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Research Article

Evolutionary Games in the Agricultural Product Quality and Safety Information System: A Multiagent Simulation Approach

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This paper aims at identifying the key factors to maintain the quality and safety of agricultural products in the agricultural product quality and safety information system (APQSIS). Based on the theoretical framework of information entropy and complexity, this paper uses the dynamic evolutionary game model and the multiagent modeling and simulation to discuss the APQSIS agents' equilibrium strategies and the effects of their interactive behaviors on the APQSIS evolutionary stability with asymmetric information. The results show that the governmental supervision and intermediary organizations are significant to assuring agricultural product quality and safety (APQS) as well as the effective transmission of APQS information in stable environments with low complexity.

1. Introduction

The Chinese government has had a persistent concern about the issues of "agriculture, countryside and farmers" in the Central Committee's Document No. 1, in which the regulations of agricultural product quality and safety (APQS) have been repeatedly stressed for 12 years. The idea "instituting an agricultural product quality and safety information system (APQSIS) of full traceability" was further emphasized in the Central Committee's Document No. 1 of 2015. According to the findings of Starbird [1] and Sheriff [2], APQSIS should be considered as a complex system consisting of multiple information agents such as producers, consumers, governments, and intermediaries. The reciprocity and coordination among multiple information agents could moderate information asymmetry, assure integrity and validity of information transmission, and finally improve agricultural product quality and safety.

Some valuable results have been found in research of complex economic system. Wognum et al. [3] tried to sketch a picture of the richness, complexity, and challenges of transparency and sustainability systems, as well as their interdependencies. Ma and Guo [4] analyzed the dynamics of a duopoly Cournot game model with players having different adjustment mechanisms and expectations. These researches lay foundation of two-stage game of complex economic system and shed light on researching multiagent dynamic game. Elsadany [5] built a dynamic Cournot game with three bounded-rational players and analyzed parameters' influences on systematic stability. Ma and Wu [6] established a discrete triopoly dynamical model, which considers multiproduct firms with heterogeneous expectations. These researches show that the adaptive parameters' variation would change systematic stability but would not lead the system to chaotic states; however, the bounded-rationality parameters might cause the systematic chaos. Fanti et al. [7] discussed the dynamics of a nonlinear Cournot duopoly with managerial delegation. Su et al. [8] applied a multiple test methodology to identify the nonlinear, fractal, and chaotic characteristics in the agricultural price system. These researches demonstrate that the agricultural product circulation is somehow a complex system, which has the distinct properties such as nonlinearity, emergence, spontaneous order, and adaptation.

The evolution with dynamic stability of APQSIS seems to be a crucial approach to assure APQS, but actually it is not. Since there is great distortion in information transmission, agents' behaviors are too difficult to coordinate and to reach evolutionary stability. So the basic issue on APQS assurance is to identify primary factors to maintain evolutionary stability by revealing the rules of agents' conduct and the rules of systematic evolution, in the context of information asymmetry. It is known that a more simple information system is conducive to APQS improvement than a complex one is. And a more complex system has greater entropy. Therefore, the entropic measurement is usually applied to evaluating the complexity of economic systems. Fan et al. [9] investigated the complexity of carbon markets by using multiscale entropy analysis method. Based on analysis of heterogeneous goods markets, Ma and Pu [10] detailed the research of the Cournot-Bertrand duopoly model with the application of nonlinear dynamics theory. Ma and Wang [11] considered a closed-loop supply chain with product recovery. These findings show that the indicated parameters should be kept in a certain range; otherwise the systems will enter chaos through flip bifurcations. Ma and Xie [12] discussed a dual-channel supply chain and found that when firms hold asymmetric channel power, as the game leader, the manufacturer could get more profit than when they hold symmetric channel power. Hong et al. [13] proposed a framework of promoting food information traceability for estimating costs and developing appropriate price strategies. Billio et al. [14] proposed a new approach based on the cross-sectional entropy of systemic risk measures and explored the forecasting abilities of entropy indicator to detect systemic events.

Along with frequent APQS accidents, the researches on APQSIS from the perspective of agent behaviors have become the mainstream in relevant researching fields. Enhancing consumer perceptions of APQS and building sane consumption concept are important to assure APQS. However, Broughton and Walker [15] considered agricultural products as public goods exhibiting externality with asymmetric information. Fares and Rouviere [16] argued that the complementation of public and private regulation would reduce food safety risk and the voluntary system would help solve APQS problems. But these researches did not design a complete incentive mechanism among each market agent nor build up an effective regulation or a coordination mechanism from the perspective of multiagent modeling.

Inspired by thermal entropy in thermodynamics, information entropy represents the disorder or uncertainty of an information system. When the information entropy of a dynamic system is quite high, it is more difficult to predict the evolutionary direction and evolutionary speed, or whether there is spontaneous order to realize self-organization in this dynamic system. Therefore, information entropy can also be regarded as a measurement of systematic orderliness. Shannon [17] gave generalized definitions of entropy and its measuring methodology. You and Wood [18] have proposed a spatial allocation model for crop production statistics based on a cross-entropy approach. Heckelei et al. [19–21] introduced a general methodological approach for the estimation of constrained optimization models and performed simulation with a maximum entropy estimator to evaluate the functionality of the approach.

In this paper, the rules of APQSIS to reach evolutionary stability are discussed within the theoretical frameworks of complex systems from the perspective of multiagent reciprocity. The evolutionary game theory is applied to analyzing the information agents' evolutionary stable strategies. Furthermore, the techniques of multiagent modeling and simulation are applied to demonstrating each agent's behavioral rules and the influences on the evolutionary stability of APQSIS. This paper might address the theoretical gap that few researches discuss and analyze the effective methods to maintain the quality and safety of agricultural products in APQSIS, from the perspective of the evolutionary game theory and applying techniques of multiagent modeling and simulation.

2. APQS Information Agents' Evolutionary Games

The producers and consumers of agricultural products are core market participants, whose transactions constitute the most basic economic relations in agricultural product markets. In order to formulate the evolutionary games among the APQSIS agents, this paper firstly analyzes the game model including 2 kinds of agents (producers and consumers) and then adds third-party agents (the government and intermediaries) into the new model. Due to information agents' bounded rationality and the uncertainty in strategy selection caused by information asymmetry, each agent chooses better strategies by constant adaptation and learning, leading evolutionary stability. Rules of reward and punishment determine the spontaneous order of APQSIS, making the evolutionary system converge to desirable or undesirable evolutionary stability. Moreover, when the proportions of participants who choose optimal strategies get below the saddle point or some parameters exceed some threshold, the evolutionary system has entirely different final equilibrium point. Therefore, the APQSIS could be seen as a complex system, which has the distinct properties such as nonlinearity, emergence, spontaneous order, and adaptation.

2.1. Agricultural Product Producer-Consumer Evolutionary Game Model. Considering the special circumstances in agricultural product market, the consumers suffer more from the asymmetric information, and the consumers' information feedback also has an impact on producers. Therefore the process of basic evolutionary game could be divided into 2 stages. The multistage producer-consumer evolutionary game model is shown in Figure 1.

In the trading stage, the integrity of information provided by producers is always difficult to ensure with asymmetric information, and the consumers need to observe the subsequence before taking specific strategies. For the customers, it is clear that the value of information entropy is high. The producers with poor credit are incentive to provide false information and attempt to sell unsafe agricultural products. So the uncertainty of agricultural products' quality is greater. For risk aversion, the consumers' strategy is to seek the

Table 1: Producer-consumer evolutionary game model I.

