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Research Article

The Credit Risk Contagion Mechanism of Financial Guarantee Network: An Application of the SEIR-Epidemic Model

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Financing guarantee is an important means and key link to solve the financing difficulties of small- and medium-size enterprises (SMEs). However, while financial guarantees alleviate the financing difficulties of SMEs, the complex guarantee relationships also constitute a new channel for credit risk contagion in the financial guarantee network. In this paper, we construct a model of credit risk contagion process of guarantee network based on SEIR and analyse the equilibrium point and stability of the model. Then, we find the threshold value of risk contagion and further simulate the SEIR model dynamically to analyse the influence of each parameter of the model. The results show that the risk of the financing guarantee network begins to be widely contagious only when risk contagion threshold is greater than 1, and the conversion rate of exposed enterprises, removal rate of infected enterprises, nodal enterprises degree, and risk contagion rate have significant effects on the changes of individual density of susceptible, exposed, infected, and recovered enterprises. Combining the above findings, it is of great theoretical and practical significance to propose relevant countermeasures for credit risk control of financial guarantee network.

1. Introduction

According to data from the China State Administration for Market Regulation, China's SMEs are distributed in agriculture, forestry, animal husbandry, fishing, mining, manufacturing, education, health, social security, catering, culture, entertainment, and other industries, contributing 50% of the taxes, 60% of GDP, 70% of invention patents, and 80% of jobs [1]. However, the combination of multiple factors such as supply-side reform and the regular prevention and control of COVID-19 makes SMEs facing huge survival pressure [2], especially the problem of difficult, slow, and expensive financing has become more prominent [3, 4]. In order to solve the financing problems of SMEs in foreign developed countries, one of the effective measures is to establish a financing guarantee system. Financing guarantee can increase the credit and risk of SMEs, and then improve the financing acquisition rate of SMEs [5]. From the current practice, western countries generally adopt the compulsory risk sharing mechanism between banks and governments in supporting small business loans, with the central and local governments sharing most of the risk losses and guarantee institutions sharing a small portion of the risk losses. They also require lenders to share a certain proportion of risk losses to prevent moral hazard, thus making the risk of financially guaranteed credit more stable [6]. But in China, due to the inadequacy of the guarantee system, financial guarantee enterprises engage in "self-financing" and "usury" and other irregular activities, resulting in a large, mutually transmitted, and regional spread of credit risks in the field of SME financing and guarantee [7]. At the end of last century, China also began to explore the establishment of a financing guarantee system of "one body and two wings." With the continuous expansion of the breadth and depth of guarantee services, the development of guarantee system then presents a new trend: guarantee institutions, banks, governments, and SMEs are more and more closely related to each other, thus forming a financing guarantee network [8]. Meanwhile, the multiagent relationship established by business connection has become a significant reason for the accumulation and contagion of credit risk, and the exposed network risk of financing guarantee can no longer be ignored [9]. For example, numerous risk contagion events occurred successively in China's financing guarantee industry, such as Hebei Financing investment crisis and Shandong Shengtong huge debt crisis, resulting in huge financial losses and paralysis of guarantee system in the region [10]. In fact, when members of the financing guarantee network fail to operate or are affected by emergencies, credit risks are generated and spread in the financing guarantee network through related relationships, resulting in an increase in the default probability of other members in the network, namely, the financing guarantee network credit risk contagion [11].

From the perspective of communication dynamics, the typical manifestation of the continuous accumulation of related credit risk to the centralized outbreak is the guarantee crisis, which can be triggered by exogenous shocks or evolved from endogenous accumulation [12]. The slow accumulation of risks before the outbreak and the sharp increase after the outbreak have greatly challenged the stable operation of the financing guarantee system. The slow accumulation of risks before the outbreak and the sharp increase after the outbreak make the stable operation of the financial guarantee system extremely challenging, and the extensive, contagious, hidden, and network characteristics of the risks also greatly increase the difficulty of risk control of multiple entities in the financial guarantee network [13]. Therefore, it is of great significance to study the risk contagion of financing guarantee network and grasp the risk contagion process and mechanism of financing guarantee network from the source, for improving the multi-agent risk identification and management ability of financing guarantee network in China.

On the basis of the above analysis, this study constructs the credit risk contagion process model of financing guarantee network based on SEIR contagion model and analyses the equilibrium point and stability of the model and finds the threshold of risk contagion. In addition, this study also simulates the contagion process of credit risk in the financing guarantee network and the changing trend of enterprise density in each state and puts forward relevant countermeasures for credit risk management of enterprises in the financing guarantee network. The main problems to be solved in this paper are as follows:

(1) What are the characteristics of the process of risk contagion in financial guarantee network?

(2) What is the internal mechanism underlying credit risk contagion in financial guarantee networks? Which factors influence the propagation threshold of credit risk contagion in the guarantee network and the density of risk infection at steady state?

(3) How should companies in the guarantee network adopt risk control and prevention measures to better control risk contagion in order to prevent guarantee crises from occurring?

Our study has several contributions. Firstly, this study examines the problem of risk contagion among enterprises due to business connection from the financial guarantee network as a whole, and proposes risk control strategies from the perspective of studying the risk contagion mechanism. Therefore, it is innovative in terms of research content. Secondly, this study innovatively combines the emerging complex network model with the well-established contagion model, and then finds the credit risk propagation threshold and the influencing factors of risk-infected node density in steady state, which provides a theoretical basis for the practical operation of risk control in financial guarantee networks. Finally, applying biological infectious disease dynamics to the field of risk contagion, we describe the risk propagation process of credit risk in financial guarantee networks through computational experimental simulations, which not only extends the applied research of contagion models but also realizes the interdisciplinary intersectionality.

The remainder of this paper is structured as follows: Section 2 analyses the relevant literature. Section 3 constructs a SEIR infectious disease model based on a small-world network. Section 4 presents the simulation results. Section 5 summarizes the paper and makes recommendations for future studies.

2. Literature Review

According to the research purposes of this paper, the relevant literature can be divided into three categories: the guarantee network, the risk contagion in guarantee network, and the application of SEIR model.

2.1. Research on Guarantee Network. The guarantee network is premised on the widespread existence of credit guarantee. Given the information asymmetry in the credit market, the widespread use of credit guarantee allows companies to connect into a network through a chain of guarantee, namely the guarantee network [14–16]. With the increasing of crisis events of guarantee chain, scholars begin to carry out in-depth research on guarantee network from various aspects. In terms of the motivation for the formation of the guarantee network, Wan and Wei [10] took Hebei Province in China as an example and found that the demand for interest transmission of major shareholders is the main internal motivation for the formation of the guarantee network; while Wang et al. [17] found that the risk investment preference of enterprises is the main internal motivation for the formation of guarantee network. At the same time, scholars have studied the external motivations of the formation of guarantee network and found that the lack of regulatory institutions [18], the dependence on social capital in the process of enterprise financing [19, 20], and the financial relevance of economic entities [21, 22] have significantly promoted the formation of guarantee network. In terms of guarantee network structure, Watts and Strogatz [23] and Barabasi and Albert [24] were the first to propose the nonuniformity of network structure, that is, network structure had topological properties. With the extensive study of network theory in finance, scholars have started to analyse the diversity of network structures through empirical explorations using data from financial institutions, manifested in scale-free network features (e.g., Japanese financial institution network and China's interbank financing network) [25, 26], small-world network features (e.g., Austrian interbank market network and U.S. bank markets trading network) [27, 28], and stochastic network structure (e.g., Italian interbank market network) [29]. On this basis, a few scholars have tried to use network theory to address the network diversity in credit guarantee markets. For example, a duplex interbanking credit networks [30] and interenterprise linked credit networks [18].

