Research on Government Subsidy Countermeasures for Tracing Fresh Agricultural Products under the Power of Blockchain Technology

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Abstract. The circulation of agricultural products is faced with many problems such as many upstream and downstream subjects, information asymmetry, and difficult traceability of product information, while the decentralized idea of blockchain can provide effective solutions. This paper takes the relationship chain of government-business-consumer as the research object, takes the government subsidy strategy as the research topic, and under the background of considering consumer freshness preference, establishes three government-led and enterprise-following game models, namely, unapplied blockchain, blockchain + technology subsidy and blockchain + production subsidy. By comparing the optimal social welfare, freshness rate and traceable product output in different situations, discuss the optimal subsidy strategy of the government.

Keywords: blockchain technology; blockchain subsidies; Fresh rate

1 Introduction

Food safety is related to people's health and life safety, and the future of the Chinese nation. Among them, the food safety and sales of fresh agricultural products have always been the "three rural" issues to which the state attaches great importance. In order to better deal with these two issues, the State Food and Material Reserve Bureau issued the announcement of "Technical Requirements for Food Security Blockchain Traceability System" in 2022, proposing to improve the blockchain-based food security traceability system. Under the two circumstances that food safety issues are highly emphasized and e-commerce has become a breakthrough in solving the problem of agricultural product sales, some e-commerce platforms are trying to cooperate more with local governments in the direct supply chain from land to table, and the General Administration of Market Supervision is also comprehensively pushing forward the construction of the traceability management platform for imported cold-chained food in order to safeguard food safety. The development mode of promoting agricultural product e-commerce with government support and subsidies and building a traceability platform is becoming an important chess move in the development of the current fresh agricultural product e-commerce platform.

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With the gradual improvement of people's living material standards, the requirements for food safety and quality have also been enhanced, and fresh food traceability technology is an important measure to ensure food safety and quality. The development of fresh food traceability technology can not only satisfy consumer safety preferences and bring higher profits for enterprises, but also improve the overall level of food safety and social welfare. At present, the traditional agricultural traceability is mainly realized through barcode, two-dimensional code, RFID (electronic tags and read-write devices, non-contact IC card) three ways, using a centralized bookkeeping mode, source information stored in a centralized data information system, the data can be easily manually tampered with or damaged and lost, so as to lose transparency and credibility. The traceability industry standard is inconsistent, the traceability management system used between subjects is different, the data can not be interacted, and it becomes an information island, resulting in a waste of resources and difficult to systematize.

Blockchain technology adopts a decentralized bookkeeping model, which ensures that the system cannot be tampered with, and brings new hope for solving the credibility of food traceability with its characteristics such as open and transparent information and traceability[1]. Before the application of blockchain traceability technology, the circulation of fresh agricultural products in various links of the supply chain is unclear and even unknowable to the government and consumers. After the application of blockchain traceability technology, the government can carry out effective real-time supervision and improve the level of food safety supervision, and at the same time, in the event of food safety problems, it can quickly and accurately trace the source of the problem and improve the efficiency of the work. In the field of cross-border e-commerce of agricultural products, the ecosystem built by the mainstream open-source technology of blockchain, with the advantage of decentralization, gradually forms a platform for the broader international market, thus increasing the cross-border trade exchanges of agricultural products and the complementarity of agricultural resources of various countries, so that the agricultural advantages and disadvantages represented by agricultural products of various countries on a global scale can be manifested and supplemented, respectively[2], and the accession of blockchain technology adds vitality to the e-commerce of agricultural products. adds vitality.

Fresh produce enterprises applying blockchain technology for agricultural product traceability will bring additional construction costs and personnel costs, etc. In order to stimulate fresh produce enterprises to build blockchain traceability platforms, the state has introduced a series of policies to subsidize enterprises in order to promote the construction of a food traceability system to ensure food safety. The Bureau of Agriculture and Rural Development of Siachen County, Anhui Province, has subsidized the purchase of electronic equipment and related consumables for the construction of agricultural product quality and safety traceability systems. The People's Government of Tumet Right Banner, Baotou City, issued a capital subsidy of nearly 500,000 yuan for the Cile One Product Agricultural Products Blockchain Anti-counterfeiting and Traceability Project. Gao County Agricultural and Rural Bureau of Sichuan Province, Gao County Agricultural Products Quality and Safety Traceability Capacity Enhancement Project proposed to build a traceability demonstration enterprise traceability demonstration enterprises (bases) according to the traceability equipment equipment and carry out the two types of information entry and the use of the traceability code performance incentives for subsidies. This paper divides the government subsidy policy into technology subsidy and yield subsidy, and explores the incentive effect of blockchain technology on agricultural product traceability based on the regulatory behavior of different government subsidy methods.

Jun Wang[3] and others found that retailers are willing to adopt blockchain when the traceability utility that blockchain brings to consumers is high relative to its unit cost of use. At this time, blockchain not only realises quality information sharing to mitigate the double marginal effect, but also brings additional utility to stimulate demand to enhance consumer surplus. Hong Huo[4] et al. established an evolutionary game model of agricultural products suppliers and processors based on blockchain technology inputs, and found that the government's subsidy mechanism can solve the "free-riding" problem of blockchain technology inputs by enterprises, and encourage the member enterprises of the supply chain to invest in blockchain technology. Qiang Lin[5] and others, on the basis of considering the information asymmetry of the production cost and detection uncertainty of fresh agricultural products, constructed the supply chain decision-making model under two sales modes of platform and self-management respectively by using game theory to explore the optimal decision-making behaviours of producers and e-commerce enterprises and their choice of sales modes.

