Optimization Analysis of Customs Supervision Strategy Based on Complex Network Evolutionary Game

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Abstract. Under the background of high-quality development, the concealment and cross-border nature of cross-border e-commerce transactions put forward higher requirements for the efficiency of government supervision. We build a network evolution game model in which three inspection strategies are taken by customs: fixed sampling probability, linearly increase sampling probability and periodically increase sampling probability, meanwhile the number of enterprises with honest strategies and the average income of the game parties are taken as indicators. The findings are as follows: the government needs hierarchical and classified dynamic supervision. When the enterprise's tax payment credit rating is at a high level, it adopts fixed and low probability to carry out supervision. When the enterprise's tax payment credit is at a low level for a long time, the government periodically increase sampling probability.

Keywords: High-quality Development · Customs Supervision Strategy · Evolutionary Game · Small World Network

1 Introduction

With the increase of the consumption scale of China's cross-border e-commerce, customs adopts the "self-reporting and self-paying" tax collection and management mode [16], which depends on the supervision level. Inefficient regulation could lead to a Matthew effect or cross-border e-commerce lemon market, and cause market confusion and tax losses [6, 17]. Efficient regulation can improve the efficiency of customs clearance, reduce dishonest behavior in enterprises and ensure tax revenue [8, 10]. Therefore, the optimization of supervision strategy plays a crucial role for customs.

In the context of improving customs supervision efficiency and promoting cross-border e-commerce development, the game between custom's regulation and activities of cross-border e-commerce enterprises has led to managerial research, which focuses on the influencing factors and reward and punishment mechanism [2, 11, 12]. Yang Fengmei built an evolutionary game model under the e-commerce model and found that strengthening credit supervision can effectively avoid the dishonesty of e-commerce. Peng Minjiao proved that improving the compliance degree of taxpayer, increasing the

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inspection probability, and reducing the tax rates are important measures for reducing the dishonest behavior of enterprises. Tiago Oliveira and MatildeAlhinho analyzed the important role of trust in e-commerce for consumers' online purchase intention.

However, there are few studies on what inspection strategy should be taken and how to make dynamic adjustment. Accordingly, the main objectives of our research are explore the optimal supervision strategy through setting static and dynamic inspection strategy of customs.

The issues could be addressed by combining evolutionary game theory with complex network theory that considers limited rationality and learning mechanisms. A two-population evolutionary game model is proposed in which each cross-border e-commerce enterprises in their population can choose to implement honest strategy or dishonest strategy and the customs also has two strategies, that is, deregulation and strict supervision. The strategies can be learned and updated according to the dynamic payoff in the process of evolutionary game. In this paper, honest strategy for cross-border e-commerce enterprises refers to enterprises paying taxes honestly during the declaration process [16]. The final tax revenue is considered as being dependent upon whether the cross-border e-commerce enterprises adopt a honest strategy. We analyze the evolution path of the population of cross-border e-commerce enterprises and customs under different strategies. Subsequently, combining with complex network evolutionary algorithm, the optimal supervision strategy is simulated by MATLAB. Finally, optimal conditions for the participants are analyzed. This paper makes contributions primarily in the following aspects: (1) The complex networks is added to the game model between customs and cross-border e-commerce enterprises, and a complex network evolutionary game model is constructed. (2) To analytically identify the optimal sampling strategy from the number of enterprises with honest strategy to the average income of game parties.

The reminder of this paper is organized as follows: A review of the literature is introduced in Sect. 2. Section 3 describes current problem and sets static and dynamic strategies. Section 4 describes assumptions and notations and proposes the basic complex network evolutionary game model. Section 5 simulates the optimal regulatory strategy. Finally, Sect. 6 summarizes the key results and discusses managerial insights.

2 Literature Review

Game theory is extensively applied in the study of supervision. Such as e-commerce credit supervision [20] asymmetric market Information [14] carbon emission reduction [19] port hazardous chemicals supervision [5] product quality supervision [13]. Compared with the traditional game model, evolutionary game theory adjusts "perfect rationality" to "limited rationality" and studies the equilibrium state of the system [15]. Customs supervision is a limited rational decision-making process, the optimization of customs supervision strategy is the result of the game and interaction between customs and enterprises. Therefore, the study on the optimization of customs supervision based on the evolutionary game theory can effectively analyze the interaction between the players. Aringhieri [3] constructed a mixed game model to analyze the online reputation system in e-commerce. Wang built a tripartite evolutionary game model and found that strengthening government supervision and increasing regulatory rewards for platform e-commerce are conducive to solving the "regulatory dilemma".

