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Research Article

Firms' Investment Behaviours in Temperature-Controlled Supply Chain Networks

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Delivering high-quality food into markets is a vital expectation of modern customers. The significant increase in consumers' awareness of food freshness, nutrition, and safety makes the temperature-controlled supply chain (TCSC) the focus of food logistics safety. However, a large number of Chinese companies are still reluctant to invest in the food supply chain, resulting in a high rate of supply chain logistics loss. This research aims to establish an economic model to explain why these companies do not invest and under what conditions they will do. The results show that high economic investment is the main reason that hinders companies' willingness to build TCSC. Large companies with bigger production are more willing to invest in TCSC than small companies. Besides, larger companies running with high-quality products could get more profit while small companies operating with normal products are less competitive.

1. Introduction

Increased demand for cold chain products makes food logistics a vital issue for food security. China has a vast consumer population for agricultural production [1–3]. Because of the enormous demand for cold chain food, the total cold chain logistics demand reached 180 million tons in 2018. As a supply chain network connecting agricultural production and food consumption, a high-quality cold chain network can effectively transport food and raw materials between upstream companies and downstream consumers [4, 5]. Consequently, temperature-controlled supply chain (TCSC) networks that provide a series of equipment to keep food in ideal condition are adopted for food logistic and supply from production to consumption [6, 7]. TCSC has demonstrated exemplary performance in controlling food quality [8, 9], reducing food loss [10], improving health and environment [9, 11], and promoting sustainability [2]. Furthermore, many innovative technologies [12], such as smart containers, are integrated into TCSC to make it play an efficient role in the food logistics system [13–15].

China's existing TCSC cannot meet its rapidly growing demand. Although the number of agricultural companies using TCSC has increased, there are still problems such as inadequate infrastructure [16, 17], uneven distribution of cold chain infrastructure [18, 19], and lack of integrated standards [20], which causes the enormous waste of fresh agricultural products [21–23]. Considering the efficient use of resources and sustainable development, the Chinese central government issued many policies and gave subsidies to promote the TCSC [24–27]. Yet, a large quantity of companies is still reluctant to invest in the construction of TCSC due to a lack of funds, professional management, and awareness of sustainable development [28, 29]. Therefore, it is necessary to explore the reasons through economic and environmental analysis for improving comprehensive TCSC.

Previous literature mainly focuses on the construction and improvement of TCSC yet ignores the reasons why companies do not build it. Many researchers have studied the TCSC system and its optimism [8]. As a network guarantee to ensure the ideal state of food, TCSC involves coherent and complex procedures such as handling, packing, storage, and transportation [30, 31]. Furthermore, the researchers worked on optimizing the transportation route [32, 33], decision-making [34], minimizing the cost [35], reaching a supply chain network equilibrium [36], and innovative technologies [2]. Many researchers studied the behaviour in the network of upstream and downstream [37, 38]. However, the improvement of TCSC has not significantly prompted some Chinese companies to be willing to build it. Few studies in the past explained the reasons behind and explored the scenario that prompted TCSC construction.

This study aims to establish an economic model to explain why these companies do not invest and under what conditions they will do. First, we build an economic model to explain why the companies are not willing to invest in a comprehensive TCSC. Subsequently, a basic economic model with a supply chain network including producers, retailers, and consumers is adopted to generalise producers' and retailers' conditions to make the investment. Furthermore, we explore how government policies affect companies' decisions. Finally, we simulate how the companies can benefit from investment in TCSC.

2. Model Design

In this part, we simplify the TCSC into 3 layers (producers, retailers, and consumers) and 2 markets (wholesale markets where producers sell products to retailers and retail markets where retailers sell products to consumers) (Figure 1). There are millions of producers and retailers in agricultural product markets. In both markets, whether firms choose to use the TCSC network could only affect the benefit of themselves and not the market price, so we assume both wholesale market and retail market are perfectly competitive.

2.1. Producers' Behaviour and Their Conditions of Investment. Let q_i be the nonnegative production output of producer i, $c_i = c_i(q_i)$ be the production cost function of producer i, v_i be the loss rate of producers from producing to selling, and ρ_1 be the price of producers selling products to retailers. As the wholesale market is perfectly competitive, ρ_1 is constant, which means the behaviour of producers will not affect the market price.

