering due to centralized data storage[9],[10]. Such systems make it challenging for consumers to access authentic traceability information[11],[12]. Blockchain technology addresses these traceability weaknesses, rebuilding trust between consumers and the market[13],[14]. Additionally, blockchain's application symbolizes the advancement of smart agriculture[15]. Owing to blockchain's advantages[16], it has garnered attention from organizations and governments, especially in green agricultural sectors. Many producers and retailers have adopted blockchain-based traceability systems (referred to as BBT systems), but the significant capital investment required raises concerns. To expedite blockchain integration across industries, several countries (e.g., China, the UK, South Korea) have issued incentive policies[14],[17],[18]. Given these circumstances, enterprises are keen on understanding investment decision-making, product pricing rules, and blockchain technology benefits under government subsidies. This inquiry aims to investigate blockchain technology investment strategies within the green agri-food supply chain (GAFSC) under a government subsidy strategy."

While extensive research delves into blockchain's technical aspects within agri-food supply chains, the adoption of blockchain technology often emerges as an outcome of strategic interactions among stakeholders[9],[19]. Yet, limited attention has been paid to examining blockchain technology investment strategies within a green agri-food supply chain under government tax subsidy strategies, despite the crucial influence of the BBT service system on demand function changes[20]-[22]. Notably, consumers' trust in BBT information significantly impacts their purchase decisions, alongside the pivotal roles of greenness and

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freshness credibility in evaluating the quality of green agricultural products.Consumer preferences predominantly lean towards high-greenness and high-freshness green agricultural products, shaping their choices in the market. Thus, our study accentuates the significance of consumers' perceived information credibility regarding greenness and freshness in steering their purchasing decisions. However, the discourse on studying blockchain technology investment strategies within the GAFSC has been limited in considering consumers' perceived information credibility regarding greenness and freshness, especially under government subsidy strategies.

Consequently, our research aims to explore blockchain technology investment strategies within the GAFSC, factoring in consumers' perceived information credibility about greenness and freshness, both with and without government tax subsidy strategies. To investigate these dynamics, we focus on a GAFSC comprising one retailer, one blockchain-based traceability service provider (BBTSP), and one producer. We assume government involvement through tax subsidy strategies for organizations involved in blockchain utilization and R&D. Following the adoption of blockchain technology and accounting for consumers' perceived information credibility regarding greenness and freshness, we revise the demand function. Additionally, we propose and analyze three subsidy models.

There are two innovations: 1) after using blockchain technology, considering the perceived information credibility of consumers on greenness and freshness, we revised the demand function. 2) Considering the tax subsidy strategy, three subsidy models were built and analyzed, and change rules about the prices and the benefits of chain members in the new background were obtained.

This research has some significance. In theory, 1) the market demand function was improved considering the perceived information credibility of consumers on greenness and freshness in the new background. It enriched the demand management theory in a GAFSC. 2) Considering the proposed three subsidy strategies in a GAFSC, three subsidy models were built. And subsidy rules were obtained. It was a new development of subsidy theory about GAFSC in the blockchain environment. In practice, 1) our research method used in obtaining the market demand is a reference for future research about the green agri-food market demand. 2) The investment decision rules will offer theory bracings for chain members to use and implement the blockchain technology with government subsidy strategies in a green agri-food industry, and then promote the coordinated development of the environment and agricultural production.

II. Literature Review

Our research involved the following two aspects. Firstly, the application of blockchain in GAFSC. Secondly, government subsidy strategy of GAFSC in the blockchain era.

A. Applications of Blockchain in GAFSC

Blockchain, as a distributed innovative technology, was widely discussed by many researchers from different fields [23]. For instance, the characteristics of decentralization, non-tampering, and traceability ensured the transparency, security, and traceability of data[24],[25]. Thus, to add food quality safety and credibility, Wal-mart, IBM, and Dole developed a traceability system by adopting blockchain technology. JD.com and Tmall (E-commerce platforms from China) also used blockchain technology to achieve product traceability[26]. The usage of blockchain in various fields had become an inevitable trend, especially in the supply chain management field[27]-[29]. Blockchain was expected to become a disruptive technology to alleviate the supply chain management problems and promote his sustainable development[30],[31].

Therefore, the applications of blockchain in a supply chain have attracted much attention. However, the levels of technology and concept were focused by many researchers. Such as, in achieving traceability and information symmetry, Lahkani found that blockchain improved the reliability and transparency of data[32], and made the e-commerce supply chain gain greater competitive advantage and profitability. Lee & Yeon discussed that blockchain could overcome the uncertainty and asymmetry of information and realize the anti-counterfeiting traceability of products[33]. Luzzani et al. discussed the application of blockchain technology in agri-food and found that the traceability and transparency of the supply chain were improved[34]. In promoting the sustainable development of the supply chain, Khan et al. and Nayak & Dhaigude discussed the impact of blockchain on sustainable supply chain management in SMEs[35],[36]. Nayal et al. and Mubarik et al. discussed the impacts of blockchain technology on sustainable agricultural supply chain and green supply chain respectively and found that there was a positive correlation between them. In addition, blockchain-based smart grids and green logistics could realize the sustainable operation of supply chains[37]-[40].

From the perspective of game theory, our research is related to the effect of blockchain on supply chain operation decision-making. Such as, in the blockchain background, Hayrutdinov et al. obtained the investment decision rules about blockchain considering the life-cycle information-sharing effort[41]. In addition, Fan et al. also gained the investment decision rules about blockchain considering consumers' traceability awareness[42]. Choi et al. discussed the blockchain-based information disclosure strategies[43]. Shen et al. discussed the strategies in combating counterfeit products[44]. Afterward, facing counterfeit goods, Shen et al. the brand dealer's choice problem regarding the distribution channel (i.e., the conditions for brands to choose blockchain-based vendors)[45]. Considering blockchain adoption, Zheng et al. discussed the risk decision issues in facilitating information sharing[46]. There are other efforts, for instance, Niu et al. [47], Choi[48] , Choi & Luo[49] , etc.

In the realm of fresh supply chains and blockchain applications, existing research by Liu & Guo, Xu et al., Liu et al., and others has explored pricing dynamics, coordination effects, and investment decisions with blockchain adoption[50]-[53]. However, these studies overlook the essential element of consumers' perceived information credibility regarding greenness and freshness.

In short, research about investment policies and government subsidy strategy (subsidy strategy will be discussed in the next section) in GAFSC failed to consider the perceived information credibility of consumers on greenness and freshness with the usage of blockchain. Therefore, we will fill this gap.

B. Government Subsidy for GAFSC

A subsidy system geared towards green-oriented agriculture plays a pivotal role in fostering the robust development of environmentally conscious agricultural products[54],[55]. Currently, several green agricultural subsidy policies have been introduced, encompassing special subsidies, capital incentives, and innovation subsidies[53]. These subsidies align agricultural progress with environmental preservation [56], and their impact on the environment has been a focal point of research. For instance, Zhang et al. investigated the influence of agricultural subsidies and product certification on the adoption rate of environmentally friendly pesticides[57]. Shou-Wei et al. analyzed the effects of factors such as environmental significance and agricultural subsidy rates on subsidy effectiveness and societal welfare, considering yield and green subsidies[58]. Accounting for preference and income variations, Eerola & Huhtala delved into the design of price subsidies and taxes on conventional products to encourage green product consumption[59]. Yj et al. examined the effects of subsidy policies, social responsibility, and quality preferences on transitioning from chemical fertilizers to organic manure, promoting sustainable agricultural practices. Tu et al. explored the efficiency and determining factors of agricultural subsidies within the framework of green development[60]. However, there remains a scarcity of research focusing on government subsidies specifically allocated to blockchain-based traceability services.

The related research about blockchain subsidy mainly focuses on qualitative description. For instance, due to the difficulty in traceability of agricultural products and frequent food safety issues, the quality and safety of agricultural products had become the focus of governments and consumers around the world[61],[62]. In order to strengthen food quality and safety management, China had actively promoted the food quality and safety traceability system and required traceability of the entire supply chain[63],[64]. Moreover, government subsidies for traceability system has been widely used and discussed because it had a huge incentive effect on ensuring the quality and safety of agricultural products. For example, to promote the development of the traceability market, Hou et al. suggested that the government should combine certification with traceability[65], and increase subsidies for the construction of traceability systems. Xu&Xie proposed a decision-making optimization model for the traceable food system based on government's public strategic decision-making[66]. However, the traditional traceability systems of agricultural products they discussed were heavily centralized, which led to a series of problems such as non-openness and transparency of data. Blockchain technology could avoid the above problems[67],[68]. The broad application prospects of blockchain had been valued by countries around the world[69], and governments have introduced relevant subsidy strategies to encourage the application and R&D of blockchain[14]. There are some documents focusing on subsidy strategy descriptions. In 2018, the South Korean government announced that it would treat enterprises applying blockchain technology as tax relief objects, 30% to 40% for SMEs, and 20% to 30% for large enterprises. Enterprises in China that used the blockchain could enjoy tax incentives (this study will consider tax subsidy), scientific and technological achievements awards, etc.

In the realm of game theory-based subsidy studies in the blockchain era, researchers like Pun [14] have discussed chain member strategies, considering counterfeiting situations, to prevent fraud with government subsidies, including options like blockchain adoption or differential pricing. Jian & Yd examined the impact of government green subsidies on stakeholders' blockchain adoption[70],[73]. Exploring government subsidy rules for Blockchain-Based Traceability Service Providers (BBTSPs) and their influence on blockchain technology investment strategies within the GAFSC holds significant practical importance. However, previous studies have not sufficiently focused on this aspect.

In summary, prior research exhibits several shortcomings: (1) overlooking the influence of blockchain on consumers' perceived information credibility regarding greenness and freshness; (2) inadequately addressing blockchain technology investment strategies for GAFSC considering government subsidy strategies. Hence, our study aims to fill these gaps and provide enriched insights.

III. Problem Presentation

A. Variable Instructions

The involved parameters of our research are shown in Table 1.