Producer	Consumer		
	Strategy 1: buy		Strategy 2: not buying
	Not certificated	Certificated	
Strategy 1: false information	$\lambda_i[D(1+\kappa_i)+C_i]-BD$, $-DR_0$	$\lambda_i[D(1+\kappa_i)+C_i-G]-BD$, $G-DR_0$	0, 0
Strategy 2: real information	$\lambda_i[D(\kappa_i-R(t))+C_i]-BD$, $\lambda_i D(1+R(t))-DR_0$	$\lambda_i[D(\kappa_i-R(t))+C_i]-BD$, $\lambda_i[D(1+R(t))-G]+G-DR_0$	0, 0

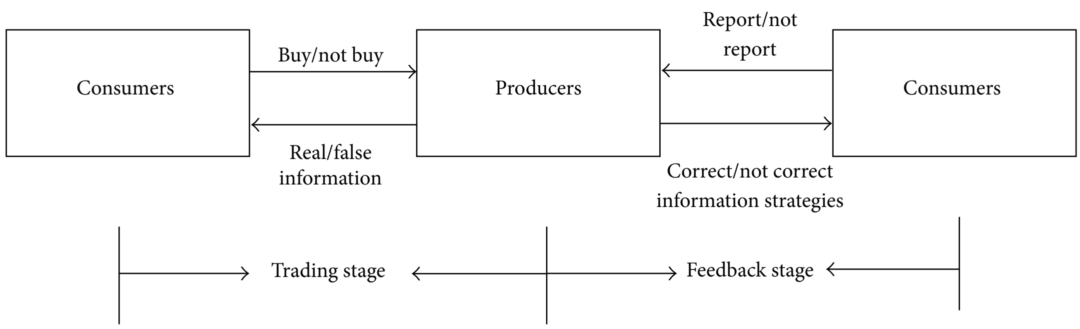


Figure 1: Multistage producer-consumer evolutionary game model.

producers providing more comprehensive information or not buy anything, based on rules of loss minimizing and utility maximizing. With the insufficient legal regulation, the producers' misconduct is extremely unlikely to be monitored, so providing false information might be the optimal choice since more sales could bring more profits. However, the consumers might report producers with misconduct to the authorities and claim reimbursement (a portion of the payment) through legal methods or buy more products at lower prices by bargaining in order to make up for previous loss. But the compromising strategies might lead consumers to the quagmire of being tricked repetitiously. According to the analysis above, the agricultural product producer-consumer evolutionary game model could be structured as follows.

2.1.1. Agricultural Product Producer-Consumer Evolutionary Game Model considering APQS Risk. When the producer E_i $(i=1,\ldots,n)$ sells a batch of agricultural products which cost D, considering generality and asymmetric information, the following hypotheses are put forward. (1) The consumers group B_i $(i=1,\ldots,n)$ could not accurately know the credit standing of producer E_i, which increases the uncertainty of the information. But they know that the average probability that these products reach the quality standard is λ_i $(0\le\lambda_i\le 1)$. The producers' rate of return is κ_i when these agricultural products are sold and it is 0 when these agricultural products are unsold. (2) The initial equity capital of the producer is C_i and the income by selling agricultural products is D $(D > C_i > 0)$, which means the equity capital could not meet the financing demand for continuous production. In addition, the marketing cost is BD. For simplification, we assume entire money to purchase goods comes from bank loans, the loaning rate is R, the loan period is t, and the capital cost rate of the consumer is R_0. (3) When the producer provides false information and gets caught, if the products are not certificated by any intermediaries and the consumer could not claim any portion of paying reimbursement, the sales earnings of the producer are D', if the products have been certificated by intermediaries and the consumer could claim a portion of payment as reimbursement which is G $(C_i > G > 0)$. Therefore the producer-consumer evolutionary game model considering APQS risk is formulated in Table 1.

According to the preceding settings of model I, there is great uncertainty and entropy in the producer-consumer evolutionary game. If group E and group B choose strategy 1, which means the proportion of producers providing false information and that of consumers purchasing agricultural products are P_1 and Q_1 ($P_1\in[0,1]$ and $Q_1\in[0,1]$), then the state $S=\{(s_1^E,s_2^E),(s_1^B,s_2^B)\}=\{(P_1,1-P_1),(Q_1,1-Q_1)\}$. Therefore the fitness (expected return) and average fitness of the producer E's strategy 1 and strategy 2 are formulated as follows.

$$\begin{aligned} f_1^E &= Q_1\{\lambda_i[D(1+\kappa_i)+C_i-G]-BD\} \\ f_2^E &= Q_1\{\lambda_i[D(\kappa_i-R(t))+C_i]-BD\} \\ \overline{f^E} &= P_1 f_1^E+(1-P_1)f_2^E. \end{aligned} \tag{1}$$

Similarly, the fitness (expected return) and average fitness of the consumer B's strategy 1 and strategy 2 are formulated as follows.

$$\begin{aligned} f_1^B &= P_1(G-DR_0) \\ &\quad +(1-P_1)\{\lambda_i[D(1+R(t))-G]+G-DR_0\} \\ f_2^B &= 0 \\ \overline{f^B} &= Q_1 f_1^B+(1-Q_1)f_2^B. \end{aligned} \tag{2}$$

Table 2: Product producer-consumer evolutionary game model II.

Producer	Consumer	
	Strategy 1: report	Strategy 2: not report
Strategy 1: false information	$\lambda_i[D(1+\kappa_i)+C_i-G]-BD-H$, $G+\lambda_i H-DR_0-U$	$\lambda_i[D(1+\kappa_i)+C_i-G]-BD$, $G-DR_0$
Strategy 2: real information	$\lambda_i[D(\kappa_i-R(t))+C_i+2H]-BD-H$, $\lambda_i[D(1+R(t))-G]+G-DR_0-U$	$\lambda_i[D(\kappa_i-R(t))+C_i]-BD$, $\lambda_i[D(1+R(t))-G]+G-DR_0$

The replicator dynamics is an explicit model of a selection process, specifying how population shares associated with different pure strategies in a game evolve over time (Weibull, 1995). If the fitness of a certain adaptive strategy or expected revenue is higher than the average fitness, the proportion that the participants choose this strategy would gradually increase in a specific population. Both groups of E and B tend to choose the strategy whose fitness exceeds the average fitness, so the replicator dynamic models of group E and group B are formulated as follows:

$$\begin{aligned}\dot{P} &= P_1\left(f_1^E-\overline{f^E}\right)=P_1\left(1-P_1\right)Q_1\lambda_i\left[D\left(1+R\left(t\right)\right)-G\right]\\ \dot{Q} &= Q_1\left(f_1^B-\overline{f^B}\right)=Q_1\left(1-Q_1\right)\cdot\left\{\lambda_i\left[D\left(1+R\left(t\right)\right)-G\right]+G-DR_0-P_1\lambda_i\left[D\left(1+R\left(t\right)\right)-G\right]\right\}.\end{aligned} \tag{3}$$

The replicator dynamic models demonstrate the evolutionary process of both the producers' and the consumers' behaviors. It is obvious that, only if $P_1=0$ or 1, or $Q_1=0$, the proportion of producers choosing strategy 1 in group E is stable; only if $Q_1=0$ or 1, or $P_1=\{\lambda_i[D(1+R(t))-G]+G-DR_0\}/\lambda_i[D(1+R(t))-G]$, the proportion of consumers choosing strategy 1 in group B is stable. Therefore model I has 5 partial equilibrium points in the plane $\{(Q_1,P_1):0\le Q_1,\ P\le 1\}$, which are E_1 (0, 0), E_2 (0, 1), E_3 (1, 0), E_4 (1, 1), and E_5 $(0,\{\lambda_i[D(1+R(t))-G]+G-DR_0\}/\lambda_i[D(1+R(t))-G])$.

2.1.2. Agricultural Product Producer-Consumer Evolutionary Game Model considering Monitoring Mechanism. According to model I, the probability that producers provide false information depends on the probability of the agricultural products being sold successfully (λ_i), subject to the certification situation, the credit standing, and other factors, of which the uncertainty is greatly increased due to the producers' characteristics of small scale, asset deficiency, and high business risk. Therefore, in order to prevent the producers from providing false information, the consumers might report producers' misconduct to monitoring departments and force them to provide the real information. In the producer-consumer evolutionary game model II, we assume consumers' reporting cost is U. If producers provide false information, they would be fined the amount of $-H$; otherwise they would be rewarded with the amount of H ($H>U$). Then the product producer-consumer evolutionary game model considering monitoring mechanism is formulated in Table 2.