The annual profit for producer i is

$$\rho_1 q_i(1-v_i) - c_i(q_i). \tag{1}$$

Now, assume that producers are considering to invest in TCSC. TCSC has a similar structure but a different network. One reason is that producers with temperature-controlled equipment are quite different from others, so they cannot use the original chain. We use apostrophe to denote the variables with investment.

With TCSC, let q_i' be the production of producer i, $c_{1i}' = c_{1i}'(q_i')$ be the production cost function of producer i, v_i' be the loss rate of producers from producing to selling, and ρ_1' be the price of producers selling products to retailers. Also, in order to use TCSC, producers should invest a fixed cost, denoted as $f_i'(q_i')$, and an additional variable cost, denoted as $c_{2i}' = c_{2i}'(q_i')$. In addition, we have, $q_i' = q_i$, $c_{1i}' = c_i$, $v_i' < v_i$, and $\rho_1' > \rho_1$.

Firms evaluate the profits with a time span of n years, and letting r be the discount rate, we could conclude producers' profit of no investment as

$$\pi_i = \sum_{t=0}^{n} \frac{\rho_1 q_i(1-v_i) - c_i(q_i)}{(1+r)^t} = [\rho_1 q_i(1-v_i) - c_i(q_i)] \frac{(1+r)^n - 1}{r(1+r)^{n-1}}. \tag{2}$$

Also, producers' profit of investment is

$$\pi_i' = \sum_{t=0}^{n} \frac{\rho_1' q_i'(1-v_i') - c_{1i}'(q_i') - c_{2i}'(q_i')}{(1+r)^t} - f_i'(q_i') = [\rho_i' q_i'(1-v_i') - c_{1i}'(q_i') - c_{2i}'(q_i')] \frac{(1+r)^n - 1}{r(1+r)^{n-1}} - f_i'(q_i'). \tag{3}$$

Producers will choose TCSC only when $\pi_i' \geq \pi_i$. As a result, we obtain the conditions of producers investing in TCSC:

$$[\rho_1' q_i'(1-v_i') - \rho_1 q_i(1-v_i)] - c_{2i}'(q_i') \geq f_i'(q_i') \frac{r(1+r)^{n-1}}{(1+r)^n - 1}. \tag{4}$$

2.2. Retailers' Behaviour and Their Conditions of Investment. Compared with producers, retailers have a similar but a little more complex condition, since they should buy products from producers and be affected by producers' behaviours.

Let q_j be the amount of the products purchased by retailer j from producers, $c_j = c_j(q_j)$ be the cost function of retailer j, v_j be the loss rate of retailers from purchasing to selling, and ρ_2 be the price of retailers selling products to

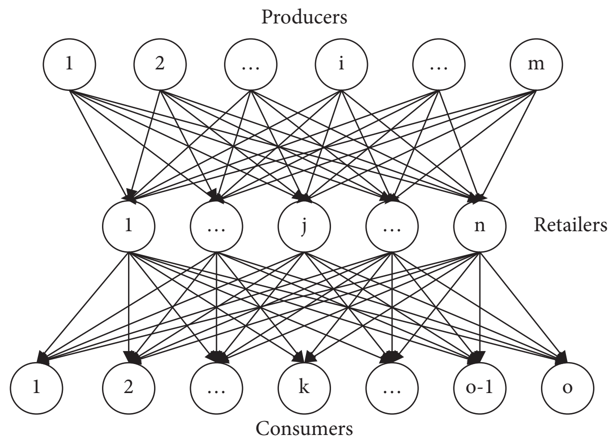

Figure 1: A simplified supply chain network including producers, retailers, and consumers.

consumers. Similarly, as the retail market is perfectly competitive, ρ_2 is also constant.

Besides operation cost, retailers should buy products from producers, so the annual profit for retailer j is

$$\rho_2 q_j\left(1-v_j\right)-c_j\left(q_j\right)-\rho_1 q_j. \tag{5}$$

Considering investment on TCSC, let q_j' be the amount of the products purchased by retailer j from producers, $c_{1j}' = c_{1j}'(q_j')$ be the cost function of retailer j, v_j' be the loss rate of retailers from purchasing to selling, and ρ_2' be the price of retailers selling products to consumers. If firms want to invest in new equipment and change into TCSC network, they should invest a fixed cost, denoted as $f_j'(q_j')$, and an additional variable cost, denoted as $c_{2j}' = c_{2j}'(q_j')$. We have $q_j' = q_j$, $c_{1j}' = c_j$, $v_j' < v_j$, and $\rho_2' > \rho_2$.