2.2. Research on Risk Contagion in Guarantee Network. As financial crises are repeatedly transmitted among countries and regions through different channels, scholars have been prompted to conduct theoretical and empirical studies on financial risk contagion and have developed influential theories and models. Theories such as the third-generation moral hazard crisis model [31, 32] and the fourth-generation financial crisis model [33] have provided guidance for the study of risk contagion in the financial domain. However, as an important part of the modern financial system, the risk contagion mechanism of guarantee has also gradually received the attention of scholars. In terms of the factors of risk contagion, scholars generally agree that default correlation is the direct driver of risk contagion, and this default correlation is summarized from macro and micro perspectives, respectively. At the level of macro factors, the main aspects are the macroeconomic downswing, the economic cycle, and the unbalanced financial environment [34, 35]. At the level of micro factors, they are mainly divided into two aspects: financial institutions and business operations. In terms of the influence of financial institutions, it is mainly manifested in the fierce competition among banks, the pressure of performance assessment [36], and the lack of financial regulation [37]. In terms of the influence of business operations, it is mainly manifested in the inadequate internal governance mechanism of financing enterprises and the single financing channel [38–40].

In terms of research trends, academic research on risk contagion effects has shown different approaches. In the early days, scholars mostly used risk metrics to measure risk contagion effects. For example, Diebold and Yilmaz [41] proposed the construction of a Spillover Index based on a VAR model to measure the size of return spillover and volatility spillover effects on assets. Glasserman and Young [42] constructed a contagion index using the size, leverage, and connectivity of a guarantee network, aiming to measure the impact of one institution's failure through the guarantee network to other institutions and systems. Chiu et al. [43] proposed a new measure of tail risk spillover, Conditional Coexceedance (CCX), and empirical analysis showed that the U.S. financial sector had significant volatility and risk spillover to the real economy from 2001 to 2011, and the risk spillover effect is stronger in industries with fierce competition. However, in recent years, with the continuous development of network theory, abundant scholars are combining networks with risk contagion studies. Sun and Li [11] constructed a network based on the guarantee relationship between enterprises, and found that guarantee network provided a channel for risk contagion, which exacerbating the risk contagion among enterprises. Wang et al. [44] constructed a risk contagion model for interenterprise credit guarantee networks and found that the larger the heterogeneity coefficient of interenterprise credit guarantee amounts, the more likely it is expected to cause contagion of interenterprise credit risk.

2.3. Research on Application of SEIR Model. Infectious disease dynamics is an important method for theoretical and quantitative research, the core ideology of which is to analyse the process of disease development, reveal epidemic patterns, predict trends, and analyse the factors and keys of disease epidemics [45]. Kermack and McKendrick [46] first proposed the classical infectious disease dynamic model SIR (susceptible infected removed) model, which divides the total population into three categories: susceptible S (susceptible), diseased I (infective), and removed R (removal). However, since this model failed to take into account the latency period of infectious diseases, the SEIR model with the concept of "exposed infected person (E)" was subsequently proposed [47–49]. The aforementioned infectious disease models have more established applications for viral transmission in the medical field, such as transmission pathways for influenza spread [50], transmission of community outbreaks [51] and transmission of viral disease risk [52]. However, the repeated contagion of financial crises across countries and regions through different channels has prompted a few scholars to identify similarities between the mechanisms of risk transmission in financial networks and those of infectious diseases. For example, Sun et al. [53] constructed a SEIR-based contagion model of individual credit risk based on complex networks, revealed the pattern and structure of credit risk, and explored the current status and influencing factors of credit risk in scale-free networks through simulation experiments. Zhao et al. [54] constructed a SEIR model of credit risk contagion in Internet P2P lending platform based on complex network theory and contagion dynamics theory, and studied and analysed the contagion path of credit risk in Internet P2P lending. Therefore, a risk propagation model based on the SEIR contagion dynamics model is applicable for studying the credit risk contagion mechanism of Chinese financial guarantee network.

Combining the above studies, we can find that the current financing guarantee network risk contagion focuses on the study of risk contagion factors and effects, which not only enriches the existing guarantee risk theory, but also lays the foundation for future multisubject and systematic risk research. However, there are also deficiencies in existing studies, which need to be further explored. First, most existing models assess and predict the risk of contagion paths in the network after constructing a complex network, which makes it difficult to portray the spread of risks in the network, and it is unclear how the network structure affects risk propagation, and further research is necessary. Second, only a small number of scholars have combined complex networks with contagion models to study the risk transmission mechanism of financial guarantee networks, and scholars have used more theoretical as well as empirical analysis of systemic risk problems, and the quantitative research on the risk transmission process and impact degree of financial guarantee networks is not deep enough.

3. Model Construction and Analysis of Risk Contagion of Financial Guarantee Network Based on SEIR

The association network of a credit subject has the same type of network nature as occurs within society, biology, and communication, and the credit risk infection is similar to the spread of infectious diseases and viruses [53, 55]. Therefore, based on the classical SEIR model and the research hypotheses of Sun and Li [11], this paper considers the existence of risk latency period, constructs a SEIR contagion model of credit risk contagion process in financial guarantee network, and explores the contagion mechanism of corporate credit risk to make the study more relevant to the actual situation. The following hypotheses are made in this paper based on the complexity of the real environment and the different forms of infectious diseases.

3.1. Research Hypotheses

Hypothesis 1. Based on the research of Zhang et al. [56], this study classifies the status of enterprises in the financing guarantee network into four categories: susceptible enterprise S, exposed enterprise E, infected enterprise I, and immune enterprise R. The total number of enterprises in the network is specified as N and remains unchanged without considering the entry of new enterprises and the bankruptcy of the original enterprises.

(1) Susceptible enterprise (S): In the financial guarantee network, susceptible enterprises are those that have low credit risk and have not been infected by default risk at t moment, but once they have financial and business dealings with latent or infected enterprises, they are at risk of being infected by default risk and turning into latent or infected enterprises. Such as the lack of financing pledges, high risk of operation of SMEs, risk control is not strict, and the capital strength of weak security institutions.

(2) Exposed enterprise (E): In the financial guarantee network, exposed enterprise refers to an enterprise that has suffered the impact of risk contagion at moment t, but the risk has not been revealed yet. After a period of time, those with strong risk resilience will turn into susceptible enterprises, while those with weak risk resilience will turn into infected enterprises.

(3) Infected enterprise (I): In the financial guarantee network, an infected enterprise refers to an enterprise that has been infected by the risk and has credit risk at time t. Some enterprises may become immune to the risk after rescue, others are infected with the risk and turn into immune enterprises after bailout, or they may not acquire immunity after bailout and turn into susceptible enterprises.

(4) Recovered enterprises (R): In a financial guarantee network, an immune enterprise is an enterprise that gains risk immunity (temporarily) from the risk of default at moment. Such enterprises have a stronger risk prevention and control capability compared to other enterprises in the network.

(5) $S(t)$, $E(t)$, $I(t)$, and$R(t)$ denotes the density of enterprises in the four types of states at the moment t, so $S(t) + E(t) + I(t) + R(t) = 1$, and satisfies $0 \le S(t), E(t), I(t), R(t) \le 1$.

Hypothesis 2. Referring to the study of Younsi et al. [50] and De la Sen et al. [47], it is assumed that when a susceptible enterprise is infected with credit risk with probability a temporarily unrevealed risk turns into a exposed enterprise, and with probability $1 - a$ revealed risk turns into an infected enterprise.

