Research Article

Effect of the Dynamic Macroeconomic Fluctuation on the Stability of a Banking Network System with Scale-Free Structure

Qianqian Gao\(^1\) and Hong Fan\(^2\)

\(^1\)School of Financial Technology, Shanghai Lixin University of Accounting and Finance, No. 995, Shangchuan Road, Shanghai, China
\(^2\)Glorious Sun School of Business and Management, Donghua University, No. 1882, West Yan’an Road, Shanghai, China

Correspondence should be addressed to Hong Fan; hongfan@dhu.edu.cn

Received 24 August 2019; Revised 24 January 2020; Accepted 30 January 2020; Published 21 February 2020

Academic Editor: Ching-Ter Chang

The stability of banking system has caused wide concerns since the global financial crisis. The present paper focuses on studying the stability of a banking network system in the case that the banking network system suffers the dynamic macroeconomic fluctuation shocks. We firstly construct a banking network system with a scale-free structure, then let the banking network system suffer the dynamic macroeconomic fluctuation (here, we consider three kinds of situations; the macro economy fluctuates in downward, upward, and random trends, respectively). Then, we study the stability of the banking network system under each situation. Firstly, the results show that the scale-free topology has an important effect on the stability of the banking network system at each macroeconomic fluctuation situation. Secondly, the investment payback period and the ratio of investment to deposit have a large effect on the stability of the banking network system in the cases of dynamic macroeconomic fluctuation. In addition, our further studies find that there is an optimal ratio of the investment to deposit under various macroeconomic fluctuation scenarios, which divides the banking system into stable and unstable regions. Finally, we discuss the regulation strategies for banks, which may provide decision supports for the relevant regulatory authority.

1. Introduction

Since the financial crisis in 2008, countries around the world have paid great attention to the stability of the financial network system, which has become an important research issue. There are many scholars who study the effect of interbank linkages on the stability of the banking network system. Freixas et al. [1], Diamond and Dybvig [2], and Allen and Gale [3] had shown that the interbank linkages played a positive risk-sharing role. While Brusco and Castiglionesi [4] constructed a banking network model that is similar to that of Allen and Gale [3], but they pointed out that the more interbank linkages would increase the contagion risk. However, Iori et al. [5], Nier et al. [6], Gai and Kapadia [7], Tedeschi et al. [8], Georg [9], Ladley [10], Grilli et al. [11], and Vitali et al. [12] all showed that the interbank linkages had a dual role of risk sharing and risk contagion in the banking network system. Iori et al. [5] constructed an interbank network model with a random network and found that the interbank market makes banks more stable under the homogeneous banking system, while there are knock-on effects under the heterogeneous banking system. Nier et al. [6] found that the initial increase of the interbank connectivity increased the contagion effect in the banking network system, but if the interbank connectivity is increased beyond a certain threshold, it improved the ability of absorbing shocks and thus made the banking system more stable. In contrast, Gai and Kapadia [7], Georg [9], and Grilli et al. [11] all found that the effect of the interbank connectivity on the banking system shifted from the initial risk sharing to risk contagion as the interbank connectivity increased. Moreover, Ladley [10] found that the effect of the interbank linkages on the stability of the banking system changed with the size of shocks that the higher interbank...
connectivity helped to resist risks at lower shocks, but it had the opposite effect at higher shocks. Lenzu and Tedeschi [13] constructed an interbank network model with different network structures to study the stability of the heterogeneous banking system in the face of random shocks and found that the banking system with the random network was more stable than that with the scale-free network. Caccioli et al. [14] proposed a network approach from the perspective of risk contagion to calculate the stability of the financial network due to overlapping portfolios. They used the "branch process" to understand the financial contagion and found that there was a critical point of leverage that the financial network was stable when the leverage was lower than the critical point, while it was unstable as the leverage increased. Karimi and Raddant [15] investigated cascades of defaults in an interbank loan market and found that the ability of a defaulted institution to start a cascade depends on an interplay of shock size and connectivity. In addition, Degryse and Nguyen [16] had also shown that the size of interbank assets, the distribution of banks’ claims and liabilities, and the level of the banks’ capital adequacy ratio were the main causes to the interbank risk contagion. The empirical studies of Mistrulli [17] and Kanno [18] showed that the contagion risk in the banking system was affected by the size of default banks.