The profit of retailers in n years without investment is

$$\pi_j = \sum_{r=0}^{n} \frac{\rho_2 q_j\left(1-v_j\right)-\rho_1 q_j - c_{1j}\left(q_j\right)}{(1+r)^t} = \left[\rho_2 q_j\left(1-v_j\right)-\rho_1 q_j - c_{1j}\left(q_j\right)\right]\frac{(1+r)^n-1}{r(1+r)^{n-1}}. \tag{6}$$

Also, the profit of retailers in n years with investment is

$$\pi_j' = \sum_{t=1}^{n} \frac{\rho_2' q_j'\left(1-v_j'\right)-\rho_1' q_j' - c_{1j}'\left(q_j'\right)-c_{2j}'\left(q_j'\right)}{(1+r)^t} - f_j'\left(q_j'\right) = \left[\rho_2' q_j'\left(1-v_j'\right)-\rho_1' q_j' - c_{1j}'\left(q_j'\right)-c_{2j}'\left(q_j'\right)\right]\frac{(1+r)^n-1}{r(1+r)^{n-1}} - f_j'\left(q_j'\right). \tag{7}$$

Retailers will invest in TCSC only when $\pi_j' \geq \pi_j$, so we obtain the conditions of retailers investing in TCSC:

$$\left[\rho_2' q_j'\left(1-v_j'\right)-\rho_2 q_j\left(1-v_j\right)\right]-\left[\rho_1' q_j' - \rho_1 q_j\right]-c_{2j}'\left(q_j'\right) \geq f_j'\left(q_j'\right)\frac{r(1+r)^{n-1}}{(1+r)^n-1}. \tag{8}$$

3. Government Policies and Firms' Behaviours

To encourage firms to use TCSC, both the central and local governments in China have issued many polices. For example, the central government announced that they will subsidise some firms with no more than 20 million yuan each, not exceeding 50% of total investment in 2020. In this part, we will analyse how these policies will affect firms' behaviours.

3.1. One-Time Reward. Some local governments give rewards to firms for building cold supply chain networks, such as building cold storage and buying a freezer truck, after finishing building. Let s denote the proportion of the reward of the fixed cost. Now, the profit of investment with one-time reward for producers is

$$\pi_i^{\prime(s)} = [\rho_1' q_i' (1 - v_i') - c_{1i}'(q_i') - c_{2i}'(q_i')] \frac{(1+r)^n - 1}{r(1+r)^{n-1}} - f_i'(q_i') + s\frac{f_i'(q_i')}{(1+r)^n}. \quad (9)$$

The profit of investment with one-time reward for retailers is

$$\pi_j^{\prime(s)} = \left[\rho_2' q_j' \left(1 - v_j'\right) - \rho_1' q_j' - c_{1j}'\left(q_j'\right) - c_{2j}'\left(q_j'\right)\right] \frac{(1+r)^n - 1}{r(1+r)^{n-1}} - f_j'\left(q_j'\right) + s\frac{f_i'(q_i')}{(1+r)^n}. \quad (10)$$

Similarly, let $\pi_i^{\prime(s)} > \pi_i$ and $\pi_j^{\prime(s)} > \pi_j$, and we obtain the conditions of producers investing in TCSC with one-time reward:

$$[\rho_1' q_i' (1 - v_i') - \rho_1 q_i (1 - v_i)] - c_{2i}'(q_i') \geq f_i'(q_i') \frac{r(1+r)^{n-1} - sr(1+r)}{(1+r)^n - 1}. \quad (11)$$

Also, we obtain the conditions of retailers investing in TCSC with one-time reward:

$$\left[\rho_2' q_j' \left(1 - v_j'\right) - \rho_2 q_j \left(1 - v_j\right)\right] - \left[\rho_1' q_j' - \rho_1 q_j\right] - c_{2j}'\left(q_j'\right) \geq f_j'\left(q_j'\right) \frac{r(1+r)^{n-1} - sr(1+r)}{(1+r)^n - 1}. \quad (12)$$

3.2. Annual Subsidies. Some local governments give subsidy annually with a period lasting 3 or 5 years. Let a denote the proportion of annual subsidy and fixed investment and t_a denote the time span for subsidy. Now, the profit of investment with annual subsidies for producers is

$$\pi_i^{\prime(a)} = [\rho_1' q_i' (1 - v_i') - c_{1i}'(q_i') - c_{2i}'(q_i')] \frac{(1+r)^n - 1}{r(1+r)^{n-1}} - f_i'(q_i') + a f_i'(q_i') \frac{(1+r)^{t_a} - 1}{r(1+r)^{t_a - 1}}. \quad (13)$$