Hypothesis 3. According to Li et al. [49], it is argued that exposed enterprises with effective risk management can move to susceptible enterprises with probability b, and ineffective or inefficient management will move to infected enterprises with probability $1 - b$, and eventually the exposed enterprises will move out of the group of exposed enterprises with proportion α.

Hypothesis 4. Referring to the study of Das et al. [48] and Zhao et al. [54], it is assumed that infected enterprises can transform into immune enterprises (temporarily immune) with probability c after rescue, and transform into susceptible enterprises with probability $1 - c$ without immunity, and infected enterprises will eventually move out of the group of infected enterprises with probability β to eliminate the risk.

Hypothesis 5. Due to problems in business operations or weakened risk management capabilities [13, 17, 20], in recovered enterprises, the loss of immunity turns to a vulnerable group of businesses with probability γ.

By analysing the state change of each node enterprise, the risk contagion process of the financial guarantee network is illustrated in Figure 1.

3.2. Model Construction. Based on the credit risk contagion process of the financial guarantee network and the above hypotheses, the SEIR financial guarantee network credit risk contagion model is established and the following set of dynamics equations representing the change in density of each type of enterprise is constructed.

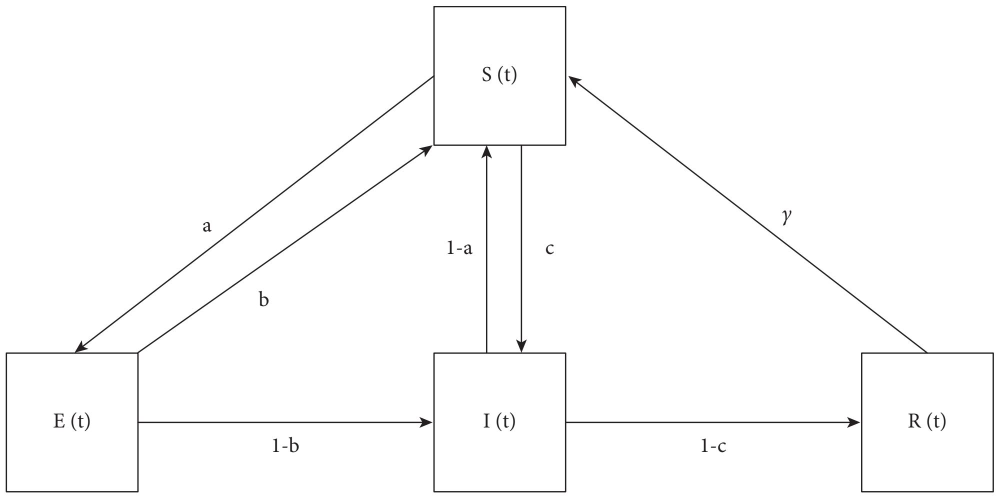

Figure 1: Credit risk contagion process of financial guarantee network.

$$\begin{cases} \dfrac{dS(t)}{dt} = -S(t)I(t) + \alpha * b * E(t) + c * \beta * I(t) + \gamma R(t) \\ \dfrac{dE(t)}{dt} = -\alpha * E(t) + a * S(t)I(t) \\ \dfrac{dI(t)}{dt} = -\beta * I(t) + (1-a) * S(t) * I(t) + (1-b) * \alpha * E(t) \\ \dfrac{dR(t)}{dt} = -\gamma R(t) + \beta * (1-c) * I(t) \end{cases}. \quad (1)$$

Considering that the financing guarantee network is a typical small-world network with small-world network characteristics [57]. Therefore, the nodes of each enterprise in the financing guarantee network cannot be in a uniform distribution. Thus, according to the topological nature of the guarantee network structure [58, 59], the node enterprise i, the network average degree k, where $k = \sum_{i=1}^{n} i * P(i)$, $k = 1, 2 \ldots n$, $P(k)$ denotes the probability that the node degree is k; $\rho(t)$ denotes the probability of being contagious through an edge in the network at moment t. The risk contagion rate is greater when the correlation between enterprises in the financial guarantee network is higher. Where, $\rho 1$ denotes the contagion rate of the group of latent enterprises and $\rho 2$ denotes the contagion rate of the group of infected enterprises; $\Theta 1(t)$ denotes the probability that any one edge in the network is associated with a latent enterprise and $\Theta 2(t)$ denotes the probability that any one edge in the network is associated with an infected enterprise, where, $\Theta 1(t) = \sum_{i=1}^{n} i * P(i) * E(i)/k$, $\Theta 2(t) = \sum_{i=1}^{n} i * P(i) * I(i)/k$. This functional equation represents the probability of being infected through an edge per unit time. $\rho(t) = \rho 1 * \Theta 1(t) + \rho 2 * \Theta 2(t)$. Based on the above analysis, the study of equation (1) can be translated as follows:

$$\begin{cases} \dfrac{dS\ k(t)}{dt} = -kSk(t)[\rho 1\Theta 1(t) + \rho 2\Theta 2(t)] + \alpha bEk(t) + c\beta Ik(t) + \gamma Rk(t) \\ \dfrac{dE\ k(t)}{dt} = -\alpha Ek(t) + kaSk(t)[\rho 1\Theta 1(t) + \rho 2\Theta 2(t)] \\ \dfrac{dI\ k(t)}{dt} = -\beta Ik(t) + k(1-a)Sk(t)[\rho 1\Theta 1(t) + \rho 2\Theta 2(t)] + (1-b); Ek(t) \\ \dfrac{dR\ k(t)}{dt} = -\gamma Rk(t) + \beta(1-c)Ik(t) \end{cases}. \quad (2)$$

Equation (2) describes the changes over time and the change of the state proportion of enterprises at each node in the process of default risk contagion in the process of credit risk outbreak in the financing guarantee network until the whole system reaches a stable state.

3.3. Equilibrium Point of the Model and Stability Analysis

3.3.1. Credit Risk Avoidance Equilibrium and Stability of Financial Guarantee Network. In the process of credit risk contagion in the financial guarantee network, the equilibrium state of risk avoidance is reached when the number of exposed (E), infected (I), and removed (R) enterprises are all zero, and all enterprises are risk-prone enterprises [18, 54]. At this point, the equilibrium point of the differential equation is $Q0\,(1,0,0,0)$, and the system is risk-free contagion at this point, but this state is ideal and does not exist in reality. The system of differential equations is discussed, and since $Sk(t)+Ek(t)+Ik(t)+Rk(t)=1$, only three of the equations in the system of kinetic equations are required to satisfy the condition.

The Jacobi matrix of the risk-free diffusion equilibrium point $Q0\,(1,0,0,0)$ is as follows:

$$J(Q0)=\begin{pmatrix} -\alpha\, 0\, 0 \\ (1-b)\alpha\ -\beta\, 0 \\ 0\, \beta(1-c)-\gamma \end{pmatrix}. \quad (3)$$

Solving the characteristic equation for the following matrix: $f(\lambda)=(\lambda+\gamma)*[(\lambda+\alpha)(\lambda+\beta)]$,

It can be seen that the three characteristic roots of the characteristic equation are $\lambda 1=-\gamma$, $\lambda 2=-\alpha$, $\lambda 3=-\beta$, and $\gamma,\alpha,\beta\in 0,1$, then $\lambda 1$, $\lambda 2$, and $\lambda 3$ are negative real numbers. According to the corollary of Lyapunov's stability discriminant theorem [60], the system equilibrium point $Q0\,(1,0,0,0)$ is found to be asymptotically stable.

