Research Article

Evolutionary Game and Simulation in Forest Rights Exchange Based on the Supplier-Demander View

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At present, the forest rights exchange market in China is in its early stages. Forest rights exchange faces low circulation problems. The strategic choices of supply and demand play an important role in enhancing the efficiency of forest rights exchange. However, only limited empirical evidence has been provided on the strategic selection of forest rights exchange from the perspective of the dynamic game. Based on field investigation, this study constructed a dynamic game model and explored the dynamic evolution process of different strategic behaviors based on evolutionary game theory. Furthermore, a numerical simulation was conducted to evaluate the rationality of the theoretical model. The results show that several factors affected the strategies of transaction subjects including transaction price, transaction cost, forestry revenue, and nonforestry revenue. These factors are important means to regulating the forest rights exchange. In terms of policy implications, we suggest that diversity measures should also be considered to formulate policies of transaction price management and to encourage forestland owners to exchange forestland with enterprises and cooperatives. Moreover, additional efforts are needed to establish and improve the forest rights exchange market.

1. Introduction

Since 2003, a new round of collective forest rights reform has been completed in the task of clarifying property rights and contracting households in China. However, after the clarification of property rights, forest resources still face problems in ensuring that the benefits of forestry management for forest farmers are preserved [1]. As the core objective of the collective forest rights reform, forest rights exchange is an important way to realize large-scale forestry management. But forest rights exchange faces many problems, such as non-smooth circulation. By the end of 2017, the area of forest rights exchange was only 0.189 hundred million hectares, occupying only 10.46% of the total area [2], and the exchange scale was relatively small. It is widely recognized that the establishment of a forest rights exchange market is an important measure for promoting and standardizing forest rights exchange [3, 4]. Many farmers are not willing to exchange idle forest resources and low-efficiency forestland, while some forestry investors are cautious about the prospect of forestry management, thus affecting the exchange scale in the forest rights exchange market. Some reports have explained this result from the perspectives of the willingness and behavior of forest farmers [5–9]. For example, Lu et al. [8] studied the influence mechanism of farmers’ intentions to choose a forest rights exchange market from the perspectives of behavioral attitude, subjective norms, and perceived behavioral control. Han et al. [9] focused on the analysis of the internal correlations between farmers’ self-reported preferences for the forest rights exchange centers and their actual choice behaviors. However, there have been limited studies on how to solve the problem of the forest rights exchange based on the supplier-demander view. Therefore, the question of how to enhance the efficiency of forest rights exchange needs to be investigated.

The choices of individual behaviors are the leading drivers of enhancing the efficiency of forest rights exchange. Hence, the extant literature exhaustively discusses the factors influencing the forest rights exchange from the perspective of individual behaviors. Hu et al. [10] constructed a
game model of transaction subjects from the perspective of a complete game in the forest rights exchange market. Transaction cost and income from forestry operations are considered as crucial factors affecting the choices of supply and demand. On this basis, policy suggestions were put forward for improving the forest rights exchange market. Lv et al. [11] analyzed the interesting relationship between relevant transaction subjects from the dynamic game. Operating costs and government regulations are considered crucial factors affecting forest rights exchange, and important suggestions were proposed to improve the forest rights exchange market. The influential work of Rong and Zhang [12] provided an introduction to studying the relationship of forest rights disputes, they focused on the analysis of evolutionary stability strategies and stability of even groups to forest rights exchanges [13]. The different abilities, experiences, and knowledge are important factors affecting the dynamic balance in the forest rights exchange market. However, an evolutionary game can explain the trend of market transactions from individual to group behaviors. In an evolutionary game, participants’ decisions are made in the process of continuous imitation and learning. Thus, evolutionary game theory has been applied to artificial intelligence in recent years [14], public participation in environmental governance [15], cultivated land protection and management [16], commercial supply chain [17], and other fields. This shows that evolutionary game theory has strong applicability in social sciences.

