Impact of blockchain technology on agricultural product circulation system: A simulation analysis with agent-based modelling

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Abstract

In the context of the Internet, the agricultural product circulation system needs to undergo corresponding changes to adapt to the modern fast-paced social system. Based on the main characteristics of blockchain technology and the summary of domestic and foreign theoretical research, this paper simulates the impacts of blockchain technology on the agricultural product circulation system. The results reveal that blockchain technology can improve the qualification rate of agricultural products and thereby ensure their quality and safety. Moreover, blockchain technology can significantly enhance the efficiency of the agricultural product circulation system, thus greatly promoting the economic benefits. Finally, the introduction of blockchain technology can effectively promotes the governance level and reduces the supervision cost of the agricultural product circulation system. These findings enrich the research on the application of blockchain technology in the management and circulation of modern agricultural products.

1. Introduction

Circulation is the intermediary and bridge between commodity production and consumption [1]. In China, great attention has been paid to the production of commodities while the circulation of commodities has been largely ignored all time. In recent years, there have been sharp fluctuations in the price of vegetables such as spinach, and the problem of "cheap vegetables hurt farmers and expensive vegetables hurt the customers" has become increasingly prominent [2,3]. Moreover, the frequent occurrence of quality and safety problems of agricultural products, such as "melamine" in Sanlu milk powder and "clenbuterol" in pork, has posed great threats to the People's health and safety as well as caused serious crisis of trust [4]. Therefore, the low quality, safety and circulation efficiency of agricultural products are the most urgent problems to be solved in China.

The newly emerging digital technologies represented by blockchain, 5G, artificial intelligence and cloud computing, which have become prevalent in all aspects of economy, society and life, are considered as the symbol of the next Kondratieff Cycle of the world economy [5]. Research on the application of blockchain technology to agriculture is still in its initial stage [6,7]. Blockchain technology has promising prospects to be applied in the circulation industry [8], as its technical features such as immutability and distributed ledger can ensure the speed and stability of the key information circulation process of agricultural products, which may solve the common problems faced by the agricultural product circulation in China. However, current research on blockchain is mostly focused on the circulation of industrial products, while little research attention has been paid to its application in the circulation of agricultural products. Therefore, this paper combines modern circulation theory and the characteristics of blockchain technology to simulate the impact of blockchain technology on the agricultural product circulation system, aiming to help promote the modernization, transformation and upgrading of the agricultural product circulation system.

2. Related Work

There has been some research on the circulation of commodities in the context of digital economy. For example, Zeng [9] analyzed the impact of informatization level on the productivity of the circulation industry in 30 provinces of China, and found that informatization can improve the logistics efficiency of both the local area and the adjacent areas. Guo and Li [10] used factor analysis to measure the informatization level of circulation in central and eastern provinces of China, and proposed that informatization has become an engine boosting the development of circulation industry. Sorina et al. [11] studied the role of informatization in the circulation industry from the perspective of information technology and supply chain, and demonstrated that the improvement of informatization can facilitate the development of the circulation industry. In addition, Xuan and Guo [12] explored the construction of port circulation from the perspective of informatization, and suggested that the rapid development of high-tech represented by informatization has shaped a new type of cross-border e-commerce, which has a large impact on the port circulation industry. Ma and Hu [13] proposed that digital technology and agricultural informatization play an important role in reconstructing the agricultural product circulation system.

Current research on the application of blockchain in agricultural field is mainly focused on the traceability system of agricultural products, rural finance, agricultural production, and operation methods. Sun et al. [14] proposed a model of agricultural product traceability system based on consortium blockchain, which solves the problem of vulnerability to network attack due to the presence of a center. Liu et al. [15] studied the application mode of blockchain technology in the circulation of agricultural products, and demonstrated that blockchain can realize the traceability of agricultural products from the production source to consumers. Wang and Wen [16] proposed that blockchain technology breaks the information barriers of traditional agricultural supply chains and reduces the difficulty for financial institutions to accurately verify the information based on their theoretical framework and case studies. Zhang and Hou [17] revealed that blockchain and agricultural crowdfunding can contribute to significant integration and innovation, which can reduce the difficulty of agricultural crowdfunding at the theoretical level, as well as optimize the operation process and reduce the risk of agricultural crowdfunding at the practical level. Lu [18] reported that blockchain technology may become an important technological path to reshape China's agricultural modernization and promote the integration of small farmer households into modern agriculture. Moreover, Liu et al. [4] analyzed the root causes of agricultural product safety problems, and theoretically investigated the role of the network system of blockchain technology in solving the safety problems of agricultural products.Xie and Wang [19] regarded that the core of the role of blockchain technology and the agricultural circulation system lied in the breakthrough of circulation efficiency supported by a new generation of information technology and adapted to the changes in supply and demand in the new digital era, which had the potential mechanism of insight into consumer needs, promoting matching supply and demand and linking the reallocation of production.

Although blockchain technology and agricultural circulation have been extensively and well researched respectively, but studies combining the two are rare. And there is disagreement on whether information technology can improve the efficiency of agricultural circulation [20,21].Therefore, this paper simulated the impacts of blockchain technology on the agricultural product circulation system, attempted to extend the research on the blockchain technology in the circulation system of agricultural products and provided a reference for related scholars.

3. Theoretical Analysis Of The Application Of Blockchain Technology In Agricultural Product Circulation System

As an emerging digital technology, blockchain has been developing rapidly since 2008, and has been gradually applied in various fields of economy and society due to its advantages of immediacy, decentralization, immutability, and traceability. When blockchain technology is applied in the agricultural product circulation system, the IoT device based on blockchain technology can collect the key data such as production, transport, processing, warehousing, and sales, and upload the related information in the blockchain database through algorithm screening and calculation. Blockchain technology has a positive impact on the agricultural product circulation system by improving the infrastructure and institutional rules for different agents in the system. Based on previous studies, the main agents of the agricultural product circulation system in China can be divided into farmers, wholesalers, retailers, consumers, and regulators(Fig. 1).