At present, there are more studies on the application of blockchain technology in fresh food supply chain and fresh food e-commerce under information asymmetry, but few scholars have considered the issue of government subsidy policy slightly under blockchain traceability technology. In addition, few scholars consider the transparency of traceability information, freshness of fresh produce, and the cost and profit of enterprises to construct the model at the same time. In this paper, we construct a three-stage supply chain consisting of government, enterprises and consumers, and establish a government-led three-stage game model. The government's subsidy strategy for enterprises is divided into technology subsidy and output subsidy. Technical subsidies refer to subsidies for the technology of quality preservation efforts made by suppliers to provide freshness rates, and yield subsidies refer to the subsidies corresponding to the traceability of agricultural products by production units. Compare the degree of improvement in information transparency as well as freshness rate of fresh traceability supply chain before and after applying blockchain technology, and under different subsidy strategies. At the same time, considering the impact of enterprise construction costs on the degree of improvement of freshness rate and yield, weighing the construction costs of the government blockchain traceability platform with the maximisation of total social welfare, we arrive at a blockchain traceability government subsidy strategy that maximises total social welfare.

2 Description and Explanation of the Problem

Consider the government investing in the construction of a blockchain technology application platform (hereinafter referred to as the blockchain platform), and enterprises are paid to use blockchain technology to produce traceable fresh products. The government supervises the freshness of the supply chain through the blockchain platform, and implements technology subsidies or production subsidies for enterprises. Enterprises reduce other costs by applying blockchain technology. Consumers trace products through blockchain technology to enhance the level of freshness trust in fresh products, where consumers' freshness preference affects the market demand for fresh products. The government needs to weigh the relationship between blockchain platform construction costs and total social welfare, and formulate optimal blockchain application decisions and quality assurance subsidy strategies to maximize social welfare.

The parameters and meanings involved in this model are shown in Table 1:

Table 1. Model parameters

Notation	Clarification
θ	Government subsidy factor for quality assurance efforts invested in the application of blockchain technology by enterprises
μ	Amount of government subsidy to enterprises for the production of individual traceable products
C_f	Freshness per unit of product
C_{f1}	Mathematical expectations for estimating the freshness rate per unit of product based on the firm's past production information, etc.
c	Unit cost of production of a product
p	Unit retail price of the product
q_1, q_2	Total market demand for traceable fresh produce when supply chain is not applied and when blockchain technology is applied, respectively
α	Initial market volume
β	Consumer Freshness Preference Coefficient
e	Unit warranty effort cost factor
F	Blockchain platform construction costs
C_b	Unit cost of applying blockchain technology
C_q	Other costs of the enterprise's units
η_q	Impact factor of enterprise adoption of blockchain technology on other expenses
π_g, π_b	Benefit Functions for Governments and Firms

The following hypotheses are presented:

Assumption 1: The output of traceable fresh products produced by the enterprise is equal to the market demand, the market can be completely cleared and the enterprise maintains a certain profit, while assuming that the initial capacity of the market:

$$\alpha > C_q \eta_q + C_b + c \tag{1}$$

Assumption 2: Firms achieve quality preservation by applying blockchain technology with a quality preservation effort cost function of $C(C_f) = \frac{1}{2} e C_f^2$.where e is the shelf-life effort cost coefficient, which is assumed to satisfy the condition $e > \beta^2 + 2\beta$, 则$\frac{\partial C(C_f)}{\partial C_f} = eC_f > 0$, This indicates that the fresher the freshness of that fresh product, the more costly it will be for the firm to improve the quality level of the fresh product.

Assumption 3: Market demand is determined by the combination of product price, freshness rate and consumers' freshness preference When blockchain technology is not used in the supply chain, the freshness of the product is difficult to determine and is replaced by its expectation C_{f1},Market demand is expressed as:

$$q_1 = \alpha - p + \beta C_{f1} \tag{2}$$

When blockchain technology is adopted in the supply chain, the traceability can enable the main bodies in the supply chain to accurately know the traceability information of fresh produce.$C_f$is a definite value, then the market demand is expressed as:

$$q_2 = \alpha - p + \beta C_f \tag{3}$$

Assumption 4: The government's return is the total social welfare, which consists of four components: producer surplus, consumer surplus, government fiscal expenditure, and improved market freshness. where the producer surplus is the firm's earnings.$\hat{p}$ denotes the maximum price consumers are willing to pay, i.e., the price when the demand for the product is zero. When the supply chain is not applying blockchain, the consumer surplus is denoted as:

$$S_1 = \frac{(\widehat{p_1} - p)q_1}{2} = \frac{(\alpha + \beta C_{f1} - p)q_1}{2} \tag{4}$$

When the supply chain applies blockchain, the consumer surplus is denoted as:

$$S_2 = \frac{(\widehat{p_2} - p)q_2}{2} = \frac{(\alpha + \beta C_f - p)q_2}{2} \tag{5}$$

Government financial expenditures include the cost of enterprise subsidies and the cost of building blockchain platforms. Fresh market freshness improvement is denoted as $C_{f1}q_1$before blockchain application and $C_f q_2$ after blockchain application, indicating the degree of change in freshness.

3 Model Building and Solving

3.1 Supply Chain Models Without the Application of Blockchain Technology

The payoff functions for the government and the firm are, respectively:

$$\pi_g{}^{(1)} = \pi_b{}^{(1)} + S_1 + C_{f1}q_1 \tag{6}$$

$$\pi_b{}^{(1)} = \left(p - c - C_q\right)q_1 - \frac{1}{2}eC_{f1}{}^2 \tag{7}$$

Theorem 1: In the unapplied model, there exists an optimal retail price $p^{(1)}$ that maximizes social welfare and firm returns.

