

Simulation of Food Supply Chain Management

Puqing Wang

College of Economics and Management, Wuhan Polytechnic University

Hang Xiong

School of Sociology, University College Dublin

Model overview

The framework of the model consists of many agents classified as follows:

- (1) n farmer agents;
- (2) m wholesaler agents;
- (3) x regulator agents.

There are n farmers in a food production base, and each farmer produces s units food. The product can be safe or unsafe and it depends on the farmer's production decision. In view of the safety-related credence attributes of product that cannot be directly observed and is difficult to measure, i.e., here is a problem of information asymmetry. Thus the wholesaler cannot distinguish the safe attribute of products.

At an food wholesale market, there are m wholesalers that deal with farmers. Corresponding to the above supply chain modes, spot market mode is that non-contractual wholesalers make transactions with non-contractual farmers stochastically. Contract transaction mode is that contractual wholesalers make contracts with certain farmers building fixed transaction relationship. Moreover, both modes can be converted to each other under certain conditions. Different types of agent are defined as below.

Farmer agent

A farmer produces a number of safe or unsafe food and sell them to one of wholesalers. The farmer's goal is to try to gain more profit. The attributes of a farmer are farmer's identification (contractual farmer or non-contractual farmer), honesty

value, wealth value, and transformational threshold. Behavior decision of the farmer is given as following.

Decision on honesty

Each farmer has a level of honesty to indicate his ability to resist the shock of benefit produced by the gap between expected returns of producing safe food and producing unsafe food. The decision of honesty is built as a function of farmers' experience. The following formulas show honesty updating as a function of farmer's experience under different situations.

$$\begin{cases} honesty_{t+1} = (1 - d^+)honesty_t + d^+minimal_honesty & (1) \\ honesty_{t+1} = (1 - d^-)honesty_t + d^- & (2) \end{cases}$$

where $honesty_t$ represent the value of honesty after t times of transaction. If the value of $honesty$ is equal to 0, it represents farmer's choice is complete dishonesty. If the value of $honesty$ is equal to 1, it represents farmer's choice is complete honesty. The parameters d^+ and d^- ($0 < d^+ < 1$, $0 < d^- < 1$, $d^- > d^+$) are impact factors of positive and negative experience respectively¹. The parameter $minimal_honesty$ ($0 < minimal_honesty < 1$) defines the minimal level of honesty. The updating model is simplified based on the assumption that the most recent experience has the stronger influence, namely, short memory. It also represents that a negative experience has stronger influence than a positive experience, which is endowment effect.

Decision on production

The farmer's productive decision mainly depends on three parts: economic benefits comparison, random factors and $honesty$. The following expresses the production decision.

$$\lambda k_i + (1 - \lambda) \rho > honesty \quad (3)$$

If such inequality is satisfied, the farmer produces a certain number of unsafe products, otherwise the farmer produces a certain number of safe products. Where λ is the weight set in the interval (0, 1); ρ is a random number ($0 < \rho < 1$); k is a normalized value which is given based on the gap between expected returns by safe producing

¹ Negative experiences are in some situation that the farmer or one of the neighbors is found out that products fail to pass the quality safety standards, and vice versa.

and unsafe producing².

Decision on product sale

The farmer sells the products to the wholesaler after production, and makes a profit that equals to total revenue minus total cost. Where the revenue is the sales revenue from the market, and the cost includes the production cost and the fine if farmer's cheating is found. Furthermore, the profit changes the farmer's wealth. We assume that each farmer sell all products regardless of the safety of the products, and there is a uniform transaction price (p_I) produced when the transaction between a farmer and a wholesaler happens³.

$$p_I(t) = \lambda c_s + (1-\lambda)c_I + \varepsilon(t) \quad (4)$$

$$\varepsilon(t) \sim N(\mu, \sigma^2)$$

The first parameter c_s is the cost of safe production. The second parameter c_I is the cost of unsafe production. The third parameter $\varepsilon(t)$ is a random real number following normal distribution, and it reflects fluctuations in the market.

Each farmer can decide whether to make contract with the wholesaler. If the farmer make contract with the wholesaler, the farmer will become a contract farmer, and vice versa. With regard to the non-contract farmers, they sell their products to the nearest non-contract wholesalers. Any farmer who produces unsafe products would be fined if the farmer is inspected. It will change the farmer's value of honesty. It is similar to the non-contract farmers, the contract farmers sell their products to certain wholesalers who have contracted with them. The contract farmer's fine mainly derives from two aspects: inspections of the government regulator and investigating and tracing of the contractual wholesaler. In this paper, we assume that the contract wholesaler could find the contract farmers who produce unsafe products⁴ and the contract wholesaler can easily know these products that cannot pass the test based on

² If one is a non-contractual farmer($i=1, k_i=k_1$), $k_1 = (c_s - c_I f_1 \theta_1 / n_1) / (c_s - c_I)$; if one is a contractual farmer($i=2, k_i=k_2$), $k_2 = [c'_s - c_I f_1 \theta_1 / n_1 - f_3 \alpha \theta_2 / m_1 b s + (f_1 + f_3) \alpha \theta_1 \theta_2 / n_1 m_1 b s] / (c'_s - c_I)$.