IoT devices based on blockchain technology can collect information on the production process of farmers, which can be uploaded and queried in the blockchain database. Farmers can release their products on the APP or Internet platform and track orders in real time. When the sales process is completed, the agricultural products are transferred from farmers to consumers, and the smart contracts based on blockchain technology will automatically complete the order.

Wholesalers are mainly involved in the transport, processing, and warehousing of agricultural products. In the transport process, the intelligent equipment equipped with transport vehicles will collect information such as the transport time, number and plot of agricultural products and “upload” it into the database. In the processing process, the sensor equipment configured in the processed products and the IoT equipment carried by the workers can collect the key data of agricultural product processing in real time and upload them to the database as well. In the warehousing process, the intelligent equipment installed in the warehouse will collect data such as the storage time, plot and producer of products, and “upload” the data. After mutual verification of the data in each process, a time stamp, a location stamp, and a quality stamp will be generated for each unit of agricultural products.

Through the blockchain technology, consumers can purchase traceable agricultural products with unique time stamps, location stamps and quality stamps, and obtain important information of each step in the circulation process of agricultural products, which can effectively solve the problem of information asymmetry between buyers and sellers.

Since the whole process of agricultural product circulation adopts blockchain IoT technology and the information of each process is stored in the database, regulators can conduct real-time supervision of every agent and step in the circulation system. In this way, unsafe products can be traced back to the production end, and relevant agents will be punished.

4. Construction Of The Simulation Model

In recent years, agent-based simulation has been widely used in the field of social science, which is more effective in research on the formation and evolution of organizations. Therefore, based on theoretical analysis, we constructed an agent-based simulation model, in which blockchain technology is applied in the agricultural product circulation system. The blockchain technology involved in this article is a consortium chain, regardless of public and private chains.

4.1. Model structure

The established simulation model includes farmers, wholesalers, retailers, consumers, and regulators, as well as the interactive behaviors among these five agents, and considers both traditional circulation and blockchain circulation (Fig. 2).

Assuming that there is an agricultural product production base in the initial state, the production base consists of n homogeneous farmers, each of which independently produces s units of agricultural products in each period. The products produced by farmers are classified into two types: safe and unsafe (unsafe products refer to products whose pesticide residues do not meet the national standards). Since quality and safety are important attributes of credit products, only the farmers know the true quality of the products, and other agents cannot identify them. There are m wholesalers and k retailers at the same time. Under the initial conditions, agricultural products are only circulated through the traditional circulation chain. In this mode, the products are sequentially circulated from traditional farmers to the wholesalers, retailers and then consumers, among which the former three agents make a profit from the difference. After the application of blockchain technology, some farmers, wholesalers, and retailers tend to use the blockchain technology, resulting in two chains in the agricultural product circulation system. In the blockchain circulation chain, blockchain farmers conduct transactions directly with blockchain retailers, and blockchain wholesalers mainly undertake the function of logistics. The farmers, wholesalers and retailers can freely switch between traditional mode and blockchain mode under certain conditions.

4.2. Setting of the farmer agent

In the traditional circulation chain, agricultural products produced by farmers are first sold to wholesalers, which are then sold to the retailers. After the application of blockchain technology, the blockchain farmers directly sell the products to the blockchain retailers. Currently, the blockchain wholesalers mainly undertake the transport function. According to the assumption of "economic man" in economics, farmers are profit-seeking, and their attributes are set as farmer identity, honesty, and wealth (Ma 2017). The specific decision-making behavior and conversion rules of farmers are as follows.

Honesty updating. Each farmer has a credit rating, and the change in its value can indicate whether the farmer produces safe products as well as his resistance to the impact of interests. The benefit impact refers to the difference in the expected benefits from the production of safe and unsafe products. If traditional farmers and blockchain farmers are not sampled for inspection, their honesty will be slightly reduced according to Eq. (1). If traditional or blockchain farmers are sampled for inspection by the regulator, their honesty will be increased based on Eq. (2). If any of the blockchain farmers, blockchain wholesalers and blockchain retailers is sampled by the regulator, the honesty of the blockchain farmers will be increased according to Eq. (2). If the traditional and blockchain farmers, blockchain wholesalers and blockchain retailers are not sampled by the regulator, the honesty of the blockchain farmers is decreased according to Eq. (1).

$$Honesty_{t+1} = (1 - f^{+})Honesty_{t} + minimal\_Honsety$$

1

$$Honesty_{t+1} = (1 - f^{-})Honesty_{t} + f^{-}$$

2

Among them, $\mathbf{honesty_t}$ represents the $\mathbf{honesty}$ of a certain farmer in period t. The minimum value of $\mathbf{Honesty_t}$ is 0. Currently, the farmer is completely dishonest, and all his products are unsafe. When $\mathbf{honesty_t}$ is 1, the farmer is completely honest, and correspondingly all his products are safe. As $\mathbf{honesty_t}$ increases, the probability of the farmer to produce safe products increases. $\mathbf{f}^{+} \in (0{,}1)$ and $\mathbf{f}^{-} \in (0{,}1)$ represent the positive and negative impact factor experienced by the farmer, respectively, and if $\mathbf{f}^{-} > \mathbf{f}^{+}$, the negative factor has a greater impact on the farmer. $\mathbf{Minimal\_Honesty}$ is the minimum value of $\mathbf{honesty}$.

Punishment. There are the following situations in which the farmers will be punished. When the regulators detect some problems in agricultural products during the blockchain circulation, they can directly trace the source through the blockchain technology (Li and Liu 2020), to find out the blockchain farmers that produce unsafe products and impose certain penalties on them. In addition, when the regulators find some problems in the agricultural products of traditional farmers by spot checks, the traditional farmers will also be punished.