The abovementioned studies explored the stability of the banking network system, but all did not consider the effect of the dynamic macroeconomic fluctuation on the banking system. While, considering the slowdown of macroeconomic growth in China since 2008, the growth rate of banks' profit has slowed down, the risk has increased, and the nonperforming loan rate of banks has increased. Macroeconomic fluctuations are closely related to the stability of the banking system. Therefore, based on the research of Iori et al. [5], the present paper constructs three kinds of macroeconomic fluctuation situations; the macroeconomy of banks showed that the banking network system had the opposite effect at higher shocks. Lenzu and Tedeschi [13] constructed an interbank network model with the scale-free structure. Caccioli et al. [14] proposed a network approach from the perspective of risk contagion to calculate the stability of the financial network due to overlapping portfolios. They used the "branch process" to understand the financial contagion and found that there was a critical point of leverage that the financial network was stable when the leverage was lower than the critical point, while it was unstable as the leverage increased. Karimi and Raddant [15] investigated cascades of defaults in an interbank loan market and found that the ability of a defaulted institution to start a cascade depends on an interplay of shock size and connectivity. In addition, Degryse and Nguyen [16] had also shown that the size of interbank assets, the distribution of banks’ claims and liabilities, and the level of the banks’ capital adequacy ratio were the main causes to the interbank risk contagion. The empirical studies of Mistrulli [17] and Kanno [18] showed that the contagion risk in the banking system was affected by the size of default banks.

Section 2 constructs a dynamical interbank network model with the scale-free structure, which includes the dynamic evolution of the banks’ balance sheet and the dynamic interbank lending under the shocks of the dynamic macroeconomic fluctuations. Section 3 presents the simulation results and discusses the regulation strategy. Section 4 provides the concluding.

2. The Model

In this section, we construct a banking network system with the scale-free structure. The dynamics of a bank’s balance sheet is shown in Figure 1, where the assets of bank $k$ are simply divided into liquidity assets $L^k$ and the investment $I^k$ (fixed assets), and the liabilities of bank $k$ are simply made up of depositors’ deposits $A^k$ and the interbank borrowings $B^k$. In the whole banking network system, all banks satisfy that their total assets equal the sum of their total liabilities and total equity. At the same time, each bank in the banking network system is affected by two kinds of shocks; one is the random deposits shock that comes from depositors and the other is the dynamic macroeconomic fluctuation shocks, which directly affects a bank’s investment income. The abovementioned two kinds of shocks will make the banks’ assets and liabilities fluctuate dynamically, and thus they affect the banks’ final survival and the stability of the whole banking network system.

We have considered the liquidity shocks of deposits, and the deposit in this model is set consistent with the model in Iori et al. [5]. Considering that in real life, depositors can observe and imitate the deposit and withdrawal behaviors of other depositors, so there is certain correlation between the depositors’ deposit behavior, that is, the deposit fluctuation is proportional to the average size of deposits, and the deposit $A^k_t$ of bank $k$ at any time $t$ is represented by (1) as follows:

$$A^k_t = |\overline{A} + \overline{\sigma}_A \varepsilon_t|, \quad \varepsilon_t \sim N(0, 1) \tag{1}$$

where $\overline{A}$ is the average deposit of the banking network system and $\overline{\sigma}_A$ is the standard deviation of deposits of the banking network system.

The investment of a bank is also random, assuming that the investment opportunities of bank $k$ $\omega^k_t$ subject to the normal distribution, which is represented by (2) as follows:

$$\omega^k_t = |\overline{\omega} + \overline{\sigma}_\omega \eta_t|, \quad \eta_t \sim N(0, 1) \tag{2}$$

where $\overline{\omega}$ is the average investment opportunities and $\overline{\sigma}_\omega$ is the standard deviation. We set that a bank’s investment at time $t$ will be in the maturity at $t + \tau$ (i.e., the investment payback period of a bank), and the corresponding investment income rate of a bank is represented by $R_0$. The present paper considers the banking network system affected by the dynamic macroeconomic fluctuation; therefore, the investment of a bank is risky, and the investment income rate $Ro$ of a bank is different under different macroeconomic scenarios, which can be described in Table 1.