TABLE 1 VARIABLE DESCRIPTION

Variable	Explanation
US	All the members of the supply chain will not invest in blockchain technology or the blockchain-based traceability service, but they adopt a traditional traceability service system. Governments will not offer subsidies.
$S1$	The producer will purchase the blockchain-based traceability service from the BBTSP. To incentivize the BBTSP to research and develop the BBT system, governments will offer tax subsidy strategy to the BBTSP.
$S2$	The producer will purchase the blockchain-based traceability service from the BBTSP. To incentivize the producer and the BBTSP to research or use the BBT system, governments will offer tax subsidy strategy to the BBTSP and the producer.
i	The different subsidy situations about the blockchain $i=\{US,S1,S2\}$.
H^i	The perceived greenness credibility coefficient of consumers in the i model. Here, $0\le H<1$.
K^i	The perceived freshness credibility coefficient of consumers in the i model. Here, $0\le K<1$.
$\theta(t)$	The decay function of freshness.
t	The product circulation time and $0\le t\le T$.
T	The product life-cycle.
$\psi(\tau^{x}t^{i})$	The effective output factor function. When $i=US$, $x=1$, otherwise, $x=0$ ..
c_2	The unit sale cost of the retailer.

c_1	The unit production cost of the fresh product.
f_r^i	Revenues of the retailer in the i situation.
f_p^i	Revenues of the producer in the i situation.
f_d^i	Benefits of the BBTSP in the i situation.
D^i	The actual market demand in the i situation, in this paper, it equals to the retailer's order quantity.
p^i	The retail price of the fresh products in the i situation.
p_d^i	The retail price of the blockchain-based traceability service in the i situation.
w^i	The wholesale price of the fresh products in the i situation.

B. Demand Function Instructions

Many research achievements and application cases about blockchain traceability service thought that using blockchain traceability service would achieve a positive influence on the market demand[67],[71]. However, whether the blockchain-based traceability information was credible or not would affect consumers' purchasing decisions[67]. In other words, consumers' perceived trustworthiness on the blockchain-based traceability information is vital in their purchasing decision process. For a GAFSC, the traceability information about products' freshness and green degree are the important factors for the purchasing decision process. Therefore, we assume that consumers' demand is price-sensitive, and will be influenced by the product green degree, the product freshness, consumers' perceived trustworthiness level about the blockchain-based greenness traceability information, and the blockchain-based freshness traceability information. Based on the research of Pan et al. [5] and Wu et al.[67], we can see that consumers' perceived trustworthiness about the product information will affect consumers' demand. Meanwhile, according to the efforts from Pan et al.[5], we know that the product green degree and the product freshness will positively affect the market demand, and they have a linear relationship with the market demand. In addition, most researchers suggest that the retail price is negatively correlated with the market demand, and with the increase of the retail price, the market demand will decrease linearly. Based on the aforementioned analyses, we can get a new demand function in the blockchain background (see Eq. (1)).

$$D^i = 1 - ep^i + H^i g + K^i\theta(\tau^x t) \tag{1}$$

e represents the price elasticity coefficient. H^i is the perceived greenness credibility coefficient in the i model, and g stands for the green degree of fresh products. K^i is the perceived freshness credibility coefficient in the i model. Based on previous efforts[50], we assume that the blockchain technology investment cost is c_3, and in the US model, the R&D cost of the BBTSP about the traceability service system is c.

In our manuscript, we chose a GAFSC with one producer, one BBTSP, and one retailer as our research object (see pic. 1). In picture 1, the BBTSP will research and develop blockchain technology, and offer the blockchain-based traceability service to the producer. To stimulate the retailer to use the blockchain-based traceability service, the producer may undertake all the costs. Meanwhile, to promote the application and R&D of blockchain, government will provide subsidies to the BBTSP and the producer. Based on our research on blockchain-related subsidy policies in different countries, the tax subsidy strategy is often adopted. The government's subsidy model has two models. One is to offer the tax subsidy strategy to the BBTSP, and we call it the S1 model. Another is to offer the tax subsidy strategy to the BBTSP and the green fresh producer, and we call it the S2 model.

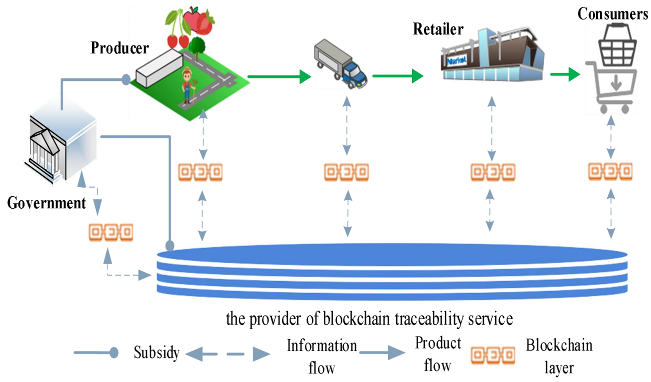

Fig. 1. Supply chain model

C. Assumptions

(1) Chain members are two types of independent groups, and they are risk-neutral and completely rational.

(2) Because fresh products are fragile and easily damaged, during the circulation process, they will be lost. The loss quantity has a positive relationship with the transportation time. Assuming the life-cycle time is T. Namely, $\Psi(1)=1, \Psi(T)=0$. To ensure the retailer's order quantity, generally, the manufacturer needs more goods, and the shipment quantity can be expressed as $D^i / \Psi(\tau^x t^i)$.

IV. Subsidy Policies Analyses

With the ongoing advancement of green development strategies, it's evident that implementing Blockchain-Based Traceability (BBT) services enhances consumer trust in green agricultural products, subsequently boosting sales for green producers. Consequently, the adoption and research and development (R&D) of blockchain technology have gained popularity within the green agricultural products market. However, the high costs associated with utilizing and developing blockchain have considerably limited the incentives for its adoption and R&D.

To expedite the fusion of BBT technology into the green agricultural products industry and enhance societal welfare, governments are poised to introduce corresponding subsidy policies, incentivizing the utilization and R&D of BBT systems. For instance, the government of Kerala, India, instituted subsidies for blockchain technology to expedite the procurement and sale of fresh food. Zhong et al. explored the impact of government-provided blockchain innovation and quantity subsidies for manufacturers adopting BBT systems on the supply chain. Moreover, several cities in China, including Hainan, Guangzhou, and Suzhou, have witnessed the emergence of government innovation subsidies for BBT systems.

The aforementioned studies collectively highlight government subsidies aimed at blockchain utilization and R&D, significantly fostering the integration of blockchain traceability systems across various industries. These findings provide substantial support for the three government subsidy models proposed in this study for the Green Agri-Food Supply Chain (GAFSC)

A. US Model

In the US model, the revenue equations about the BBTSP, the producer, and the retailer are as follows, respectively.

$$f_d^{US} = [(1-r)p_d^{US} - c]\frac{D^{US}}{\psi(\tau t)} \tag{2}$$

$$f_p^{US} = [(1-b_1)w^{US} - p_d^{US} - c_1]\frac{D^{US}}{\psi(\tau t)} - zg^2/2 \tag{3}$$

$$f_r^{US} = [(1-b_2)p^{US} - w^{US} - c_2]D^{US} \tag{4}$$

r represents the tax paid by the BBTSP to the government per unit of traceability service. b_1 represents the tax paid by the producer to the government per unit of green agri-food produced. b_2 represents the tax paid by the retailer to the government per unit of green agri-food sold.

Based on the master-slave game, we use the reverse analysis method. Then, we get the optimal decisions and benefits of stakeholders as shown in Proposition 1.

Proposition 1:

$$p_d^{US*} = \frac{2ce - A}{2e(1-r)} \tag{5}$$

$$w^{US*} = \frac{A - 2c_1 e(1-r)}{4e(1-r)(1-b_1)} \tag{6}$$

$$p^{US*} = \frac{A + 6(1-r)(1+H^{US}g + K^{US}\theta(\lambda t))(b_1 + b_2 - 1 - b_1 b_2)]}{8e(1-r)(1-b_1)(1-b_2)} \tag{7}$$

$$f_d^{US*} = \frac{A^2}{16e\psi(\tau t)(1-b_1)(1-b_2)(1-r)} \tag{8}$$

$$f_p^{US*} = \frac{A^2}{32e\psi(\lambda t)(1-b_1)(1-b_2)(1-r)^2} - \frac{zg^2}{2} \tag{9}$$

$$f_r^{US*} = \frac{A^2}{64e(1-b_1)^2(1-b_2)(1-r)^2} \tag{10}$$

Here,

$$A = (1-r)[e(c_1 + c_2 - b_1 c_2) + (1 + Hg + K\theta(\tau t))(b_1 + b_2 - 1 - b_1 b_2)] + ec$$

. According to Proposition 1, we can get $D^{US*} = A > 0$.

B. S1 Model

In the S1 model, to overcome the shortcomings of the traditional traceability system and improve the credibility of agricultural product green degree, the producer may adopt the BBT system. We assume that the producer does not enough strength to build a BBT system. Thus, they will purchase the blockchain-based traceability service from the BBTSP. To incentivize the BBTSP to research and develop the BBT system, governments will offer a tax subsidy strategy to the BBTSP. We assume that the tax subsidy rate offered to the BBTSP s' , then the tax rate paid by the BBTSP is $sr = (1-s')r$. Thence, we constructed the revenue equations about the BBTSP, the producer and the retailer (see Eq. (11), Eq. (12) , and Eq. (13)).

$$f_d^{S1} = [(1-sr)p_d^{S1} - c_3]\frac{D^{S1}}{\psi(t)} \tag{11}$$

$$f_p^{S1} = [(1-b_1)w^{S1} - p_d^{S1} - c_1]\frac{D^{S1}}{\psi(t)} - zg^2/2 \tag{12}$$

$$f_r^{S1} = [(1-b_2)p^{S1} - w^{S1} - c_2]D^{S1} \tag{13}$$

Based on the master-slave game, we use the reverse analysis method. Then, we get the optimal decisions and benefits of stakeholders as shown in Proposition 2.

Proposition 2:

$$p_d^{S1*} = \frac{2ec_3 - B}{2e(1-rs)} \tag{14}$$

$$w^{S1*} = \frac{2ec_3 - B + 2ec_1(1-rs)}{4e(1-rs)(1-b_1)} + \frac{\psi(t)(1-b_2)[2ec_3 + (1+H^{S1}g + K^{S1}\theta(t))]}{2e} \tag{15}$$

$$p^{S1*} = \frac{6(1-rs)[1 + H^{S1}g + K^{S1}\theta(t)](1-b_1)(1-b_2) + B}{8e(1-rs)(1-b_1)(1-b_2)} \tag{16}$$

$$f_d^{S1*} = \frac{B^2}{16e\psi(t)(1-b_1)(1-b_2)(1-\gamma s)} \tag{17}$$

$$f_p^{S1*} = \frac{B^2}{32e\psi(t)(1-rs)^2(1-b_1)(1-b_2)} - \frac{zg^2}{2} \tag{18}$$

$$f_r^{S1*} = \frac{B^2}{64e(1-rs)^2(1-b_1)^2(1-b_2)} \tag{19}$$

Here, $B = (1-rs)[(b_1 + b_2 - b_1 b_2 - 1)(1 + H^{S1}g + K^{S1}\theta(t) + e(c_1 + c_2 - b_1 c_2)] + ec_3$. According to proposition 1, we can get

$$D^{S1*} = B/8(1-rs)(1-b_1)(b_2 - 1) > 0,$$

thus, $B < 0$. By comparing the benefits of chain members in the US model and the S1 model, we get conclusion 1.