Farmers' production decision. Farmers in the production base have two choices: producing safe products or unsafe products. Profit, $\mathbf{honesty}$ and other random factors jointly determine the production decision of farmers as shown in Eq. (3).

$$\alpha k_{i} + (1 - \alpha)p > Honesty$$

3

In the equation, $k_i \in (0,1)$ represents the standardized value of the difference between the two expected benefits to produce safe and unsafe products. Weights $\alpha \in (0,1)$,ρ is any random number on $(0,1)$. If this equation is satisfied, the farmers will produce safe products; otherwise, they will produce unsafe products.

Product trading decision. Traditional farmers sell their products to the wholesalers at the price of *P1*, and the profit of the farmer is the income minus the production cost (any penalty will be deducted). Blockchain farmers sell their products to the blockchain retailers at price *P2*, and the profit is the income minus the production and technology costs. Profits will change the attributes of farmers' wealth. If the farmer sells all his products in the current period, regardless of whether the products are safe or unsafe, the transactions between the farmers and wholesalers are conducted at a consistent price *P1*. Because of blockchain technology, the blockchain farmers have to be responsible for the quality and safety of the agricultural products in the whole process, and as a result, *P2* is generally higher than *P1*. *P3* is the price at which the wholesalers sell agricultural products to the retailers. *P4* and *P5* are the prices of agricultural products sold to consumers by blockchain retailers and traditional retailers, respectively. The calculation of *P1, P2, P3, P4* and *P5* can be conducted with equations (4)-(8).

$$P_1(t) = \alpha \mathrm{C_u} + (1-\alpha)\mathrm{C_s} + \epsilon_1(\mathrm{t})$$

4

$$P_2(t) = \alpha \mathrm{C_u} + (1-\alpha)\mathrm{C_s} + \epsilon_2(\mathrm{t})$$

5

$$P_3(t) = (1+\eta)P_1(t)$$

6

$$P_4(t) = (1+\beta)P_2(t)$$

7

$$P_5(t) = (1+\delta)P_3(t)$$

8

In these equations, $\varepsilon(t) \sim N(\mu, \sigma^2)$ is the random item; C_s and C_u indicate the unit cost of producing a safe and unsafe product, respectively; $\eta \in (0,1)$,$\beta \in (0,1)$, $\delta \in (0,1)$. If the agricultural products produced by the farmers are detected as unsafe by the regulator, they will be fined *B1* per unit, and their honesty will be changed accordingly. For traditional farmers, there are profit functions.

$\phi_1 = s(P_1 - C_u)$: farmers produce unsafe products that are not sampled.

$\phi_2 = s(P_1 - C_u - B_1)$: farmers produce unsafe products that are detected by regulators.

$\phi_3 = s(P_1 - C_s)$: farmers produce safe products.

Ct is the cost of introducing blockchain technology. For blockchain farmers, there are also three profit functions.

$\pi_1 = s(P_2 - C_u - C_t)$: blockchain farmers produce unsafe products that are not detected.

$\pi_2 = s(P_2 - C_u - C_t - B_1)$: blockchain farmers produce unsafe products that are detected by regulators.

$\pi_3 = s(P_2 - C_s - C_t)$: blockchain farmers produce safe products.

Conversion strategy. Considering that farmers have certain adaptability and their pursuit of maximum profits, different types of farmers can be converted to each other. The following issues need to be considered in the conversion: The conditions for conversion are mainly based on the comparison of the average income between different types of farmers; the threshold for conversion (*G*) reflects the resistance of the conversion (Jin and Yuan 2019). When Eq. (9) is satisfied, the type of the farmer will be converted; otherwise, the farmer type will not be changed.

$$\alpha(\pi_i' - \pi_i) / \pi_i' + (1 - \alpha)p > G$$

9

In the equation, π_i is the current profit of the farmer; π_i' is the current average profit of different types of farmers around the farmer; $\mathbf{p} \in (0,1)$; *G* is the conversion threshold, and its dynamic change can be expressed as follows:

$$G_{t+1} = (1 - v_1^+) G_t + v_1^+$$

10

$$G_{t+1} = (1 - v_1^-) G_t$$

11

$$G_{t+1} = (1 - v_2^+) G_t + v_2^+$$

12

$$G_{t+1} = (1 - v_2^-) G_t$$

13

$\mathbf{v}_2^- > \mathbf{v}_1^- > \mathbf{v}_1^+ > \mathbf{v}_2^+$. $\mathbf{v}_1^+$ indicates that the personal income of the farmer is greater than the average income of different types of farmers without fines. In this case, his/her conversion threshold will be significantly increased. $\mathbf{v}_1^-$ means that the personal income is low without fines, when the conversion threshold will be slightly decreased. $\mathbf{v}_2^+$ means that the personal benefit is high, but a fine is imposed, when the conversion threshold will be slightly increased; $\mathbf{v}_2^-$ means that the farmer has a low income with a fine, when the conversion threshold will be significantly decreased.

4.3. Setting of the wholesaler agent

Product acquisition and sales decision. The blockchain wholesaler obtains a fixed income θ per unit by providing logistics services for the blockchain circulation. The price of agricultural products purchased by traditional wholesalers is *P1*, and that of agricultural products sold to traditional retailers is *P3*.

For traditional wholesalers, there are two scenarios for their profit margins.

$r_1 = P_3 - P_1$, when the agricultural product has not been tested or passed the test.

$r_2 = P_3 - P_1 - B_2$, when the agricultural products are detected as unsafe.

Punishment. When the agricultural products in the circulation of the wholesaler are detected as unsafe, there are two situations. First, the products transported by the blockchain wholesalers are detected as unsafe, and the unsafe products can be traced through the blockchain technology. In this case, the blockchain farmers producing the products will be punished. Second, the products of traditional wholesalers are detected to be unsafe. In this case, the regulator will impose a penalty of *B2* per unit on traditional wholesalers.