Keynes’s macroeconomic theory shows that the macroeconomy is always volatile and exhibits certain cyclical characteristics, while the New Keynesians believe that the banks’ credit behavior has a greater impact on the macroeconomic fluctuations. Owing to the bank has typical procyclical characteristics, that is, the credit of the banking industry and macroeconomic conditions have similar trends. The empirical research by Mare [24] also shows the necessity of considering macroeconomics when studying the risk of the banking system. Furthermore, Nickell et al. [25]
and Pesola [26] have found that macroeconomic fluctuations are closely related to the credit risk of the banking system. The empirical studies of the Brazilian banking system by Mendonça and Silva [27] show that the main banking variables affecting the systemic risk are leverage and return on assets. Therefore, based on the basic model of Iori et al. [5], this paper introduces the dynamic macroeconomic fluctuation and measures the fluctuation by the investment income rate of banks. This paper draws on the formula of the investment income rate in Fan [28] and also considers the influence of volatility, trend, and correlation, then further expands the investment income rate $R_o$ under the three different macroeconomic fluctuation situations shown in Table 1 (when the banking system is facing macroeconomic shocks in an upward trend, we can construct the banks’ investment income rate with increasing changes by adjusting the trend and systemic shock parameters. Similarly, when it is facing a downward or random trend of macroeconomic shocks, we can construct the banks’ investment income rate with decreasing or stochastic changes). The formula of the investment income rate $R_o$ when the macroeconomy fluctuates in a random trend is different from the other two cases. In the random trend, $R_o$ is set to fluctuate randomly around its mean value and is not affected by the trend and the correlation. This situation is similar to the developed countries (such as Japan from 1993 to 2008 and the United States from 2006 to 2013); their GDP growth rate shows a positive trend sometimes or negative sometimes. In Table 1, the parameters $\zeta_k(t)$, $\phi(t)$, and $\psi(t)$ are all random numbers that subject to the standard normal distribution; $\lambda_1$ and $\lambda_2$ control the volatility of the investment income rate $R_o$; $\varepsilon_1$ and $\varepsilon_2$ control the trend; $\alpha_2$ and $\alpha_3$ control the random shock on individual bank, while $1 - \alpha_2$ and $1 - \alpha_3$ control the systematic shock on the whole banking network system; $\beta_1$, $\beta_2$, and $\beta_3$ control the mean value of the investment income rate $R_o$. Each bank’s investment income rate $R_o$ changes dynamically at each time step under the macroeconomic fluctuation, and therefore the investment of a bank is risky.

In addition to the dynamic changes of the banks’ own assets and liabilities in the banking network system, we also consider the interbank market so that an insolvent bank still has an opportunity to survive by the interbank lending. The dynamic interbank lending process of the banking network system in the present paper is shown in Figure 2. In Figure 2, firstly we should classify banks according to their liquidity assets at time $t$. We know that each bank’s liquidity assets will change at time $t$, which includes inheriting the liquidity assets from the time $t - 1$, the changes of deposit between time $t$ and $t - 1$, paying the deposit interests of time $t - 1$, and obtaining the investment income and the original

---

**Table 1: The investment income rate ($R_o$) of a bank under different macroeconomic situations.**

| Various macroeconomic fluctuation scenarios | The formula of investment income rate |
|-------------------------------------------|-------------------------------------|
| In random case                            | $R_{o_k}(t) = \alpha_1 * \zeta_{k}(t) + \beta_1$ |
| In downward case                          | $R_{o_k}(t) = \lambda_1 * [\varepsilon_1 R_{o_k}(t - 1) + \alpha_2 * \zeta_{k}(t) + (1 - \alpha_2) * \phi(t)] + \beta_2$ |
| In upward case                            | $R_{o_k}(t) = \lambda_2 * [\varepsilon_2 R_{o_k}(t - 1) + \alpha_3 * \zeta_{k}(t) + (1 - \alpha_3) * \psi(t)] + \beta_3$ |
The liquidity assets of bank $k$ is updated, and if:

$$L_t^k - \beta A_t^k \geq 0$$

Temporary creditor bank $k$ at time $t$

Liquidity assets of bank $k$ is updated after the lending:

$$L_t^k = L_{t-1}^k + (1 + r_b) b_{t-1}^k$$

Interbank lending randomly

If the interbank lending is not enough to repay the loan

Bank $j$ is lack of liquidity

Bank $j$ at time $t$

The general debt bank

The borrowing of dept bank $j$ at time $t - 1$:

$$(1 + r_b) \sum b_{t-1}^k, k \in \Phi$$

Payback

Liquidity assets is updated after the repayment:

$$L_t^j = 0$$

Figure 2: The dynamic process of the interbank lending.

The capital of investment. Therefore, the liquidity assets $\tilde{L}_t^k$ of bank $k$ at time $t$ can be expressed as follows:

$$\tilde{L}_t^k = L_{t-1}^k + (A_t^k - A_{t-1}^k) - r_a A_{t-1}^k + R_{t}(t) \sum_{s=1}^{t-1} I_{t-s}^k + I_{t-1}^k,$$  \hspace{1cm} (3)

where $L_{t-1}^k$ is given as follows:

$$L_{t-1}^k = A_{t-1}^k + B_{t-1}^k + V_{t-1}^k - \sum_{s=1}^{t-1} I_{t-s}^k, \hspace{1cm} (4)$$

where $\sum_{s=1}^{t} I_{t-s}^k$ in (4) is the sum of the investments of bank $k$ during the investment period of $t$; $B_{t-1}^k = \sum_{i=1}^{M} b_{t-1}^{ik}$, and $b_{t-1}^{ik}$ represents the interbank lending of bank $k$ at time $t - 1$; $b_{t-1}^{ik} > 0$ means that bank $k$ borrows from bank $i$, and $b_{t-1}^{ik} < 0$ means that bank $k$ lends to bank $i$; while $b_{t-1}^{ik} = 0$ means that there is no interbank lending between bank $k$ and bank $i$.