In addition, evolutionary game theory has been applied to land problem research [18, 19]. However, only limited attention has been paid to the strategic selections of forest rights exchange subjects from the perspective of the dynamic game, with the exception of Liu et al. [20]. To the best of our knowledge, the factors influencing the strategic choices of the supplier-demander demonstrate still a lack of compatibility between research and grass-roots practice. Therefore, this study attempts to fill the gap in the existing literature by examining the dynamic evolution path in the forest rights exchange market. Previous studies have discussed that the evolutionary stable strategies of the transaction behaviors are affected by various factors, including transaction price, transaction cost, benefit distribution, and revenue [10, 18, 20]. Combined with the actual situation in the forest rights exchange market, we focus on showing how four important factors (i.e., transaction price, transaction cost, forestry revenue, and nonforestry revenue) affect the dynamic process of the two parties’ choices in this study. These factors are more realistic and feasible in the forest rights exchange market, making them different from those of previous studies. Moreover, our research develops a numerical simulation in the evolutionary game. Based on the availability of survey data on typical regions of forest rights exchange, this study uses data sets of forestry farmers in Fujian, Zhejiang, and Jiangxi provinces in China for a numerical simulation, which makes the results of numerical simulation more reliable.

The rest of the study is structured as follows: In Section 2, we establish a mathematical model based on evolutionary game theory. Then, we analyze the factors affecting the evolutionary stability of both parties. In Section 3, the numerical simulation is introduced in detail, which also includes the influence of parameter changes on the model results. Section 4 provides conclusions and policy suggestions.

2. Model Introduction

2.1. Evolutionary Game Model and Parameters. It is assumed that suppliers mainly refer to farmers who manage idle forest resources or operate forestry with low efficiency in the forest rights exchange market and receive income from the forestland circulation. The features of suppliers are embodied in forestry cultivation, the ability to engage in other work, and the natural attributes of forestland.

(1) Transaction price reflects the effective measures taken by the supplier and demander to realize the transaction. A higher transaction price can translate into a greater incentive for forestland users in the forest rights exchange market [21]. From this point of view, we assume that the transaction price of the supplier is $T$ in this study.

(2) Previous experience shows that a significant correlation between nonforestry revenue and forestland circulation is also evident [22]. When the supplier realizes the transaction, the nonforestry revenue is $M$, and the nonforestry investment income of the demander is $R$.

(3) Forestry revenue is the prerequisite for realizing forest rights exchange. The circulation decisions of forestland users were previously found to be significantly correlated with their income structure [23]. In this study, if the supplier does not realize the transaction, the forestry revenue is $M1$, and the forestry revenue of the demander is $I$.

(4) Transaction cost is also one of the reasons for affecting forest rights exchange [20, 24]. Both sides need to bear certain transaction costs in the process of circulation. This study divides the transaction cost into two parts. The first part covers the cost before, during, and after circulation, which mainly includes the information search cost, forest asset appraisal cost, deposit cost, negotiation and contract cost, default cost, and supervision cost [24]. It is assumed that the transaction costs of the supplier and demander are the same, and the symbol definitions are $CS$ and $Cd$, respectively. The second part is that the two sides need to pay a certain commission to the
forest rights exchange center [20]. For ease of calculation, it is assumed that the commission paid by both sides is C1.

In the process of forest rights exchange, the transaction subjects cannot choose the optimal strategy every time owing to their different abilities, experiences, and knowledge. They need several evolutionary processes, such as game learning and imitation, which are continuous and gradual. By comparing the revenue increase before and after the circulation, the suppliers and demanders decide whether to choose a forest rights exchange center to realize the transaction.

In this study, the transaction probability of the supplier is \( x \), so the probability of a nontransaction is \( 1 - x \); the transaction probability of the demander is \( y \), and the probability of a nontransaction is \( 1 - y \).