3.3.2. Analysis of Risk Contagion Equilibrium and Stability of the Guarantee Network. According to the definition of the equilibrium point of the system, the differential of all variables at the position of the equilibrium point needs to be satisfied as 0 [18, 54]. The following equation can be obtained:

$$\begin{cases} \dfrac{dS\,k(t)}{dt}=-kSk(t)[\rho 1\Theta 1(t)+\rho 2\Theta 2(t)]+\alpha bEk(t)+c\beta Ik(t)+\gamma Rk(t)=0 \\ \dfrac{dE\,k(t)}{dt}=-\alpha Ek(t)+kaSk(t)[\rho 1\Theta 1(t)+\rho 2\Theta 2(t)]=0 \\ \dfrac{dI\,k(t)}{dt}=-\beta Ik(t)+k(1-a)Sk(t)[\rho 1\Theta 1(t)+\rho 2\Theta 2(t)]+(1-b)\alpha Ek(t)=0 \\ \dfrac{dR\,k(t)}{dt}=-\gamma Rk(t)+\beta(1-c)Ik(t)=0 \end{cases}. \quad (4)$$

the solution of the system of (4) as follows:

$$\begin{cases} Sk(t)=\dfrac{\alpha\beta\gamma}{A} \\ Ek(t)=\dfrac{\beta\gamma ak\rho(t)}{A} \\ Ik(t)=\dfrac{\alpha\gamma k\rho(t)(1-ab)}{A} \\ Rk(t)=\dfrac{\alpha\beta k\rho(t)(1-ab)(1-c)}{A} \\ A=\beta\gamma[\alpha+ak\rho]+\alpha k\rho(1-ab)[\gamma+\beta(1-c)] \end{cases}. \quad (5)$$

From the previous hypotheses, we obtain $\rho=\rho(t)=\rho 1*\Theta 1(t)+\rho 2*\Theta 2(t)=\rho 1*\sum_{k=1}^{n}k*P(k)*E(k)/k+\rho 2*\sum_{k=1}^{n}k*P(k)*I(k)/k$, Substitute $Ek(t)=\beta\gamma ak\rho(t)/A$, $Ik(t)=\alpha\gamma k\rho(t)(1-ab)/A$ into the above equation, we can get follow equation: $\rho=\rho 1*1/k*\sum_{k=1}^{n}kP(k)*Ek(t)+\rho 2*1/k*\sum_{k=1}^{n}kP(k)*Ik(t)=\rho*\{1/k*[\rho 1a\beta\gamma+\rho 2\,\alpha\gamma(1-ab)]*\sum_{k=1}^{n}kP(k)\}$.

Therefore, $f(\rho)=1-1/k*[\rho 1a\beta\gamma+\rho 2\alpha\gamma(1-ab)]*\sum_{k=1}^{n}k^2P(k)$, since $f'(\rho)>0$, obviously, $f(\rho)$ is a monotonically increasing function. Only when $f(\rho)=0$, $f(0)<0$, and $f(\rho)$ is a unique positive equilibrium solution, note $\sum_{k=1}^{n}k^2P(k)=k^2$, we get $f(0)=1-[\rho 1a\beta+\rho 2\alpha(1-ab)]*k^2/k\alpha\beta<0$, then there is $[\rho 1a\beta+\rho 2\alpha(1-ab)]*k^2/k\alpha\beta>1$. When this critical point is reached, credit risk begins to be contagious in the collateral network. Therefore, let $R0=[\rho 1a\beta+\rho 2\alpha(1-ab)]*k^2/k\alpha\beta$, $R0$ is the equilibrium point threshold for the contagion of default risk in the guarantee network. Combining the hypotheses, substituting $R0$ into equation (5) yields a unique positive risk-transmission equilibrium for the system, and the risk-transmission equilibrium is $Q1\,(Sk,Ek,Ik,Rk)$.

From the above model and analysis, it is obviously that when individual risks are highlighted in the process of credit risk contagion in the guarantee network, it does not cause a large area of contagion. From the above model and analysis, it can be seen that when individual risks are highlighted in the credit risk contagion process of the guarantee network, it does not cause a large area of contagion. And the risk contagion threshold determines whether credit risk exists in the financing guarantee network, when $R0 > 1$, credit risk will be propagated in the guarantee network; when $R0 < 1$, credit risk in the guarantee network will be terminated. Therefore, further analysis of the factors influencing the risk transmission threshold is necessary.

4. Model Simulation Analysis

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

In order to reflect the contagion process of credit risk in the financing guarantee network more clearly and intuitively, according to the parameter assignments in the studies of Zhao et al. [54] and Rădulescu et al. [51], the parameters in the model are assigned for the two cases of $R0 < 1$ and $R0 > 1$, and in the simulation experiments, the initial conditions given $S(0) = 0.9$, $E(0) = 0.05$, $I(0) = 0.05$, and $R(0) = 0$, and the other parameters in the model are $\alpha = 0.7$, $\beta = 0.4$, $\gamma = 0.3$, $c = 0.5$, and $\rho = 0.1$, and let the time period be $t \in [0, 30]$, with the help of MATLAB 2016b simulation tool, the trend of change in the density of enterprises in each state and the action process of the relevant parameters are simulated for calculation experiments, and the simulation results are analysed and discussed after simulation.

4.1. Simulation of Infection Scenario. In order to better explore the scenarios under which large contagion of credit risk occurs, the parameters in the model are assigned, and then simulated for two scenarios, $R0 < 1$ and $R0 > 1$, respectively, as discussed below.

4.1.1. Scenario I. With the above parameters set constant, the other parameters in the model are assumed to be $a = 0.6$, $b = 0.4$, and $k = 10$. Substituting the values set for each of the above parameters into the risk contagion threshold $R0$, and it can be seen that $R0 > 1$. At this time, the credit risk starts to be contagious in the guarantee network, and the proportion of each state node enterprise in the guarantee network is obtained over time as shown in Figure 2.

From the simulation results, it can be seen that the density of susceptible enterprises decreases sharply at the beginning and eventually stabilizes as time goes on. The density of exposed enterprises first increases sharply at the beginning, and then falls back slowly until it stabilizes after reaching a peak. The change trend of the density of infected enterprises is similar to that of exposed enterprises, and the time of reaching the peak is later than that of latent enterprises, although there is a slight decline after the peak, but the density of infected enterprises has been stable at a relatively high level, when the risk is still spreading contagion in the guarantee network. The recovered enterprise shows a slow upward trend in the beginning, and then gradually stabilizes.

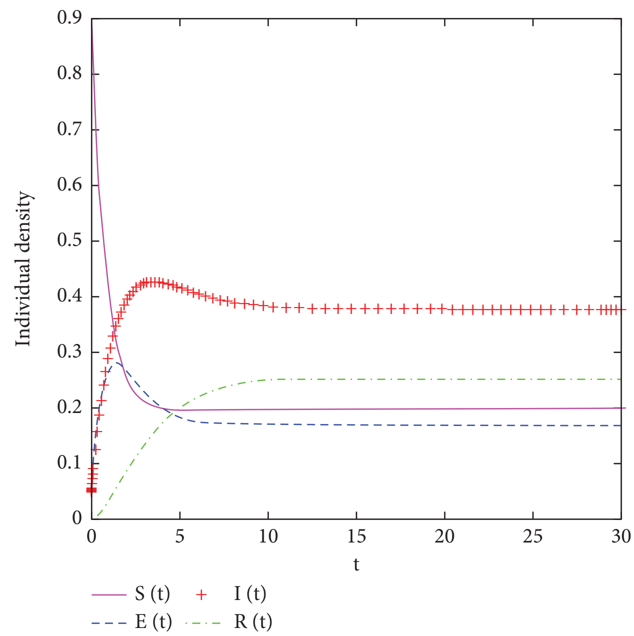

Figure 2: Simulation result of risk contagion in the case of $R0 > 1$.