In Figure 2, next we determine the type of bank $k$ according to its liquidity assets calculated by (3). There are two types of banks: one is temporary potential creditor banks and the other is the general debt bank. If its liquidity assets $\tilde{L}_t^k > 0$ and interbank lending $B_{t-1}^k < 0$, or $\tilde{L}_t^k > 0$, $B_{t-1}^k > 0$, and $\tilde{L}_t^k \geq (1 + r_b) \sum b_{t-1}^{ik}, i \in \Phi$ ($\Phi$ represents all of the debt banks of bank $k$ in time step $t - 1$), bank $k$ is classified as the temporary potential creditor bank; while in the other cases, the bank $k$ is designated as the general debt bank. For the temporary potential creditor banks with sufficient liquidity assets, they are able to make dividends and investments, respectively, according to (5) and (6), and banks’ dividends are required to satisfy

$$E_t^k > \chi,$$

where $E_t^k = \tilde{V}_t^k/A_t^k$ and

$$\tilde{V}_t = \tilde{L}_t + \sum_{s=1}^{t-1} I_{t-s}^k - A_t^k.$$

$\chi$ is the ratio of the capital to deposit.

$$D_t^k = \max \left[ 0, \min \left[ R_{t}(t) \sum_{s=1}^{t-1} I_{t-s}^k - r_a A_{t-1}^k, \tilde{L}_t^k - R_{t}(t) I_{t-1}^k, \tilde{L}_t^k + \sum_{s=1}^{t-1} I_{t-s}^k - (1 + \chi) A_t^k \right] \right],$$  \hspace{1cm} (5)

where $\alpha$ is interest rate; $R_t^k = \beta A_t^k$ is the statutory deposit reserve of bank $k$ that need to hand over to the central bank. (5) means that the dividends of bank $k$ must meet the minimum requirements for profits, deposit reserves, and the capital. After the dividend is paid, the bank can make investments. The investment of bank $k$ needs to meet the requirements of the existing liquidity assets and stochastic investment opportunities, which is represented by (6) as follows:

$$I_t^k = \min \left[ \max \left[ 0, \tilde{L}_t^k - D_t^k - \beta A_t^k \right], \omega_t^k \right],$$  \hspace{1cm} (6)

In Figure 2, for the type of temporary potential creditor banks, if the bank’s liquidity assets are still remaining after
the dividends and investments and still meets the require-
ments of the deposit reserve, then the bank is identified as a
temporary creditor bank and it can lend its surplus liquidity
in the interbank market; while for the type of the debt banks
(lack of liquidity assets), they need to borrow liquidity in
the interbank market to survive. After the interbank lending, the
temporary creditor bank and debt bank both update their
liquidity assets. For the debt bank, if the interbank lending is
sufficient to repay the debts of the previous period, it paid
back the debts and its liquidity assets is zero after repudiated;
however, if the debt bank cannot obtain the interbank
lending or the interbank lending is not enough to repay the
debts of the previous period, the debt bank will default and
go into the bankruptcy liquidation. After the liquidation,
recalculate the rest banks’ liquidity assets. Thus, the banking
network system is iterated at the next time step according to
the dynamic process shown in Figure 2, and it will be end
when reaching the total time steps.

3. Results and Discussion

In the existing related studies, most scholars have studied the
effect of the interbank linkages and deposit reserve ratio on
the stability of the banking network system; the present
paper considers the stability of the banking network system
under the dynamic macroeconomic fluctuation (the macro-
economy fluctuates in downward trend, in upward trend,
and in random trend) and considers the following factors
such as the scale-free network parameter \( m \) (i.e., the in-
terbank linkages), the deposit reserve ratio, the banks’ in-
vestment payback period \( \tau \), and the ratio of the investment
to deposit.

In the simulation, we set the total bank number \( M_t = 400 \)
and the total time steps of the simulation \( t = 1000 \). The
number of banks and simulation time steps set here are
based on the settings in Iori et al. [5]; on the other hand, the
simulation results in this paper have been stable under such
settings, which is the most suitable for research. If the two
parameters are set too small, the simulation results are
variable and not scientific enough; if the settings are too
large, the simulation results are consistent with the results
under the values set in this paper; at the same time, the
simulation calculation time is increased, namely, it has in-
creased the research workload invisibly. Therefore, this
paper sets the number of banks \( M_t = 400 \) and the total time
steps \( t = 1000 \). Considering that banks’ investment behavior in
the interbank market in China is similar, we study the
homogeneous banking network system, so the size of all
banks’ deposits is subject to a normal distribution with a
mean \( \bar{A} = 1000 \) and a variance \( (\bar{A}\sigma_A)^2 (\sigma_A = 0.5) \) (it
should be noted that \( \bar{A} \) is only a reference value for other pa-
rameters. For example, we set banks’ initial equity as 0.3\( \bar{A} \);