The profit of investment with annual subsidies for retailers is

$$\pi_j^{\prime(a)} = \left[\rho_2' q_j' \left(1 - v_j'\right) - \rho_1' q_j' - c_{1j}'\left(q_j'\right) - c_{2j}'\left(q_j'\right)\right] \frac{(1+r)^n - 1}{r(1+r)^{n-1}} - f_j'\left(q_j'\right) + a f_i'(q_i') \frac{(1+r)^{t_a} - 1}{r(1+r)^{t_a - 1}}. \quad (14)$$

Let $\pi_i^{\prime(a)} > \pi_i$ and $\pi_j^{\prime(a)} > \pi_j$, and we obtain the condition of producers investing in TCSC with governments' annual subsidies:

$$[\rho_1' q_i' (1 - v_i') - \rho_1 q_i (1 - v_i)] - c_{2i}'(q_i') \geq f_i'(q_i') \frac{r(1+r)^{n-1}}{(1+r)^n - 1} - a f_i'(q_i') \frac{\left[(1+r)^{t_a} - 1\right] r(1+r)^{n-1}}{r(1+r)^{t_a - 1}\left[(1+r)^n - 1\right]}. \quad (15)$$

Also, we obtain the condition of retailers investing in TCSC with governments' annual subsidies:

$$\left[\rho_2' q_j'\left(1 - v_j'\right) - \rho_2 q_j\left(1 - v_j\right)\right] - \left[\rho_1' q_j' - \rho_1 q_j\right] - c_{2j}'\left(q_j'\right) \geq f_j'\left(q_j'\right)\frac{r\left(1 + r\right)^{n-1}}{\left(1 + r\right)^n - 1} - a f_i'\left(q_i'\right)\frac{\left[\left(1 + r\right)^{t_a} - 1\right] r\left(1 + r\right)^{n-1}}{r\left(1 + r\right)^{t_a - 1}\left[\left(1 + r\right)^n - 1\right]}. \quad (16)$$

4. Simulation and Analysis

To evaluate the model, we use simulation data to see how the results will change with different parameters. Table 1 gives the values of different parameters. Now, we evaluate the decisions of firms with different scales and different return period.

4.1. Decision-Making with Different Return Periods. At first, fixing firms' scale as constant, $q_i = q_i' = 50,000\,\text{kg}$, and $q_j = q_j' = 300,000\,\text{kg}$, the time is independent, and we have

$$\begin{aligned}
\pi_i &= \left[\rho_1 q_i\left(1 - v_i\right) - c_i\left(q_i\right)\right]\frac{\left(1 + r\right)^n - 1}{r\left(1 + r\right)^{n-1}} = 55,000^* \frac{\left(1.04^n - 1\right)}{0.04^* 1.04^{n-1}}, \\
\pi_i' &= \left[\rho_1' q_i'\left(1 - v_i'\right) - c_{1i}'\left(q_i'\right) - c_{2i}'\left(q_i'\right)\right]\frac{\left(1 + r\right)^n - 1}{r\left(1 + r\right)^{n-1}} - f_i'\left(q_i'\right) = 110,000^* \frac{\left(1.04^n - 1\right)}{0.04^* 1.04^{n-1}} - 200,000, \\
\pi_j &= \left[\rho_2 q_j\left(1 - v_j\right) - \rho_1 q_j - c_{1j}\left(q_j\right)\right]\frac{\left(1 + r\right)^n - 1}{r\left(1 + r\right)^{n-1}} = 300,000^* \frac{\left(1.04^n - 1\right)}{0.04^* 1.04^{n-1}}, \\
\pi_j' &= \left[\rho_2 q_j'\left(1 - v_j'\right) - \rho_1 q_j' - c_{1j}'\left(q_j'\right) - c_{2j}'\left(q_j'\right)\right]\frac{\left(1 + r\right)^n - 1}{r\left(1 + r\right)^{n-1}} - f_j'\left(q_j'\right) = 405,000^* \frac{\left(1.04^n - 1\right)}{0.04^* 1.04^{n-1}} - 300,000.
\end{aligned} \quad (17)$$

Figures 2 and 3 demonstrate the profits changing with time for increasing of investment and no investment for producers and retailers. Let $\pi_i = \pi_i'$, and we can obtain the intersection $n = \log_{(26/25)}(143/123) \approx 3.84$ for producers and similarly $n = \log_{(26/25)}(91/81) \approx 2.97$ for retailers. It means that producers with a production of 50,000 kg/year will invest in TCSC if they hope to recover investment and get more profit within 4 or more years and retailers with a production of 300,000 kg/year will invest in TCSC if they hope to recover investment and get more profit within 3 or more years.