In addition, the reason why the density of exposed enterprises rises to a peak, and then falls back to a stable state may be that enterprises with better risk identification skills effectively identify risks at the early stage of risk contagion, thus nabbing them in the cradle. The reason why the density of infected enterprises peaked, and then fell back later than that of exposed enterprises may be that enterprises have been infected by the risk after the risk resistance system has been damaged and need more time to react in order to adopt more effective risk prevention and control methods to reasonably control or avoid the risk. The reason why the density of infected enterprises peaked, and then fell back later than that of exposed enterprises may be that enterprises have been infected by the risk after the risk resistance system has been damaged and need more time to react in order to adopt more effective risk prevention and control methods to reasonably control or avoid the risk.

4.1.2. Scenario II. With the above parameters set constant, the other parameters in the model are assumed to be $a = 0.6$, $b = 0.4$, and $k = 3$. Substituting the set values of each parameter into the risk contagion threshold $R0$, it is apparently that $R0 < 1$. At this point, the risk starts to be hedged in the guarantee network, and the proportion of enterprises in each state node in the guarantee network changes over time as shown in Figure 3.

From the simulation results, it can be seen that, as time goes on, the density of susceptible enterprises decreases slowly at the beginning and finally stabilizes at a higher density level; the density of exposed enterprises increases

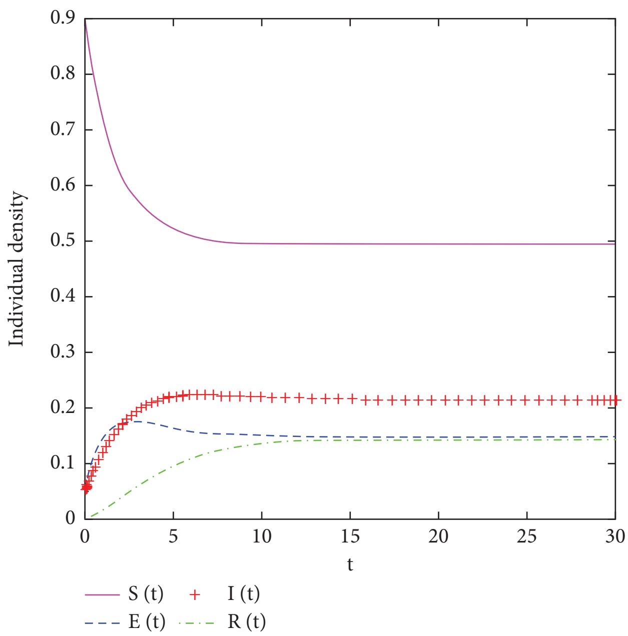

Figure 3: Simulation result of risk contagion in the case of $R0 < 1$.

slightly at the beginning, and then falls back slowly until it stabilizes after reaching a peak; the density of infected enterprises increases slowly at the beginning for a short period, and then stabilizes; the density of immune enterprises shows a slowly increasing trend at the initial stage, and then gradually stabilizes.

The above simulations for two different scenarios of risk contagion thresholds not only verify the decisive role of risk contagion thresholds in affecting default risk contagion in the guarantee network, but also further corroborate the previous discussion on the stability of the two equilibrium points of the system. Next, the hypotheses of scenario 1 is taken as the premise, the discussion focuses on the case where the risk contagion threshold is greater than 1. At this point, credit risk spreads in the guarantee network and the impact of different key parameter changes on the risk contagion effect is analysed.

4.2. Simulation Analysis of Credit Risk Contagion from Changes in Key Parameters

4.2.1. Impact of Conversion Rate of Exposed Enterprises on Credit Risk Contagion. Under the abovementioned parameters, adjusting the values of the conversion rate of exposed enterprises to 0.2 and 0.8, respectively, the effect on the evolution of the density of enterprises in each state is shown in the figures below. From Figure 4, as the conversion rate b of exposed enterprises increases, the number of exposed state enterprises gradually decreases, the number of infected state enterprises decreases significantly, and the density of enterprises in each state node in the final financing guarantee network tends to be stable. That is, the conversion rate of exposed enterprises will act on the diffusion rate of credit risk in the guarantee network, which will also lead to a certain magnitude of decrease in the density of infected enterprises. It shows that nodal companies can effectively reduce not only their own exposure to credit risk contagion but also the probability of their own credit risk outbreak by establishing a complete early warning mechanism for risk management, maintaining sensitivity to risk information, and reacting in a timely manner when risks occur.

4.2.2. Impact of Infected Enterprises' Switching Out Rate on Credit Risk Contagion. Under the above parameters, the values of the transfer rate of infected enterprises are adjusted to 0.2 and 0.8, respectively. The effect on the evolution of the density of enterprises in each state is shown in the following figures. From Figure 5, it can be seen that the density of infected enterprises decreases significantly and the density of recovered enterprises increases gradually after the density of enterprises in each state node in the financing guarantee network stabilizes with the increase of the transfer rate of infected enterprises, that is, the rate of transfer out of infected enterprises β will act on the rate of risk diffusion in the financial guarantee network, which will also lead to a certain magnitude of decrease in the density of infected enterprises. It shows that after enterprises are affected by risk contagion, they can effectively reduce their exposure to credit risk contagion by continuously strengthening their risk management ability and developing and learning new risk management ability, thus reducing the probability of their own credit risk outbreak.

4.2.3. Impact of Risk Contagion Rate on Credit Risk Contagion. With the above parameters, the risk contagion rate is adjusted to 0.2 and 0.4, respectively. The evolutionary impact on the density of enterprises in each state is shown in the figures below. From Figure 6, it can be seen that with the increase of risk contagion rate ρ, the density of susceptible state enterprises decreases precipitously and the density of infected state enterprises increases gradually. Eventually, the density of enterprises in each state node in the financial guarantee network tends to be stable. That is, the risk contagion rate ρ acts on the rate of risk diffusion in the guarantee network, and also causes a certain magnitude of increase in the density of infected enterprises. It shows that maintaining a low-risk contagion rate in the financial guarantee network can effectively reduce not only the impact of credit risk contagion suffered by the subjects in the guarantee network, but also the probability of enterprises' credit risk outbreak in the financial guarantee network.