However, most evolutionary game studies take the replication dynamic equation as the evolutionary mechanism [4, 7, 10], ignoring the fact that customs and enterprises are heterogeneous groups with different functional goals [9]. Heterogeneous groups are composed of different individuals who have different external environment, strategy learning rules and learning objects [7]. In the complex economic and trade progress, the relationship between customs and enterprise groups is also more complex, thus the evolutionary game model needs to be improved.

In recent years, from the perspective of complex network to explore the mechanism of group evolution has become a hot topic. The complex network theory shows that the contact between individuals in the real world is not fully coupled or completely random, and many systems in the real world are embedded in the social system with topological statistical characteristics [18]. In the customs network, the business relationship between departments forms the infrastructure of the complex network, so the evolutionary game method on the complex network is suitable for the study of customs supervision strategy. Andrikopoulos and Andreas [1] found that the network of audit researchers has the characteristics of small world. These studies provide new ideas for the optimization of customs supervision.

The existing studies focus on macro decision-making by game analysis, ignore the fact that customs supervision is embedded in the complex process of social networks, and the real situation is more similar to the small world network. Based on this, this paper combines the evolutionary game model with the small-world network, explores the optimal supervision strategy and boundary conditions through simulation, in order to provide useful reference for the relevant policy formulation of the customs.

3 Problem and Strategy Description

Cross-border e-commerce transactions are highly virtual, and dishonest behaviors are often found in enterprises (for example, some enterprises embezzling others' information to break the tax threshold of 2,000 yuan and evade tariffs) [2]. The strategy of sampling inspection by customs is an effective means of controlling tax revenue. When the proportion of dishonest declaration of enterprise groups is large, customs should improve the probability of random inspection until full inspection. When the proportion of honest declaration of enterprise groups is large, customs should reduce the probability of spot check, until exemption.

Based on the above analysis, we developed three sampling strategies. Customs use a fixed probability a_0 to sample enterprises with honest strategy, the regulatory strategies about enterprises with dishonest strategy are divided as follows:

A fixed probability a_1 to sample dishonest enterprises;

A linearly increasing probability a_2 to sample dishonest enterprises, $a_2 = a_1 * (1 + \alpha_2)^{t-1}$, $t = 1, 2, 3 \ldots\ldots, n$, $a_2 \in (0, 1)$;

A periodically increasing probability a_3 to sample dishonest enterprises: set m as a period, every period at the rate of $\alpha_2\%$ increasing sampling probability, $a_3 = a_1 * (1 + \alpha_2)^{[ceil(t/2)-1]}$, $a_1 \in (0, 1)$.

For these three different ways, the optimal judgment criteria can be divided into the following ones according to their importance: (1) The number of enterprises with

honest declaration in the customs supervision; (2) The average income of customs and enterprises; (3) The time for an ecosystem to achieve honesty and stability.

4 Network Evolution Game Model

In customs supervision ecosystem, most enterprises are not directly connected to each other, but they can establish connections by declaring the same kind of goods. The network has connectivity, thus the speed of risk transfer is fast, therefore changing a few connections can change the performance of the network. This reflects their small world network nature. Therefore, this paper combines the small world network model to study the optimization of customs supervision strategy. By combining the evolutionary game model with the small world network, the topological characteristics and individual heterogeneity of the real network can be considered synthetically, and the policy path in the dynamic development can be explored.

4.1 Evolutionary Game Model

In the customs supervision ecosystem, the decision goal of the enterprise is to reduce the tax cost as far as possible, and the decision goal of the customs is the least tax loss and regulatory cost. There is game behavior between customs and enterprises. In order to explore the relationship and benefit balance between customs' regulations and decisions of cross-border e-commerce enterprises, we make the following assumptions:

Assumption 1. A population of customs and cross-border e-commerce enterprises are the participants of the game, they use limited rationality and continuous learning from multiple gaming and seeking the Evolutionary Stable Strategy (ESS) to achieve the optimal equilibrium.

Assumption 2. The cross-border e-commerce enterprises have two strategies: honest declaration and dishonest declaration. The customs also have two strategies: deregulation and strict supervision. When the enterprise with honest strategy, the tax paid is T_1; when the enterprise with dishonest strategy, the tax paid is $T_2 = T_1 - \Delta t$. The benefits of the dishonest strategy over the honest strategy is Δt. When Customs adopts deregulation strategy, the inspection cost is c_0, When Customs adopts strengthening supervision strategy, the inspection cost is $c_1 = c_0 + \Delta c$.