³ The assumption is that the market environment between farmers and wholesaler is more approximate to the condition of complete competition. Meanwhile the presence of adverse selection due to asymmetry of information leads to market failure, which can not reflect the principle of good quality and high price.

⁴ Contrary to the contractual wholesaler, the non-contractual wholesaler could not find the farmers who produce unsafe products because of random transaction and a large number of trading partners(non-contractual farmers). Therefore, the non-contractual farmer's fine only derives from government regulator inspections.

quality safety standards. Farmer's profit are given as below.

■ The non-contract farmer's profit

There are three situations for non-contract farmers.

(1) When the farmer produces unsafe products and is not inspected by government, the profit is: $\varphi_1 = s(p_l - c_l)$.

(2) When the farmer produces unsafe products and fails to pass the inspection, the profit is: $\varphi_2 = s(p_l - c_l - f_l)$.

(3) When the farmer produces safe products, the profit is: $\varphi_3 = s(p_l - c_s)$.

■ The contract farmer's profit

There are many situations for contract farmer.

(1) When the farmer produces unsafe products and transaction price between farmer and wholesaler is more than minimum protective price ($p_l \geq p_r$), the profit is:

① $\pi_1 = s(p_l - c_l)$, if the farmer is not fined;

② $\pi_2 = s(p_l - c_l - f_l)$, if the farmer does not pass the inspection conducted by the government;

③ $\pi_3 = s(p_l - c_l - f_3)$, if the farmer is fined by one's own contract wholesaler;

④ $\pi_4 = s(p_l - c_l - f_l - f_3)$, if the farmer is fined by the government and his contract wholesaler.

(2) When the farmer produces safe products and ($p_l \geq p_r$), the profit is:

$\pi_5 = s(p_l - c'_s)$.

(3) When the farmer produces unsafe products and ($p_l < p_r$), the profit is:

① $\pi_6 = s(p_r - c_l)$, if the farmer is not fined;

② $\pi_7 = s(p_r - c_l - f_l)$, if the farmer does not pass the inspection conducted by the government;

③ $\pi_8 = s(p_r - c_l - f_3)$, if the farmer is fined by his contract wholesaler;

④ $\pi_9 = s(p_r - c_l - f_l - f_3)$, if the farmer is fined by the government and the contract wholesaler.

(4) When the farmer produces safe products and ($p_l < p_r$), the profit is:

$\pi_{10} = s(p_r - c'_s)$.

Decision on transformation

Considering the learning capacity in this model, farmers can learn and imitate from each other. If the non-contract farmer's profit is less than the average profit of his neighbors who are contract farmers, he would transform into a contract farmer under certain conditions. Otherwise, the non-contract farmer's identification remains the same. The contract farmer is in the similar situation. If the contract farmer's profit is less than the average profit of his neighbors who are non-contract farmers, the contract farmer would transform into a non-contract farmer under certain conditions. Otherwise, the contract farmer will continue the contract with wholesalers. More specifically, such transformation can be considered with three conditions. Firstly, the different types of farmers coexist simultaneously in one term. Secondly, the farmer need to take fully into account the benefit and the cost of the transformation. The last thing is transforming threshold (g) which can be regared as a transforming trigger when the difference of the benefit between two types of farmers is more than a certain value. The following formula expresses the transformation decision.

$$\lambda(\pi'_i - \pi_i) / \pi'_i + (1-\lambda) \rho > g \quad (5)$$

where π_i is farmer(i)'s profit, and π'_i is the average profit of his neighbors who are different type of farmers; parameter λ is weight set in the interval (0, 1); parameter ρ is a random number ($0 < \rho < 1$); g is the transforming threshold. If such inequality (5) is satisfied, the farmer would change from one type to another, otherwise the farmer remains the same.

Each farmer has his own transforming threshold that is varing under different conditions. It implies farmers' adaptability to the environment. The farmer's transforming threshold updates according to the formulas as below.

$$\begin{cases} g_{t+1} = (1 - s_1^+)g_t + s_1^+ & (6) \\ g_{t+1} = (1 - s_1^-)g_t & (7) \\ g_{t+1} = (1 - s_2^+)g_t + s_2^+ & (8) \\ g_{t+1} = (1 - s_2^-)g_t & (9) \end{cases}$$

where the parameters s_1^+ and s_2^+ are impact factors of the positive experience, and s_1^-

and s_2^- are impact factors of the negative experience⁵. The value of these parameters is ranged from 0 to 1 and follows $s_2^- > s_1^- > s_1^+ > s_2^+$.

Wholesaler agent

A wholesaler purchases products from farmers with different ways, and sell them to those downstream customer in the supply chain, such as wet market, supermarket and so on. The wholesaler's goal is to gain more profit. The attributes of a wholesaler are contract status (non-contracted or contracted), wealth value, and transforming threshold. The behavior decision of the wholesaler follows the rules as below.