Therefore, the value of \( \bar{A} \) determines the initial value of all
parameters of the banking system. \( \bar{A} \) can be determined
according to the actual deposits size, but its value does not
affect the simulation results of this paper. For convenience,
we set \( \bar{A} = 1000 \). The banks’ investment opportunities are
taken from the normal distribution with a mean \( \delta\bar{A} (\delta = 0.5) \)
and a variance \( (\delta\bar{A}\sigma_A)^2 (\sigma_A = 0.5) \). Set the banks’ initial equity

\[ V_1 = 300, \]

and the average of the investment income rate \( Ro \)

is consistent under different macroeconomic fluctuation
scenarios. The interest margin between the investment in-
come rate and the interest rate guarantees that the current
banking system has certain interest margin returns. The
larger the interest margin returns, the more stable the
banking system is. In order to study the impact of other
factors on the stability of the banking system, we choose the
moderate interest margin. Therefore, we set \( Ro = 0.3\% \), the
interest rate \( r_p = 0.1\% \), and the interbank lending rates
\( r_b = 0.2\% \); set the ratio of the capital to deposit \( \chi = 30\% \), and
it ensures that only profitable banks can make dividends. In
addition, it should be noted that the parameter settings in
this paper refer to the actual data from the official website of
the central bank, while considering the parameter dimension
problem and the convenience of research, the setting values
reduce a certain multiple on the basis of the actual data,
which will not affect the final simulation results.

The detailed process of setting different macroeconomic fluctuation situations is as follows. When the macro-
economy fluctuates in downward trend, according to the
formula in Table 1, set \( \epsilon_1 = 1 \) and \( \lambda_1 = 1 \) so that the in-
vestment income rate \( Ro \) presents a strong trend. The pa-
parameter \( \zeta_k(t) \) generates a \( 400 \times 1000 \) matrix of random
numbers in the simulation process, and it represents random
shocks on the banking network system. While the parameter
\( \phi(t) \) generates a \( 1 \times 1000 \) matrix of random numbers in
the simulation process, it represents systemic shocks. Then, we
set \( \alpha = 0 \) and adjust the other parameters to ensure that

\[ Ro = 0.3\%. \]

The method of setting the parameters in the
upward trend is similar to the downward trend. While \( Ro \)
only fluctuates randomly around its average in random
trend, so it is only necessary to set the mean value \( \beta_1 \) and
consider the parameter \( \alpha_1 \).

Figure 3(a) shows that the scale-free network parameter \( m \) (the interbank linkages) is positively correlated with the
stability of the banking network system under the three
macroeconomic fluctuation situations, namely, the scale-
free network parameter \( m \) (the interbank linkages) is larger
and the banking network system is more stable, which is
consistent with the most of existing research. We analyze
that the greater the interbank linkages, the more liquidity
supplements banks can get from the interbank lending
market to resist risks, so the stability of the banking system
can be improved. It should be noted that the risk of the
banking network system has been extremely high when the
macroeconomy fluctuates in downward trend, and it is not
effective to improve the stability of the banking network
system by increasing the scale-free network parameter \( m \).

According to Figure 3(b), it is found that increasing the
banks’ deposit reserve ratio effectively enhances the stability
of the banking network system when the macroeconomy
fluctuates in downward trend. There is a critical value of
the deposit reserve ratios 0.6 and 0.7, respectively, under the
upward and random cases, and the stability of the banking
network system increases as the banks’ deposit reserve ratio
increases when the banks’ deposit reserve ratio is less than
the threshold; while it is opposite if the banks’ deposit re-
serve ratio is greater than the threshold. From our
perspectives, the banking network system has a high risk when the macroeconomy fluctuates in downward trend, and at this case, it is not suitable for banks to invest too much, therefore increasing the banks’ deposit reserve ratio inhibits banks’ investments, and thus help banks to resist risks, accordingly enhances their stability. However, when the macroeconomy fluctuates in upward and random trends, the stability of the banking network system increases gradually with the increase of the deposit reserve ratio at first, and the stability of the banking network system is the highest when the deposit reserve ratio increases to a critical value. Once it is more than the critical value, the higher deposit reserve ratio will suppress banks’ investments, making it impossible for banks to obtain the dividends brought by higher return on investment, and thus unable to obtain liquidity supplements from interbank lending market and capital market, so the stability of the whole banking system instead reduces.