4.2.4. Impact of Nodal Enterprise Degree on Credit Risk Contagion. Keep other parameters unchanged, adjust the value of enterprise degree k of node, which is 5, 10, 20, and 50, respectively, and the evolution influence on enterprise density of various states is shown in the figures below. From Figure 7, it can be seen that when the node degree of enterprises is small, the resistance of enterprises to credit risk contagion in the financing guarantee network is stronger. With the increase of node enterprise degree, the density of

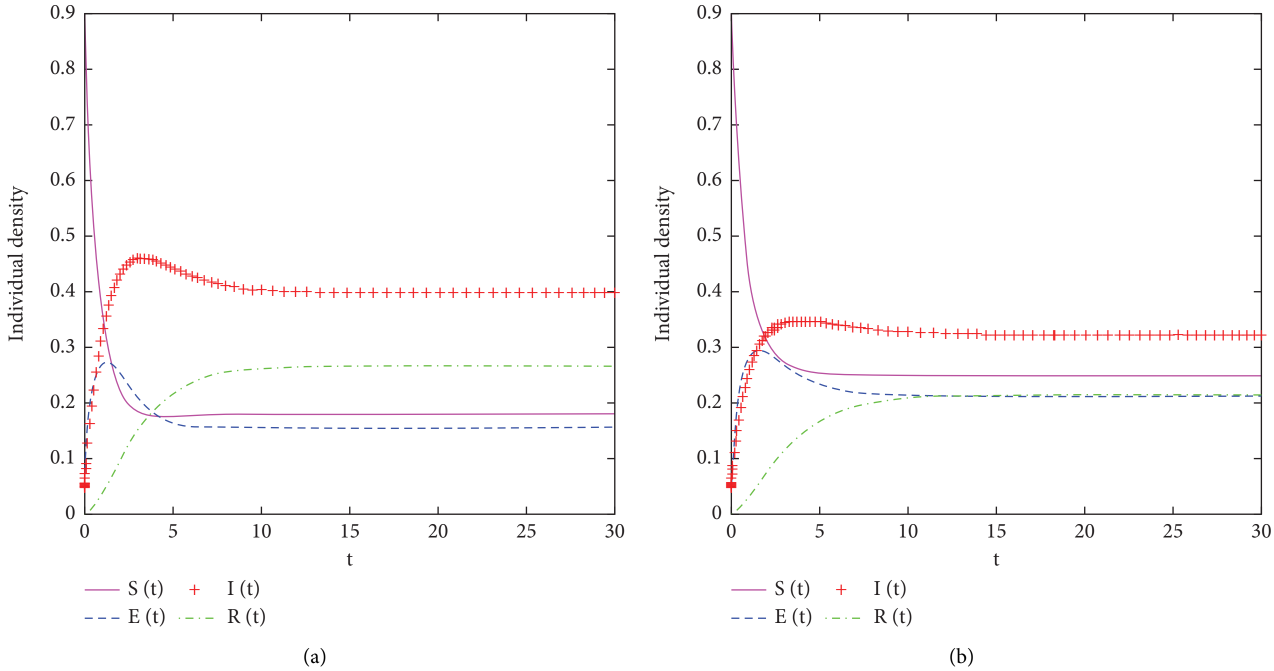

Figure 4: Simulation results of conversion rate of exposed enterprises on credit risk contagion. (a) $b = 0.2$. (b) $b = 0.8$.

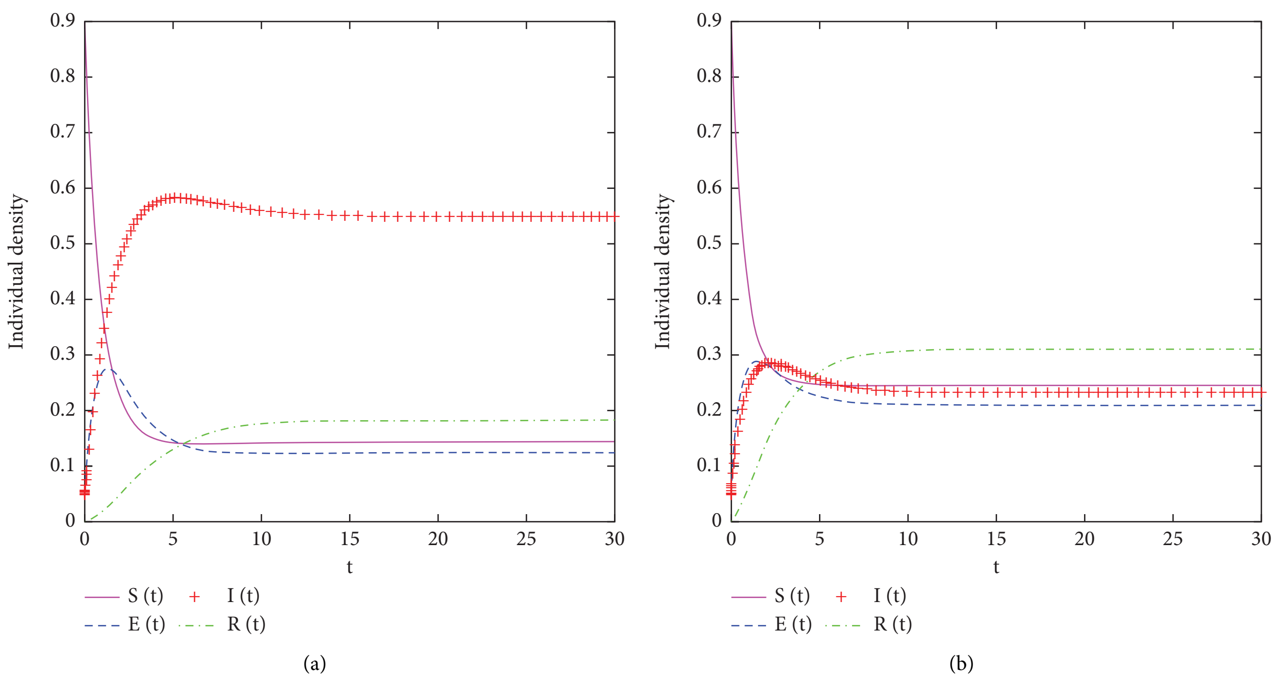

Figure 5: Simulation results of infected enterprises' switching out rate on credit risk contagion. (a) $\beta = 0.2$. (b) $\beta = 0.8$.

enterprises in each state node in the guarantee network stabilizes, and then the density of infected state enterprises increases significantly, the density of exposed state enterprises rises rapidly at the beginning and then falls back to a stable level, and the density of susceptible state enterprises plummets to a lower density level.

That is, the change of node enterprise degree will act on the diffusion rate of risk in the guarantee network, so that the susceptible state enterprise in the network declines rapidly, and the latent state enterprise and infected state enterprise show a higher density level in general. It indicates that the higher the degree of nodes in the guarantee network, the closer the connection between enterprises in terms of business and capital, the faster the transmission of risk in the guarantee network and the greater the damage caused to the guarantee network.