Assuming that both sides realize the transaction, and the utility of the supplier is \( U_{S1} \). If the transaction is unsuccessful, the utility of the supplier is \( U_{S2} \). In addition, when the supplier chooses a nontransaction and the demander chooses transaction or nontransaction, the utilities of the corresponding suppliers are \( U_{S3} \) and \( U_{S4} \), respectively. The specific functions are shown as follows:

\[
U_{S1} = T + M - CS - C1, \\
U_{S2} = M_1 - C_S, \\
U_{S3} = U_{S4} = M_1. 
\]

Similarly, when the supplier and demander realize the transaction, the utility of the demander is \( U_{D1} \). If the transaction is not reached, the utility of the demander is \( U_{D3} \). Moreover, when the demander chooses nontransaction and the supplier chooses transaction or nontransaction, the utilities of the demanders are \( U_{D2} \) and \( U_{D4} \), respectively, and their specific functions are shown in formulas (4)-(6).

\[
U_{D1} = I - T - C_d - C_1, \\
U_{D2} = U_{D4} = R, \\
U_{D3} = R - C_d. 
\]

Here, there are four types of strategies (transaction, transaction), (transaction, nontransaction), (nontransaction, transaction), and (nontransaction, nontransaction). Thus, the game matrix of supply and demand is shown in Table 1.

| Table 1: Evolutionary game payoff matrix. |
|------------------------------------------|
| Supplier/demander | Transaction (\( y \)) | Nontransaction (\( 1 - y \)) |
|-------------------|------------------------|-------------------------------|
| Transaction (\( x \)) | \( (U_{S1}, U_{D1}) \) | \( (U_{S2}, U_{D2}) \) |
| Nontransaction (\( 1 - x \)) | \( (U_{S3}, U_{D3}) \) | \( (U_{S4}, U_{D4}) \) |

(Note: the symbol definitions in Table 1 are the same as those in Table 2).

\[
U_{Sa} = yU_{S1} + (1 - y)U_{S2}, \quad (7) \\
U_{Sb} = yU_{S3} + (1 - y)U_{S4}. \quad (8)
\]

In this case, the average utility of the supplier is \( U_S = xU_{Sa} + (1 - x)U_{Sb} \).

The expected utility values of the transaction and nontransaction by the demander is shown in the following formulas (9) and (10):

\[
U_{Da} = xU_{D1} + (1 - x)U_{D3}, \quad (9) \\
U_{Db} = xU_{D2} + (1 - x)U_{D4}. \quad (10)
\]

The average utility of demander is \( U_d = yU_{Da} + (1 - y)U_{Db} \).

In the evolutionary game strategy, supplier and demander can achieve market equilibrium by constantly adjusting their trading strategies. The replicable equations of the transactions are shown in formulas (11) and (12):

\[
F(x) = \frac{dx}{dt} = x(U_{sa} - U_S) = x(1 - x)(U_{sa} - U_{sb}) \\
= x(1 - x)[y(U_{s1} - U_{s2} - U_{s3} + U_{s4}) + U_{s2} - U_{s4}]. \\
F(y) = \frac{dy}{dt} = y(U_{Da} - U_D) = y(1 - y)(U_{Da} - U_{Db}) \\
= y(1 - y)[x(U_{D1} - U_{D2} - U_{D3} + U_{D4}) + U_{D3} - U_{D4}]. \quad (12)
\]

Here, it can be known that there are five possible local equilibrium points in the equation: (0, 0), (0, 1), (1, 0), (1, 1), and (\( x^*, y^* \)). Among them, the symbol of (0, 0) means that the transaction possibility of both sides is 0. Also, the symbols of (0, 1) and (0, 0) mean that the transaction probability of one party is 0, while the other party chooses the trading strategy. Moreover, the symbol of (\( x^*, y^* \)) indicates that the transaction proportion of both sides is 1.

2.2. Replicator Dynamic Equations. Assume that mutual learning and strategic imitation are confined to each transaction party’s group. At this point, the replication dynamic equation can be constructed to analyze the dynamic evolutionary game process between supply and demand. The expected utility of the transaction and nontransaction by the suppliers is as follows:

2.3. Evolutionary Stable Strategies. Considering that the above equilibrium points are not necessarily the evolutionary stability strategy in the system, then the stability of the above equilibrium points should be judged by the local stability analysis of the Jacobi matrix. The Jacobi matrix of the corresponding system is as follows:
\[ J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix} \]  \tag{13}

When the Jacobian determinant is \( \text{Det}_J > 0 \), the local equilibrium points represent the evolutionary stability strategy of the system. At this point, the equilibrium strategy of the system has a certain antiterror ability in a stable state. According to the matrix formula, stable numerical expressions of the local equilibrium points can be obtained as shown in Table 3.