Conversion strategy. Wholesalers also obey the assumption of "economic man". After the introduction of blockchain technology, different types of wholesalers can also be converted to each other, but the following conditions need to be considered. The premise of conversion is that there are different types of wholesalers in the circulation system. The conversion conditions are mainly based on the comparison of the average income of different wholesaler types. Conversion threshold *G1* is used to evaluate the resistance to conversion. When Eq. (14) is satisfied, the type of wholesalers will be converted.

$$\alpha(r_i' - r_i) / r_i' + (1 - r)p > G_1$$

14

In the equation, $\mathrm{r_i}$ is the current profit margin of a wholesaler; $\mathrm{r_i'}$ is the average profit margin of another type of wholesaler, $\alpha \in (0,1)$, $\mathrm{p} \in (0,1)$ and *G1* is the conversion threshold.

4.4 Setting of the retailer agent

Product acquisition and sales decision. Under the initial conditions, all retailers buy agricultural products from wholesalers. After the introduction of blockchain technology, some traditional retailers are converted into blockchain retailers. There are also two situations at this time. First, the blockchain retailers directly purchase agricultural products at the price of *P2* from the blockchain farmers, and pay the transport cost per unit θ of the blockchain circulation, and then sell the products to consumers at the price of *P4*. Second, traditional retailers buy agricultural products from traditional wholesalers at the price of *P3* and sell them to consumers at the price of *P5*.

At this time, the profit margin function of the blockchain retailer is $y_1 = P_4 - P_2 - \vartheta - C_t$, and that of a traditional retailer is $y_2 = P_5 - P_3$ when the product is not found to be unsafe by random inspection, and $y_3 = P_5 - P_3 - B_3$ when the product is sampled and found to be unsafe.

Punishment. When the blockchain retailer's products are detected to be unsafe, the source of the products can be traced through blockchain technology, and the blockchain farmers who produce unsafe agricultural products will be fined *B1* per unit. When the traditional retailer's products are detected to be unsafe, the regulator will impose a fine of *B3* per unit.

Conversion strategy. The retailers also have the characteristics of "economic man", and thus different types of retailers can be converted to each other. The following factors need to be considered for the conversion. The premise for the conversion is that after the introduction of blockchain technology, there are different types of retailers. The conversion conditions are also based on the comparison of the average income of different types of retailers. The conversion threshold *G2* reflects the resistance to conversion. When Eq. (15) is satisfied, the type of retailers will be converted.

$$\alpha(C_i' - C_i) / C_i' + (1 - \alpha)p < G_2$$

15

In the equation, $\mathrm{C_i}$ is the current profit margin of a retailer, and $\mathrm{C_i'}$ is the average profit margin of other types of retailers, $\alpha \in (0,1)$, $\mathrm{p} \in (0,1)$, and *G2* is the conversion threshold.

4.5. Setting of the regulator agent

In the initial state, it is assumed that the sampling frequency of the supervisor for the farmers, wholesalers and retailers is *a1, a2* and *a3*, and the fine for unsafe products is *B1, B2* and *B3* per unit, respectively. After the introduction of blockchain technology, the supervision of the traditional circulation chain remains unchanged. In the blockchain circulation chain, any unsafe products randomly detected in any link can be traced back to the blockchain farmers, and correspondingly a fine of *B1* per unit is imposed on the farmer.

5. Simulation Experiments And Results

Based on the above simulation model, the Netlogo6.2 simulation software was used to simulate the agricultural product circulation system, and simulation experiments were carried out to explore the dynamic changes in the system under the application of blockchain technology. The parameters for the simulation experiments were derived from real cases, field investigations and related studies (see Table 1).

After the introduction of blockchain technology, we observed the dynamic changes in product qualification rate and circulation efficiency in the blockchain circulation chain and traditional circulation chain. The circulation efficiency is calculated from the product qualification rate and the input-output ratio of the circulation process according to a certain weighting.The data obtained from the simulation experiments are all generated by the simulation system.

Table 1
Values of basic parameters in the simulation

Parameter	Value	Parameter definition
n	1000	Number of farmers
m	100	Number of wholesalers
k	100	Number of retailers
x	2	Number of regulators
s	30	Yield of a single farmer
C_s	[2.25,2.5]	Unit cost of producing a safe product
C_u	[1.58,1.75]	Unit cost of producing unsafe products
C_t	0.2	Cost per unit of product using blockchain technology
P_1	[2.3,3.2]	The selling price of traditional farmers' products
P_2	[2.6,3.5]	The selling price of blockchain farmers' products
η	[0.2,0.4]	Rate at which P3 exceeds P1
β	[0.3,0.5]	Rate at which P4 exceeds P2
δ	[0.1,0.4]	Rate at which P5 exceeds P3
α	[0.6,0.65]	Weights
p	(0,1)	Random variables

5.1. Simulation analysis of qualification rate of agricultural products

Figure 3 shows that the qualification rate of agricultural products in the blockchain circulation chain increases slowly before the 60th period. Despite of slight fluctuations, the qualification rate is maintained at high levels after the 60th period, and reaches about 70%. The qualification rate of agricultural products in the traditional circulation chain fluctuates considerably in the first two periods, and maintained at relatively low levels of 47–48% after the second period with occasional slight fluctuations. Therefore, the application of blockchain technology can improve the qualification rate of agricultural products in the circulation system, which is clearly conducive to ensuring the quality and safety of agricultural products.

5.2. Simulation of the circulation efficiency of agricultural products

Figure 4 presents the changes in the circulation efficiency of the traditional circulation chain with time under the initial conditions and a certain supervision intensity. The circulation efficiency of agricultural products fluctuated considerably until the 18th period in the traditional distribution chain, especially in the first four periods. After the 18th period, the circulation efficiency gradually remains at a relatively low level around 0.56. The green line is a fitted curve of circulation efficiency with time in the traditional circulation chain.