Conclusion 1:

When $c_3 < \min(\zeta_1, \zeta_2, \zeta_3)$, the benefits of supply chain stakeholders in condition 1 will be higher than those in the US model. (The proof process shows in Appendix A.)

In Conclusion 1, we find that the R&D cost of the BBT system is negatively related to the tax subsidy rate s of the BBTSP. Namely, the tax subsidy strategy of government will help the BBTSP reduce the R&D input of the BBT system. Meanwhile, when the relationship in conclusion 1 can be met, the producer and the retailer will gain more income after the producer adopts the BBT service. This calls the producer's input the "spillover effect".

Based on proposition 2, we can get deduction 1.

Lemma 1:

(1) $\frac{\partial p_d^{S1*}}{\partial s} > 0$, $\frac{\partial p_d^{S1*}}{\partial H^{S1}} > 0$, $\frac{\partial p_d^{S1*}}{\partial K^{S1}} > 0$, $\frac{\partial p_d^{S1*}}{\partial c_3} > 0$;

(2) $\frac{\partial w^{S1*}}{\partial s}>0, \frac{\partial w^{S1*}}{\partial H^{S1}}>0, \frac{\partial w^{S1*}}{\partial K^{S1}}>0, \frac{\partial w^{S1*}}{\partial c_3}>0$;

(3) $\frac{\partial p^{S1*}}{\partial s}>0, \frac{\partial p^{S1*}}{\partial H^{S1}}>0, \frac{\partial p^{S1*}}{\partial K^{S1}}>0, \frac{\partial p^{S1*}}{\partial c_3}>0$;

Lemma 2:

(1) $\frac{\partial f_d^{S1*}}{\partial s}<0, \frac{\partial f_d^{S1*}}{\partial H^{S1}}>0, \frac{\partial f_d^{S1*}}{\partial K^{S1}}>0, \frac{\partial f_d^{S1*}}{\partial c_3}<0$;

(2) $\frac{\partial f_p^{S1*}}{\partial s}<0, \frac{\partial f_d^{S1*}}{\partial H^{S1}}>0, \frac{\partial f_d^{S1*}}{\partial K^{S1}}>0, \frac{\partial f_d^{S1*}}{\partial c_3}<0$;

(3) $\frac{\partial f_r^{S1*}}{\partial s}<0, \frac{\partial f_r^{S1*}}{\partial H^{S1}}>0, \frac{\partial f_r^{S1*}}{\partial K^{S1}}>0, \frac{\partial f_r^{S1*}}{\partial c_3}<0$;

Based on lemma 1 in deduction 1, we obtain that with the growth of the tax discount coefficient of the BBTSP, the retail price about the BBT service, the retail price about the green fresh product, and the wholesale price of the green fresh product will go up. However, based on the lemma 2 in deduction 1, following the advance of the tax discount coefficient of the BBTSP, the benefits of chain members will decrease. Based on $s'=1-s$, we can understand that with the tax subsidy rate of the BBTSP from government, chain members can gain more earnings compared with those in the no subsidy model (i.e., US model).

Secondly, as the perceived credibility coefficient for greenness increases in the S1 model, optimal prices for supply chain members rise. Consequently, to secure lower prices, chain members should prioritize enhancing consumers' perceived credibility coefficient for greenness through blockchain technology. This increase in perceived credibility boosts revenues for chain members in the S1 model. Notably, in the S1 tax subsidy model, chain member benefits surpass those in the no-tax subsidy model (i.e., US model). This trend is likely attributed to the utilization of Blockchain-Based Traceability Service Providers (BBTSPs), improving consumers' perceived credibility for greenness, thus augmenting market demand. The subsequent rise in market demand potentially leads to increased profits. Furthermore, despite the government only subsidizing BBTSPs in the S1 model, the incomes of producers and retailers also experience growth, referred to as the subsidy 'Spillover Effect' of government support.

Thirdly, with an increase in the perceived freshness credibility coefficient in the S1 model, optimal prices for supply chain members similarly rise. To secure lower prices, chain members should strive to enhance consumers' perceived freshness credibility coefficient through blockchain technology. This rise in perceived credibility leads to increased revenues for chain members in the S1 model. Additionally, in the tax subsidy model, chain member benefits surpass those in the no-tax subsidy model (i.e., US model). Again, this can be attributed to the BBTSPs' role in enhancing consumers' perceived freshness credibility, thereby amplifying market demand and potentially increasing profits. Notably, similar to the effect observed in the greenness credibility scenario, the government's subsidy to BBTSPs positively impacts the incomes of producers and retailers in the S1 model, demonstrating the subsidy's 'Spillover Effect.'

Finally, as the investment cost of blockchain technology rises in the S1 model, optimal prices for supply chain members also increase. Similarly, to secure lower prices, chain members should focus on enhancing consumers' perceived freshness credibility coefficient through blockchain technology. Interestingly, in the US model, chain member prices remain unchanged with the rise in blockchain technology investment costs. However, in the S1 subsidy model, chain member revenues decrease as blockchain technology investment costs increase. This trend aligns with the concept that utilizing BBTSPs improves consumers' perceived freshness credibility, potentially driving market demand and increasing profits.

C. S2 Model

In the S2 model, to overcome the shortcomings of the traditional traceability system and improve the credibility of agricultural product green degree, the producer may adopt the BBT system. We assume that the producer does not enough strength to build a BBT platform. Thus, they will purchase the BBT service from the BBTSP. To incentivize the producer to apply the BBT system and the BBTSP to research and develop the BBT system, governments will offer tax subsidy strategy to the BBTSP and the producer.

We assume that the tax rate paid by the BBTSP is $(1-s^{'})r$ (i.e., sr) and the tax subsidy rate paid by the producer is $(1-s_1^{'})b_1$ (i.e., $s_1 b_1$). Here, $s^{'}$ and $s_1^{'}$ are the tax subsidy rates of government to the BBTSP and the producer, respectively. And s_1 the tax discount coefficient of the producer. Thence, we constructed the revenue equations about the BBTSP of blockchain traceability service, the producer and the retailer (see Eq. (20), Eq. (21) and Eq. (22)).

$$f_d^{S2}=[(1-sr)p_d^{S2}-c_3]\frac{D^{S2}}{\psi(t)} \tag{20}$$

$$f_p^{S2}=[(1-s_1b_1)w^{S2}-p_d^{S2}-c_1]\frac{D^{S2}}{\psi(t)}-zg^2/2 \tag{21}$$

$$f_r^{S2}=[(1-b_2)p^{S2}-w^{S2}-c_2]D^{S2} \tag{22}$$

Based on the master-slave game, we use reverse analysis method. Then, we get the optimal decisions and benefits of stakeholders as shown in Proposition 3.

Proposition 3:

$$p_d^{S2*}=\frac{2ec_3-B_1}{2e(1-rs)} \tag{23}$$

$$w^{S2*}=\frac{2ec_3-B_1+2ec_1(1-rs)}{4e(1-rs)(1-b_1s_1)}+\frac{\psi(t)(1-b_2)[2ec_3+(1+H^{S2}g+K^{S2}\theta(t))]}{2e} \tag{24}$$

$$p^{S2*}=\frac{6(1-rs)[1+H^{S2}g+K^{S2}\theta(t)](1-b_1s_1)(1-b_2)+B_1}{8e(1-rs)(1-b_1s_1)(1-b_2)} \tag{25}$$

$$f_d^{S2*}=\frac{B_1^2}{16e\psi(t)(1-b_1s_1)(1-rs)(1-b_2)} \tag{26}$$

$$f_p^{S2*}=\frac{B_1^2}{32e\psi(t)(1-b_1s_1)(1-rs)^2(1-b_2)}-\frac{zg^2}{2} \tag{27}$$

$$f_r^{S2*}=\frac{B_1^2}{64e(1-b_1s_1)^2(1-rs)^2(1-b_2)} \tag{28}$$

Here,
$B_1=(1-rs)[(b_2-1)(1-b_1s_1)(1+H^{S2}g+K^{S2}\theta(t))+e(c_1+c_2-b_1c_2s_1)]+ec_3$.

According to Proposition 3, we get $D^{S2*}=B_1/8(1-rs)(1-s_1b_1)(b_2-1)>0$, thus, $B_1<0$. By comparing benefits of chain members in the US model and the S2 model, we get Conclusion 2.

Conclusion 2:

When $c_3<\min(\omega_1,\omega_2,\omega_3)$, the benefits of supply chain stakeholders in condition 2 model will be higher than those in the US model. (The proof process shows in the Appendix B.)

By comparing benefits of chain members in the S1 model and the S2 model, we get Conclusion 3.

Conclusion 3:

When $c_3<\min(\rho_1,\rho_2)$, stakeholders' revenues in condition 2 will be higher than those in condition 1, in contrast, stakeholders' benefits in condition 1 will be higher than those in condition 2. (The proof process shows in Appendix C.)

Based on Proposition 3, we can get deduction 2.

Lemma 1:

(1) $\frac{\partial p_d^{S2*}}{\partial s}>0,\frac{\partial p_d^{S2*}}{\partial s_1}<0,\frac{\partial p_d^{S2*}}{\partial H^{S2}}>0,\frac{\partial p_d^{S2*}}{\partial K^{S2}}>0,\frac{\partial p_d^{S2*}}{\partial c_3}>0$;

(2) $\frac{\partial w^{S2*}}{\partial s}>0,\frac{\partial w^{S2*}}{\partial s_1}>0,\frac{\partial w^{S2*}}{\partial H^{S2}}>0,\frac{\partial w^{S2*}}{\partial K^{S2}}>0,\frac{\partial w^{S2*}}{\partial c_3}>0$;

(3) $\frac{\partial p^{S2*}}{\partial s}>0\frac{\partial p^{S2*}}{\partial s_1}>0,\frac{\partial p^{S2*}}{\partial H^{S2}}>0,\frac{\partial p^{S2*}}{\partial K^{S2}}>0,\frac{\partial p^{S2*}}{\partial c_3}>0$;

Lemma 2:

(1) $\frac{\partial f_d^{S2*}}{\partial s}<0,\frac{\partial f_d^{S2*}}{\partial s_1}<0,\frac{\partial f_d^{S2*}}{\partial H^{S2}}>0,\frac{\partial f_d^{S2*}}{\partial K^{S2}}>0,\frac{\partial f_d^{S2*}}{\partial c_3}<0$;

(2) $\frac{\partial f_p^{S2*}}{\partial s}<0,\frac{\partial f_p^{S2*}}{\partial s_1}<0,\frac{\partial f_d^{S2*}}{\partial H^{S2}}>0,\frac{\partial f_d^{S2*}}{\partial K^{S1}}>0,\frac{\partial f_d^{S2*}}{\partial c_3}<0$;

(3) $\frac{\partial f_r^{S2*}}{\partial s}<0,\frac{\partial f_r^{S2*}}{\partial s_1}<0,\frac{\partial f_r^{S2*}}{\partial H^{S2}}>0,\frac{\partial f_r^{S2*}}{\partial K^{S2}}>0,\frac{\partial f_r^{S1*}}{\partial c_3}<0$;

Based on lemma 1 in deduction 2, we obtain that the growth of the tax discount coefficient of the BBTSP, the retail price about the BBT service, the retail price about the green fresh product, and the wholesale price of the green fresh product will go up in the S2 model. However, based on the lemma 2 in deduction 2, following the advance of the tax discount coefficient of the BBTSP, the benefits of chain members will decrease. Based on $s'=1-s$, we can understand that with the tax subsidy rate of the BBTSP from government, chain members can gain more earnings compared with those in the no subsidy model (i.e., US model).