In addition, we find that the stability of the banking system with the scale-free network is slightly better under the random trend than the upward trend. Our analysis believes that due to the characteristics of the scale-free network, it shows a strong clustering, that is, fewer banks in the system have more interbank linkages in the banking system, and quite a few banks have relatively less interbank linkages. In this case, when the banking system is facing an upward trend of macroshocks, those banks with fewer interbank linkages make more investment, but they cannot obtain corresponding liquidity supplements from the interbank lending market, making them a factor of instability in the whole banking system. For example, the United States implemented low interest rates in the market in order to revitalize the economy during 2001–2004, represented by the real estate market, the stocks, securities, and other booming markets, and then the economy increased significantly and the GDP growth rate steadily increased (from 0.98% to 3.79%). At this time, banks invested more and the assets flowed out. The current large amount of investment implied potential liquidity risks, and the subprime mortgage crisis broke out during 2006–2009. A large number of loans were not repaid and the nonperforming loan rate increased sharply (from 0.8% to 4.96%). Among them, the small- and medium-sized banks represented by the Douglass National Bank failed to get liquidity supplement in the interbank market. While in the random case, there is no lure of high returns in the banking system, so the banks’ investment in the whole system is relatively uniform. Therefore, the risk faced by the banking system under the random trend is smaller than the upward trend, and the stability of the banking system under upward trend is not as good as the random trend.

We know that the stability of the banking network system could be improved by adjusting the banks’ scale-free network parameter \( m \) (i.e., the interbank linkages) and the deposit reserve ratio in the abovementioned three kinds of macroeconomic fluctuation situations, but they are usually necessary to be adjusted to a large value that can ensure the banking network system is completely stable, which is actually difficult in real life. We consider that the dynamic macroeconomic fluctuation constructed in our model will directly affect the banks’ investment income, the present paper therefore considers the effect of the investment payback period \( \tau \), and the ratio of the investment to deposit of the banking network system. The simulation results are shown in Figure 4. From Figure 4, we can see that the two factors have a significant effect under the three macroeconomic fluctuation situations. According to Figure 4(a), when the macroeconomy fluctuates in upward trend and in random trend, the banking network system is completely stable only when banks make the short-term investment (the banks’ investment payback period meets \( \tau < 3 \)), while when
banks make the long-term investment (the banks’ investment payback period meets $\tau \geq 3$), the stability of the banking network system is relatively low. Especially the banking network system is completely unstable (all banks default) when the banks’ investment payback period $\tau = 4$ and $\tau = 5$, although the default probability of the banking network system is greater than 0.7 when the banks’ investment payback period $\tau = 3$. However, when the macroeconomy fluctuates in downward trend, the banking network system can be completely stable only when the banks’ investment payback period $\tau = 1$, and the default probability is extremely high when $\tau = 2$; the banking network system is completely unstable at every period when banks make the long-term investments (i.e., $\tau \geq 3$). According to Figure 4(b), the banking network system is completely unstable under the three kinds of macroeconomic fluctuation situations when the ratio of the investment to deposit of banks is relatively high, and the stability of the banking network system is enhanced significantly when the ratio of the investment to deposit of banks gradually reduces. Moreover, when the ratio of the investment to deposit ratio of banks is less than 0.3 under the upward trend and random trend, as well as when it is smaller than 0.2 under the downward trend, the banking network system will be completely stable. In the present paper, we think that adjusting the ratio of the investment to deposit is applicable for every macroeconomic fluctuation situation to improve the stability of the banking network system, and it is very convenient to achieve in real life. Therefore, we focus on studying the ratio of the investment to deposit of banks. We try to explore how much should it be adjusted to ensure the banking network system completely stable under each macroeconomic fluctuation situation. Furthermore, how much should it be adjusted to at each investment payback period?

3.1. Optimal Ratio of the Investment to Deposit. According to the simulation results, we find that when the banks’ scale-free network parameter $m$ is fixed, there is an optimal ratio of the investment to deposit at each investment payback period, which makes the banking network system completely stable when the ratio of the investment to deposit is under the optimal value (the white area in Figure 5), and it is unstable when above the optimal value (the red area in Figure 5). Furthermore, the optimal ratio of the investment to deposit means the banks’ maximum investment on the basis of the completely stable banking network system. Because of the banking network system is completely stable when the banks’ investment payback period $\tau = 1$ under the three macroeconomic fluctuation situations; here, we set $\tau \in [2, 5]$ (\(\tau\) is integer), and the banks’ scale-free network parameter $m = 25$, and then the simulation results are shown in Figure 5.