Figure 5 presents the changes in the circulation efficiency of the traditional circulation chain with time under the initial conditions and a certain supervision intensity.As we can see in Fig. 5, there is a turning point in the 4th period when the circulation efficiency of agricultural products in the blockchain circulation chain changes from a rapid decrease to a slow increase. After the 4th period, the circulation efficiency is high and shows a rising trend with time, reaching the highest level in around the 70th period and then staying stable.

Figure 6 compares the change in circulation efficiency with the time of the traditional circulation chain and blockchain circulation chain after the introduction of blockchain technology. The results show that the circulation efficiency in traditional circulation chain stays at a low level after the 4th period, while the circulation efficiency in blockchain circulation chain grows consistently until the 70th period and then stays at a high level. The results also demonstrate that blockchain technology can improve the efficiency of agricultural circulation system.The reason is that the introduction of blockchain technology changes the way of information transmission, which in turn alters the circulation mode of agricultural products, and reduces the circulation links.

5.3. Impact of regulatory intensity on the circulation efficiency and qualification rate of agricultural products

When other conditions remain unchanged, the impact of changes in regulatory intensity on the agricultural product circulation system was simulated by setting different sampling probabilities. When the sampling probability is 0.1, the product qualification rate of the traditional circulation chain is stable at 8.45%, with a circulation efficiency of 0.1693. Currently, the qualification rate of products in the blockchain circulation chain is 47.04%, and the circulation efficiency is 0.6953. When the sampling probability is increased to 0.3, the product qualification rate of the traditional circulation chain is stable at 38.65%, and the circulation efficiency is 0.2488. For the blockchain circulation chain, the product qualification rate is 65.82%, and the circulation efficiency is 0.7016 (see Table 4). Overall, with the gradual increase in the probability of sampling inspection, the qualification rate of agricultural products increases rapidly in the traditional circulation chain, and accordingly the circulation efficiency also increases; in contrast, the product qualification rate and circulation efficiency in the blockchain circulation chain are always relatively high and only increase slightly with increasing sampling probability. Therefore, the increase in regulatory intensity has an obvious effect on the traditional circulation chain, but a rather limited effect on the blockchain circulation chain. The reason is that the probability of random inspection directly affects the economic benefits of each agent as well as the product qualification rate and circulation efficiency in the traditional circulation chain; however, the blockchain technology itself has "internal regulation attributes", and accordingly external regulation has a relatively less significant effect on it. Hence, it can be speculated that the introduction of blockchain technology can effectively reduce the regulation costs.

Table 4
Impacts of changes in regulatory intensity on product qualification rate and circulation efficiency

Sampling probability	Qualification rate of traditional circulation chain products	Qualification rate of blockchain circulation chain products	Circulation efficiency of traditional circulation chain	Circulation efficiency of Blockchain circulation chain
0.1	0.0845	0.4704	0.1693	0.4953
0.2	0.2436	0.6076	0.2488	0.6961
0.3	0.3865	0.6582	0.3191	0.7016

6. Conclusion

With the advent of the digital era, more and more cases of the successful integration of digital technology and agriculture have emerged. With the advancement of digital technology such as blockchain, the agriculture circulation industry, with the blessing of blockchain, will break through the traditional model and find a new revolution. By combining the technical characteristics of blockchain and the operation mode of China's agricultural product circulation system, this paper uses the method of agent-based modelling to establish a system to simulate the effect of blockchain technology on the agricultural product circulation system.

The simulation analysis revealed that blockchain technology can improve the qualification rate and ensure the quality and safety of agricultural products, as well as effectively enhance the circulation efficiency of the agricultural product circulation system and gain greater benefits. Finally, simulation experiments demonstrated that the increase in regulatory intensity has no significant impact on the blockchain circulation chain. Therefore, the introduction of blockchain technology can reduce the regulation costs and improve governance to a certain extent.

The innovations inthis article are that, firstly, from the perspective of new technology application, the impact of the citation of blockchain technology on the agricultural products circulation system is analysed. Secondly, a simulation analysis is used to simulate the impact of blockchain technology on the circulation system of agricultural products.

There are still some shortcomings in this article. The main reason is that there are few applications of blockchain technology in the Chinese agricultural sector. The analysis of the behaviour of the simulation agents in this article is also not comprehensive enough. However, with the rapid development of blockchain technology, it is believed that the agricultural products circulation industry based on blockchain technology will develop better and better.

Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Material preparation and analysis were performed by Liukun Wang, Chunjie Qi, Peng Jiang and Si Xiang. The first draft of the manuscript was written by Liukun Wang and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability

The datasets generated during or analysed during the current study are not publicly available due to some data required for unfinished research and confidentiality measures but are available from the corresponding author on reasonable request.

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Figures

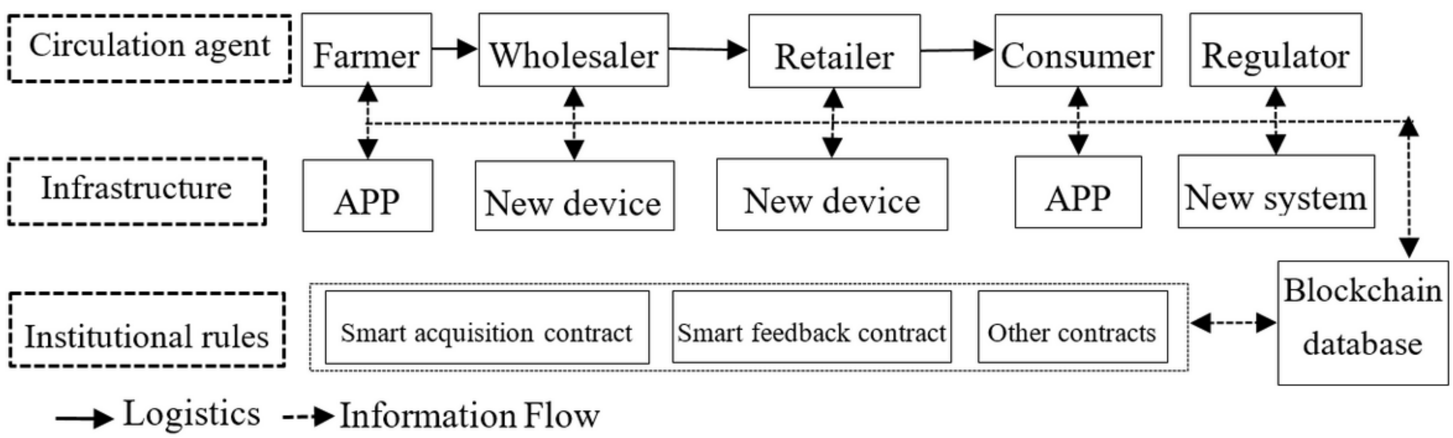

Figure 1

Operation diagram of blockchain technology in the agricultural product circulation system