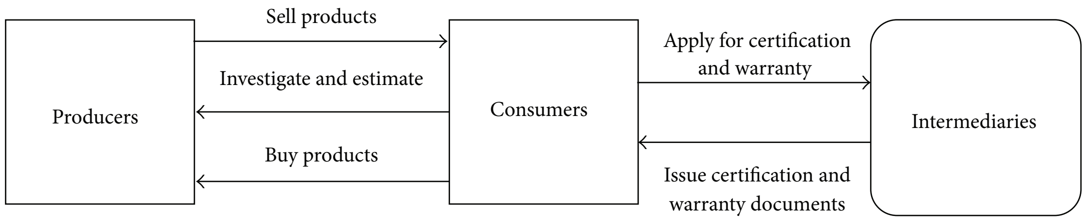
In group B, we set the proportion of the ones choosing to report the misconduct as V_1 ($V_1\in[0,1]$); then the state $S^B=(s_1^B,s_2^B)=(V_1,1-V_1)$. Similarly, the fitness (expected return) and average fitness of the group E and the group B choosing strategy 1 and strategy 2 could be calculated, and the replicator dynamic models could be formulated as follows.

$$\begin{aligned}\dot{P} &= P_1\left(f_1^E-\overline{f^E}\right)\\ &= P_1\left(1-P_1\right)\lambda_i\left[D\left(1+R\left(t\right)\right)-G-2HV_1\right]\\ \dot{V} &= V_1\left(f_1^B-\overline{f^B}\right)=V_1\left(1-V_1\right)\left(\lambda_i HP_1-U\right).\end{aligned} \tag{4}$$

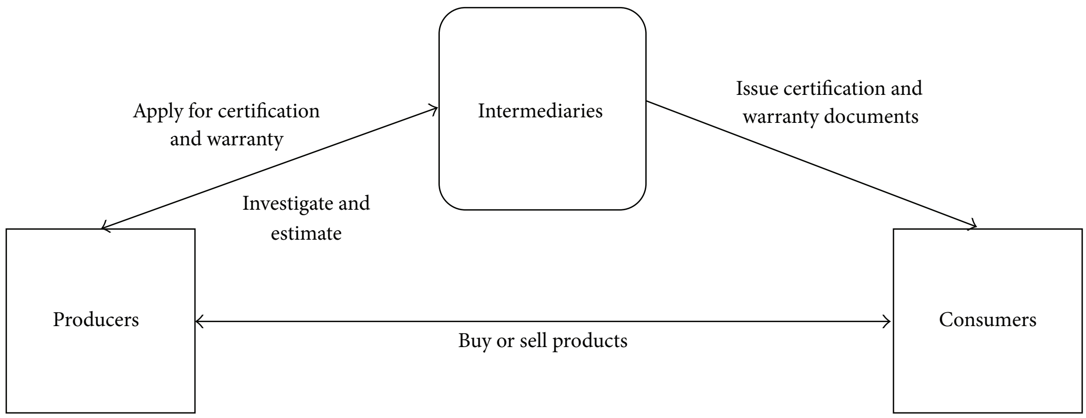
Therefore model II has 5 partial equilibrium points in the plane $\{(V_1,P_1):0\le V_1,\ P_1\le 1\}$, which are E_1' (0, 0), E_2' (0, 1), E_3' (1, 0), E_4' (1, 1), and E_5' $(U/\lambda_i H,[D(1+R(t))-G]/2H)$. The local stability analysis would be applied to illustrating the system stability of both model I and model II, considering the innovation risk and monitoring mechanism.

2.2. The Modified Model Including Government and Intermediaries. In order to decrease the uncertainty and entropy, the government might support the trading subsystem of APQSIS but does not intervene in the game process of both producers and consumers. We assume the support (in terms of money) from the government is F. The return of the government over a period of time is J, if the government does not support the trading subsystem by governmental investment or policymaking. When the government adopts a series of supportive policies to encourage producers to improve technology and quality, the producers would get the premium δ driven by innovation, and the government would get the return ρ from the extraneous earnings of producers. Under the condition that the probability that producers provide the real information is λ_i, the expected return of the government is $f_1^G=J-F+\lambda_i\rho$.

In the information circulation subsystem, the intermediaries bear the functions of quality certification and credit warrant, affiliating with consumers, producers, and government agencies in the micro level, which might decrease the uncertainty and entropy. Besides, they are influenced by macro factors such as the quality and safety regulation, credit warrant policy, and legal institutions. The current certification intermediaries in China could be classified into 3 types, including the commercial, policy, and production supportive ones. The former two are primary. They could



(a) Authorized certification warrant mode



(b) Direct certification warrant mode

Figure 2: The certification warrant mode of intermediaries.

also be classified as the authorized certification warrant ones and the direct certification warrant ones based on the mode of operation. In the authorized certification warrant mode, the consumers are the core and the intermediaries would not contact the producers directly (as shown in Figure 2(a)). In the direct certification warrant mode, the intermediaries are the core and they would inspect the producers directly and reach security agreement with the consumers (as shown in Figure 2(b)).

When the producers provide false information, the intermediaries would fulfill obligations of substitutive compensation to ensure the completion of transaction, which builds up the foundation of the cooperation between the intermediaries and consumers. The intermediaries' cooperation with producers depends on their cooperative relations with consumers. Therefore, we assume that the fee rate of certification and warranty is R_{DB}, the loss rate of substitutive compensation is R_{DC}, the operating cost of certification and warranty is FD, the proportion of the producers getting certificated and warranted is I, and the probability that the intermediaries violate regulations is Z_1. The probability that producers sell products successfully is high, and the consumers have an incentive to collaborate with the intermediaries if they were deemed to have great substitutive compensation ability, especially when the intermediaries are policy-based and sponsored by the government. On the contrary, the probability that producers sell products successfully is low and the consumers are reluctant to collaborate with the intermediaries in order to avoid risks, if their compensation ability is poor. According to the assumptions above in model I and model II, when the intermediaries provide certification and warranty, and honor the agreement, their fitness is $f_1^C = DIR_{DB} - FD$; otherwise the fitness of the intermediaries is $f_2^C = DIR_{DB} - FD - P_1 \cdot DIR_{DC}$ if they break the contracts.

When the governmental supportive policies are added to the model, the probability that the producers provide false information would fall, and the consumers' buying enthusiasm would rise inevitably. Since the information becomes more transparent, the information system entropy and information asymmetry decrease. Then the efficiency of transactions and recognition would be enhanced. So the evolutionary game model III could be established based on model I, considering the governmental monitoring and supporting, as well as the functions of intermediaries. In model III, the fitness (expected return) of the producer E's strategy 1 and strategy 2 could be formulated as follows:

$$\begin{aligned} f_1^E &= Q_1 \{\lambda_i [D(1+\kappa_i) + C_i - G - F] - BD - DIR_{DB}\} \\ f_2^E &= Q_1 \{\lambda_i [D(\kappa_i - R(t)) + C_i + F] - BD - DIR_{DB}\}. \end{aligned} \tag{5}$$

Then, the fitness (expected return) of consumer B's strategy 1 and strategy 2 could be formulated as follows:

$$\begin{aligned} f_1^B &= G + DIR_{DC} + F_B - DR_0 \\ &\quad + \lambda_i (1 - P_1) [D(1 + R(t)) - G - DIR_{DC} - F_B] \\ f_2^B &= 0. \end{aligned} \tag{6}$$

For further investigation of the functions that the government and intermediaries' supporting and monitoring have in the evolutionary process of agricultural product trading behaviors, we build model IV. In model IV there are 2 strategies available for consumers: one is demanding the intervention of the government and intermediaries in the feedback stage (rewarding for consumers' reporting, penalizing producers' misconducts, helping claim reimbursement, and so forth), and the other one is not demanding. Therefore, suppose the proportion of the consumers choosing the strategy 1 is V_1 ($V_1 \in [0,1]$); then the state $S^B = (s_1^B, s_2^B) = (V_1, 1 - V_1)$. And suppose the proportion of the producers choosing strategy 1 (providing false information) is P_1 ($P_1 \in [0,1]$); then the state $S^E = (s_1^E, s_2^E) = (P_1, 1 - P_1)$. The fitness of producer E providing false or real information could be formulated as follows:

$$\begin{aligned} f_1^E &= \lambda_i \left[D\left(1 + \kappa_i\right) + C_i - G - F \right] - BD - DIR_{DB} \\ &\quad - V_1 H \\ f_2^E &= \lambda_i \left[D\left(\kappa_i - R\left(t\right)\right) + C_i + F \right] - BD - DIR_{DB} \\ &\quad + V_1 \left(2\lambda_i H - H\right). \end{aligned} \tag{7}$$