Assumption 3. The reward for enterprises with honest strategy is e_1, such as customs clearance convenience and credit accumulation. The loss of enterprises with dishonest strategy is e_2, such as credit loss and downgrade.

Assumption 4. The customs will randomly check the products submitted by enterprises, and the sampling probability of honest enterprises is a_0. $a = 0$ represent exemption, and $a = 1$ represent the whole inspection. The lower the enterprise credit rating, the higher the probability of spot check. But strict control and multiple spot checks will slow down the clearance speed, thus causing losses r to enterprises.

Table 1. Customs and enterprise's game matrix

The game		Enterprises	
		honest declaration	Dishonest declaration
Customs	deregulation	0 0	$\Delta t - a_1 * (e_1 + e_2 + n * \Delta t)$ $-\Delta t + a_1 * n * \Delta t$
	Strict supervision	$-a_0 * r$ $-\Delta c$	$\Delta t - a_1 * (e_1 + e_2 + n * \Delta t + r)$ $-\Delta c - \Delta t + a_1 * n * \Delta t$

Assumption 5. The penalty imposed by the customs on dishonest enterprises is $f = n * \Delta t, \ \ n \geq 1$.

Based on the above assumptions, the game matrix between customs and enterprises are shown in the Table 1. when $a_1 * (e_1 + e_2) > (1 - a_1 * n) * \Delta t$, the only stable point of the system is (1, 1), and the evolutionary stable strategies(ESS) between customs and enterprises is (deregulation, honest declaration). when $a_1 * (e_1 + e_2) < (1 - a_1 * n) * \Delta t$, the only stable point of the system is (0, 1), and the evolutionary stable strategies(ESS) is (deregulation, dishonest declaration). Based on this, increasing the reward for honest enterprises, the punishment for dishonest enterprises and the probability of spot check are beneficial to the evolution of the game between customs and enterprises towards the ideal direction.

4.2 Complex Network Evolutionary Algorithm

Complex network evolutionary game analyzes the evolutionary stable results of the game played by participants in a group in accordance with local interactive association, and the game players in the customs supervision ecosystem adjust the current strategies by learning the strategies of neighborhoods in the game. Complex network evolutionary can better describe the interaction between individuals and the selection of strategies in the next round, thus we introduce the complex network evolution game into the field of customs regulation in cross-border e-commerce.

Based on the structural characteristics of network and the realistic consideration of the game model construction, we propose the following assumptions:

enterprise specific network structure is composed of $G = (V, E)$. Among them, $V = \{v_1, v_2, \cdots, v_N\}$ represents the implementation of honest strategy. N represents the number of enterprises. $E = \{e_1, e_2, \cdots, e_n\}$ represents the existence of direct or indirect links (or edges) between enterprises. If there is an edge between enterprise i and enterprise j, and any pair of points (i, j) and (j, i) corresponds to the same edge, $ij = 1$ represents undirected network, $ij = 0$ represents directed network.

As to four different kinds of income, the game is played between nodes in the neighborhood with radius $r = 1$. Enterprises establish links with distant enterprises through "broken edge reconnection".

Customs and business groups will learn from the benefits of their closer neighbors [21]. Assuming that the probability of enterprise j adopting the strategy of its neighbor

enterprise i in the next iteration follows the Fermi rule, k represents noise and refers to the degree of environmental uncertainty. Usually $k = 0.1$, Π_i Represents the return of the adopted by the enterprise i, Π_j Represents the return of the adopted by the enterprise j. In each evolution cycle, the players randomly chooses a strategy to update the strategy according to the same learning algorithm.

$$\tau(A_j \to A_i) = \frac{1}{1 + \exp[(\Pi_i - \Pi_j)/k]} \tag{1}$$

5 Optimal Regulatory Strategy Simulation Analysis

Based on above complex network evolutionary game model, we use MATLAB to analyze participants' dynamic behavior trends and their long-term game relationships. We each set of parameters are tested 50 times to ensure the stability of the simulation results. For the convenience of comparison and analysis, we carry out simulation experiments based on the proposed strategies. First, we use evolutionary analysis to obtain the optimal regulatory strategy, then use the complex network evolution game to further verify and analyze the results.