Secondly, as the tax discount coefficient of the producer rises in the S2 model, the retail price of the BBTSP decreases, while the wholesale and retailer prices for green fresh products increase. Conversely, in the other two models, the tax discount coefficient of the producer does not impact their pricing strategy. This underscores that government tax subsidies to the producer assist the BBTSP in increasing its retail price while enabling the producer and retailer to set lower prices. Consequently, with the producer's tax discount coefficient increase, chain member incomes decrease in the S2 model. Contrarily, in the other two models, the producer's tax discount coefficient does not affect their incomes, indicating that government tax subsidies to the producer benefit supply chain members in gaining greater profits in the S2 model.

Thirdly, as the perceived greenness credibility coefficient rises in the proposed three models, optimal prices for supply chain members increase. Additionally, in the two subsidy models, enhancing consumers' perceived greenness credibility through blockchain technology is key for achieving lower prices. The rise in perceived greenness credibility leads to increased revenues for chain members in the proposed models. Moreover, in the tax subsidy models (S1 and S2), chain member benefits surpass those in the no-tax subsidy model. Notably, even in the S1 model where the government solely subsidizes the BBTSP, the incomes of producers and retailers increase. However, when the government subsidizes both the BBTSP and the producer, the incomes of supply chain members may not significantly improve compared to the S1 model.

Fourthly, with the rise in the perceived freshness credibility coefficient in the proposed three models, chain member revenues increase. Moreover, in the tax subsidy model, chain member benefits surpass those in the no-tax subsidy model. Additionally, in the S1 model where the government solely subsidizes the BBTSP, the incomes of the producer and the retailer also increase. However, when the government subsidizes both the BBTSP and the producer, the incomes of supply chain members may not necessarily improve significantly compared to the S1 model. This implies that despite government tax subsidies, not all supply chain members experience increased incomes, which correlates with the tax subsidy rate.

Finally, as the blockchain technology investment cost rises in the two subsidy models, optimal prices for supply chain members increase. Additionally, in these models, improving consumers' perceived freshness and greenness using blockchain technology is pivotal for attaining lower prices. With the growth in blockchain technology investment cost, chain member revenues decrease in the two subsidy models. It is notable that only when the BBTSP's blockchain technology investment cost falls within a specific range, investing in blockchain technology and employing the BBT system assists in generating higher revenues for both the BBTSP and the producer.

V. Numerical Simulation

To explain the applicability of the proposed conclusions and inferences, we will implement a practical case. Based on the research of Wen-Li & Zhao[2], we chose a company producing cherries coming from Shandong, China. After collating information, the unit production cost of cherries c_1 is 0.2 ten thousand RMB/ton. Assume that the market demand $a=1$ ton. The transportation time $t=4$ days. The life cycle of cherries T days.Assume that

$$\varphi(t)=1-\lambda(t)=2-e_1^{\frac{\ln 2}{T}t}$$

$$\lambda(t)=e_1^{\frac{\ln 2}{T}t}-1 .$$

According to the report about JD Blockchain Open

Platform Digital (2020), we set $e=0.5$, $c_2=0.3$, $g=0.2$, z=08, $b_1=0.2$ and $b_2=0.2$. Based on the proof process of the propositions, we get picture 2.

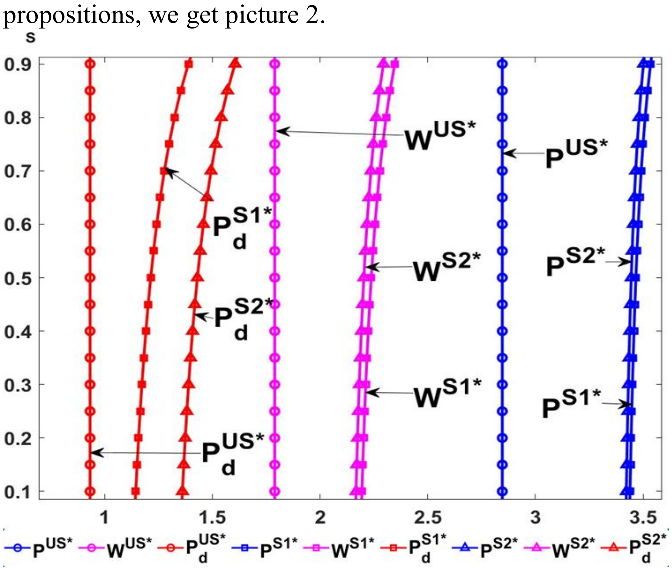

Fig.2. Change trends of Optimal prices and benefits with the growth of the tax discount coefficient of the BBTSP

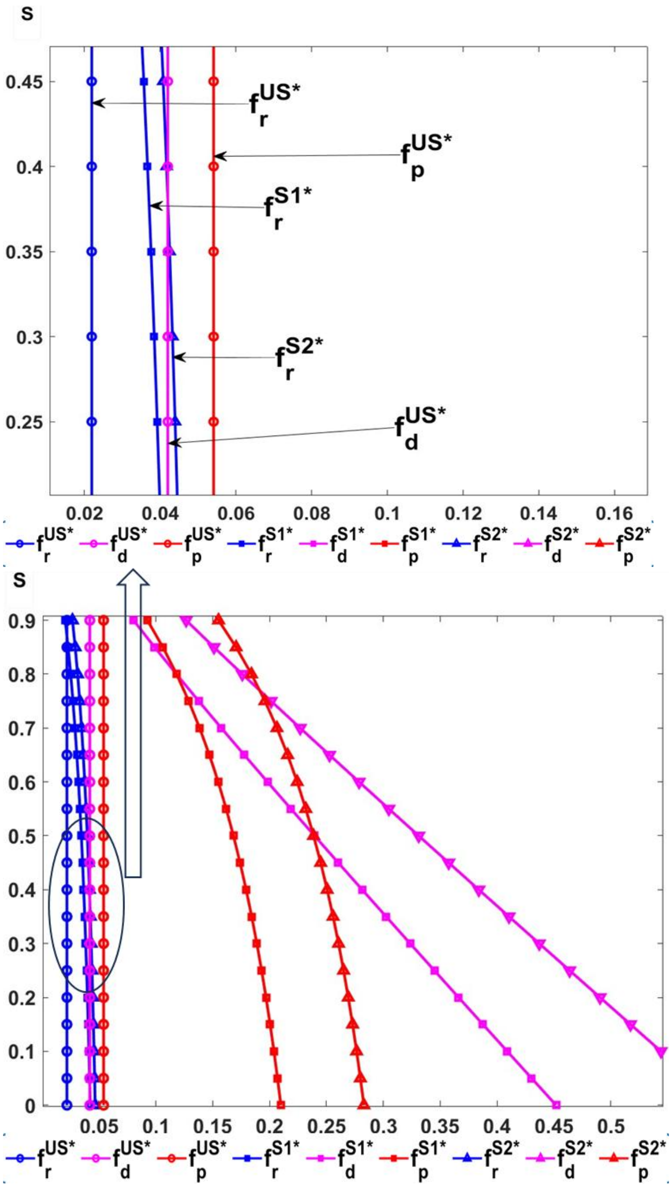

Fig.3. Change trends of Optimal prices and benefits with the growth of the tax discount coefficient of the BBTSP

From picture2, we know that with the rise of the tax discount coefficient of the BBTSP, the prices of chain members in the two tax subsidy models will increase. This tells us that governments' tax subsidy to the BBTSP will not only help the BBTSP reduce its retail price but also help the producer and the retailer set low prices.

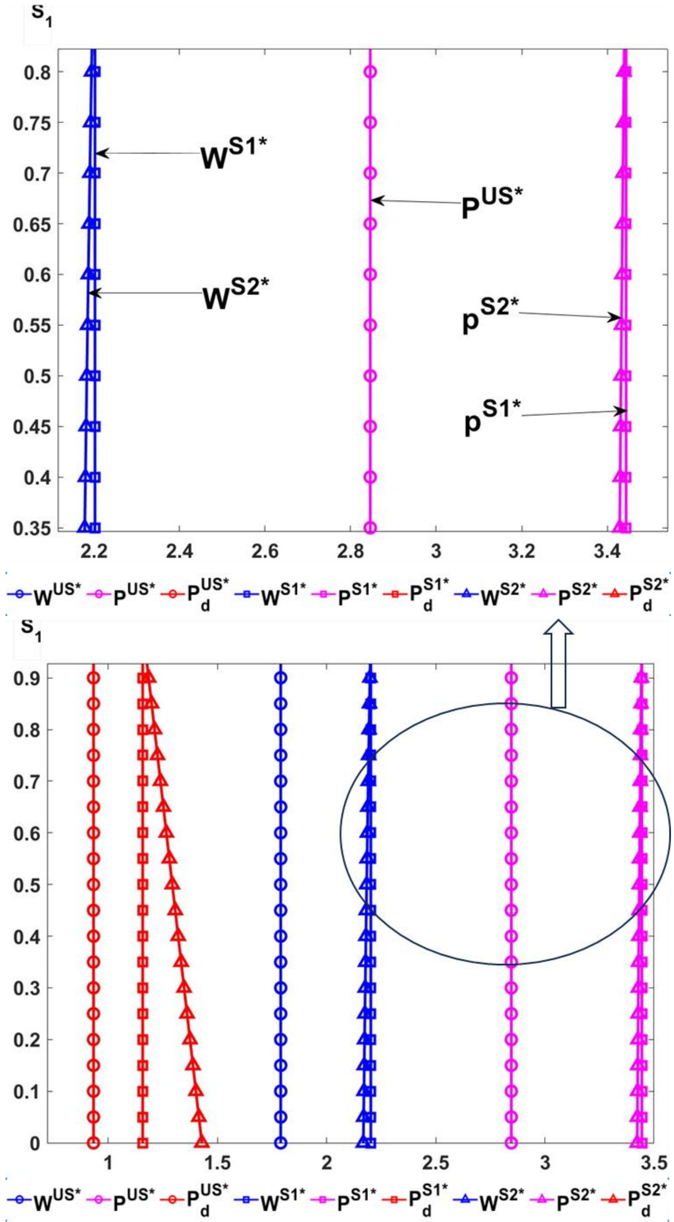

Fig.4. Change trends of optimal prices and benefits with the growth of the tax discount coefficient of the producer

From picture 3, we know that with the rise of the tax discount coefficient of the BBTSP, revenues of chain members in the two tax subsidy models will increase. This tells us that governments' tax subsidy to the BBTSP will not only help the BBTSP gain more incomes but also help the producer and the retailer obtain more benefits. This calls the "Spillover effect" of subsidy strategies. In addition, we can find that benefits of chain members in the S2 model will be higher than those in the other two models.