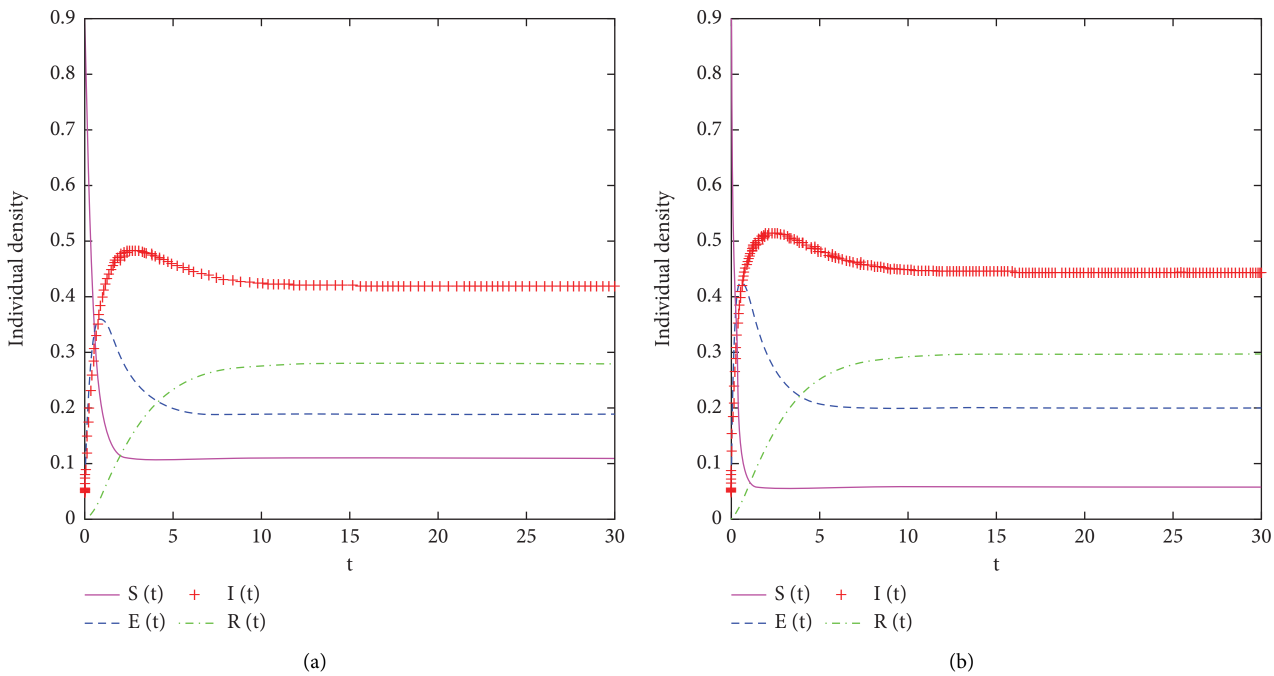

FIGURE 6: Simulation results of infected enterprises' switching out rate on credit risk contagion. (a) $\rho = 0.2$. (b) $\rho = 0.4$.

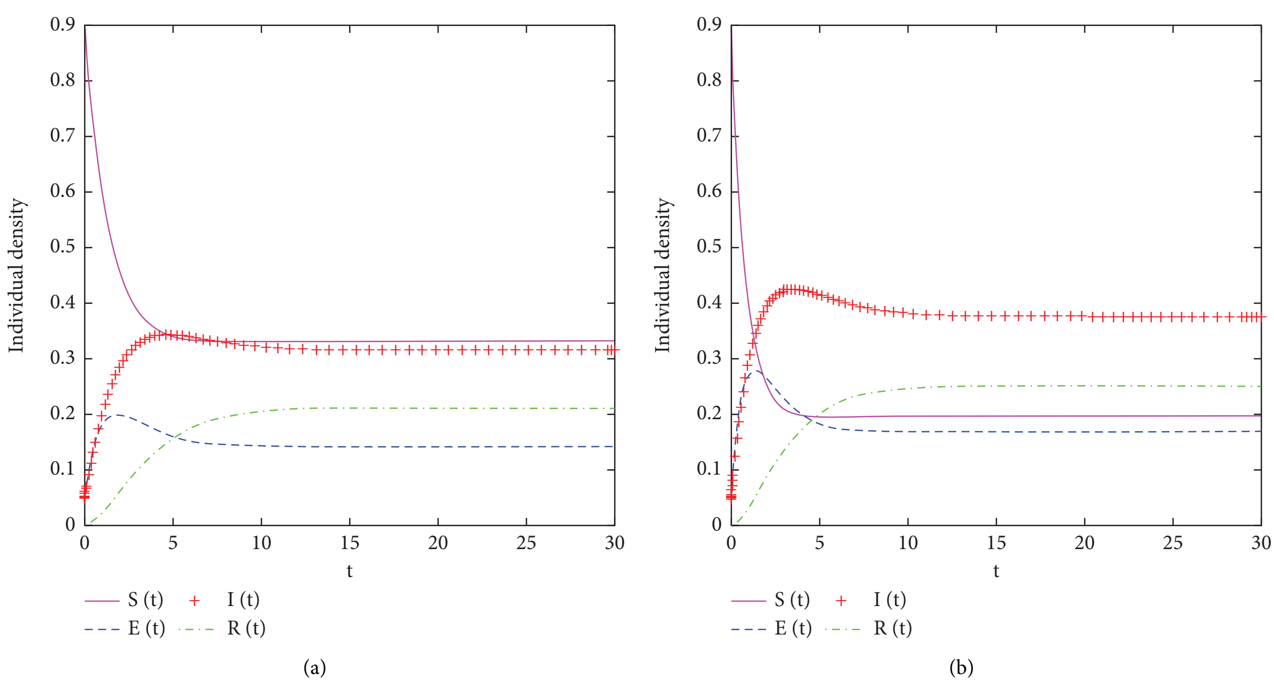

FIGURE 7: Continued.

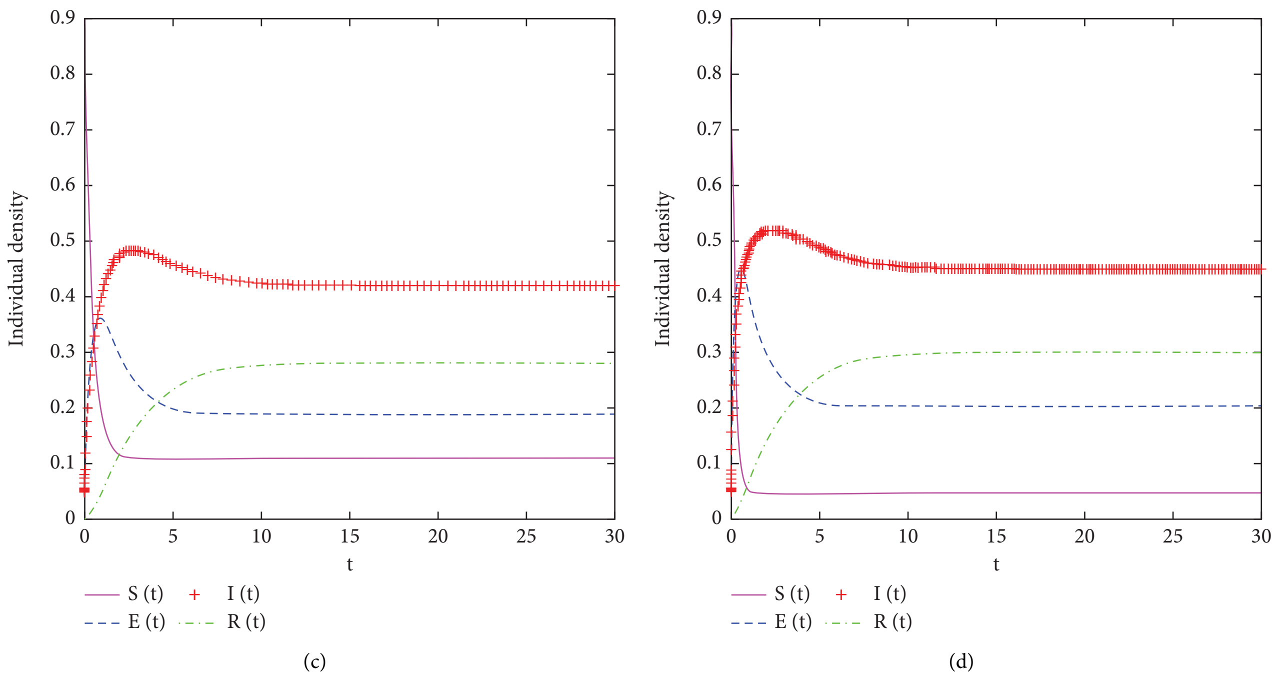

Figure 7: Simulation results of nodal enterprise degree on credit risk contagion. (a) $k = 5$. (b) $k = 10$. (c) $k = 20$. (d) $k = 50$.