According to the above-given analysis, the four inferences are drawn:

**Corollary 1.** When \( U_d > U_s \) and \( U_{D1} > U_{D2} \), both the supplier and demander choose the transaction strategy, and the points of (0, 0) and (1, 1) are stable nodes. When the system dynamic evolution path converges to 0, the strategies chosen by the two participants are (nontransaction, nontransaction). When the dynamic changes of the system converge to 1, the strategies chosen by the two participants are (transaction, transaction).

**Corollary 2.** When \( U_d > U_s \) and \( U_{D1} < U_{D2} \), the point (0, 0) is a stable node. That is, the nontransaction strategy is the evolutionary game equilibrium state. After a period of mutual learning and imitation, both sides choose nontransaction strategies.

**Corollary 3.** When \( U_d < U_s \) and \( U_{D1} > U_{D2} \), the point (0, 0) is a stable node. That is, the strategies chosen by the two participants are (transaction and nontransaction). If the transaction price and the nonforest income level are very low, the supplier may choose the nontransaction strategy. At the same time, the demander believes that the revenue of managing forestland is greater than the nonforestry revenue level.

**Corollary 4.** When \( U_d < U_s \) and \( U_{D1} < U_{D2} \), the point (0, 0) is a stable node. The supplier believes that the benefits of managing forestland are higher than other investments. However, the demander may choose the nontransaction strategy owing to the low income in forestry management. Therefore, the evolutionary equilibrium of the system converges to the point (0, 0).

2.4. Discussions. According to the evolution strategy analysis, the system has two possible equilibrium conditions, such as (0, 0) and (1, 1). Moreover, transaction price, transaction cost, forestry revenue, and nonforestry revenue are the important factors influencing the forest rights transaction scales.

(1) According to the transaction price level, the transaction subjects decide whether to choose the forest rights exchange. The purpose of the supplier is that the nonforestry revenue is greater than the forestry revenue. At this time, transaction price is proportional to the opportunity cost of forest rights exchange. When the forestry revenue and the dependence of supplier on forestland are lower, the transaction price is lower. The purpose of the demander is that forestry revenue is greater than the nonforestry revenue. At the same time, the transaction price is inversely proportional to the nonforestry revenue of the demander.

(2) When other variables remain unchanged, transaction cost is an important factor hindering the exchange behaviors. Transaction cost covers two types of cost (i.e., the before, during, and after cost, and the commission). Thus, it is necessary for forest rights exchange centers to provide more open pretransaction information to reduce the information search cost. Moreover, a simplified transaction procedure should be used to reduce the negotiation and signing cost. In addition, on the premise of maintaining small profits, differentiated commission fee standards should be adopted by the forest rights exchange centers to reduce the transaction cost.

(3) When the forest is more concentrated and fertile, the forestry production efficiency in the per-unit area is higher. At this time, forestry enterprises may have a higher enthusiasm for forestry operations. However, owing to the characteristics of forestry operation (e.g., long cycle, high risk, and large capital investment), the investors may hold a wait-and-see attitude toward forestry investment. To increase the transaction scales, several forestry support policies can be formulated to increase the willingness of investors in forestry.

For the suppliers, the higher the forestry revenue, the lower the possibility of transactions. Based on the previous research, this study holds that the basic output function of the suppliers in forestry is \( M1 = (1 - \varepsilon)\alpha p \) (note: the symbol definitions are the same as those in Table 2). The larger the value of \( \sigma \), the more obvious the role of social security. At present, the supplier can have a higher dependence on forestland. The more cognizant farmers are of forest rights exchange centers, the more likely they are to exchange through the transaction institutions. According to 575 questionnaires from the field survey, 58.26% of the farmers were not aware of the forest rights exchange centers in the local area. Thus, the publicity and promotion of the forest rights exchange centers should be strengthened.
(4) Nonforestry revenue is also an important factor for promoting the possibility of the transactions. The suppliers mainly include forest farmers, state-owned forest farms, and village collective organizations in the forest rights exchange market. Among them, the income level of forest farmers mainly depends on the nonforestry revenue. To realize income maximization, a deep-rooted passion for forestry operations has gradually been weakened and changed in several forest farmers. As long as sustainable and stable nonforestry revenue can be generated and the level of the rural social security system can be improved, the forest rights are more likely to be exchanged by farmers. For demanders, the higher the efficiency of nonforestry management, the lower the possibility of forestry management.
3. Numerical Simulation