PROOF: According to the inverse solution method, Eq. (1) is first substituted into

Eq. (6) to obtain the firm's return function. Find the second-order derivative of the return function with respect to the retail price $\frac{\partial^2 \pi_b{}^{(1)}}{\partial p^2} = -2 < 0$.Then the function takes its maximum value when the first-order derivative is 0.Find by making$\frac{\partial \pi_b{}^{(1)}}{\partial p} = 0$:

$$p^{(1)} = \frac{1}{2}\left(c + C_q + \alpha + \beta C_{f1}\right) \tag{8}$$

Equations (1), (3) and (7) lead to optimal output and optimal social welfare:

$$q^{(1)} = \frac{1}{2}\left(-c - C_q + \alpha + \beta C_{f1}\right) \tag{9}$$

$$\pi_g{}^{(1)} = \frac{1}{8}\left[3c^2 + 3\left(C_q - \alpha\right)\left(C_q - \alpha + 2c\right) - 2C_{f1}\left(C_q - \alpha + c\right)(2 + 3\beta) + C_{f1}{}^2(-4e + 4\beta + 3\beta^2)\right] \tag{10}$$

3.2 A model for Technology Subsidies Under Blockchain Technology Applications

The government needs to determine the technology subsidy coefficient θ given to enterprises, at which time the government′s financial expenditure includes the cost of technology subsidy to enterprises and the cost of blockchain platform construction, and enterprises need to pay the cost of blockchain technology application. The benefit functions of the government and enterprises are respectively:

$$\pi_g{}^{(2)} = \pi_b{}^{(2)} + \frac{(\alpha + \beta C_f - p)q_2}{2} + C_f q_2 - \frac{1}{2}\theta e C_f{}^2 - F \tag{11}$$

$$\pi_b{}^{(2)} = \left(p - c - \eta_q C_q - C_b\right)q_2 - \frac{(1-\theta)eC_f{}^2}{2} \tag{12}$$

Theorem 2: In the technology subsidy model, there exist optimal subsidy coefficients $\theta^{(2)}$, freshness rate $C_f{}^{(2)}$and retail price $p^{(2)}$ that maximize social welfare and firms' profitability.

PROOF: According to the inverse solution method, the Hessian matrix of $\pi_b{}^{(2)}$with respect to $p^{(2)}$ and $C_f{}^{(2)}$ can be obtained by first substituting Eq. (2) into Eq. (11):

$$H^{(1)} = \begin{bmatrix} \frac{\partial^2 \pi_b{}^{(2)}}{\partial p^2} & \frac{\partial^2 \pi_b{}^{(2)}}{\partial p\, \partial C_{f1}} \\ \frac{\partial^2 \pi_b{}^{(2)}}{\partial p\, \partial C_{f1}} & \frac{\partial^2 \pi_b{}^{(2)}}{\partial C_{f1}{}^2} \end{bmatrix} = \begin{bmatrix} -2 & \beta \\ \beta & e(-1+\theta) \end{bmatrix} \tag{13}$$

From (12), -2<0, because the government's subsidy coefficient for enterprises to apply blockchain technology for quality preservation effort input is smaller than 1,so $e(-1 + \theta) < 0$, and because $e > \beta^2 + 2$, so the second−order sequential principal subequation $2e(1 - \theta) > \beta^2$, he Hesser matrix is negatively definite, and there exists an optimal freshness rate and retail price to make the enterprise get the maximum benefit. Let $\frac{\partial \pi_b{}^{(2)}}{\partial p} = 0$,$\frac{\partial \pi_b{}^{(2)}}{\partial C_f} = 0$, and the joint equations can be used to find $p^{(2)}$ and

${C_f}^{(2)}$:

$$p^{(2)} = \frac{-\beta^2(c+C_b+C_q\eta_q)-e(c+C_b+\alpha+C_q\eta_q)(-1+\theta)}{\beta^2+2e(-1+\theta)} \tag{14}$$

$$C_f^{(2)} = \frac{\beta(c+C_b-\alpha+C_q\eta_q)}{\beta^2+2e(-1+\theta)} \tag{15}$$

After substituting Eqs. (11), (13), and (14) into Eq. (10) to obtain the government's benefit function, the optimal subsidy rate $\theta^{(2)}$ is obtained by making $\frac{\partial \pi_g^{(2)}}{\partial \theta} = 0$:

$$\theta^{(2)} = \frac{2e+e\beta+\beta^2}{2e+3e\beta} \tag{16}$$

Equations (13), (14) and (15) yield the fresh rate, optimal yield and optimal social welfare:

$$C_f^{(2)} = \frac{(2+3\beta)(c+C_b-\alpha+C_q\eta_q)}{-4e+\beta(4+3\beta)} \tag{17}$$

$$q^{(2)} = -\frac{(2e-\beta)(c+C_b-\alpha+C_q\eta_q)}{4e-\beta(4+3\beta)} \tag{18}$$

$$\pi_g^{(2)} = \frac{(1+3e)[C_q\eta_q(2C_b+2c-2\alpha+C_q\eta_q)+c(2C_b-2\alpha+c)+(C_b-\alpha)^2]+2F(3\beta^2+4\beta-4e)}{8e-2\beta(4+3\beta)} \tag{19}$$

3.3 Yield Subsidy Modelling with the Application of Blockchain Technology

The government needs to determine the subsidy μ per unit of traceability product given to the enterprise, at which time the government's financial expenditure includes the production subsidy cost to the enterprise and the blockchain platform construction cost, and the enterprise needs to pay the blockchain technology application cost. The revenue functions of the government and the enterprise are respectively:

$$\pi_g^{(3)} = \pi_b^{(3)} + \frac{(\alpha+\beta C_f-p)q_2}{2} + C_f q_2 - \mu q_2 - F \tag{20}$$

$$\pi_b^{(3)} = (p - c - \eta_q C_q - C_b + \mu)q_2 - \frac{1}{2}eC_f^2 \tag{21}$$

Theorem 3: In the yield subsidy model under the application of blockchain technology, there exist optimal subsidy coefficients $\mu^{(3)}$, freshness rate $C_f^{(3)}$ and retail price $p^{(3)}$ to maximise the social welfare and firms' returns.