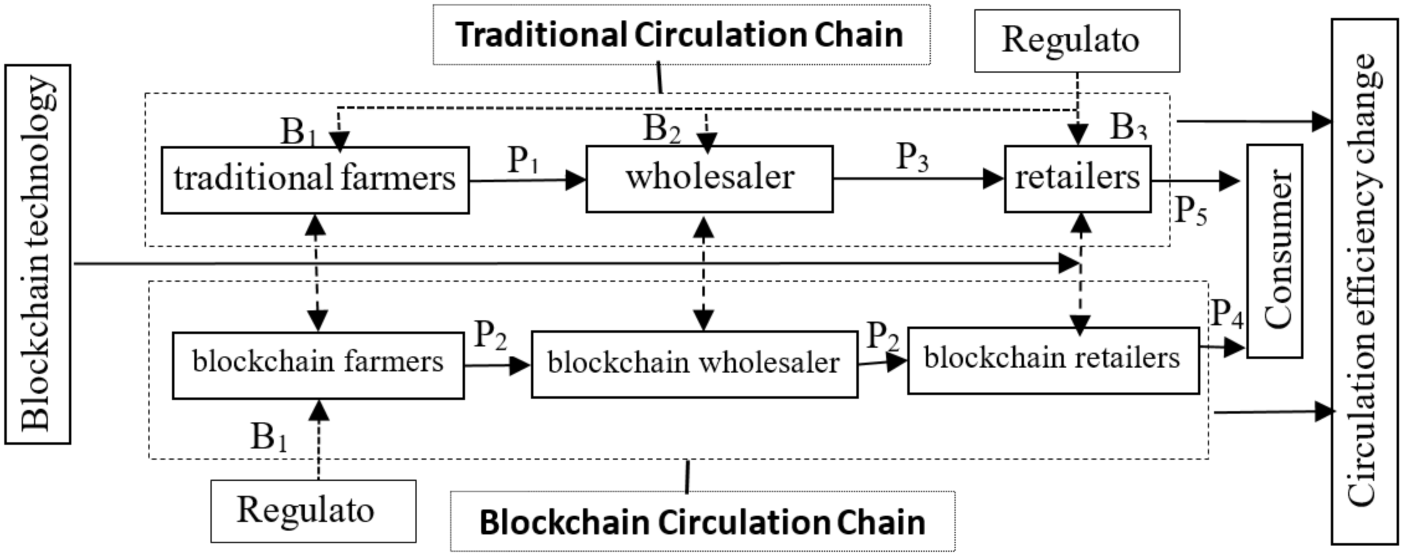

Figure 2

Frame diagram of the simulation model of agricultural product circulation system.