First of all, we know that the larger the banks’ investment payback period $\tau$, the more unstable the banking network system from Figure 4. In this case, it is necessary to decrease the ratio of the investment to deposit of banks to improve the stability of the banking network system. Therefore, the larger the banks’ investment payback period $\tau$ under the three macroeconomic fluctuation situations in Figure 5, the smaller the optimal ratio of the investment to deposit. Secondly, the optimal ratio of the investment to deposit is the smallest at each period when the macroeconomy fluctuates in downward trend, and they are close in upward and random trends. When the banks’ investment payback period $\tau = 2$ (short-term investment), the optimal ratio of the investment to deposit is about 0.275 when the macroeconomy fluctuates in downward trend, which indicates that the banking network system is high of risk when the economy is not good. In this case, only a small part of the deposits are allowed to be used for investment, and most of the
remaining liquidity are used as banks’ liquidity funds, so as to resist risk to ensure the stability of the banking network system. In the case of the upward and random trends, the optimal ratio of the investment to deposit ratio are both more than 0.4, especially it is close to 0.5 in random trend, which shows that the banking network system is relatively stable under these two cases, thus the banks have relatively more liquidity for investment. When the bank changes from the short-term investment to long-term investment (i.e., $\tau \geq 3$), it is found that the optimal ratio of the investment to deposit all decreases significantly under the three macroeconomic fluctuation situations. Furthermore, the optimal ratio of the investment to deposit is lower than 0.15 when the banks’ investment payback period $\tau = 4$ and $\tau = 5$, which indicates that there is little liquidity in the banking network system to invest, accordingly avoiding the shortage of liquidity caused by long-term investments. In general, the optimal ratio of the investment to deposit is the lowest at each period when the macroeconomy fluctuates in downward trend, and it is the highest in random trend. While the optimal ratio of the investment to deposit when the macroeconomy fluctuates in upward trend is close to that of the random trend.

3.2 Regulation Strategy Research. In the abovementioned research, we consider the effect of some different factors on the stability of the banking network system. According to our simulation results, we know that different adjustment measures have different effects on the stability of the banking network system. Therefore, based on the perspective of the banking sector’s regulatory authorities, we discuss which adjustment measures should be taken to improve the stability of the banking network system when the macroeconomy fluctuates under the various dynamic fluctuation scenarios, and we have made the following suggestions.

When the macroeconomy fluctuates in downward trend, the regulators can carry out the following measures to enhance the stability of the banking network system: increasing the banks’ deposit reserve ratio, decreasing the banks’
investment payback period $\tau$, and decreasing the ratio of the investment to deposit of banks. Among the abovementioned measures, only adjusting the banks’ deposit reserve ratio to a larger value or adjusting the banks’ investment payback period $\tau = 1$ can make the banking network system completely stable when the macroeconomy fluctuates in downward trend. In contrast, it is easier and more flexible to adjust the ratio of the investment to deposit, the banking network system will be completely stable as long as the ratio of the investment to deposit is adjusted under the optimal value. When the macroeconomy fluctuates in upward and random trends, the abovementioned summary regulation measures are also applicable. In addition, it is also effective to improve the stability of the banking network system by increasing the scale-free network parameter $m$ (the inter-bank linkages). Since the banking network system is the most difficult to regulate when the macroeconomy fluctuates in downward trend, here we simulate the regulation process of the banking network system in the downward case according to the abovementioned summary of the regulation measures and take the following case as an example; set the banks’ scale-free network parameter $m = 25$ and the banks’ investment payback period $\tau = 3$. The simulation results are shown in Figure 6.

Figure 6 shows the simulation process that the banking system changes from unstable to stable according to the arrows’ direction; when the banks’ deposit reserve ratio increases from 0.2 to 0.7, the surviving banks gradually increase, and the banking network system is basically very stable when adjusting it more than 0.5. While the ratio of the investment to the deposit and the investment payback period $\tau$ are both needed to be decreased when adjusting them to improve the banks’ stability, it can be seen from Figure 6 that all banks default when the ratio of the investment to the deposit ratio is greater than or equal to 0.5, and the survival banks increase gradually when it is decreased. When adjusting the banks’ investment payback period $\tau$ to improve the bank’s stability, it is found that the banks’ long-term investments (i.e., $\tau \geq 3$) will make all the banks default, and there are only about 100 banks which survive when the

![Figure 6: The regulation process of the banking network system when the macroeconomic fluctuates in downward trend.](image-url)
banks’ investment payback period $\tau$ is adjusted to $\tau = 2$. The banking network system can be completely stable only by adjusting the banks’ investment payback period to $\tau = 1$.

The abovementioned regulation process is based on the banks’ investment payback period $\tau = 3$ when the macroeconomy fluctuates in downward trend. Then, we do the simulation in the case of different investment payback period $\tau$, which is shown in Figure 7. It can be seen that when the banks’ investment payback period $\tau \geq 3$, it is basically not effective to improve the stability of the banking network system by increasing the scale-free network parameter $m$(the interbank linkages), while it is very effective that the banking network system can reach completely stable at each investment payback period $\tau$ by decreasing the ratio of the investment to deposit.

4. Conclusion

The present paper studied the stability of the banking network system with the scale-free structure under the dynamic macroeconomic fluctuation. We discussed the effect of some factors on the stability of the banking network system under different macroeconomic situations and then summarized some regulation measures from the perspective of regulators.