4.2. Decision-Making with Different Scales for Fixed Return Period. Now, fixing time as constant $n = 6$, the firms' production is independent, and we have

$$\begin{aligned}
\pi_i &= \left[\rho_1 q_i\left(1 - v_i\right) - c_i\left(q_i\right)\right]\frac{\left(1 + r\right)^n - 1}{r\left(1 + r\right)^{n-1}} \approx 6.00 q_i, \\
\pi_i' &= \left[\rho_1' q_i'\left(1 - v_i'\right) - c_{1i}'\left(q_i'\right) - c_{2i}'\left(q_i'\right)\right]\frac{\left(1 + r\right)^n - 1}{r\left(1 + r\right)^{n-1}} - f_i'\left(q_i'\right) \approx 12.00 q_i' - 200000, \\
\pi_j &= \left[\rho_2 q_j\left(1 - v_j\right) - \rho_1 q_j - c_{1j}\left(q_j\right)\right]\frac{\left(1 + r\right)^n - 1}{r\left(1 + r\right)^{n-1}} \approx 5.45 q_j, \\
\pi_j' &= \left[\rho_2' q_j'\left(1 - v_j'\right) - \rho_1' q_j' - c_{1j}'\left(q_j'\right) - c_{2j}'\left(q_j'\right)\right]\frac{\left(1 + r\right)^n - 1}{r\left(1 + r\right)^{n-1}} - f_j'\left(q_j'\right) \approx 7.36 q_j' - 300000.
\end{aligned} \quad (18)$$

Table 1: Data used to simulate the benefits change with variables of different values.

Variables	Value	Variables	Value
$\mathbf{q_i}$	50,000 kg	q_i'	50,000 kg
$\mathbf{v_i}$	0.15	v_i'	0.10
ρ_1	6 yuan/kg	ρ_1'	8 yuan/kg
$\mathbf{c_i}$	4 yuan/kg	c_{1i}'	4 yuan/kg
$\mathbf{f_i'}$	200,000 yuan	c_{2i}'	1 yuan/kg
$\mathbf{q_j}$	300,000 kg	q_j'	300,000 kg
$\mathbf{v_j}$	0.1	v_j'	0.05
ρ_2	10 yuan/kg	ρ_2'	13 yuan/kg
$\mathbf{c_j}$	2 yuan/kg	c_{1j}'	2 yuan/kg
$\mathbf{f_j'}$	300,000 yuan	c_{2j}'	1 yuan/kg
$\mathbf{r}$	0.04		

Figures 4 and 5 demonstrate the profits changing with different firms' scales for producers and retailers of investment and no investment. Let $\pi_i = \pi_i'$, then we can obtain the intersection $q_i = q_i' \approx 33350$; let $\pi_j = \pi_j'$, then we can obtain $q_j = q_j' \approx 157221$. It means that if producers want to get more profits within 6 years, they should have a production bigger than 33350 kg/year and if retailers want to get more profits within 6 years, they should have a production bigger than 157221 kg/year.

4.3. One-Time Reward from the Government. We use different values of s to calculate the changing situations of profits. Let $s = 0.1$, 0.3, 05. The profits of investment with one-time reward for producers and retailers are

$$\begin{aligned}\pi_i^{'(s)} &= \left[\rho_1' q_i'(1-v_i') - c_{1i}'(q_i') - c_{2i}'(q_i')\right]\frac{(1+r)^n-1}{r(1+r)^{n-1}} - f_i'(q_i') + s\frac{f_i'(q_i')}{(1+r)^n},\\ \pi_j' &= \left[\rho_2' q_j'(1-v_j') - \rho_1' q_j' - c_{1j}'(q_j') - c_{2j}'(q_j')\right]\frac{(1+r)^n-1}{r(1+r)^{n-1}} - f_j'(q_j') + s\frac{f_i'(q_i')}{(1+r)^n}.\end{aligned} \tag{19}$$

Figures 6 and 7 demonstrate the profits of producers and retailers with different rewards. For both producers and retailers, with increase in rewards, the profits increase and the intersections decrease. We can conclude that if governments give more rewards, more firms will choose to invest in TCSC.