Proof: Same as Theorem 2, according to the inverse solution method, make $\frac{\partial \pi_b^{(3)}}{\partial p} = 0$, $\frac{\partial \pi_b^{(3)}}{\partial C_f} = 0$, $\frac{\partial \pi_g^{(3)}}{\partial \mu} = 0$ joint equations to find $\mu^{(3)}$, $C_f^{(3)}$ and $p^{(3)}$ as follows:

$$\mu^{(3)} = -\frac{(e+2\beta)(c+C_b-\alpha+C_q\eta_q)}{e-\beta(2+\beta)} \tag{22}$$

$$p^{(3)} = \frac{-2\alpha\beta+(e-\beta^2)(c+C_b+C_q\eta_q)}{e-\beta(2+\beta)} \tag{23}$$

$$C_f^{(3)} = \frac{\beta(c+C_b-\alpha+C_q\eta_q)}{-e+\beta(2+\beta)} \tag{24}$$

The optimal output and optimal social welfare can be obtained from the above equation:

$$q^{(3)} = -\frac{e(c+C_b-\alpha+C_q\eta_q)}{e-\beta(2+\beta)} \tag{25}$$

$$\pi_g^{(3)} = \frac{e[(c+C_b)^2-2C_b\alpha-2c\alpha]+eC_q\eta_q(C_q\eta_q+2C_b+2c-2\alpha)+e\alpha^2+2F(-e+2\beta+\beta^2)}{2(e-\beta(2+\beta))} \tag{26}$$

3.4 Comparative Analysis of Three Scenarios

Summarising the results of the game for the above three scenarios, Table 2 can be obtained:

Table 2. Collection of three scenarios

Blockchain technology not applied	$q^{(1)} = \frac{1}{2}(-c-C_q+\alpha+\beta C_{f1})$ $\pi_g^{(1)} = \frac{1}{8}[3c^2+3(C_q-\alpha)(C_q-\alpha+2c)-2C_{f1}(C_q-\alpha+c)(2+3\beta)$ $+C_{f1}^2(-4e+4\beta+3\beta^2)]$
Application of blockchain technology + technology subsidies	$C_f^{(2)} = \frac{(2+3\beta)(c+C_b-\alpha+C_q\eta_q)}{-4e+\beta(4+3\beta)}$ $q^{(2)} = -\frac{(2e-\beta)(c+C_b-\alpha+C_q\eta_q)}{4e-\beta(4+3\beta)}$ $\pi_g^{(2)}$ $= \frac{(1+3e)[C_q\eta_q(2C_b+2c-2\alpha+C_q\eta_q)+c(2C_b-2\alpha+c)+(C_b-\alpha)^2]}{8e-2\beta(4+3\beta)}$ $\frac{+2F(3\beta^2+4\beta-4e)}{8e-2\beta(4+3\beta)}$
Application of blockchain technology + yield subsidies	$C_f^{(3)} = \frac{\beta(c+C_b-\alpha+C_q\eta_q)}{-e+\beta(2+\beta)}$ $q^{(3)} = -\frac{e(c+C_b-\alpha+C_q\eta_q)}{e-\beta(2+\beta)}$ $\pi_g^{(3)}$ $\frac{e[(c+C_b)^2-2C_b\alpha-2c\alpha]+eC_q\eta_q(C_q\eta_q+2C_b+2c-2\alpha)}{2(e-\beta(2+\beta))}$ $\frac{+e\alpha^2+2F(-e+2\beta+\beta^2)}{2(e-\beta(2+\beta))}$

3.5 Analysis of Building Models

(1) Optimal supply chain based on maximising the improvement of supply chain information transparency

For the problem of low supply chain information transparency, Qiang Gong et al[7] classify information into two categories, verifiable information and difficult-to-verify information, and argue that improving the quality of information on the blockchain (i.e., determining a good proportionality between the two categories of information) is the key to solving the problem. In this regard, this paper compares the changes in the probability of detection of corporate fraud under different supply chains, so as to determine that the supply chain applying blockchain technology is the optimal supply chain for improving the transparency of supply chain information.

The probability of a firm's fraud being detected under a traditional supply chain is:

$$p_0 = 1 - (1 - z)(1 - \rho z)(1 - \rho^2 z) \cdots (1 - \rho^n z) = 1 - \prod_{i=1}^{n}\big(1 - (x + \epsilon)\big) \quad (27)$$

The probability of detection of corporate fraud under the blockchain supply chain is:

$$p_{bc} = 1 - (1 - x)^{n+1} \quad (28)$$

n denotes the number of upstream firms, in the model studied in this paper only one supplier one retailer is considered, so it is obtained by taking 1:

$$p_0 = 1 - \big(1 - (x + \epsilon)\big)\big(1 - \rho(x + \epsilon)\big) \quad (29)$$

$$p_{bc} = 1 - (1 - x)^2 \quad (30)$$

The probability of detection of corporate fraud in the two supply chain models can be obtained by subtracting the probability of detection of corporate fraud in the two supply chain models:

$$p_{bc} - p_0 = (\rho - 1)x^2 + (2\rho\epsilon + 1 - \rho)x + \rho\epsilon^2 - \rho\epsilon - \epsilon \quad (31)$$

To simplify the presentation, the function can be obtained by denoting a for ρ,b for x, c for ϵ,and $z = x + \epsilon$, where $a \in (0,1), z \in (0,1), b \in (0, z)$:

$$p(a, b, c) = (a - 1)b^2 + (2ac + 1 - a)b + ac^2 - ac - c \quad (32)$$

The final approximation, obtained through nearly a billion random value comparisons, is: when a =0.0002766443343942271, b =0.4898568294868126,c=1.3795048922349284e-05, and z=0.48987062453573493, max p=0.24981418834430322. The specific process of random value is shown in Fig. 1

At this time, it can be known that the application of blockchain to improve the supply chain information transparency of the optimal supply chain, the application of blockchain after the probability of enterprise fraud is detected than the traditional supply chain to improve the probability of about 0.25, at the same time, can be obtained to improve the probability of fraud is detected optimal information proportionality relationship, which is conducive to improving the consumer's trust index of the fresh food products.