Similarly the fitness (expected return) of the consumer B's strategy 1 and strategy 2 could be formulated as follows:

$$\begin{aligned} f_1^B &= G + DIR_{DC} + F_B - DR_0 - U + H + \lambda_i \left(1 - P_1\right) \\ &\quad \cdot \left[D\left(1 + R\left(t\right)\right) - G - DIR_{DC} - H - F_B \right] \\ f_2^B &= G - DR_0 - U + H + \lambda_i \left(1 - P_1\right) \\ &\quad \cdot \left[D\left(1 + R\left(t\right)\right) - G - H \right]. \end{aligned} \tag{8}$$

2.3. Stable Strategies of Agents' Evolutionary Reciprocity. According to the expected return of each agent in APQSIS, the replicator dynamic models of consumers and producers in model III could be formulated as follows:

$$\begin{aligned} \dot{P} &= P_1 \left(f_1^E - \overline{f^E} \right) = P_1 \left(1 - P_1\right) Q_1 \lambda_i \left[D\left(1 + R\left(t\right)\right) \right. \\ &\quad \left. - G - 2F \right] \\ \dot{Q} &= Q_1 \left(f_1^B - \overline{f^B} \right) = Q_1 \left(1 - Q_1\right) \left\{ G + DIR_{DC} + F_B \right. \\ &\quad - DR_0 \\ &\quad \left. + \lambda_i \left(1 - P_1\right) \left[D\left(1 + R\left(t\right)\right) - G - DIR_{DC} - F_B \right] \right\}. \end{aligned} \tag{9}$$

There are 5 equilibrium points in the evolutionary game system of model III, which are E_1 $(0,0)$, E_2 $(0,1)$, E_3 $(1,0)$, E_4 $(1,1)$, and E_5 $(0, 1 + (G + DIR_{DC} + F_B - DR_0)/\lambda_i[D(1+R(t)) - G - DIR_{DC} - F_B])$. In the case that the producers sell agricultural poor-quality products and have incentive to provide false information, the value (G) of collateral for intermediaries generally exceeds the consumers' financial cost (DR_0), $G > DR_0$. But considering the fact that the capital cost and time cost, the sum of collateral value, substitutive compensation, and governmental supportive subsidy are actually less than the consumers' expected return when the producers provide high-quality products and real information, it is obvious that $1 + (G + DIR_{DC} + F_B - DR_0)/\lambda_i[D(1+R(t)) - G - DIR_{DC} - F_B] > 1$, so E_5 is not the real equilibrium point of model III. When $D(1 + R(T)) > G + 2F$, $\dot{P} > 0$, and $\dot{Q} > 0$, E_4 is the asymptotic stability point. When $D(1 + R(T)) < G + 2F$, $\dot{P} < 0$, the return of producers who provide false information is lower than the average return of the group, so $P_1 = 0$ would be an evolutionary stable strategy. Now, E_2 is the sole stable point of the model; E_1 and E_3 are the unstable points; E_4 is a saddle point. The functions of governmental support in the evolutionary equilibrium of APQSIS are testified. When F enlarges, which means the strength of governmental support is intensified, the producers' systematic environment gets improved, the uncertainty and risk of agricultural production projects are reduced, and therefore the producers could operate steadily and develop sustainably. Then the producers have incentive to provide real information and the consumers would have positive strategies to buy agricultural products.

Based on model III, the APQSIS evolutionary stable equilibrium in the reciprocity of consumers, the government, and intermediaries could be further investigated. In model IV, the replicator dynamic models of producers and consumers could be formulated as follows:

$$\begin{aligned} \dot{P} &= P_1 \left(f_1^E - \overline{f^E} \right) \\ &= P_1 \left(1 - P_1\right) \left\{ \lambda_i \left[D\left(1 + R\left(t\right)\right) - G - 2F \right] - 2\lambda_i V_1 H \right\} \end{aligned} \tag{10}$$

$$\begin{aligned} \dot{V} &= V_1 \left(f_1^B - \overline{f^B} \right) \\ &= V_1 \left(1 - V_1\right) \left(DIR_{DC} + F_B\right) \left(1 - \lambda_i + \lambda_i P_1\right). \end{aligned} \tag{11}$$

The equilibrium points of evolutionary game model IV are E_1' $(0, 0)$, E_2' $(0, 1)$, E_3' $(1, 0)$, E_4' $(1, 1)$, and E_5' $((\lambda_i - 1)/\lambda_i, [D(1 + R(t)) - G - 2F]/2H)$. Moreover, the equilibrium of the system must satisfy the condition that P_1 and V_1 are located in $[0, 1]$. Since $0 \le \lambda_i \le 1$, $(\lambda_i - 1)/\lambda_i < 0$, E_5' does not belong to the set of equilibrium points. Through calculating the Jacobian matrix of the system and its eigenvalues, we could know that when $D(1 + R(T)) > G + 2F + 2H$, E_4' (1, 1) is the asymptotic stability point, E_1' is the unstable point, and E_2' and E_3' are the saddle points. When $D(1 + R(T)) < G + 2F + 2H$, E_2' (0, 1) is the asymptotic stability point, E_3' is the unstable point, and E_1' and E_4' are the saddle points. It means the evolutionary stable strategy is the government providing sufficient support, the consumers participating in strict monitoring mechanism, and the producers providing real information, which would reduce information entropy according to the information theory. Therefore the system would evolve into the equilibrium state E_2', which means the systematic agents would cooperate with each other, the producers have incentive to provide real information, and the consumers tend to buy actively. But the functions of intermediaries are not obvious in the final evolutionary stable strategies. The high fee rate of certification and warranty, the high level of risk-taking, and small size in assets might hamper the intermediaries' cooperation with both producers and consumers, which helps account for the problem above.

Table 3: Initial parameter settings of the model.

Number	Parameter setting	Demonstration	Quantitative value
(1)	PNumber	The initial number of the producers	1000
(2)	CNumber	The initial number of the consumers	20
(3)	Initial Product	The initial value of the products	U (200, 2000)
(4)	Invest return	The rate of return on investment of producers	U (20%, 40%)
(5)	λ	The success rate of production	0.3
(6)	R	The initial interest rate of consumers	U (8%-9%)
(7)	Costrate	The capital cost rate of consumers	0.25%
(8)	Mortagage Value	The value of producers' mortgage	U (60%, 80%)
(9)	U	The initial rate of consumers' reporting cost	1%
(10)	H	The initial rate of consumers' rewards & punishments	2%
(11)	F	The strength of governmental support to producers	5%
(12)	R_{DB}	The warranty fee rate of intermediaries	U (3%, 5%)
(13)	Repayment	The repayment rate of intermediaries	U (0.5%, 2%)
(14)	Guarantee Proportion	The proportion of intermediaries' guarantees	U (60%, 100%)
(15)	F_B	The strength of governmental support to credit loans	10%
(16)	Time	The number of simulation	200

3. The Simulation of APQSIS Agents' Behaviors

According to the agents' stable strategies in the dynamic game, this paper uses the multiagent modeling techniques to simulate the agents' reciprocity. Firstly, the settings of main initial parameters in the model should be demonstrated, which are closely related to the evolutionary process and the multivariate structure system. The number of simulations is set as 200 and then the simulation results could be observed. In Table 3, the main parameters are defined and their initial values are set.

On the basis of the evolutionary game simulation model and the designs of implemental process rules, the simulating program of APQSIS is tested and operated according to 2 stages (trading and feedback) and 4 types in order to demonstrate the dynamics of systematic entropy. Then main simulation results could be obtained as follows.

3.1. Simulation Results Analysis of Model I. In the simulation process of model I, the producers and consumers' behavioral changes and strategy selection are, respectively, discussed in different levels of production risk. According to the analog data, we could get Figures 3 and 4, in which the producers and consumers trend to accord in macroscopic behaviors in the level λ of production risk, signifying that bilateral cooperation is superior to noncooperation. But within the perspective of variation trend, the numerical magnitude of λ has influences on expected returns of both producers and consumers, resulting in the variation of group behavioral evolution. The evolutionary trend of the producers' strategy selection in model I is shown in Figure 3.