From picture 4, we know that with the rise of the tax discount coefficient of the producer, the retail price of the BBTSP will go down and the wholesale price and the retailer price about the green fresh product will go up in the S2 model. In the other two models, the tax discount coefficient of the producer does not affect their pricing strategies. This tells us that governments' tax subsidy to the producer will help the BBTSP increase its retail price and help the producer and the retailer set low prices.

From picture 5, we know that with the rise of the tax discount coefficient of the producer, the incomes of chain members will go down in the S2 model. In the other two models, the tax discount coefficient of the producer does not affect their incomes. This tells us that governments' tax subsidy to the producer will help supply chain members gain more benefits in the S2 model.

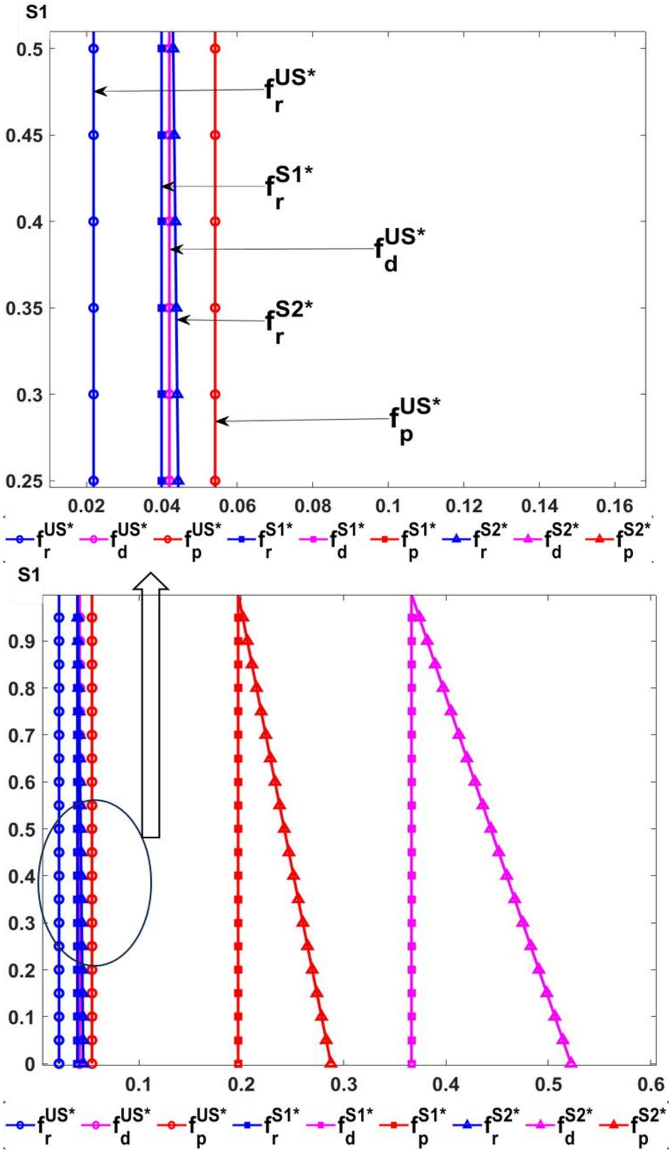

Fig.5. Change trends of optimal prices and benefits with the growth of the tax discount coefficient of the producer

From picture 6, we know that with the rise of the perceived greenness credibility coefficient, the optimal prices about supply chain members will go up in the proposed three models. Moreover, in the two subsidy models, if chain members want to gain a low price, they should try their best to improve the perceived greenness credibility coefficient of consumers by using blockchain technology.

From picture 7, we know that with the rise of the perceived greenness credibility coefficient, revenues of chain members in the proposed three models will increase. In addition, in the tax subsidy model, benefits of chain members will be higher than those in the no-tax subsidy model. Meanwhile, we can get from picture 13 that in the S1 model, the government only subsidises BBTSP, and the revenue of BBTSP and producer achieves the best.

From picture 8, we know that with the rise of the perceived freshness credibility coefficient, revenues of chain members in the proposed three models will increase. In addition, in the tax subsidy models, benefits of chain members will be higher than those in the no-tax subsidy model. Meanwhile, we can obtain that although in the S1 model, the government only subsidies to the BBTSP, incomes of the producer and the retailer also go up. At the same time, we can see from Figure 8 that with the increase of the perceived fresh confidence coefficient, in the S1 model, the government only subsidizes BBTSP, and the income of BBTSP and producers achieves the best.

From picture 9, we know that with the rise of the perceived freshness credibility coefficient, the optimal prices about supply chain members will go up in the proposed three models. Moreover, in the two subsidy models, if chain members want to gain a low price, they should try their best to improve the perceived freshness credibility coefficient of consumers by using the blockchain technology.

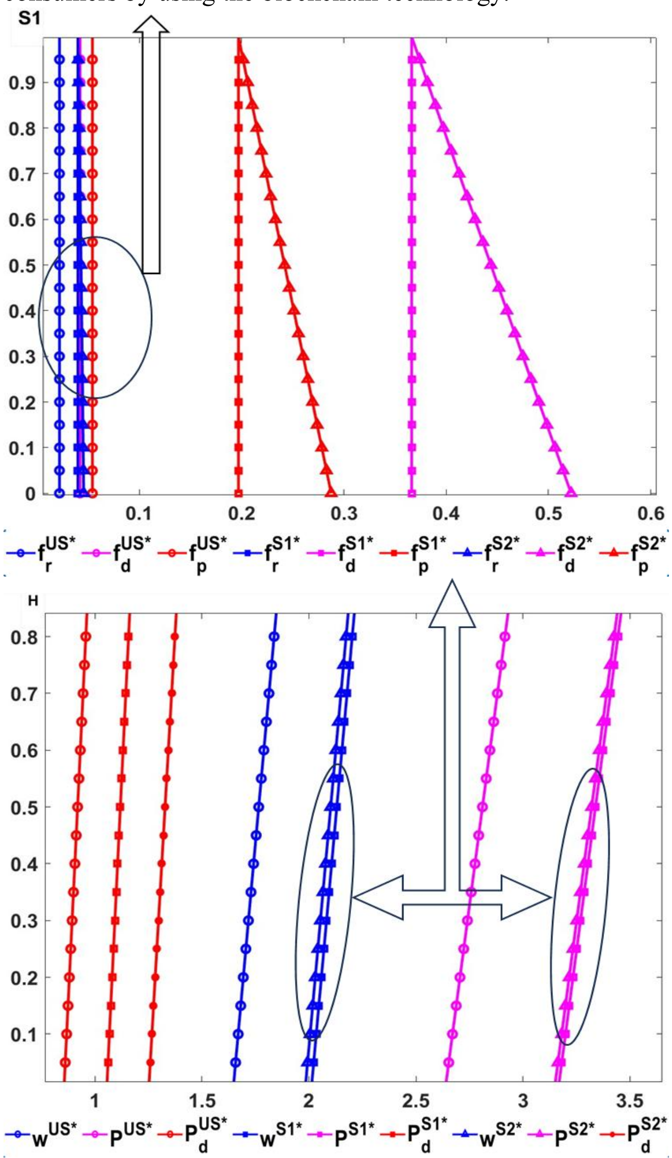

Fig.6. Change trends of optimal prices and benefits with the growth of the perceived greenness credibility coefficient

From picture 10, we know that with the rise of the blockchain technology investment cost, the optimal prices about supply chain members will go up in the two subsidy models. Moreover, in the two subsidy models, if chain members want to gain a low price, they should try their best to improve the perceived freshness credibility coefficient of consumers by using the blockchain technology. In addition, with the growth of the blockchain technology investment cost, prices of chain members in the US model has not changed.

From picture 11,12, we know that with the rise of the blockchain technology investment cost, revenues of chain members will decrease in the two subsidy models. In Figure 11, we can also see that as the investment cost of BBTSP's blockchain technology increases, the benefits of supply chain members are optimized in S2 mode.

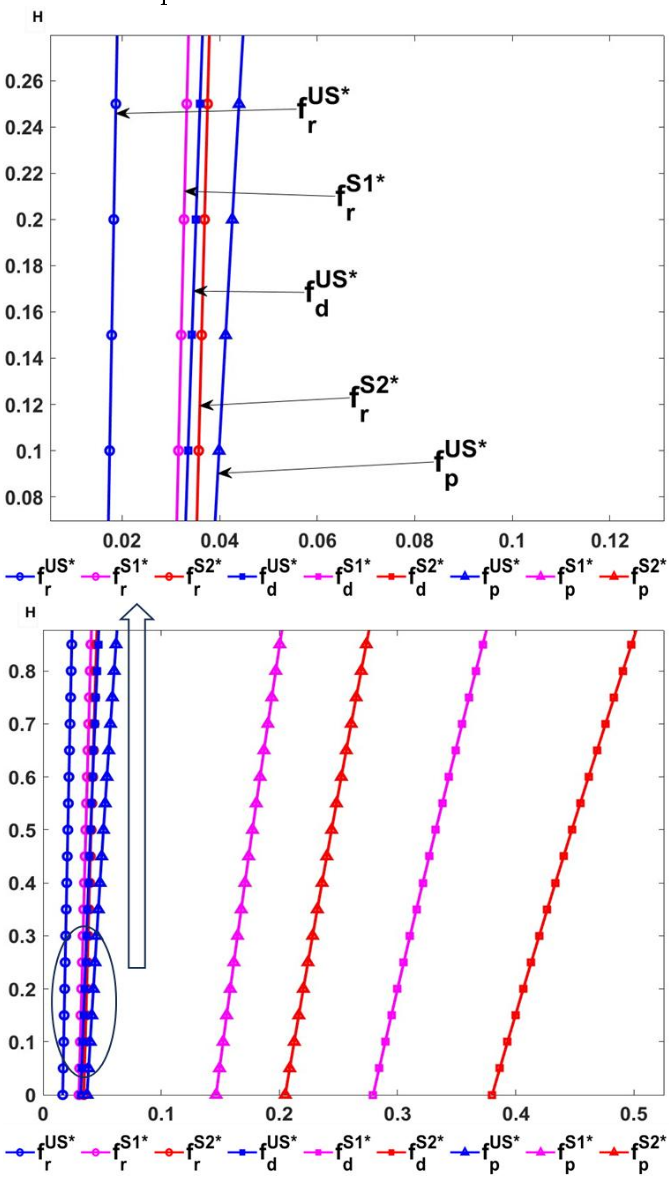

Fig.7. Change trends of optimal prices and benefits with the growth of the perceived greenness credibility coefficient

Picture 13 reflects the relationships between the benefit differences of chain members in the models of US and S1 and the BBTSP's blockchain technology investment cost. From picture 13, we know that with the rise of the blockchain technology investment cost, the benefit differences of chain members in the models of US and S1 will decline. In picture 7, when the BBTSP's blockchain technology investment cost c_3 is lower than ζ_1, investing in the blockchain technology and using the BBT system can support chain members to gain more earnings. The above demonstrated the feasibility of conclusion 1.