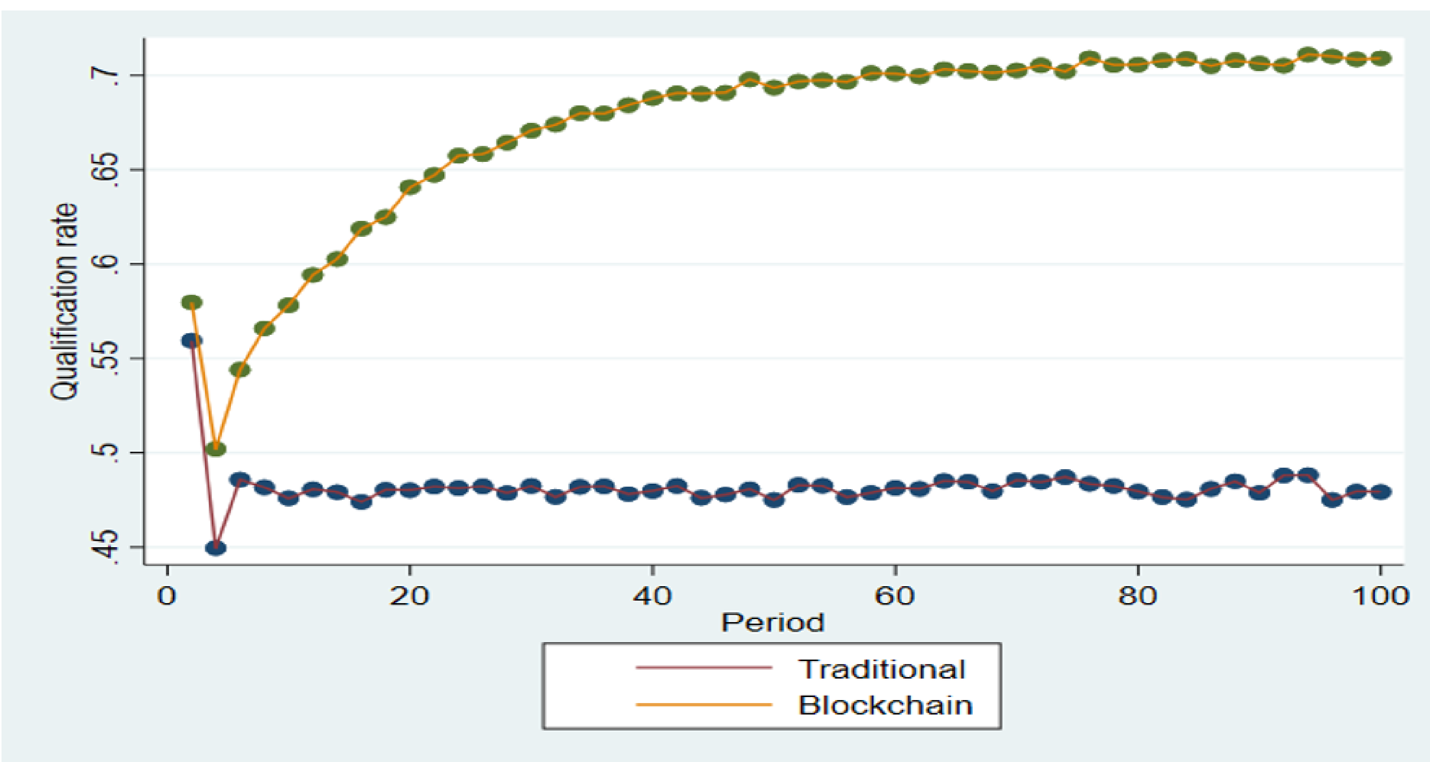

Figure 3

Qualification rate of agricultural products in blockchain circulation chain and traditional circulation chain