4.2.5. Impact of Recovered Enterprise Removal Rate on Credit Risk Contagion. Under the above parameters, adjusting the removal rate γ of recovered enterprises to 0.2 and 0.5, respectively. The effect on the evolution of the density of enterprises in each state is shown in the figures below.

From Figure 8, it can be seen that with the increase of the removal rate γ of immune enterprises, the density of immune state enterprises shows a substantial decrease and the density of infected state enterprises gradually increases. Finally, the density of enterprises in each state node in the guaranteed network tends to be stable, that is, the recovered enterprise removal rate γ acts on the rate of risk diffusion in the guarantee network and also causes a certain increase in the density of infected enterprises. It shows that when the removal rate of recovered enterprises is at a low level, extending the immunization period of recovered enterprises can effectively reduce the impact of credit risk contagion on each subject in the guarantee network, and thus reduce the probability of credit risk outbreak of enterprises in the guarantee network.

5. Conclusions and Suggestions

Based on the SEIR contagion model, this paper constructs a credit risk contagion model for financial guarantee networks based on the characteristics of financial guarantee small-world networks and explores the risk contagion threshold. MATLAB is used to simulate the risk contagion process among nodal enterprises in the financing guarantee network and analyzes the changes of the risk status of the nodal enterprises in the guarantee network and the influence of each key parameter on the risk contagion effect. The main research conclusions are as follows:

First, risk contagion does not necessarily occur in a network when individual subjects in a guarantee network incur risk, it will only create a contagion effect in a network when the effective contagion rate of risk in the network reaches or exceeds a risk threshold. Second, the density of individual exposed enterprises varies in the same direction as the conversion rate of exposed enterprises, the removal rate of infected enterprises and the node enterprise degree of the guarantee network, while it varies in the same direction as the risk contagion rate only at the beginning of the contagion. Again, the density of infected individuals shows a decreasing trend with increasing the conversion rate of exposed enterprises or the removal rate of infected enterprises. In contrast, the density of infected individuals tends to increase with the increase of risk contagion rate, the network enterprise node degree, or the removal rate of recovered enterprises; Finally, the density of recovered individuals varies in the same direction as the degree of node enterprise and the removal rate of infected enterprises in the guarantee network, and in the opposite direction as the removal rate of recovered enterprises and the conversion rate of exposed enterprises.

Based on the above analysis and conclusions, the following countermeasures and suggestions are put forward.

First, in the context of the continuous development of the financial guarantee industry, the credit risk faced by each enterprise has changed drastically, and it needs to pay attention not only to the impact of its own risk factors, but also to the comprehensive impact of various factors such as the overall operation of the financial guarantee network and the risk status of cooperative enterprises, any of which may lead to its own credit risk. Therefore, enterprises should pay more attention to the credit risk status of their partners and improve their ability to identify risks, so that they can take effective and

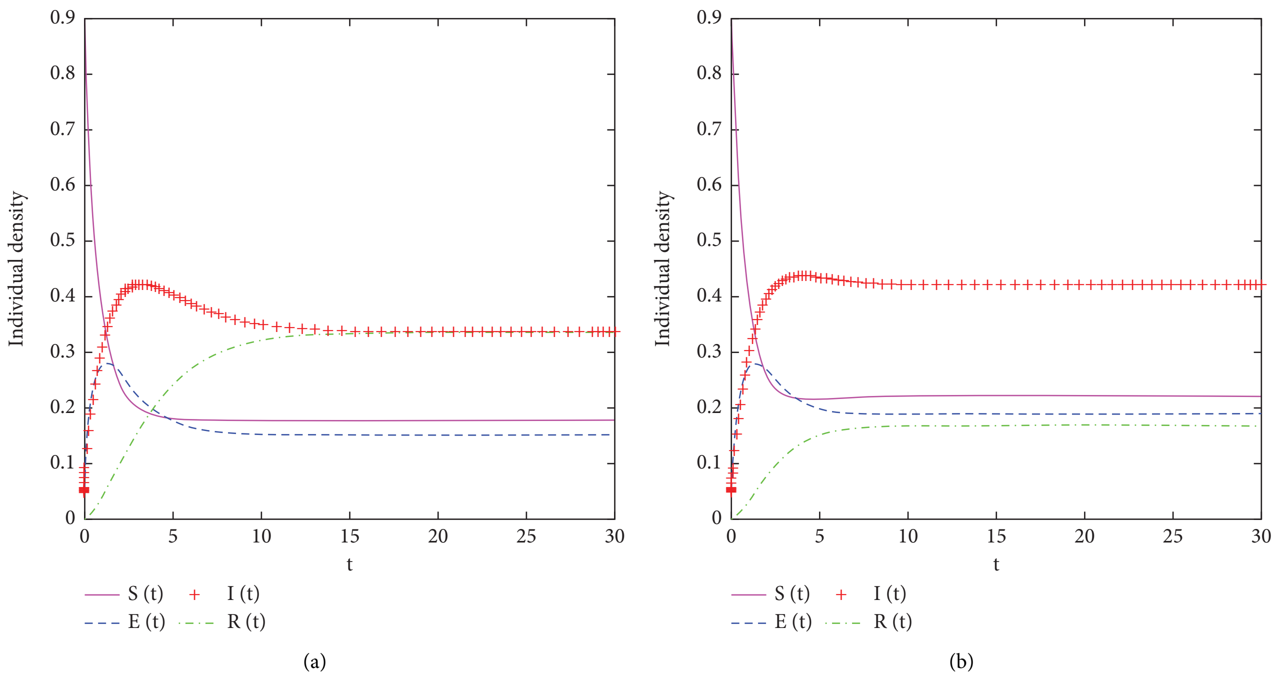

Figure 8: Simulation results of recovered enterprise removal rate on credit risk contagion. (a) $\gamma = 0.2$. (b) $\gamma = 0.5$.

preventive control measures in time when credit risks occur in their partners or their affiliates, reduce the impact of direct and indirect transmission of credit risks on themselves, and reduce the probability of their own credit risks.

Second, when credit risk starts to be transmitted in the financial guarantee network, the enterprises in the network should take the initiative to cooperate with the requirements of the relevant regulatory authorities and take the initiative to disclose their own financial information and related reports. Financial guarantee network enterprises need to enhance credit risk resilience and improve their own credit risk positions in order to reduce the impact of credit risk contagion.

Third, relevant departments should strictly supervise and strengthen the access management of financing guarantee enterprises, carefully assess the credit level of guarantee enterprises, and prevent enterprises with low credit level and complicated borrowing and lending relationships from entering the financing guarantee network. In addition, the authorities should control the degree of nodes of enterprises in the financial guarantee network, so that the size of affiliated enterprises is controlled within a reasonable range.

Finally, enterprises in the financing guarantee network are relatively safe in the immunity period. Thus, enterprises can make full use of resources such as information sharing platforms, combine the information they have, establish credit risk early warning mechanisms, discover sources of contagion in a timely manner, continuously improve their own risk prevention and control programs, and extend their own immunity period, thus reducing the impact of credit risk contagion on enterprises and reducing the probability of their own credit risk outbreak.

The main shortcomings of this paper are as follows: first, some scholars argue that financial guarantee networks also have scale-free characteristics, so this study will further compare the differences in risk contagion mechanisms in financial guarantee small-world networks and scale-free networks. Second, this study will further subdivide the state of enterprises in the financing guarantee network and investigate the multidimensional dynamic relationship between different state of enterprises to improve the SEIR model.

Data Availability

All data or code used to support the findings of this study are available from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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