The evolutionary trend of the consumers' strategy selection in model I is shown in Figure 4.

3.2. Simulation Result Analysis of Model II. After the reporting and bonus-penalty mechanisms are introduced into model II, the initial rates of consumers' reporting cost (U), rewards, and punishments (H) are set to satisfy (U, H) = (1%, 2%), (U, H) = (1.5%, 2.5%), and (U, H) = (2%, 3%). According to the analog data, we could get Figures 5 and 6, in which the producers' and consumers' strategy choices are circulated in macroscopic trend and do not reach an evolutionary stable state, in accord with the previous analysis of evolutionary stability in model II. But in the microscopic trend, the rates of consumers' reporting cost (U) and rewards and punishments (H) dramatically affect the variation frequency and fluctuation amplitude in strategy selection. The evolutionary trend of the producers' strategy selection in model II is shown in Figure 5.

The evolutionary trend of the consumers' strategy selection in model II is shown in Figure 6.

3.3. Simulation Result Analysis of Model III. Based on the simulation result analysis of evolutionary game in model II, we introduce third-party agents (the government and intermediaries) into model III and inspect their effects on the variation in strategy selection and group evolutionary trend of both producers and consumers. By adjusting the parameters of the strength of governmental support to producers (F) and consumers (F_B), we collect the simulation data of producers' and consumers' strategy selection in different parameter combination (F, F_B), including (F, F_B) = (5%, 10%), (F, F_B) = (10%, 15%), and (F, F_B) = (15%, 20%), which is just shown in Figures 7 and 8. According to the evolutionary trend, it is obvious that a bilateral-cooperation strategy is superior to the strategy of noncooperation when the third parties intervene. Besides, the amplitude of nodes' variation is larger in the earlier period, which signifies that it takes less

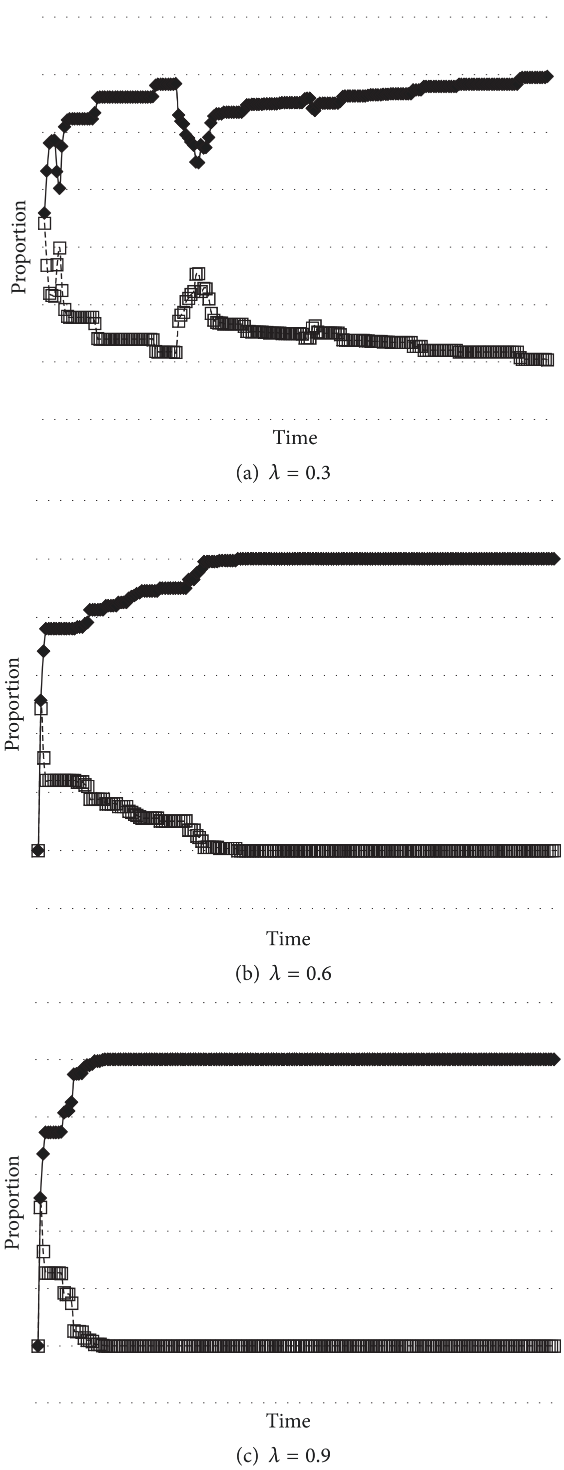


Figure 3: The evolutionary trend of the producers' strategy selection in model I.

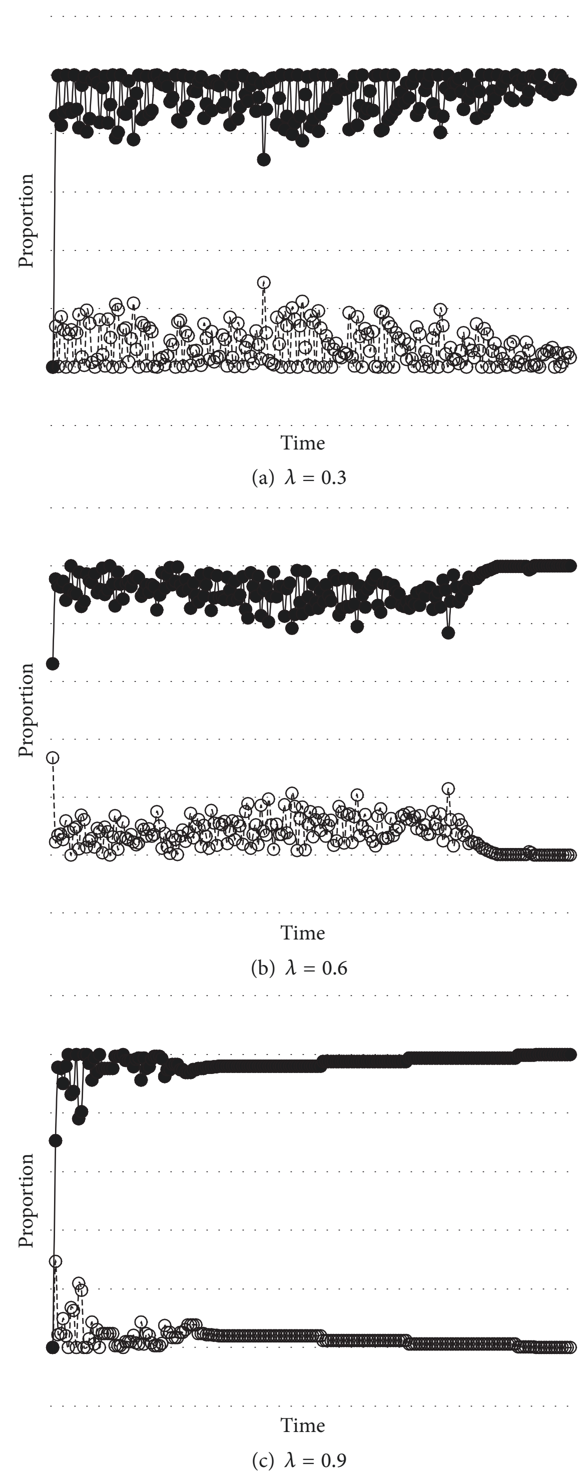
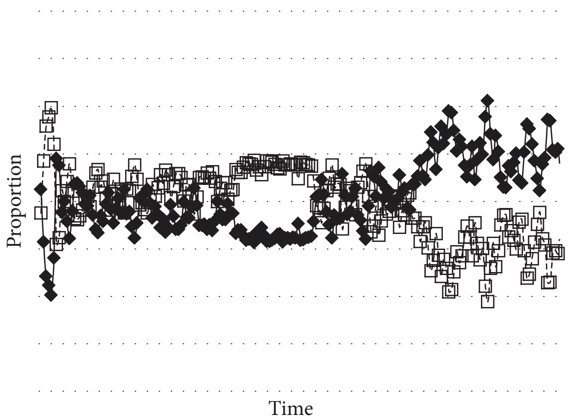


Figure 4: The evolutionary trend of the consumers' strategy selection in model I.