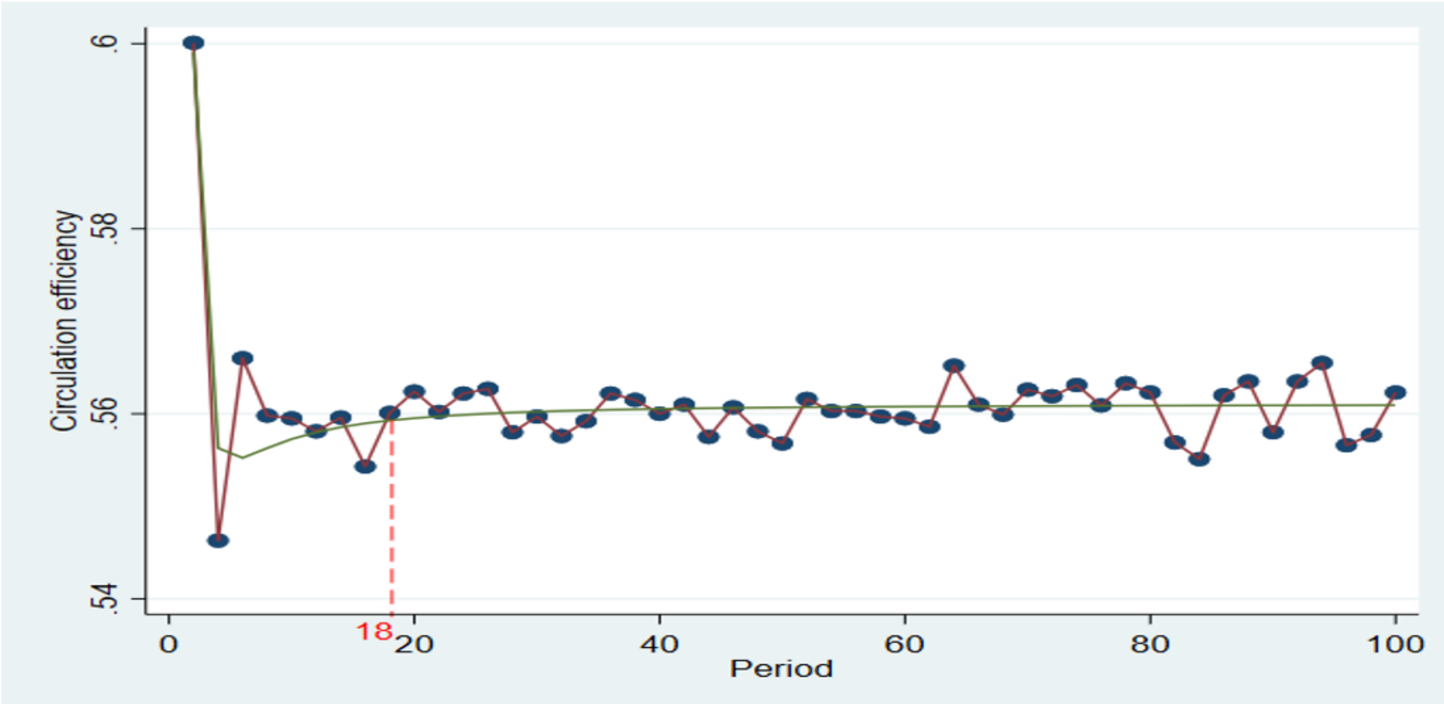

Figure 4

Circulation efficiency of agricultural products in traditional circulation chain

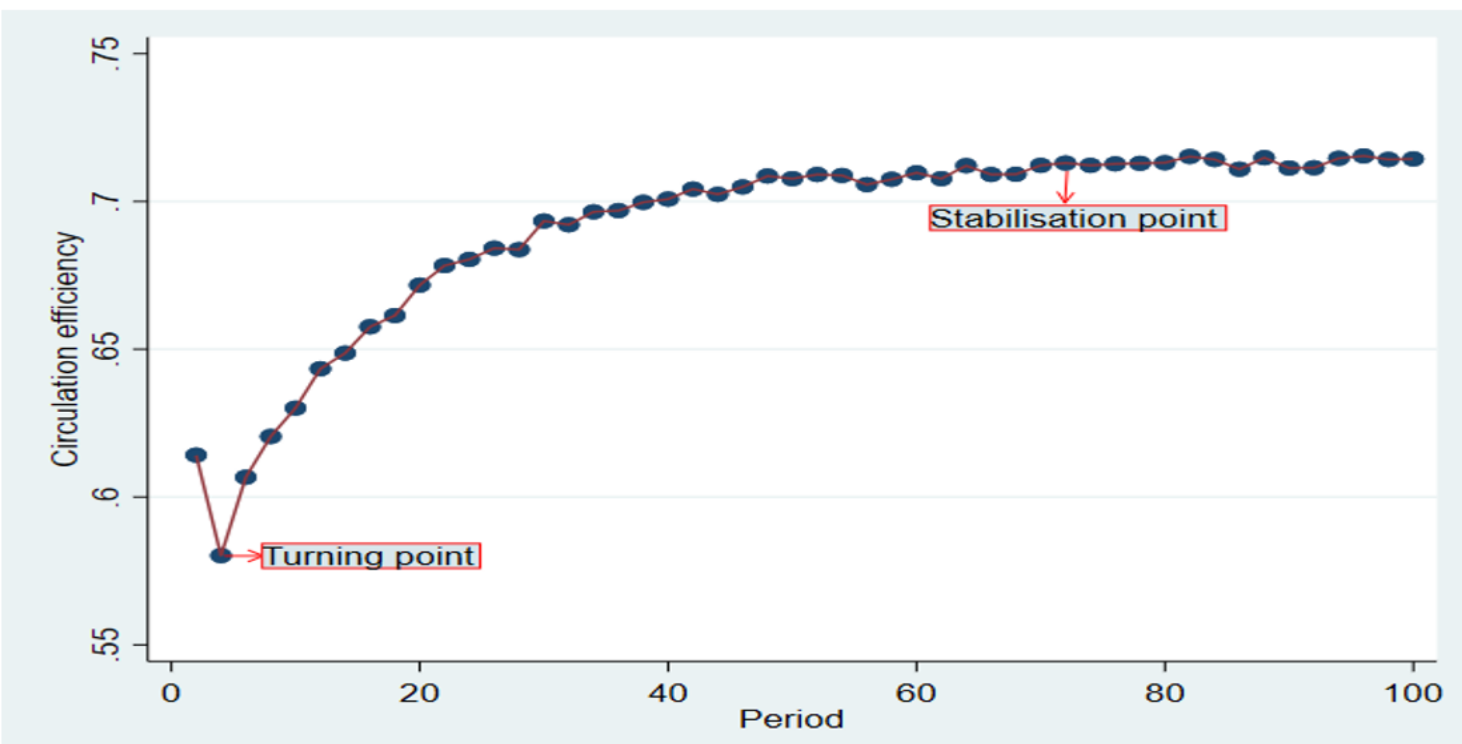

Figure 5

Circulation efficiency of agricultural products in blockchain circulation chain

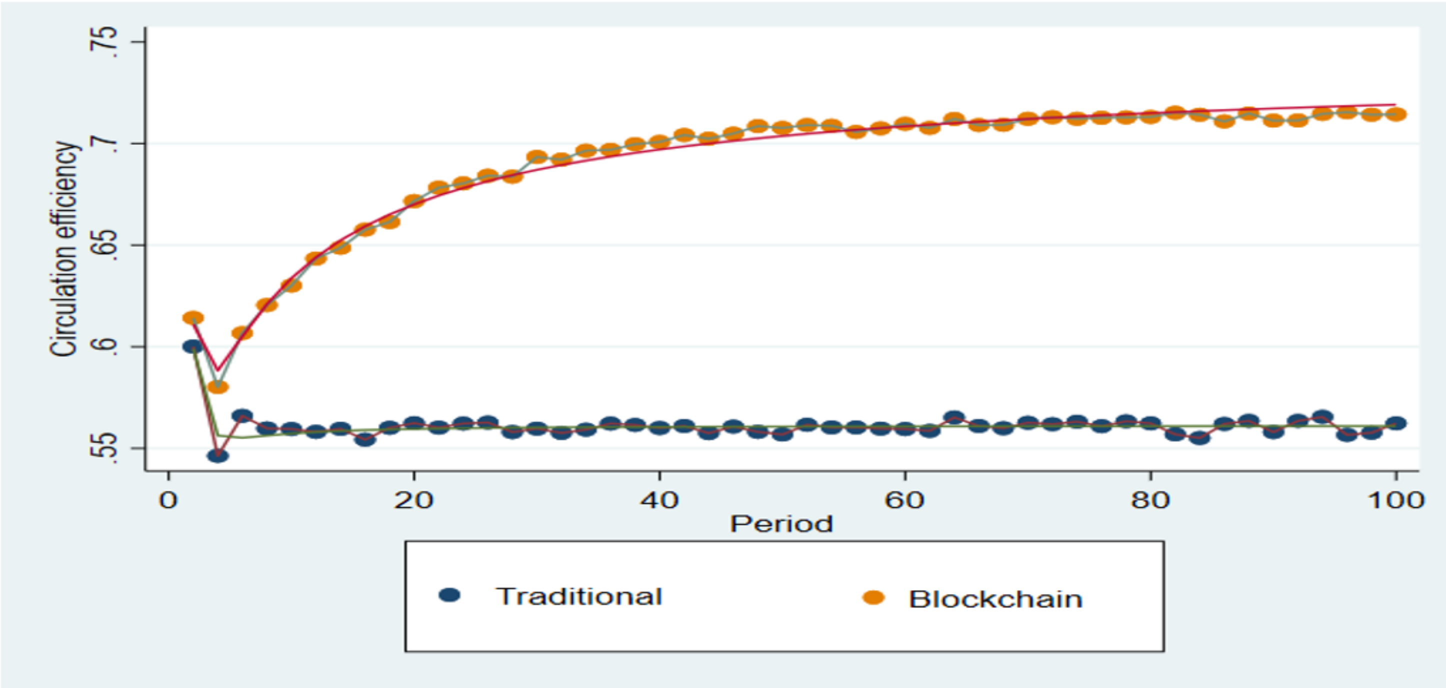

Figure 6

Circulation efficiency of blockchain circulation chain and traditional circulation chain