Picture 14 describes the relationships between the blockchain technology investment cost and the tax discount coefficient of the BBTSP in the proposed three models. From picture 14, we know that with the ascension of the BBTSP's blockchain technology investment cost, the tax discount coefficient of the BBTSP will go down. This tells us that the tax subsidy rate has a positive effect on the BBTSP's blockchain technology investment cost, namely, the government tax subsidy strategies will stimulate the BBTSP to research and develop blockchain technology. The above demonstrated the feasibility of conclusion 1.

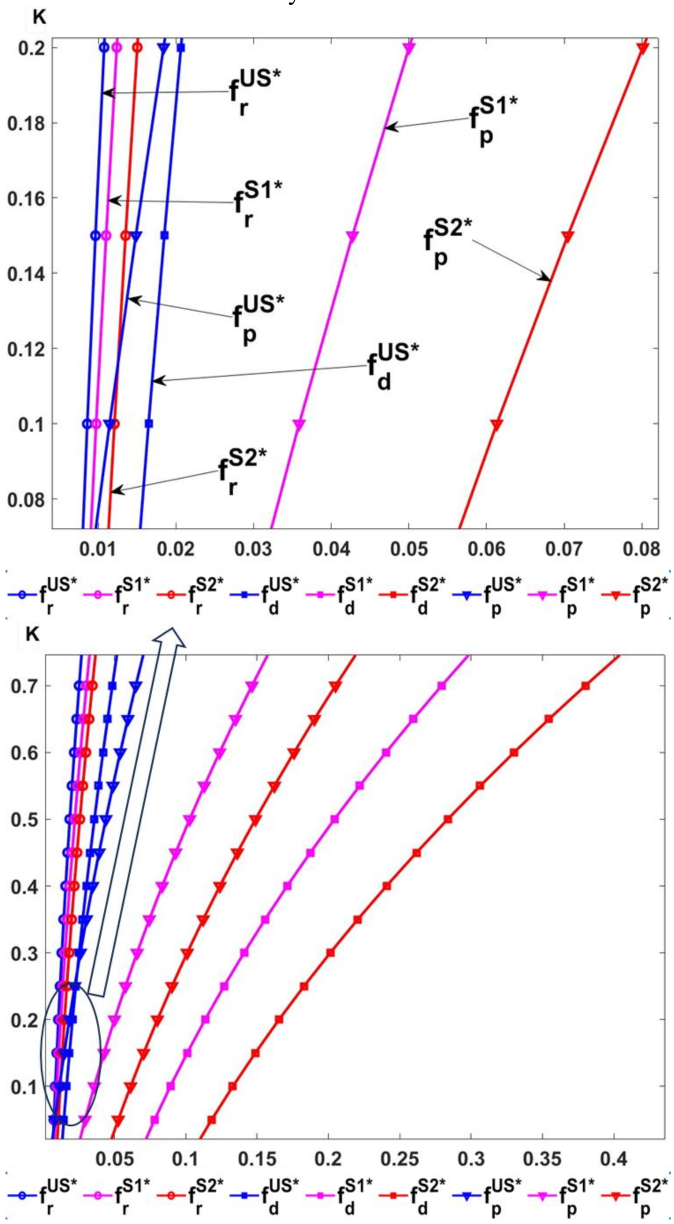

Fig.8. Change trends of optimal prices and benefits with the growth of the perceived freshness credibility coefficient

Picture 15 reflects the relationships between the benefit differences of chain members in the models of US and S2 and the BBTSP's blockchain technology investment cost. From picture 15, we know that with the rise of the blockchain technology investment cost, the benefit differences of chain members in the models of US and S2 will decline. In picture 15, when the BBTSP's blockchain technology investment cost c_3 is lower than ω_1, investing in the blockchain technology and using the BBT system can support chain members to gain more earnings.

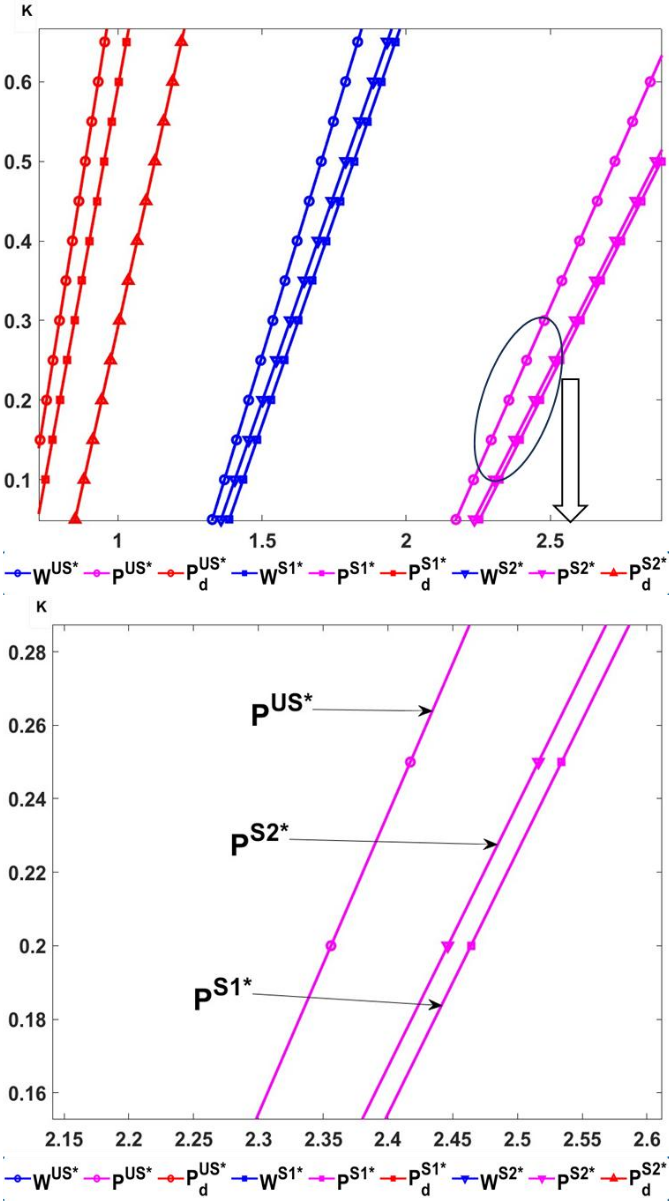

Fig.9. Change trends of optimal prices and benefits with the growth of the perceived freshness credibility coefficient

The above demonstrated the feasibility of conclusion 2. In addition, with the ascension of the BBTSP's blockchain technology investment cost, the tax discount coefficient of the producer will go down. This tells us that the tax subsidy rate of the producer from government has a positive effect with the BBTSP's blockchain technology investment cost, namely, the government tax subsidy strategies will stimulate the producer to use the blockchain-based traceability system. The above demonstrated the feasibility of conclusion 1.

Picture 16 reflects the relationships between the benefit differences of chain members in the models of S1 and S2 and the BBTSP's blockchain technology investment cost. From picture 16, we know that with the rise of the blockchain technology investment cost, the benefit differences of chain members in the models of S1 and S2 will decline. In picture 10, when the BBTSP's blockchain technology investment cost c_3 is lower than ρ_1 , investing in the blockchain technology and using the BBT system can support chain members to gain more earnings in different subsidy models.

The above demonstrated the feasibility of conclusion 3.

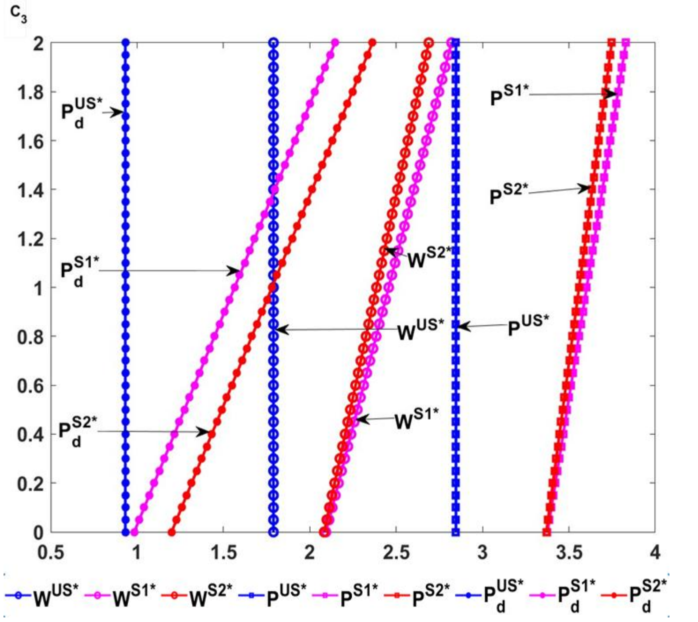

Fig. 10. Optimal price change trends of chain members with the growth of the blockchain technology investment cost