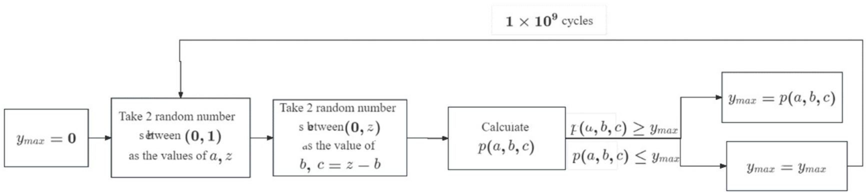

Fig. 1. Specific implementation process of randomised value taking

(2) Optimal supply chain based on maximising yield increase

The cost of the pair is obtained by subtracting the yield function:

$$q^{(2)} - q^{(1)} = \frac{3\beta^3 C_{f0} + \left(-3c - 3C_q + 3\alpha + 4C_{f0}\right)\beta^2}{-6\beta^2 - 8\beta + 8e} + \frac{+\left(\left(2\eta_q - 4\right)C_q - 4eC_{f0} - 2c + 2C_b + 2\alpha\right)\beta - 4e\left(\left(\eta_q - 1\right)C_q + C_b\right)}{-6\beta^2 - 8\beta + 8e}$$

$$q^{(3)} - q^{(1)} = \frac{\beta^3 C_{f0} + \left(-c - C_q + \alpha + 2C_{f0}\right)\beta^2}{-2\beta^2 - 4\beta + 2e} + \frac{+\left(-eC_{f0} - 2C_q + 2\alpha - 2c\right)\beta - e\left(\left(2\eta_q - 1\right)C_q + c + 2C_b - \alpha\right)}{-2\beta^2 - 4\beta + 2e}$$

and derive it for the cost:

$$\frac{\partial\left(q^{(2)} - q^{(1)}\right)}{\partial c} = \frac{-3\beta^2 - 2\beta}{-6\beta^2 - 8\beta + 8e}$$

$$\frac{\partial\left(q^{(3)} - q^{(1)}\right)}{\partial c} = \frac{-\beta^2 - 2\beta - e}{-2\beta^2 - 4\beta + 2e}$$

Since $\beta \in (0,1), e \in (0,1), -3\beta^2 - 2\beta \leq 0, -\beta^2 - 2\beta - e \leq 0$.

Let $f_1(\beta) = -6\beta^2 - 8\beta + 8e$, $f_2(\beta) = -2\beta^2 - 4\beta + 2e$

Solve for the interval $f_1(\beta) < 0$ as:

$$\beta_1 \in \left(-\frac{2}{3} - \frac{2\sqrt{1+3e}}{3}, -\frac{2}{3} + \frac{2\sqrt{1+3e}}{3}\right)$$

The intervals for which $f_2(\beta) < 0$ is solved are:

$$\beta_2 \in \left(-1 - \sqrt{1+e}, -1 + \sqrt{1+e}\right)$$

Due to the assumption condition $e > \beta^2 + 2\beta$, β needs to satisfy $\beta \in \left(0, -1 + \sqrt{1+e}\right)$, so by comparing the intervals, $\frac{\partial\left(q^{(2)}-q^{(1)}\right)}{\partial c}$与$\frac{\partial\left(q^{(3)}-q^{(1)}\right)}{\partial c}$ are always less than 0. That is, when cis inversely proportional to $q^{(2)} - q^{(1)}$ and $q^{(3)} - q^{(1)}$, the incremental output achieved by adopting blockchain technology is more significant when the production cost of the enterprise is smaller.

(3) Optimal Subsidy Strategy Based on Maximising Government Benefits

This is obtained by subtracting the benefit functions under the two subsidy policies:

$$\pi_g{}^{(2)} - \pi_g{}^{(3)} = \frac{-(\beta^2 + 2\beta e + e^2 + 2\beta - e)\left(C_q\eta_q + C_b - \alpha + c\right)^2}{2(3\beta^2 + 4\beta - 4e)(\beta^2 + 2\beta - e)}$$

Since $\left(C_q\eta_q + C_b - \alpha + c\right)^2 > 0$ is constant, let $f_1(\beta) = \beta^2 + 2\beta e + e^2 + 2\beta - e$, $f_2(\beta) = 3\beta^2 + 4\beta - 4e$, $f_3(\beta) = \beta^2 + 2\beta - e$, consider $f_1(\beta)$, $f_2(\beta)$, $f_3(\beta)$ as quadratic functions with openings upward about β.

The discriminant is $\Delta_1 = 12e + 4$, $\Delta_2 = 48e + 16$, $\Delta_3 = 4e + 4$ and $\Delta_1, \Delta_2, \Delta_3$ is always greater than 0. The interval for which the solution is $f_1(\beta) < 0$ is:

$$\beta_1 \in \left(-e - 1 - \sqrt{1+3e}, -e - 1 + \sqrt{1+3e}\right)$$

The intervals for which $f_2(\beta) < 0$ is solved are:

$$\beta_2 \in \left(-\frac{2}{3} - \frac{2\sqrt{1+3e}}{3}, -\frac{2}{3} + \frac{2\sqrt{1+3e}}{3}\right)$$

The intervals for which $f_3(\beta) < 0$ is solved are:

$$\beta_3 \in \left(-1 - \sqrt{1+e}, -1 + \sqrt{1+e}\right)$$

Due to the assumption that $e > \beta^2 + 2\beta$, β needs to satisfy $\beta \in \left(0, -1 + \sqrt{1+e}\right)$, which is obtained by comparing the intervals when the government adopts blockchain technology and:

$$0 < \beta < -e - 1 + \sqrt{1+3e}$$

The government receives a higher benefit from subsidising the technology.