4.4. Annual Subsidies from the Government. Let $a = 0.1$ and $t_a = 3, 4, 5$. Now, the profits of investment with annual subsidies for producers and retailers are

$$\begin{aligned}\pi_i^{'(a)} &= \left[\rho_1' q_i'(1-v_i') - c_{1i}'(q_i') - c_{2i}'(q_i')\right]\frac{(1+r)^n-1}{r(1+r)^{n-1}} - f_i'(q_i') + a f_i'(q_i')\frac{(1+r)^{t_a}-1}{r(1+r)^{t_a-1}},\\ \pi_j^{'(a)} &= \left[\rho_2' q_j'(1-v_j') - \rho_1' q_j' - c_{1j}'(q_j') - c_{2j}'(q_j')\right]\frac{(1+r)^n-1}{r(1+r)^{n-1}} - f_j'(q_j') + a f_i'(q_i')\frac{(1+r)^{t_a}-1}{r(1+r)^{t_a-1}}.\end{aligned} \tag{20}$$

Figures 8 and 9 show the profits of producers and retailers with the change of different subsidy period. Also, with more subsidies, both producers' and retailers' profits increase and the intersections decrease. We can conclude that if governments give annual subsidies for a longer period, more firms will choose to invest in TCSC.

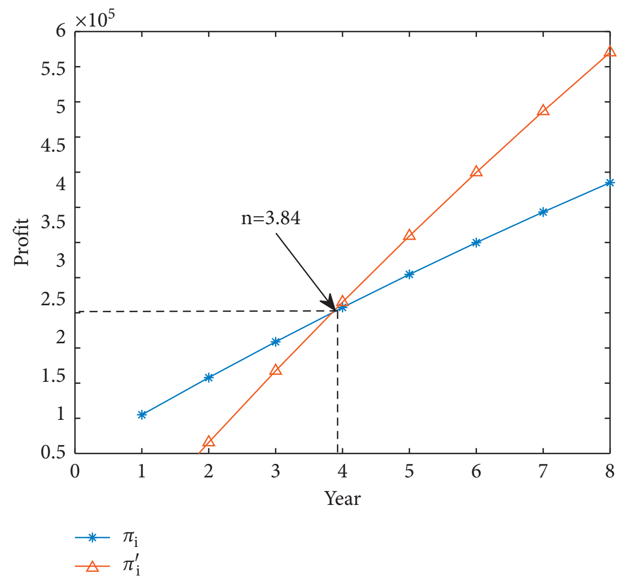

Figure 2: Profits of producers with $q_i = q'_i = 50,000$.

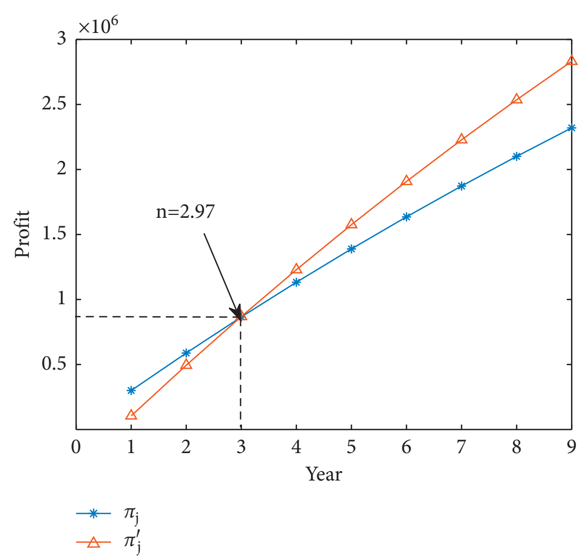

Figure 3: Profits of retailers with $q_j = q'_j = 300,000$.