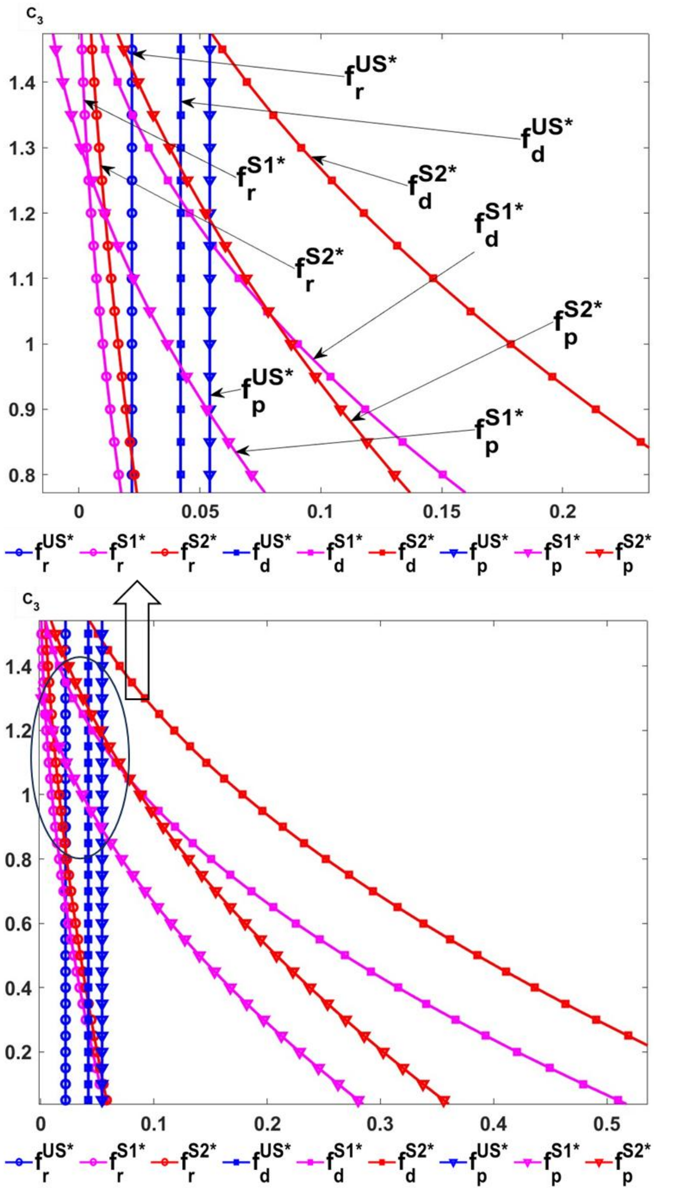

Fig.11. Optimal price change trends of chain members with the growth of the blockchain technology investment cost

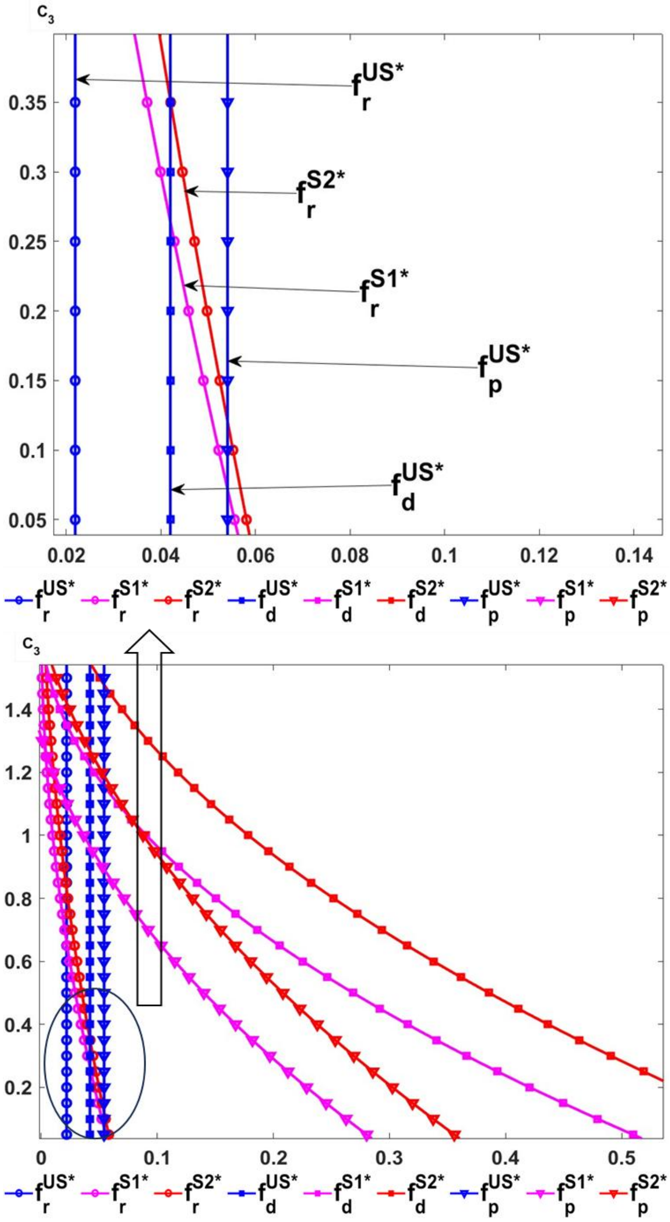

Fig.12. Optimal price change trends of chain members with the growth of the blockchain technology investment cost

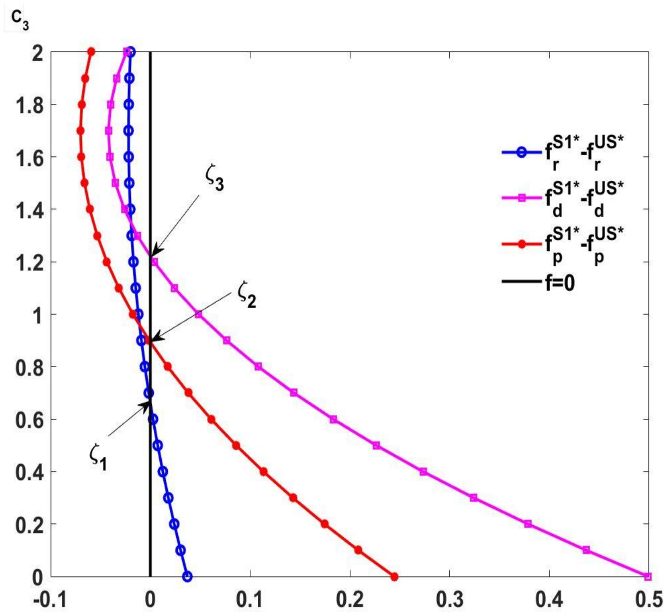

Fig. 13. The threshold value of the blockchain technology investment cost in the proposed S1 model

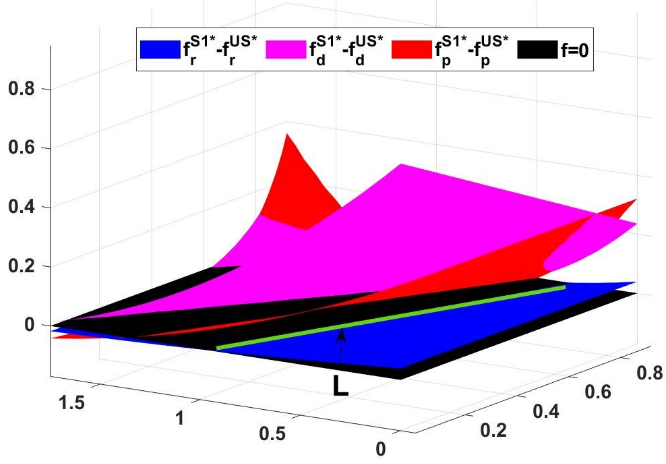

Fig. 14. Relations between the blockchain technology investment cost and the tax discount coefficient of the BBTSP in the proposed three models

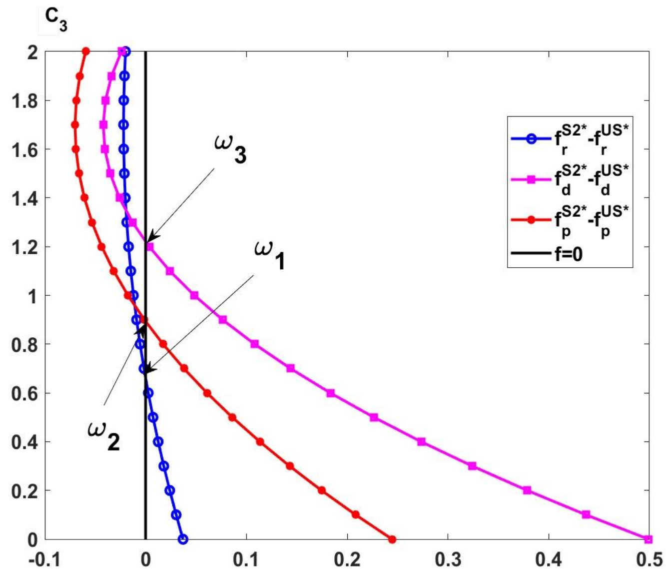

Fig. 15.The threshold value of the blockchain technology investment cost in the proposed S2 model

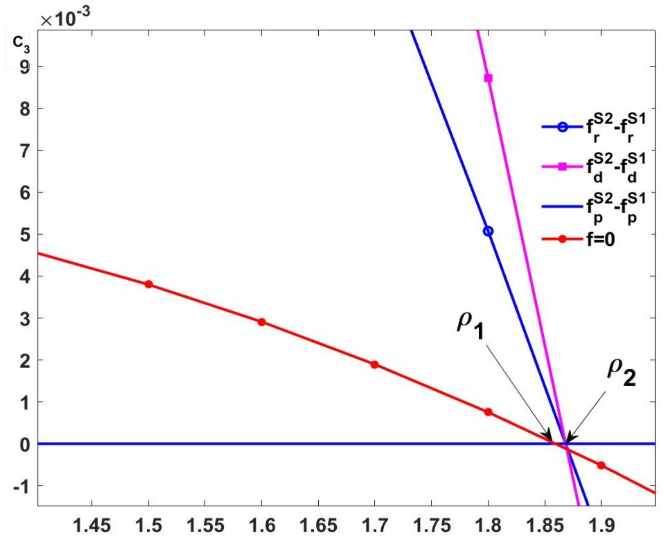

Fig. 16.The blockchain technology investment decisions in the two tax subsidy models

In addition, with the ascension of the BBTSP's blockchain technology investment cost, the tax discount coefficients of the producer and the BBTSP will go down. This tells us that the tax subsidy rates of the producer and the BBTSP from government have a positive effect with the BBTSP's blockchain technology investment cost, namely, the government tax subsidy strategies will stimulate the producer and the BBTSP to use the blockchain technology. The above demonstrated the feasibility of conclusion 1.

VI. Conclusions And Research Values

A. Conclusions

To research subsidy strategies of a green agri-food supply chain considering the application of Blockchain, the perceived information credibility of consumers on greenness and freshness after are considered. Based on this, we put forward a new demand function. Afterward, three subsidy models were built and analyzed. Findings:

1) The subsidies offered by the government to the producer and the Blockchain-based Green Agri-Food Technology Service Provider (BBTSP) positively impact the investment in blockchain technology. However, it doesn't guarantee an increase in the income of supply chain members despite these tax subsidies.
2) BBTSP’s blockchain technology investment cost has a negative relationship with the tax discount coefficients of the BBTSP and the producer. Tax subsidies don't always lead to increased income for supply chain members, and this complexity is influenced by the subsidy rates and the BBTSP's technology costs. Therefore, it's crucial for the government to align tax subsidy strategies with the BBTSP's technology investment costs.
3) As the perceived credibility of greenness and freshness increases, the optimal price and profits of supply chain members also increase across the three subsidy models. Particularly in the S1 subsidy model where the government only subsidizes the BBTSP, higher credibility coefficients result in optimal benefits for both the BBTSP and manufacturers.
4) Government subsidies to producers influence the BBTSP's retail prices and encourage producers and retailers to set lower prices. Subsidies directed at the BBTSP not only boost its income but also benefit producers and retailers, demonstrating a "Spillover effect" of subsidy strategies.