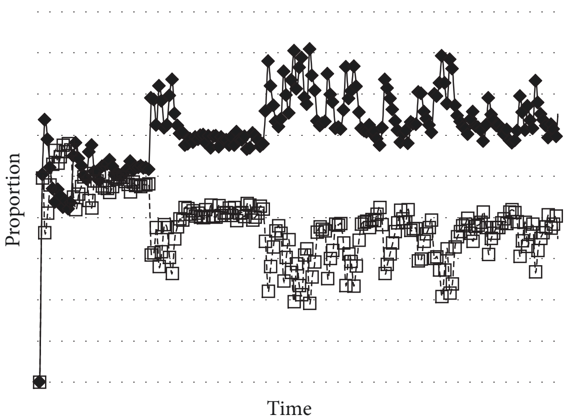
time for the 2 groups to reach an evolutionary stable state than in model I; the evolutionary trend of the producers' strategy selection in model III is shown in Figure 7.

The evolutionary trend of the consumers' strategy selection in model III is shown in Figure 8.

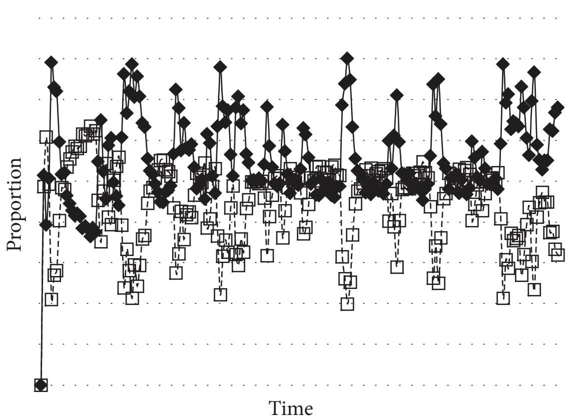
3.4. Simulation Results Analysis of Model IV. Model IV introduces the supporting functions of the government and intermediaries and then we could inspect the external factors' effects on the consumers' reporting mechanism and the evolutionary trend of contracting parties' cooperation. On the basis of Figure 9, by increasing the strength of third-party



(a) $U = 1\%$; $H = 2\%$

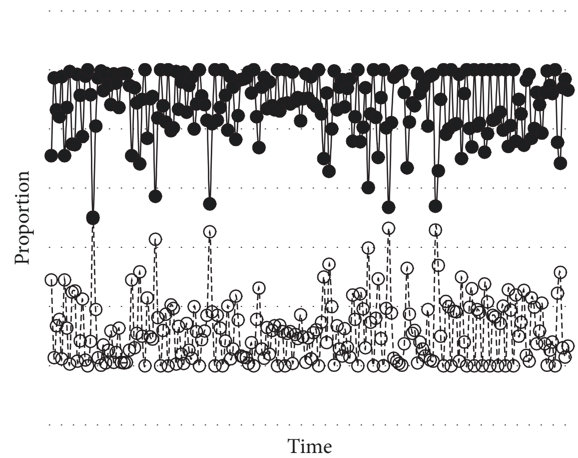


(b) $U = 1.5\%$; $H = 2.5\%$

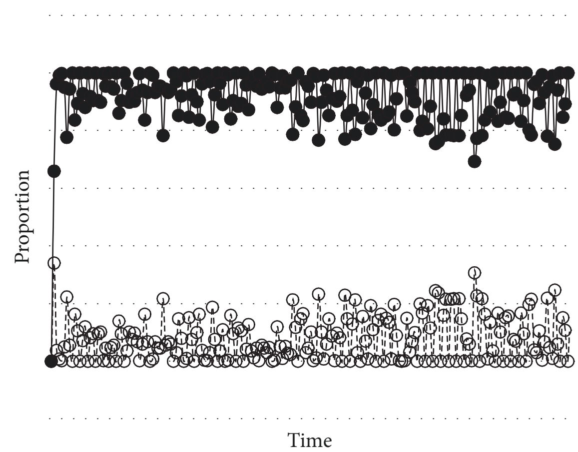


(c) $U = 2\%$; $H = 3\%$

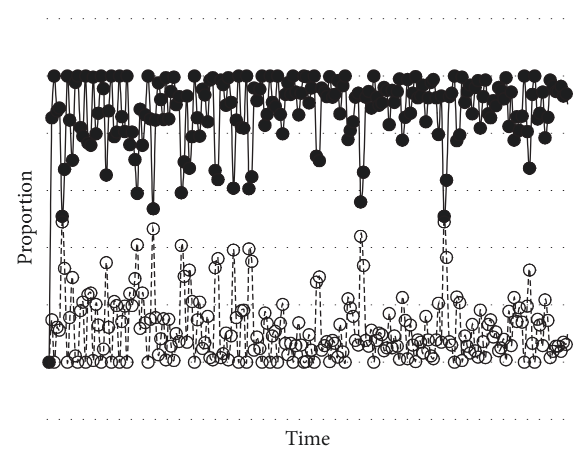
Figure 5: The evolutionary trend of the producers' strategy selection in model II.



(a) $U = 1\%$; $H = 2\%$



(b) $U = 1.5\%$; $H = 2.5\%$

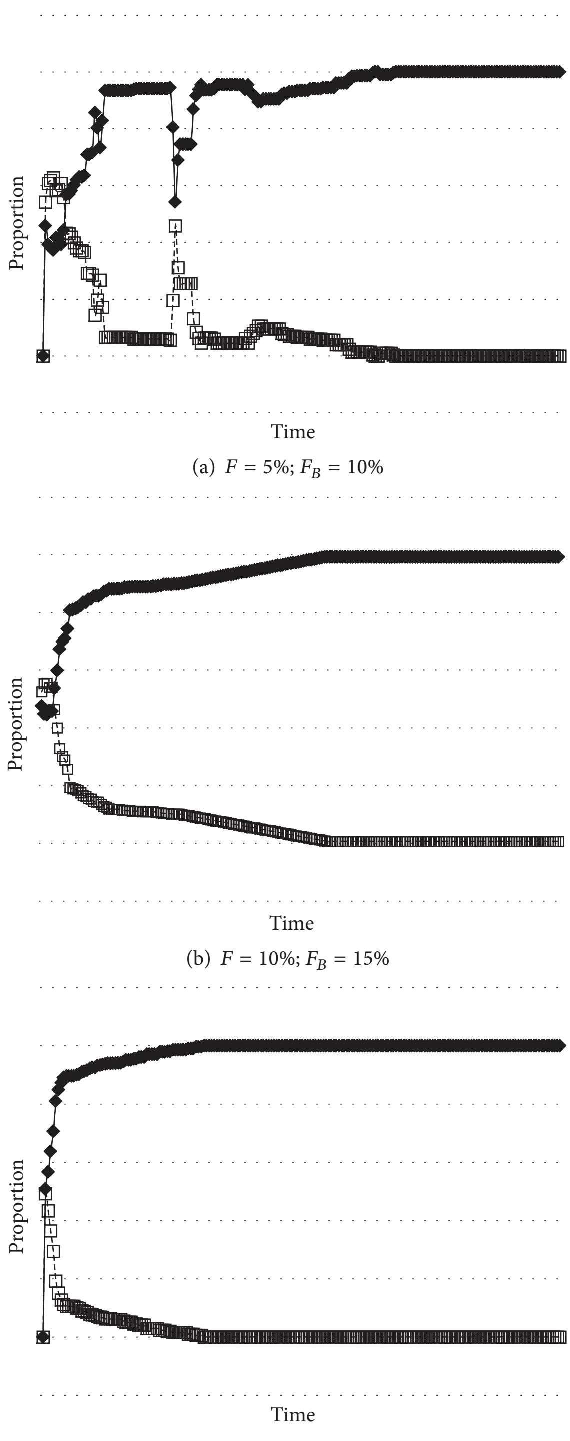


(c) $U = 2\%$; $H = 3\%$

Figure 6: The evolutionary trend of the consumers' strategy selection in model II.

investment, the R&D capacity and production efficiency would be enhanced and the proportion of false information provided by producers would be reduced, so the cooperative willingness of 2 groups would be promoted. Figure 10 shows the variation tendency of strategy selection in the stage of consumers' feedback, affected by the functions of the government and intermediaries. The consumers eventually tend to collaborate with the government and intermediaries to monitor the agricultural production after a long-term evolution, which effectively solves the problem that the evolutionary system could not reach a stable state automatically in model 2. The evolutionary trend of the producers' strategy selection in model IV is shown in Figure 9.