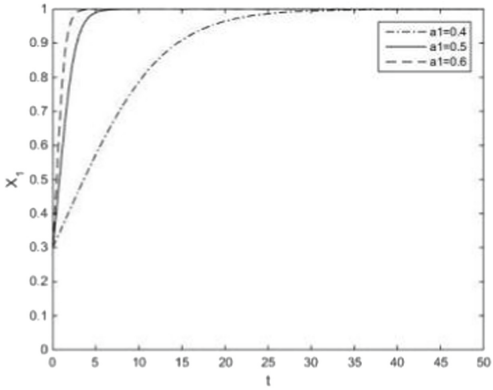
5.1 Simulation Analysis of Evolutionary Game

The control variable method is used to analyze the evolution paths of different sampling inspection strategies. Experiment a set the sampling probability of honest enterprises a_0 is 0.2, and change the sampling probability of dishonest enterprise a_1; Experiment b set the sampling probability of dishonest enterprises a_1 is 0.6, and change the sampling probability of honest enterprise a_0; Experiment c set the sampling probability of honest enterprises a_0 is 0.2, and change the sampling probability of dishonest enterprise a_1 in different ways.

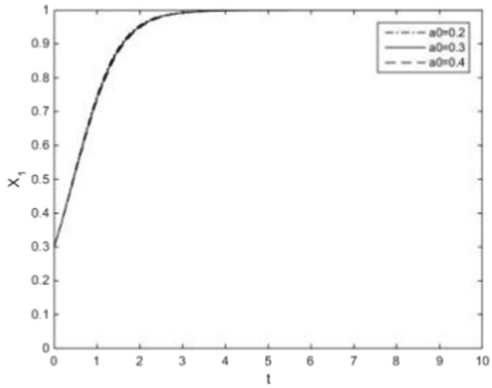
Figure 1 shows the evolution of different sampling strategies over time(t) the probability(x) of enterprises choosing honesty in the supervision process. Figure 1(a)(b) shows that when the sampling probability a_1 is 0.6, the evolution effect is the best, and the sensitivity of the honest enterprise to the government supervision degree is less than that of dishonest enterprises. Enterprises will eventually choose integrity. Customs in the formulation of strategies can choose to less probability spot check for honest enterprises. We can see from Fig. 1(c) that dishonest enterprises will eventually tend to be honest. However, in terms of evolution speed, the probability of phased growth effect is the best, followed by linear and fixed. From the simulation results, The probability of sampling test has little influence on honest enterprise strategy selection, periodically increasing sampling probability has the best effect on dishonest enterprises, and the difference between stage increase and linear increase is small.

5.2 Network Evolution Simulation Analysis

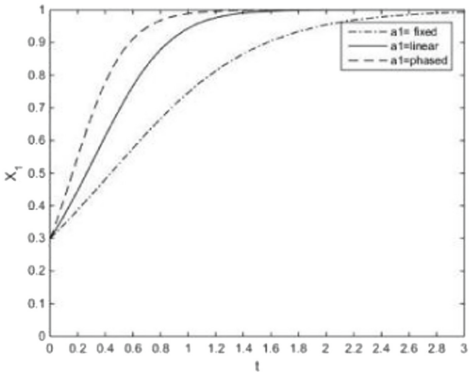
Figure 2 shows that at the evolution time of 200, more and more enterprises choose the honest strategy, but the number of companies choosing honesty are different. In