3.1. Parameter Settings. Based on the above-given theoretical derivation, we design the real parameter values for the numerical simulation. The research group conducts field research on forest rights exchange markets in Fujian, Jiangxi, and Zhejiang provinces in China from 2016 to 2019. Based on the results of 575 valid questionnaires, 77 samples are exchanged through the forest rights exchange centers, among which five samples are from suppliers, and 72 samples are from demanders. According to the average annual transaction price of forest rights exchange centers, we conclude that transaction price (T) is 0.36 ten thousand CNY. The average transaction commission (C1) is about 0.02 ten thousand CNY. The nonforestry revenue of the supplier (M) is about 0.2 ten thousand CNY. The average forestry revenue (I) is about 0.06 ten thousand CNY. In this study, it is estimated that the average transaction cost of the supplier (C2) is 0.02 ten thousand CNY, and the average transaction cost of demander (C3) is also 0.02 ten thousand CNY. The average nonforestry revenue of demander (R) is about 0.16 ten thousand CNY. Following a detailed consultation on the expected forestry income of large households, we estimate that the average forestry revenue (I) is 0.8 ten thousand CNY.

3.2. Simulation Results. According to the above-given data sources, this section describes the simulation analysis of the different strategic behaviors by the suppliers and demanders and their influencing factors to verify the rationality of the evolutionary game equilibrium results.

(1) On the premise of satisfying relevant constraint conditions, when $U_{s1} > U_{s3}$ and $U_{D1} < U_{D2}$, it is assumed that each parameter of the payment matrix is assigned values. Meanwhile, we set the initial value of $(x, y)$ as (0.1, 0.1). The horizontal axis represents time, while the vertical axis represents the probability of the transaction strategy. At this time, the stable equilibrium result of the system is (0, 0), and the nontransaction choice is the best strategy for both sides. The specific evolution path is shown in Figure 1.

(2) When $U_{s1} > U_{s3}$ and $U_{D1} < U_{D2}$, it is assumed that all parameters of the game pay for the deal matrix for the assignment. The value of $R$ is 0.41, and other parameter values remain unchanged. At this point, the system's stable equilibrium result is (0, 0), and the nontransaction strategy is stable. The specific evolution path is shown in Figure 2.

(3) In the case of $U_{s1} < U_{s3}$ and $U_{D1} > U_{D2}$, it is assumed that the initial value of $(x, y)$ is (0.1, 0.1). The values of $T$ and $M$ are 0.04 and 0.05, respectively, and other parameter values remain unchanged. It is concluded that the stable equilibrium result of the system is (0, 0); that is, the nontransaction choice is the best strategy for both sides. The specific evolution path is shown in Figure 3.

(4) When $U_{s1} < U_{s3}$ and $U_{D1} < U_{D2}$, it is assumed that the values of $T$ and $M$ are 0.04 and 0.05, respectively. At the same time, the values of $I$ and $R$ are 0.4 and 0.35, respectively, and other parameter values remain unchanged. In this case, the stable equilibrium result of the system is (0, 0), and the nontransaction choice is the best strategy for both sides. The specific evolution path is shown in Figure 4.

(5) In the case of $U_{s1} > U_{s3}$ and $U_{D1} > U_{D2}$, it is assumed that the values of $T$ are 0.26, 0.36, and 0.46, respectively. When the transaction price is higher, the system converges to the equilibrium point faster. Also, the supplier has a greater possibility of selling the forest rights, as shown in Figure 5.
In the case of $U_{s1} < U_{s3}$ and $U_{d1} > U_{d2}$, it is assumed that the values of $C_s$ are at 0.01, 0.02, and 0.03. The lower the transaction cost of both parties, the faster the system converges to the equilibrium point. At the same time, they are more likely to choose transactions, as shown in Figure 6.