When the government adopts blockchain technology and:

$$-e - 1 + \sqrt{1+3e} < \beta < -1 + \sqrt{1+e}$$

the government receives a higher return through yield subsidies.

(4) Optimal subsidy strategy based on market freshness maximisation

Obtained by subtracting the freshness function:

$$C_f{}^{(2)} - C_f{}^{(3)} = \frac{\left(C_q\eta_q + C_b - \alpha + c\right)(4\beta^2 + \beta e + 4\beta - 2e)}{(\beta^2 + 2\beta - e)(3\beta^2 + 4\beta - 4e)}$$

Let $f_1(\beta) = 4\beta^2 + \beta e + 4\beta - 2e$, $f_2(\beta) = \beta^2 + 2\beta - e$, $f_3(\beta) = 3\beta^2 + 4\beta - 4e$, consider $f_1(\beta)$, $f_2(\beta)$, $f_3(\beta)$ as quadratic functions with openings upward about β.

The discriminant is $\Delta_1 = e^2 + 40e + 16$, $\Delta_2 = 4e + 4$, $\Delta_3 = 48e + 16$ respectively.

The intervals for which $f_1(\beta) < 0$ is solved are:

$$\beta_1 \in \left(-\frac{e}{8} - \frac{1}{2} - \frac{\sqrt{e^2 + 40e + 16}}{8}, -\frac{e}{8} - \frac{1}{2} + \frac{\sqrt{e^2 + 40e + 16}}{8}\right)$$

The intervals for which $f_2(\beta) < 0$ is solved are:

$$\beta_2 \in \left(-1 - \sqrt{1 + e}, -1 + \sqrt{1 + e}\right)$$

The intervals for which $f_3(\beta) < 0$ is solved are:

$$\beta_3 \in \left(-\frac{2}{3} - \frac{2\sqrt{1 + 3e}}{3}, -\frac{2}{3} + \frac{2\sqrt{1 + 3e}}{3}\right)$$

Due to the assumption of condition $\alpha > C_q\eta_q + C_b + c$, it can be proved by comparing the intervals when the government adopts the blockchain technology and fulfils it:

$$0 < \beta < -\frac{e}{8} - \frac{1}{2} + \frac{\sqrt{e^2 + 40e + 16}}{8}$$

The freshness of fresh produce obtained by the government through technological subsidies is higher, and vice versa for those obtained through yield subsidies.

(5) Optimal subsidy strategy based on yield maximisation

If only the market capacity is considered, it is found through the function ratio and derivation that in the fresh food traceability supply chain, regardless of whether blockchain technology is adopted or not, for the government through financial subsidies than technical subsidies can obtain a higher market demand.

By subtracting the yield function under the two subsidy policies:

$$q^{(2)} - q^{(3)} = \frac{\left(C_q\eta_q + C_b - \alpha + c\right)(2e^2 + (\beta - \beta^2)e - 2\beta^2 - \beta^3)}{4e^2 - (7\beta^2 + 12\beta)e + 3\beta^4 + 10\beta^3 + 8\beta^2}$$

Let $f_1(e) = 2e^2 + (\beta - \beta^2)e - 2\beta^2 - \beta^3$, $f_2(e) = 4e^2 - (7\beta^2 + 12\beta)e + 3\beta^4 + 10\beta^3 + 8\beta^2$, consider $f_1(e)$, $f_2(e)$ as a quadratic function with an opening upward on e.

The discriminant equations are $\Delta_1 = \beta^2(\beta^2 + 6\beta + 17)$, $\Delta_2 = \beta^2(\beta + 4)^2$ respectively.

Solve for the interval $f_1(e) < 0$ as:

$$e \in \left(\left(\frac{\beta}{4} - \frac{1}{4} - \frac{\sqrt{\beta^2 + 6\beta + 17}}{4} \right) \beta, \left(\frac{\beta}{4} - \frac{1}{4} + \frac{\sqrt{\beta^2 + 6\beta + 17}}{4} \right) \beta \right)$$

Solve for the interval $f_2(e) < 0$ as:

$$e \in \left(\frac{3}{4}\beta^2 + \beta, \beta^2 + 2\beta \right)$$

Due to the assumption that $e > \beta^2 + 2, \alpha > C_q \eta_q + C_b + c$, by comparing the intervals when the government adopts the blockchain technology and the government adopts the yield subsidy to get a higher yield.

4 Example Analysis

The following numerical analysis further explores the impact of total social welfare π_g, freshness rate C_f and traceable product output q on the choice of optimal subsidy strategy. Under the condition of satisfying the model assumptions, drawing on the assignment ideas in the literature[6,8,9,10] and others, let: the unit production cost of the product $c = 5$, the other expenses of the enterprise unit $C_q = 1$, the unit cost of applying the blockchain technology $C_b = 0.12$, the coefficient of the enterprise's impact on the other expenses by adopting the blockchain technology $\eta_q = 0.8$, the cost of building the blockchain platform $F = 30$, and the estimation based on the enterprise's previous production information of the mathematical expectation of the freshness rate per unit of product C_{f1} =0.6.