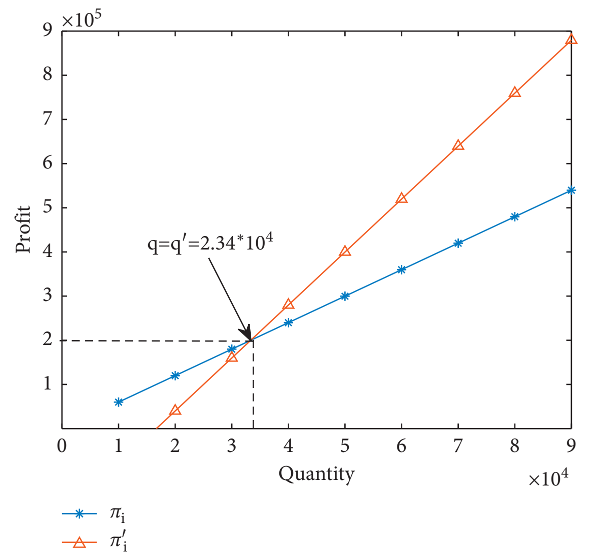

Figure 4: Profits of producers with different scales when $n = 6$.

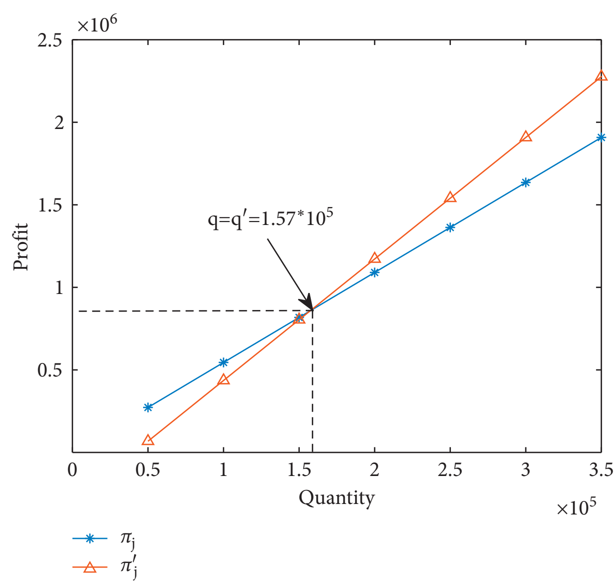

Figure 5: Profits of retailers with different scales when $n = 6$.

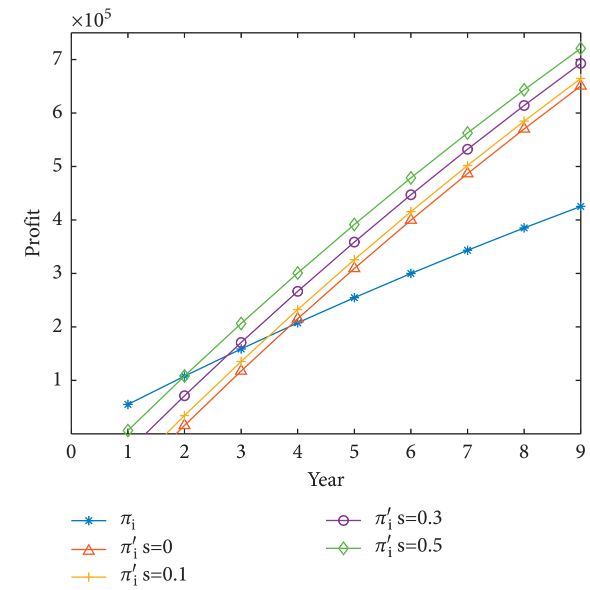

Figure 6: Profits of producers with $q_i = q_i' = 50,000$ and $s = 0,\ 0.1, 0.3, 0.5$.

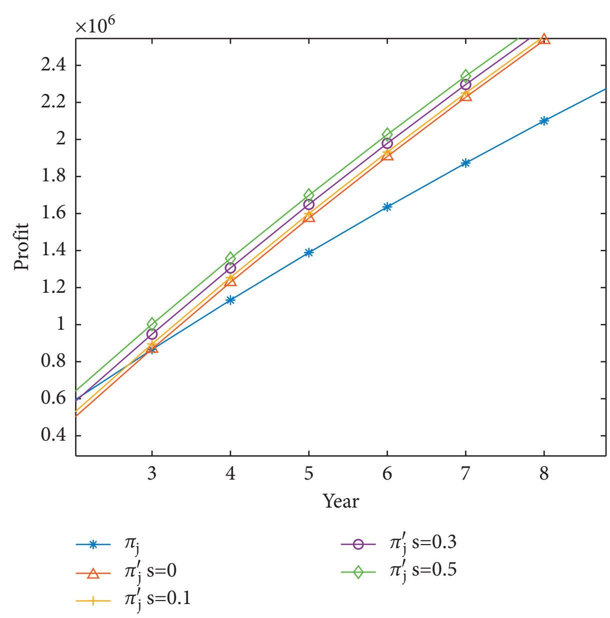

Figure 7: Profits of retailers with $q_j = q_j' = 300,000$ and $s = 0, 0.1, 0.3, 0.5$.