In the case of $U_{s1} > U_{s3}$ and $U_{d1} > U_{d2}$, it is assumed that the values of $I$ are 0.7, 0.8, and 0.83. The higher the demanders’ forestry revenue, the faster the system converges to the equilibrium point; that is, the more possible it is to manage the forestland for the demander, the higher the transaction possibility (Figure 7).

When $U_{s1} > U_{s3}$ and $U_{d1} > U_{d2}$, it is assumed that the values of $M$ are 0.1, 0.2, and 0.3. The initial value of $(x, y)$ is set as (0.1, 0.1). The higher the level of the suppliers’ nonforestry revenue, the faster the system converges to the equilibrium point. At this moment, the higher the supplier’s enthusiasm to exchange the forestland, the higher the transaction possibility, as shown in Figure 8.
Conclusions and Policy Recommendations

The forest rights exchange is an important driving force for realizing large-scale forestry management in China. However, forest rights exchange faces low circulation problems at present. The strategy choices of the supplier and demander play an important role in improving the efficiency of forest rights exchange. So far, only limited empirical evidence has been provided on the strategic selection of forest rights exchange from the perspective of the dynamic game. Based on field investigation, this study formulates a forest rights exchange evolution strategy of indicators by constructing a dynamic game model of the evolution between the two parties and analyzing the important factors that affect the forest rights exchange scale. A numerical simulation is conducted to evaluate the rationality of the theoretical model. The conclusions and policy recommendations of this paper are as follows:

(1) In terms of conclusions, the dynamic game model demonstrates how four factors (transaction price, transaction cost, forestry revenue, and nonforestry revenue) affect the choices of the suppliers and demanders in the forest rights exchange market. Firstly, we find that transaction price is an important means to regulating the forest rights exchange. The higher the transaction price, the more possible it is for suppliers to sell, but the less willing the demanders are to buy. Previous studies have revealed similar results [20, 25]. Secondly, transaction cost is an important factor that hinders exchange behaviors. Thus, it is necessary to standardize the management of the forest rights exchange market from the aspects of transaction procedures and commissions. Thirdly, forestry revenue and nonforestry revenue are important factors affecting the choices of suppliers and demanders. A higher forestry revenue is beneficial for the transaction possibility of the demanders. However, forestry revenue has a negative effect on the possibility of transactions occurring for the suppliers. Furthermore, nonforestry revenue can contribute to promoting the transaction possibility of the suppliers. For demanders, the higher the nonforestry revenue, the lower the possibility of forestry management.

(2) Several policy implications can also be drawn from the results of this study. Firstly, the government should formulate corresponding policies of transaction price management, for example, by dynamically forecasting the transaction price in the local market, and understanding the changing trend of the transaction price in a timely manner.

Secondly, it is necessary to encourage and guide forestland owners to exchange forestland with enterprises and cooperatives to enable higher efficiency in resource allocation. For example, Shaxian County has adopted preferential measures to assign an asset appraisal fee to forest resources by the institutions, which is helpful to improve the investors’ income on forestland investment. Meanwhile, the government should provide a rural social security system to improve the household welfare of farmers and increase the stable nonforest income of suppliers.

Thirdly, additional efforts are needed to establish and improve the forest rights exchange market. For example, establishing forest rights exchange centers can reduce the transaction costs of forestland users by simplifying the approval process, shortening the approval time limit and service distance. In addition, forest rights exchange centers can improve the awareness of market subjects and eliminate their doubts about forest rights exchange centers through diversity measures, such as on-site publicity, television, public accounts, and websites.
This study used evolutionary game theory to analyze the choices of the suppliers and demanders in the forest rights exchange. However, there are some limitations to this study. Further research is required to construct a multi-strategy model to analyze the choices of more participants (e.g., suppliers, demanders, government, and forest rights exchange centers).

Data Availability

The data generated and analyzed in this manuscript are available from the corresponding author upon reasonable request.

Conflicts of Interest

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

Authors’ Contributions

All authors have read and approved the final manuscript. Junjie Lin is the first author in this study. Yuanzhu Wei is the corresponding author in this study.

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