4.1 Optimal Social Welfare Analysis

In order to demonstrate and verify the conclusion of Corollary 3.5.3 more intuitively, on the basis of the above setting, set α=17 and e=1 to find the optimal social welfare under different values of β.Comparing the optimal social welfare of the supply chain using technology subsidy and yield subsidy in Fig. 2, it can be seen that when $\beta \in \left(0, -1 + \sqrt{2}\right)$, the cost per unit of preservation of effort coefficient e satisfies the assumption that $e > \beta^2 + 2\beta$.In this interval, the total social welfare ${\pi_g}^{(3)}$ obtained by using yield subsidy first increases and then decreases with the increase of consumer freshness preference coefficient, and the total social welfare ${\pi_g}^{(2)}$ obtained by yield subsidy increases with the increase of consumer freshness preference coefficient. Meanwhile, since $-e - 1 - \sqrt{1 + 3e} = 0$, the conclusion that ${\pi_g}^{(3)}$ is greater than ${\pi_g}^{(2)}$ always holds within $0 < \beta < -1 + \sqrt{2}$, and ${\pi_g}^{(3)}$ achieves a great value when $\beta = 0.4$, which is consistent with that described in 3.5.3.

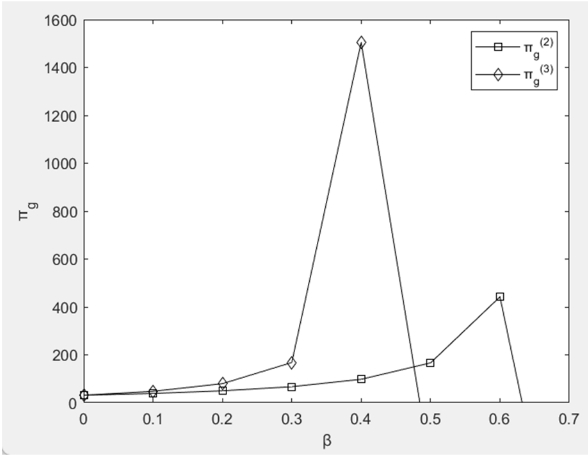

Fig. 2. Effect of consumer freshness preference coefficient on optimal social welfare

4.2 Optimal Fresh Rate Analysis

In order to demonstrate and verify the conclusion of Corollary 3.5.4 more intuitively, on the basis of the above setting, set e=1 to find the optimal social welfare under different values of β and α.If α=10 , $\alpha > C_q\eta_q + C_b + c$, it can be seen from Fig. 3 that the freshness rate increases with the increase of the consumer freshness preference coefficient, and when $0 < \beta < -1 + \sqrt{3}$, the freshness rate of fresh produce obtained by the government through technological subsidies, ${C_f}^{(2)}$ s greater than the production rate The freshness rate of fresh produce ${C_f}^{(3)}$ obtained by subsidy is greater than that of the production. When $\beta > -1 + \sqrt{3}$, the freshness rate of fresh produce ${C_f}^{(3)}$ obtained by the government through yield subsidy is superior.

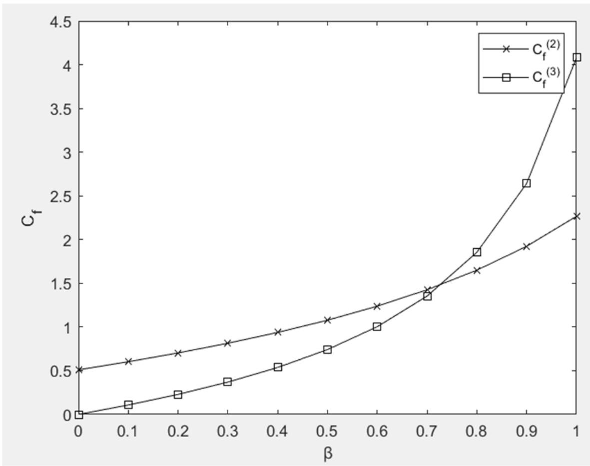

Fig. 3. Effect of consumer freshness preference coefficient on optimal freshness rate

4.3 Production Analysis of Best Traceability Products

In order to demonstrate and verify the conclusion of Corollary 3.5.2 more intuitively, on the basis of the above setting, set α=17, e=2, β=0.7, satisfying $\beta < -1 + \sqrt{1+e}$, and find the optimal traceability product yield under c taking different values. As can be seen from Fig. 4, the incremental product yield after applying blockchain technology in this interval increases with the reduction of cost. When the production cost of the enterprise is smaller, the incremental yield achieved by adopting blockchain technology is more significant.