We obtained the following results. Firstly, we found that the banks’ scale-free network parameter (the interbank linkages) was positively correlated with the stability of the banking network system when the macroeconomy fluctuates in upward and random trends; however, the effect was not obvious under the downward case. Secondly, it was found that there was a critical value of the banks’ deposit reserve ratio when the macroeconomy fluctuated in upward and random trends, which made the banking network system more stable with the increase of the banks’ deposit reserve ratio when it was less than the threshold, while it was opposite when it was more than the threshold. However, it was found that the banks’ deposit reserve ratio was positively correlated with the stability of the banking network system when the macroeconomy fluctuates in downward trend. Thirdly, we found that the banks’ investment payback period and the ratio of the investment to the deposit ratio had a large effect on the banking network system. Furthermore, there was an optimal ratio of the investment to deposit under each macroeconomic scenario, which made the banking network system completely stable when the ratio was less than the optimal value. Moreover, the optimal ratio of the investment to deposit was the smallest at each period when the macroeconomy fluctuates in downward trend. Finally, we have summarized the regulation measures that can make the banking network system completely stable. Thus, the relevant regulators can choose those measures according to the actual situation.

This study has enriched the research about the stability of the banking network system and can provide some reference for relevant regulatory authorities. In the future work, we will consider the deposits that are insured, in this case, we will further consider the measures of insurance companies or central banks. Also, we may conduct empirical analysis by collecting the actual data of the Chinese banking system. Furthermore, we may consider other network structures, such as random network and small-world network, and then conduct comparative analysis.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.
Conflicts of Interest
The authors declare no conflicts of interest.

Acknowledgments
This research was funded by the National Natural Science Foundation of China under Grant no. 19ZR1402100 and Natural Science Foundation of Shanghai under Grant no. 19ZR1402100.

References
[1] X. Freixas, B. M. Parigi, and J.-C. Rochet, “Systemic risk, interbank relations, and liquidity provision by the central bank,” Journal of Money, Credit and Banking, vol. 32, no. 3, pp. 611–638, 2000.
[2] D. W. Diamond and P. H. Dybvig, “Bank runs, deposit insurance, and liquidity,” Journal of Political Economy, vol. 91, no. 3, pp. 401–419, 1983.
[3] F. Allen and D. Gale, “Financial contagion,” Journal of Political Economy, vol. 108, no. 1, pp. 1–33, 2000.
[4] S. Brusco and F. Castiglionesi, “Liquidity coinsurance, moral hazard, and financial contagion,” The Journal of Finance, vol. 62, no. 5, pp. 2275–2302, 2007.
[5] G. Iori, S. Jafarey, and F. G. Padilla, “Systemic risk on the interbank market,” Journal of Economic Behavior & Organization, vol. 61, no. 4, pp. 525–542, 2006.
[6] E. Nier, J. Yang, T. Yorulmazer, and A. Alentorn, “Network models and financial stability,” Journal of Economic Dynamics and Control, vol. 31, no. 6, pp. 2033–2060, 2007.
[7] P. Gai and S. Kapadia, “Contagion in financial networks,” Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, vol. 466, no. 2120, pp. 2401–2423, 2010.
[8] G. Tedeschi, A. Mazloumian, M. Gallegati, and D. Helbing, “Bankruptcy cascades in interbank markets,” PLoS One, vol. 7, no. 12, Article ID e52749, 2012.
[9] C.-P. Georg, "The effect of the interbank network structure on contagion and common shocks," Journal of Banking & Finance, vol. 37, no. 7, pp. 2216–2228, 2013.
[10] D. Ladley, "Contagion and risk-sharing on the inter-bank market," Journal of Economic Dynamics and Control, vol. 37, no. 7, pp. 1384–1400, 2013.
[11] R. Grilli, G. Tedeschi, and M. Gallegati, "Bank interlinkages and macroeconomic stability," International Review of Economics & Finance, vol. 34, pp. 72–88, 2014.
[12] S. Vitali, S. Battiston, and M. Gallegati, "Financial fragility and distress propagation in a network of regions," Journal of Economic Dynamics and Control, vol. 62, pp. 56–75, 2016.
[13] S. Lenzu and G. Tedeschi, "Systemic risk on different interbank network topologies," Physica A: Statistical Mechanics and Its Applications, vol. 391, no. 18, pp. 4331–4341, 2012.
[14] F. Caccioli, M. Shrestha, C. Moore, and J. D. Farmer, "Stability analysis of financial contagion due to overlapping portfolios," Journal of Banking & Finance, vol. 46, no. 9, pp. 233–245, 2014.
[15] F. Karimi and M. Raddant, "Cascades in real interbank markets," Computational Economics, vol. 47, no. 1, pp. 49–66, 2016.
[16] H. Degryse and G. Nguyen, "Interbank exposures: an empirical examination of contagion risk in the Belgian banking system," International Journal of Banking Central, vol. 3, no. 2, pp. 123–171, 2007.