B. Research values

This research has some significance.

In theory,

1) In the new background, the market demand was improved considering the perceived information credibility of consumers on greenness and freshness . It enriched the demand management theory.
2) Considering the proposed three subsidy strategies in a green fresh supply chain, three-game models were built. And then subsidy rules were obtained. It was a new development of subsidy rules in the blockchain environment.

In practice,

1) our research method used in obtaining the market demand is a reference for future research about the green agri-food market demand.
2) The investment decision rules will offer theory bracings for chain members to use and implement the blockchain technology with government subsidy strategies in a green agri-food industry, and then promote the coordinated development of the environment and agricultural production.

VII. Limitations and Future Research

This study did not distinguish the sales channels of green fresh products. Today, fresh products are already sold through online and offline channels, and investment decision rules about blockchain may differ from channel to channel. Therefore, blockchain investment decisions and coordination of green fresh supply chains under the dual-channel background can be studied in the future. In addition, based on behavioral game theory, different decision-makers will show different risk preferences. Future studies can relax the restriction conditions and explore the influences of different risk preferences on decision makers' investment behaviors.

Appendix

Appendix A:

Proof. If stakeholders want their profits to be higher after they gain the subsidy,

$$\begin{cases} f_p^{S1*} > f_p^{US*} \\ f_r^{S1*} > f_r^{US*} \\ f_d^{S1*} > f_d^{US*} \end{cases} \text{.Namely,} \quad \begin{cases} f_d^{S1*} - f_d^{US*} > 0 \\ f_p^{S1*} - f_p^{US*} > 0 \\ f_r^{S1*} - f_r^{US*} > 0 \end{cases}.$$

(1) $f_r^{S1*} - f_r^{US*} = \dfrac{B^2}{64e(1-rs)^2(1-b_1)^2(1-b_2)} - \dfrac{A^2}{64e(1-b_1)^2(1-b_2)(1-r)^2} > 0$,

we get that when

$$c_3 < \frac{(1-sr)(1-r)[(1+b_1b_2-b_1-b_2)(2+H^{S1}g+K^{S1}\theta(t)+Hg+K\theta(\tau t))]}{e(1-r)} - \frac{(1-sr)(1-r)[2e(c_1+c_2-b_1c_2)]+(1-rs)ec}{e(1-r)},$$

$f_r^{S1*} - f_r^{US*} > 0$, and we call this as ζ_1 .

(2) $f_d^{S1*} - f_d^{US*} = \dfrac{B^2}{16e\psi(t)(1-b_1)(1-b_2)(1-\gamma s)} - \dfrac{A^2}{16e\psi(\tau t)(1-b_1)(1-b_2)(1-r)}$

, we get that when

$$c_3 < \frac{(1-sr)[(1-b_1)(1-b_2)(1+H^{S1}g+K^{S1}\theta(t))-e(c_1+c_2-b_1c_2)]-A\sqrt{\psi(t)(1-rs)}}{e\sqrt{\psi(\tau t)(1-r)}}$$

, $f_d^{S1*} - f_d^{US*} > 0$, and we call this as ζ_2 .

(3) $f_p^{S1*} - f_p^{US*} = \dfrac{1}{32e(1-b_1)(1-b_2)}[\dfrac{B^2}{\psi(t)(1-rs)^2} - \dfrac{A^2}{\psi(\tau t)(1-r)^2}]$,

we get that when

$$c_3 < \frac{(1-sr)[(1-b_1)(1-b_2)(1+H^{S1}g+K^{S1}\theta(t))-e(c_1+c_2-b_1c_2)]-A(1-rs)\sqrt{\psi(t)}}{e\sqrt{\psi(\tau t)(1-r)}},$$

$f_p^{S1*} - f_p^{US*} > 0$, and we call this as ζ_3.

Thus, we get that when $c_3 < \min(\zeta_1, \zeta_2, \zeta_3)$, benefits of supply chain stakeholders in condition 1 will be higher than those in the US model.

Appendix B:

Proof. If stakeholders want their profits to be higher after they gain the subsidy, $f_p^{S2*} > f_p^{US*}$, $f_r^{S2*} > f_r^{US*}$ and $f_d^{S2*} > f_d^{US*}$.

Namely, $f_d^{S2*} - f_d^{US*} > 0$, $f_p^{S2*} - f_p^{US*} > 0$ and $f_r^{S2*} - f_r^{US*} > 0$.

(1) $f_r^{S2*} - f_r^{US*} = \frac{B_1^2}{64e(1-b_1s_1)^2(1-rs)^2(1-b_2)} - \frac{A^2}{64e(1-b_1)^2(1-b_2)(1-r)^2} > 0$,

we get that when

$$c_3 < \frac{(1-rs)[(1-b_2)(1-b_1s_1)(1+H^{S2}g+K^{S2}\theta(t)) + e(c_1+c_2-b_1c_2s_1)]}{e(1-b_1)(1-r)} - \frac{A(1-b_1s_1)(1-rs)}{e(1-b_1)(1-r)},$$

$f_r^{S2*} - f_r^{US*} > 0$, and we call this as ω_1.

(2) $f_d^{S2*} - f_d^{US*} = \frac{B_1^2}{16e\psi(t)(1-b_1s_1)(1-rs)(1-b_2)} - \frac{A^2}{16e\psi(\pi t)(1-b_1)(1-b_2)(1-r)}$,

when

$$c_3 < \frac{(1-rs)[(1-b_2)(1-b_1s_1)(1+H^{S2}g+K^{S2}\theta(t)) + e(c_1+c_2-b_1c_2s_1)]}{e\sqrt{\psi(\pi t)(1-b_1)(1-r)}} - \frac{A\sqrt{\psi(t)(1-b_1s_1)(1-rs)}}{e\psi(\pi t)(1-b_1)(1-r)},$$

$f_d^{S2*} - f_d^{US*} > 0$, and we call this as ω_2.

(3) $f_p^{S2*} - f_p^{US*} = \frac{B_1^2}{32e\psi(t)(1-b_1s_1)(1-rs)^2(1-b_2)} - \frac{A^2}{32e\psi(\pi t)(1-b_1)(1-b_2)(1-r)^2}$,

we get that when

$$c_3 < \frac{(1-rs)[(1-b_2)(1-b_1s_1)(1+H^{S2}g+K^{S2}\theta(t)) + e(c_1+c_2-b_1c_2s_1)]}{e(1-r)\sqrt{\psi(\pi t)(1-b_1)}} - \frac{-A(1-rs)\sqrt{\psi(t)(1-b_1s_1)}}{e(1-r)\sqrt{\psi(\pi t)(1-b_1)}},$$

$f_p^{S2*} - f_p^{US*} > 0$, and we call this as ω_3.

Thus, we get that in condition 2, benefits of supply chain stakeholders will be higher than those in the US model.

Appendix C:

Proof. If chain members want their profits to be higher after they gain the subsidy, $f_p^{S2*} > f_p^{S1*}$, $f_r^{S2*} > f_r^{S1*}$ and $f_d^{S2*} > f_d^{S1*}$. Namely, $f_d^{S2*} - f_d^{S1*} > 0$, $f_p^{S2*} - f_p^{S1*} > 0$ and $f_r^{S2*} - f_r^{S1*} > 0$.

(1)

$f_d^{S2*} - f_d^{S1*} = \frac{B_1^2}{16e\psi(t)(1-b_1s_1)(1-rs)(1-b_2)} - \frac{B^2}{16e\psi(t)(1-b_1)(1-b_2)(1-\gamma s)}$

.We get when

$$c_3 > \frac{\sqrt{1-b_1}(1-rs)[(b_2-1)(1-b_1s_1)(1+H^{S2}g+K^{S2}\theta(t)) + e(c_1+c_2-b_1c_2s_1)]}{e(\sqrt{1-b_1s_1} - \sqrt{1-b_1})} - \frac{(1-rs)\sqrt{1-b_1s_1}[(b_1+b_2-b_1b_2-1)(1+H^{S1}g+K^{S1}\theta(t)) + e(c_1+c_2-b_1c_2)]}{e(\sqrt{1-b_1s_1} - \sqrt{1-b_1})}$$

, $f_d^{S2*} > f_d^{S1*}$, and we call this as ρ_1.

(2)

$f_r^{S2*} - f_r^{S1*} = \frac{1}{64e(1-rs)^2(1-b_2)}[\frac{B_1^2}{(1-b_1s_1)^2} - \frac{B^2}{(1-b_1)^2}] < 0$,

when

$$c_3 > \frac{(1-b_1)(1-rs)[(b_2-1)(1-b_1s_1)(1+H^{S2}g+K^{S2}\theta(t)) + e(c_1+c_2-b_1c_2s_1)]}{e(1-b_1s_1+1-b_1)} - \frac{(1-rs)(1-b_1s_1)[(b_1+b_2-b_1b_2-1)(1+H^{S1}g+K^{S1}\theta(t)) + e(c_1+c_2-b_1c_2)]}{e(1-b_1s_1+1-b_1)}$$

, $f_r^{S2*} > f_r^{S1*}$, and we call this as ρ_2.

(3)

$$f_p^{S2*} - f_p^{S1*} = \frac{B_1^2}{32e\psi(t)(1-b_1s_1)(1-rs)^2(1-b_2)} - \frac{zg^2}{2} - \frac{B^2}{32e\psi(t)(1-rs)^2(1-b_1)(1-b_2)} + \frac{zg^2}{2},$$

We get when

$$c_3 > \frac{\sqrt{1-b_1}(1-rs)[(b_2-1)(1-b_1s_1)(1+H^{S2}g+K^{S2}\theta(t)) + e(c_1+c_2-b_1c_2s_1)]}{e(\sqrt{1-b_1s_1} - \sqrt{1-b_1})} - \frac{(1-rs)\sqrt{1-b_1s_1}[(b_1+b_2-b_1b_2-1)(1+H^{S1}g+K^{S1}\theta(t)) + e(c_1+c_2-b_1c_2)]}{e(\sqrt{1-b_1s_1} - \sqrt{1-b_1})}$$

, $f_p^{S2*} > f_p^{S1*}$, and we call this as ρ_1.

Thus, we get that when $c_3 < \min(\rho_1, \rho_2)$, benefits of supply chain stakeholders in condition 2 will be higher than those in condition 1, otherwise, benefits of supply chain stakeholders in condition 1 will be higher than those in condition 2.

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