The evolutionary trend of the consumers' strategy selection with third-party intervention is shown in Figure 10.

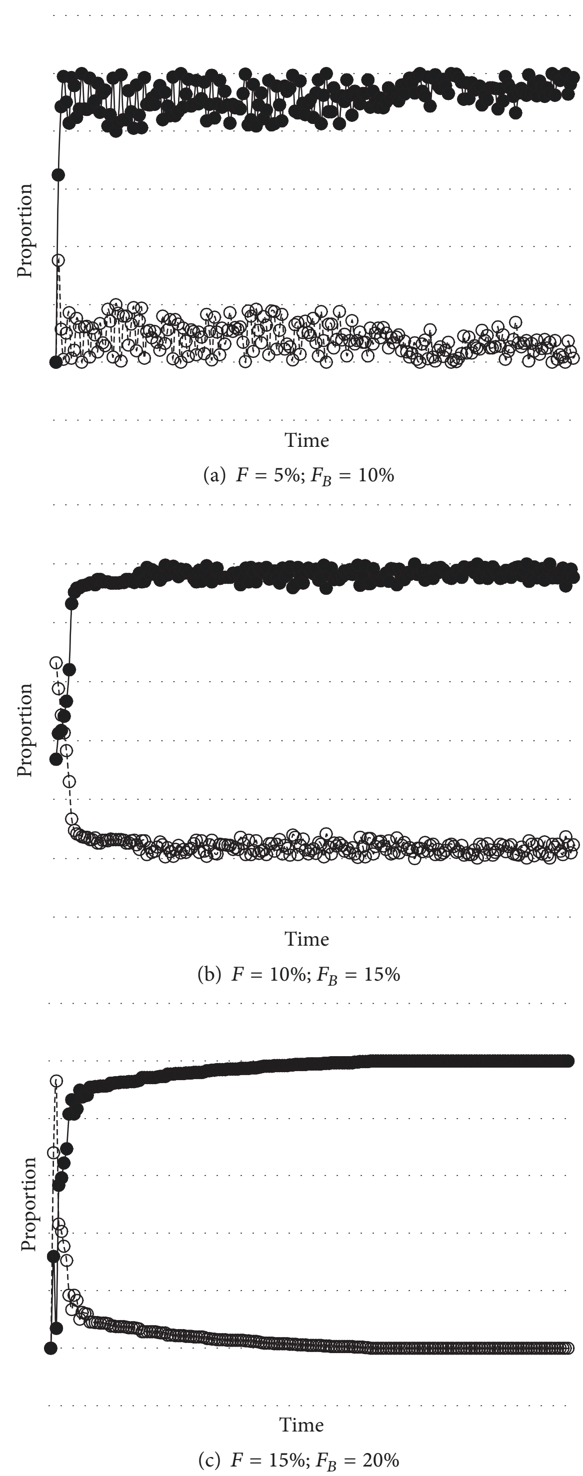


(a) $F = 5\%$; $F_B = 10\%$

(b) $F = 10\%$; $F_B = 15\%$

(c) $F = 15\%$; $F_B = 20\%$

Figure 7: The evolutionary trend of the producers' strategy selection in model III.



(a) $F = 5\%$; $F_B = 10\%$

(b) $F = 10\%$; $F_B = 15\%$

(c) $F = 15\%$; $F_B = 20\%$

Figure 8: The evolutionary trend of the consumers' strategy selection in model III.

The comparison of producers' strategy variation under the condition of consumers' unilateral monitoring and collaborative monitoring is shown in Figure 11.

For further investigation of the effects of consumers, the government, and intermediaries' three-party collaborative monitoring and consumers' unilateral monitoring on producers' credit strategies, Figure 11 compares the evolutionary trends of producers' strategy selection proportion under 2 conditions. We could infer from the curve variation that the proportion of producers providing false information (P) declines slowly and maintains the level of 0.2, signifying

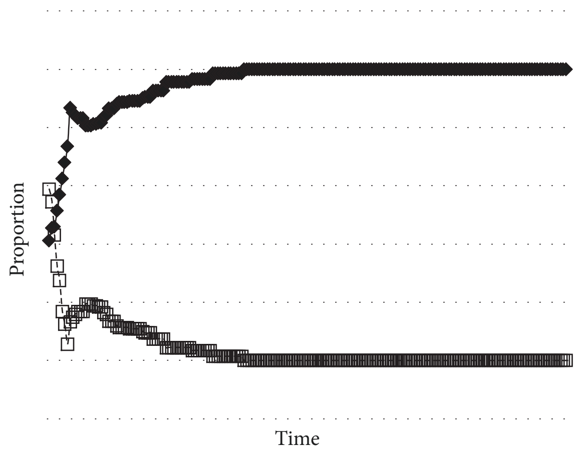


FIGURE 9: The evolutionary trend of the producers' strategy selection in model IV.

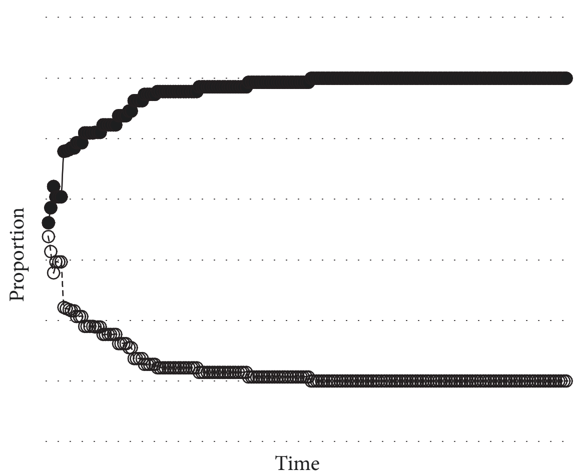


FIGURE 10: The evolutionary trend of the consumers' strategy selection with third-party intervention.

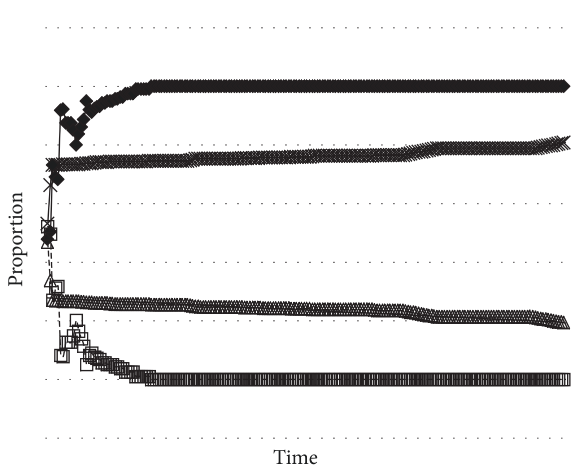


FIGURE 11: The comparison of producers' strategy variation under the condition of consumers' unilateral monitoring and collaborative monitoring.

that the consumers' unilateral monitoring does not influence the return brought on by providing false information significantly nor compel the producers to introspect and change strategies. But under the condition of consumers, the government, and intermediaries' three-party collaborative monitoring, the supporting strength producers gained and their return brought on by providing real information rise obviously, and the fine and loss due to providing false information increase dramatically, so the quantitative value of P converges to 0 within 50 iterations, signifying that the evolution of the producers' information strategies reaches a stable state. From the perspective of information theory, uncertainty has been reduced, and the entropy of the system's information transmitted is decreased according to the model.