(a) Experiment a

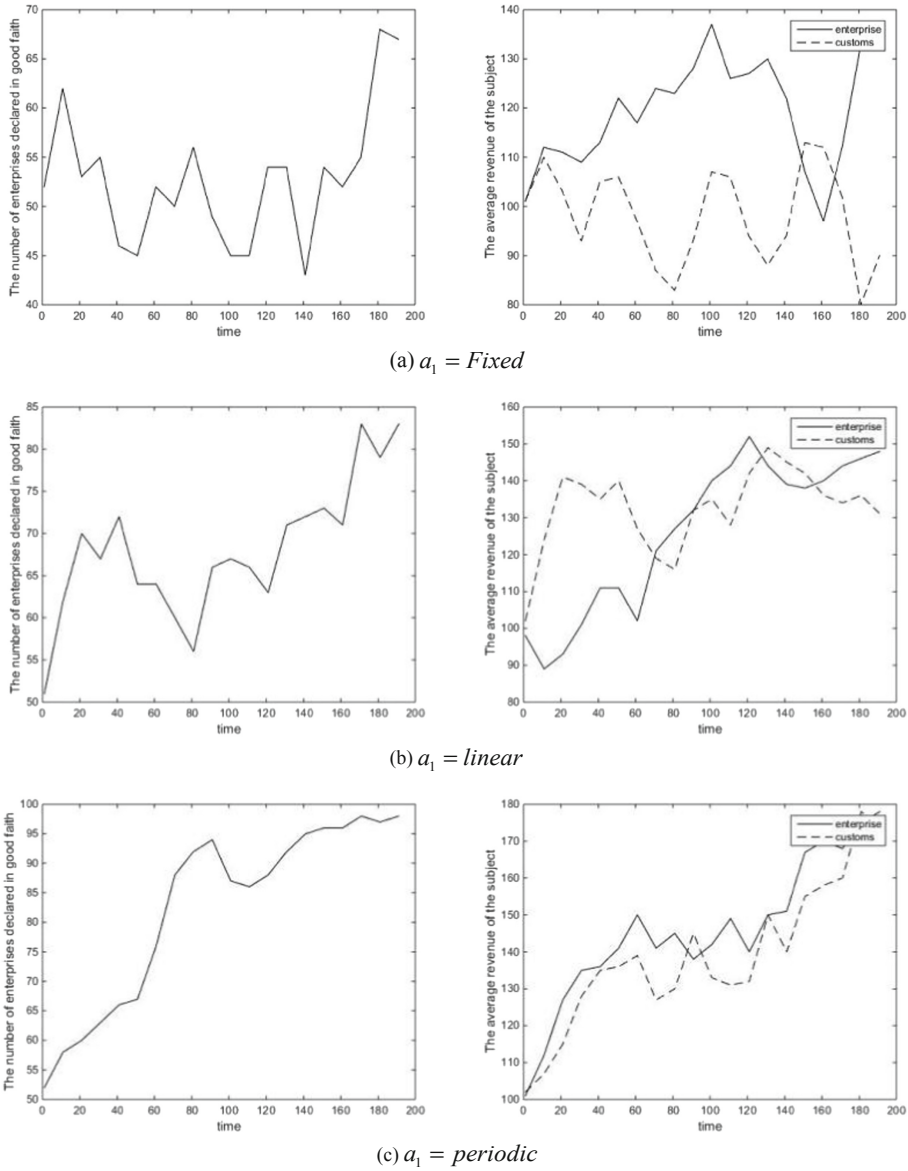


(b) Experiment b



(c) Experiment c

Fig. 1. The evolvement of enterprise choice probability of good faith under different strategies (Photo credit: Original)



(a) $a_1 = Fixed$

(b) $a_1 = linear$

(c) $a_1 = periodic$

Fig. 2. The number of enterprises declared in good faith and average revenue of the subject under different strategies

experiment a, the number is volatile; In experiment b, the number of enterprises choosing honest strategy is not high; In experiment c, the number of enterprises choosing honesty is large and stable. Figure 2 shows that the value of customs income follows periodic > linear > Fixed.

From the view of enterprise income, In experiment a and b enterprise income is higher, but in experiment b, enterprise income is not good. From the view of system stability, In Fig. 2(a), the benefits of game players fluctuate greatly; in Fig. 2(b), the benefits of game players are stable; and in Fig. 2(c), the benefits of game players are stable and on the rising. Based on this, the best sampling probability method for dishonest enterprises is to increase the sampling probability periodically.

Compared with evolutionary game, the optimization model of customs supervision strategy based on small world network has the following characteristics: (1) the evolutionary game can obtain optimal sampling strategies, but it can not be explained at the micro level. The complex network model can further analyze the number of enterprises and the change of average income. (2) Customs supervision ecosystem is a complex network, and the game parties are not actually two single individuals, but two groups of customs supervision group and enterprise group. (3) The game parties are limited rationality, they maximize the expected benefits in the dynamic process of continuous learning and adjusting strategy.

6 Conclusions

The rapid development of cross-border e-commerce has put forward higher requirements for China's customs supervision, and the customs supervision system and measures must keep pace with the times. This paper constructs a complex network evolutionary game model between customs and enterprises, designs different sampling inspection strategies, and discusses the optimal control strategies.

The main conclusions and recommendations for customs from this study are as follows:

In the dynamic game process, the strategies of customs and enterprises change with their neighbor's behavior. Customs should focus on the dynamic development of cross-border e-commerce market. When a high proportion of enterprises adopt honest strategy, customs just with small probability to sample them. On the contrary, if most of the enterprises maintain a dishonest strategy, sampling probability should be increased periodically.

(2) The Custom's strategy is related to the degree of incentives and penalties, reputation loss, and the noise in the environment. Customs should adjust existing mechanism to formulate the best possible reward and punishment regulation. More incentives should be provided for honest enterprises and penalties should be strengthened for dishonest enterprises, and at the same time reduce the noise in the environment as much as possible.

This paper provides effective decision support for the customs in formulating supervision and spot check scheme, specific spot check strategy and punishment mechanism, and improves the credit management level of the customs. There also exist several limitations in our work, and we can further analyze behaviors of customs and enterprises by empirical research which may provide more objective and practical results.

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