Decision on product sale

The wholesaler sells the products to the downstream of supply chain after purchase, and makes a profit that equals to the total revenue minus the total cost. Where the revenue is sales revenue from market, and the cost is the purchasing cost and the fine part. Furthermore, the profit makes the wholesaler's wealth changing. We assume that each wholesaler sells out all products regardless of the safety of the products, and there is a uniform transaction cost (p_2) produced when the transaction between the wholesaler and the downstream customer is done.

$$P_2(t) = P_1(t)(1+\delta) \quad (10)$$

Parameter δ is real number set in the interval (0, 1). p_2 fluctuates according to p_1 on certain scale.

Any wholesaler who has unsafe products would be fined if the wholesaler's products is inspected at a random occasion. With regard to the contract wholesalers, they make contract with contract farmers and provide minimum protective price (p_r). When market price p_1 is higher than the protective price, the purchasing price fluctuates along with the market changes; when market price p_1 is lower than protective price, the purchasing price is protective price. Farmer's profit are given as below.

⁵ The parameter s_1^+ is in the situation that the farmer's profit (π_i) is more than the average profit of one's neighbors (π_i'), and the farmer is not fined; s_2^+ is for the contractual farmer in the situation that $\pi_i > \pi_i'$ and the farmer is fined by the own contractual wholesaler; s_1^- is in the situation that $\pi_i < \pi_i'$ and the farmer is not fined; s_2^- is in the situation that $\pi_i < \pi_i'$ and the farmer is fined by the own contractual wholesaler.

■ The non-contract wholesaler's profit

There are two situations for non-contract farmer.

(1) When the wholesaler is not inspected by government, the profit is:

$$v_1 = bs (p_2 - p_1).$$

(2) When the wholesaler does not pass the inspection, the profit is:

$$v_2 = bs (p_2 - p_1 - f_2).$$

■ The contract wholesaler's profit

There are many situations for contract wholesaler.

(1) When $p_1 \geq p_r$, the profit is:

① $u_1 = bs (p_2 - p_1)$, if the wholesaler is not fined;

② $u_2 = bs (p_2 - p_1 - f_2) - c_i + sq f_3$, if the wholesaler is fined by the government.

Where q is the number of contract farmers who are inspected by their contract wholesalers.

(2) When $p_1 < p_r$, the profit is:

① $u_3 = bs (p_2 - p_r)$, if the wholesaler is not fined;

② $u_4 = bs (p_2 - p_r - f_2) - c_i + sq f_3$, if the wholesaler is fined by the government.

Decision on tracing and punishing

For the non-contract wholesalers, they cannot find out those farmers who produce unsafe products if their products are failed to meet the quality safety standards under the inspection, because they stochastically transact with some of the large number of small-scale farmers in market. Consequently, the non-contract wholesalers would bear the fine from the government. In contrast, the contract wholesalers can find out those farmers who produce unsafe products if the product inspection is not passed. Contract wholesalers build up a stable transaction relationship with their farmers. Moreover, most of them are familiar with each other and the trust between the wholesalers and farmers could be more easily constructed, especially with the increasing times of their transaction from term to term. We assume that the contract wholesaler could find the contract farmers who produced unsafe products by all means (such as traceability system, field management and certification). When the contract wholesaler is fined,

he would conduct an investigation about the unsafe products at a cost (c_i), and punish those contract farmers in default. The punishment is fine in the form of deposit (f_3) that the contract farmer have paid in advance, and it would have an impact on the honesty of the contract farmers who have the same contract wholesaler.

Decision on transformation

In this model, the two types of wholesalers can learn and imitate from each other. When the non-contract wholesaler's profit is less than the average profit of the contract wholesalers, he would transform into contract wholesaler under certain conditions. Otherwise, the his contract status remains the same. So is the contract wholesaler.

In particular, the transformation can be considered if the following conditions are satisfied. First of all, the different types of wholesalers coexist in one term. Second, the wholesaler need to take fully into account the benefit and the cost of such transformation. In the end, the transforming threshold (β) is a trigger for them to change the contract status if the difference in benefit between both types of wholesalers is more than a certain value. The following formula expresses the decision of wholesalers' transformation.

$$\lambda(u'_i - u_i) / u'_i + (1 - \lambda) \rho > \beta \quad (11)$$

Where u_i is wholesaler(i)'s profit, and u'_i is the average profit of the wholesalers who are different type of wholesalers; parameter λ is weight set in the interval (0, 1); parameter ρ is a random number ($0 < \rho < 1$); β is transforming threshold. If such inequality (11) is satisfied, the wholesaler would change from one type to another, otherwise the wholesaler will remain the same.

Regulator agent

In the model, the regulator agents are several government departments which supervise different parts of the supply chain, respectively. Here, for simplicity, we assume that one regulator agent supervise farmers and another regulator agent supervise wholesalers. The goal of government is to improve the rate of qualified products by means of sampling inspection and punishment under certain constrains.

The inspecting frequency of farmers is θ_1 , and the ratio of θ_1 to the number of farmers is the inspecting rate of farmers. The inspecting frequency of wholesalers is θ_2 , and ratio of θ_2 to the number of wholesalers is the inspecting rate of wholesalers. The sampling frequency of wholesaler's products is α . The fine on farmers is f_1 , and the fine on wholesalers is f_2 .