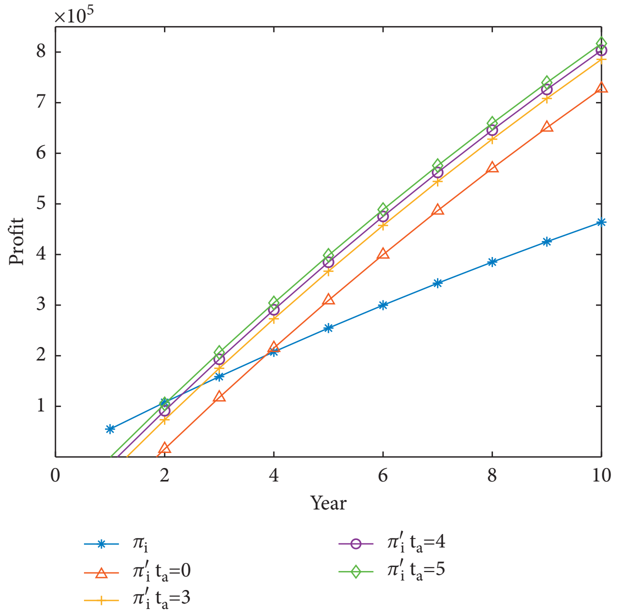

FIGURE 8: Profits of producers with $q_i = q_i' = 50,000$ and $t_a = 0, 3, 4, 5$.

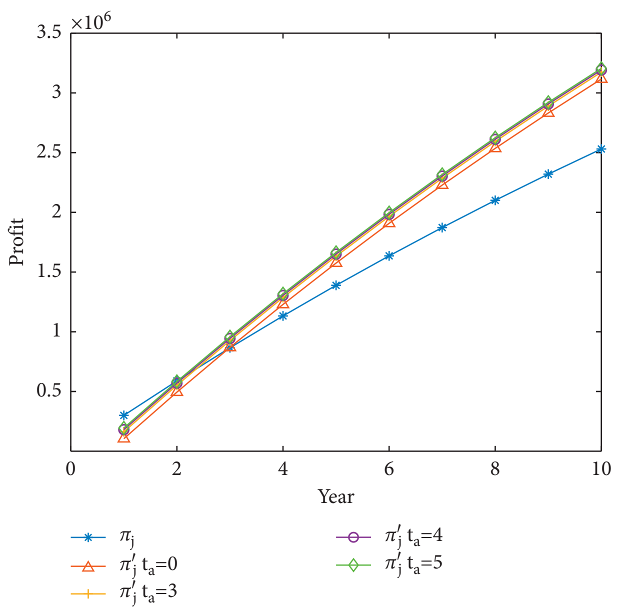

FIGURE 9: Profits of retailers with $q_j = q_j' = 300,000$ and $t_a = 0, 3, 4, 5$.

5. Conclusions

The TCSC is a necessary part for logistics to deliver food from producers to consumers. Besides improving the technologies of TCSC, studying firms' behaviours is also of great meaning. This paper has built an economic model to give explanations about why and when firms will choose to invest in TCSC. In general, firms with greater production tend to invest more in new equipment to get additional benefits. This will result in market segmentation, where bigger firms running with high-quality products get more profit and smaller firms running with normal products are less competitive relatively.

There are still some parts that need to be improved. At first, we assume that both wholesale market and retail market are perfect competitive. With more and more firms choose to run with TCSC, the market price will be affected, and the assumption that both market prices are constant is too strict in a long run. Second, when considering the time span, we think prices will not change in different years, but food prices are always fluctuating. In some years, for some varieties, prices may even fluctuate heavily. The evaluation will become more complicated if we take this into account. Third, while doing the simulation, only some numbers are used to assess the model. It would be better if we do the simulation with a specific variety such as banana or cabbage.

Firms' behaviours are not affected only by economic benefits. In fact, every player in the supply chain networks will have influence. When considering the behaviours of competitors and collaborators, producers and retailers will be faced with a more complex situation. How to maximize their profits needs further discussion. Also, the Chinese government has issued policies supporting food cold chain logistics. Different policies give firms more choices, and how to maximize their profits will need more research.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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