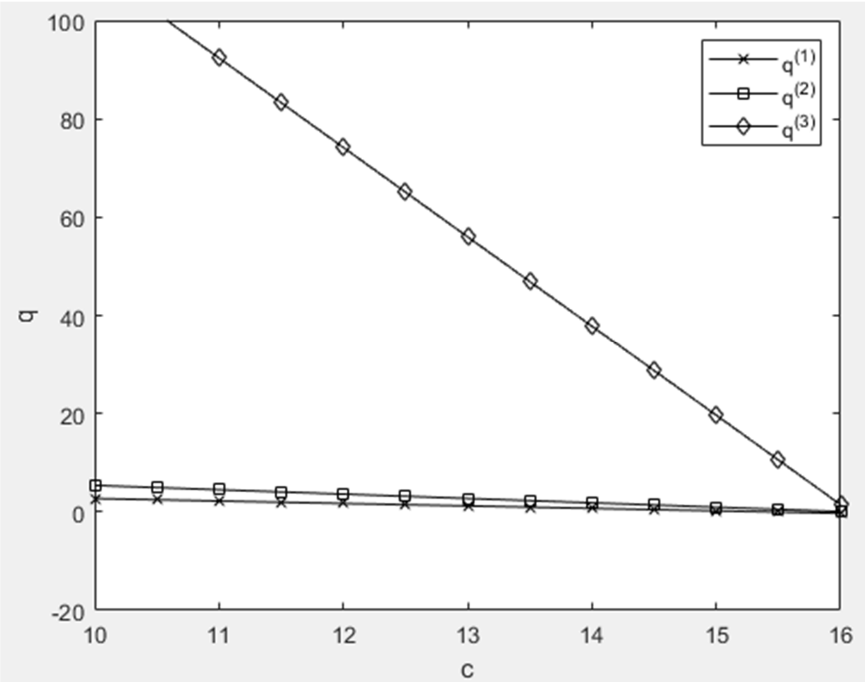

Fig. 4. Effect of cost on incremental product yield

In order to show and verify the conclusion of Corollary 3.5.5 more intuitively, on the basis of the above setting, set e=2、β=0.7、c=5.If α=10, $\alpha > C_q\eta_q + C_b + c$, it can be seen from Fig. 5 that the output increases with the increase in the coefficient of consumers' freshness preference, and the output with the adoption of yield subsidy is constantly greater than the output with the adoption of yield when technology subsidy is used, and the government obtains a better product yield through yield subsidy.

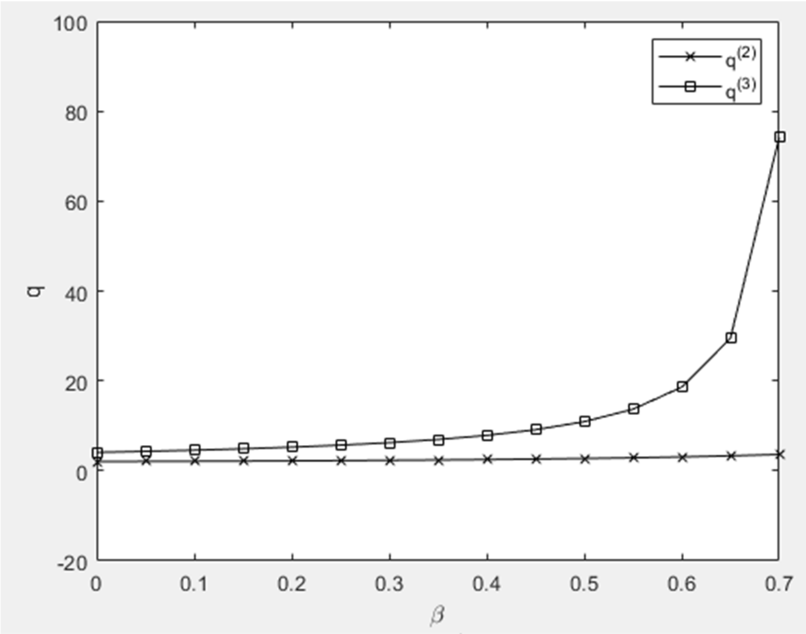

Fig. 5. Effect of consumer freshness preference coefficient on yield

5 Conclusions

This paper explores the government subsidy strategy for fresh supply chain based on blockchain technology, and considers the blockchain platform construction cost, blockchain technology application cost and consumer freshness preference, and conducts comparative analyses of total social welfare, freshness and traceable product yield for the model without blockchain application, the model with blockchain+technology subsidy, and the model with blockchain+yield subsidy, and arrives at the following conclusions and management insights:

(1) Conclusions of the study

If the coefficient of consumer preference for freshness is greater than $-e-1+\sqrt{1+3e}$ and the coefficient of cost per unit of shelf-life effort satisfies a certain range, the government achieves higher aggregate social welfare through technology subsidies. If the coefficient of consumer preference for freshness is less than $-\frac{e}{8}-\frac{1}{2}+\frac{\sqrt{e^2+40e+16}}{8}$ and the initial capacity of the market is greater than a certain threshold, the government is able to obtain a higher freshness rate through technology subsidies; If the coefficient of consumer preference for freshness is greater than $-\frac{e}{8}-\frac{1}{2}+\frac{\sqrt{e^2+40e+16}}{8}$ and the initial capacity of the market is greater than a certain threshold, the government is able to obtain a higher freshness rate through production subsidies. When the consumer freshness preference coefficient is less than a certain value, the incremental production of the product after blockchain application increases as the cost decreases. When the initial market capacity is greater than a certain threshold value, the government can always promote the demand for traceability products through yield subsidies.

(2) Management Revelations

The frequent occurrence of food safety problems and the improvement of people's living standards have prompted people to pay more attention to food safety issues, providing an opportunity for the growth of the fresh food traceability market. Consumers prefer fresh agricultural products with high freshness and transparency of food information. Fresh food enterprises improve the transparency of supply chain information and generate traceable food to meet consumer demand, which can effectively increase sales and added value of the products, and increase corporate profits. Enterprises to improve the transparency of production information at the same time, but also on the production of enterprises to form an external supervision, constraints on enterprises to improve the level of food safety, and at the same time have the benefit of the government to carry out supervision, to protect the public's food safety. This paper verifies through research that the application of blockchain technology is the optimal way to improve the transparency of supply chain information. The government should raise consumers' awareness of food safety and encourage them to buy safe and traceable fresh food. At the same time, the government should invest in a unified, open, and multi-departmental platform for blockchain technology application, develop a set of universal and practical, reasonable and legal market guidelines, and carry out a strong reform of the market. At the same time, it should adjust the government's subsidy strategy according to the actual situation, encourage enterprises to apply blockchain technology to produce fresh agricultural products with high freshness and safety, reduce the extra costs incurred during the introduction of blockchain technology, and increase the motivation of enterprises.

The discussion in this paper is based on the ideal situation that the government fully supports the application of blockchain technology, but in the process of the actual promotion of the policy may appear inconsistent with the assumptions of the initiative, it is necessary to adjust the assumptions according to the actual situation of the research and analysis to arrive at the optimal government subsidy strategy. As well as this paper does not consider the interactions between the upstream and downstream of the supply chain, the above issues deserve further attention and research.

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