4. Conclusion

Within the complex system and entropy theory framework, this paper uses the dynamic evolutionary game model and the multiagent modeling and simulation to discuss the APQSIS agents' equilibrium strategies and the effects of their interactive behaviors on the APQSIS evolutionary stability with asymmetric information. According to the simulation result analysis of each model, the following conclusions could be drawn.

(1) The mechanism and environment of agents' coordinating and cooperating should be promoted. The evolution of APQSIS is driven by the combined actions of multiple systematic agents. In the evolutionary process, every little change of each agent's behavior might exert profound influence on the APQSI cooperative control, which leads to the increase of systematic uncertainty and entropy. In addition, the fluctuation of external environmental factors might affect directly the evolutionary stability and the formation of APQSI cooperative control.

(2) The APQSIS agents should be cultivated as learning organizations. Both groups of producers and consumers constantly introspect on the original strategies, learning and imitating the credit strategies with higher profits. According to the 4 models above, the 2 groups of agents would introspect on their own strategies with some probability and change the current strategies if imitating the strategies chosen by the other participants would bring higher profits. Minimizing the systematic uncertainty and entropy facilitates the optimization of mechanism design, as well as the improvement of agents' learning. As a result, the 2 groups of agents would reach a collaborative stable state by the mechanism of introspecting, learning, and imitating.

(3) The technological innovation ability and survival skills of agricultural producers should be improved. The success rate of production (λ) has positive influence on the strategic selection and cooperative stability of both producers and consumers. With the increase of λ, the 2 groups' expected return and cooperative willingness would be improved, yet the proportion of false information provided by the producers would be reduced. Therefore, only if we improve the technical innovative mechanism and productive managerial system according to producers' own growth pattern, are the quality

and safety of agricultural products and the information integrity assured.

(4) The consumers' reporting and bonus-penalty mechanisms should be established. The consumers should set the cost rates of reporting, rewarding, and punishing according to their demands, producers' status, and prospective earnings. The simulation results show that the variation of the cost rates of reporting, rewarding, and punishing has no monotone increasing relationship with the proportion of collaborative participants and the evolutionary stability. The system is in a state of low entropy which orderly is also stronger. However, the evolutionary trends of 2 groups have been relatively stable only if the cost rate is located in some intermediate level. It is thus obvious that the consumers should take scientific measurements to monitor the production and to control the information integrity of APQS specifically based on the characteristics of different producers.

(5) The functions of governmental regulation and intermediary monitoring should be reinforced. The monitoring from third parties (the government and intermediaries) has exerted huge effect on increasing the proportion of cooperators and promoting the APQSIS evolutionary stability. The simulation results of model II show that the APQSIS could not achieve the stable state automatically. Yet the simulation results of models III and IV show that the proportion of false information provided by the producers would decrease dramatically and the consumers' purchasing intention would increase thereupon, because providing false information is no longer economic with the increasing of supporting funds and the penalty amounts, after introducing the governmental and intermediary functions of certification and warranty. The crucial factors to improve the APQS information integrity and realize the APQSIS cooperative control are to provide good environments of survival and development for agricultural producers, in all the aspects of governmental regulation, financial investment, credit system, and intermediary service.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

Xin Su, Shengsen Duan, Shubing Guo, and Haolong Liu all contributed to this study. Xin Su generated the idea and collected the data. Shengsen Duan and Shubing Guo chose the method, analyzed the data, and performed programming. Xin Su and Shengsen Duan reviewed the literature and provided research funding for the study. Xin Su and Haolong Liu drafted the article. Xin Su, Shengsen Duan, Shubing Guo, and Haolong Liu reviewed and edited the manuscript. All authors have read and approved the final manuscript.

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References

[1] S. A. Starbird, "Designing food safety regulations: the effect of inspection policy and penalties for noncompliance on food processor behavior," *Journal of Agricultural and Resource Economics*, vol. 25, no. 2, pp. 616–635, 2000.

[2] G. Sheriff, "Efficient waste? Why farmers over-apply nutrients and the implications for policy design," *Review of Agricultural Economics*, vol. 27, no. 4, pp. 542–557, 2005.

[3] P. M. Wognum, H. Bremmers, J. H. Trienekens, J. G. A. J. Van Der Vorst, and J. M. Bloemhof, "Systems for sustainability and transparency of food supply chains - Current status and challenges," *Advanced Engineering Informatics*, vol. 25, no. 1, pp. 65–76, 2011.

[4] J. Ma and Z. Guo, "The parameter basin and complex of dynamic game with estimation and two-stage consideration," *Applied Mathematics Computation*, vol. 248, pp. 131–142, 2014.

[5] A. A. Elsadany, "Competition analysis of a triopoly game with bounded rationality," *Chaos Solitons and Fractals the Interdisciplinary Journal of Nonlinear Science and Nonequilibrium and Complex Phenomena*, vol. 45, no. 11, pp. 1343–1348, 2012.

[6] J. Ma and F. Wu, "The application and complexity analysis about a high-dimension discrete dynamical system based on heterogeneous triopoly game with multi-product," *Nonlinear Dynamics*, vol. 77, no. 3, pp. 781–792, 2014.

[7] L. Fanti, L. Gori, and M. Sodini, "Nonlinear dynamics in a Cournot duopoly with relative profit delegation," *Chaos, Solitons & Fractals*, vol. 45, no. 12, pp. 1469–1478, 2012.

[8] X. Su, Y. Wang, S. Duan, and J. Ma, "Detecting chaos from agricultural product price time series," *Entropy*, vol. 16, no. 12, pp. 6415–6433, 2014.

[9] X. Fan, S. Li, and L. Tian, "Complexity of carbon market from multi-scale entropy analysis," *Physica A: Statistical Mechanics and its Applications*, vol. 452, pp. 79–85, 2016.

[10] J. Ma and X. Pu, "The research on Cournot-Bertrand duopoly model with heterogeneous goods and its complex characteristics," *Nonlinear Dynamics*, vol. 72, no. 4, pp. 895–903, 2013.

[11] J. Ma and H. Wang, "Complexity analysis of dynamic noncooperative game models for closed-loop supply chain with product recovery," *Applied Mathematical Modelling: Simulation and Computation for Engineering and Environmental Systems*, vol. 38, no. 23, pp. 5562–5572, 2014.

[12] J. Ma and L. Xie, "The comparison and complex analysis on dual-channel supply chain under different channel power structures and uncertain demand," *Nonlinear Dynamics*, vol. 83, no. 3, pp. 1–15, 2016.

[13] I. H. Hong, J. F. Dang, Y. H. Tsai, C. S. Liu, W. T. Lee, M. L. Wang et al., "An RFID application in the food supply chain: a case study of convenience stores in taiwan," *Journal of Food Engineering*, vol. 106, no. 2, pp. 119–126, 2011.

[14] M. Billio, R. Casarin, M. Costola, and A. Pasqualini, "An entropy-based early warning indicator for systemic risk," *Journal of International Financial Markets, Institutions & Money*, vol. 45, pp. 42–59, 2016.

[15] E. I. Broughton and D. G. Walker, "Policies and practices for aquaculture food safety in China," *Food Policy*, vol. 35, no. 5, pp. 471–478, 2010.

[16] M. Fares and E. Rouviere, "The implementation mechanisms of voluntary food safety systems," *Food Policy*, vol. 35, no. 5, pp. 412–418, 2010.

[17] C. E. Shannon, "A mathematical theory of communication," *Bell Labs Technical Journal*, vol. 27, pp. 379–423, 1948.

[18] L. You and S. Wood, "An entropy approach to spatial disaggregation of agricultural production," *Agricultural Systems*, vol. 90, no. 1-3, pp. 329–347, 2006.

[19] T. Heckelei and H. Wolff, "Estimation of constrained optimisation models for agricultural supply analysis based on generalised maximum entropy," *European Review of Agricultural Economics*, vol. 30, no. 1, pp. 27–50, 2003.

[20] J. Ma and X. Ma, "Measure of the bullwhip effect considering the market competition between two retailers," *International Journal of Production Research*, vol. 55, no. 2, pp. 1–14, 2016.

[21] J. Ma and B. Bao, "Research on bullwhip effect in energy-efficient air conditioning supply chain," *Journal of Cleaner Production*, vol. 143, pp. 854–865, 2017.