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Research Article

Dynamic Contagion of Systemic Risk in an Endogenous Banking System

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An endogenous banking system is proposed based on dynamic mechanisms of interbank loans and investment strategies to explore the behavioral incentives of diversification and its effects on systemic risk. The results highlight the advantages of different diversification strategies for different environments in preventing contagions of systemic risk. The evidence from the interbank market shows that big banks are more crucial for systemic risk prevention, and the intermediate scale of big banks is optimal for a stable banking system. As for the investment market, evidence shows that regulatory intervention should pay attention to the appropriate risk attitude for individual banks to promote systemic stability. These results provide a perspective of behavioral supervision for preventing contagions of systemic risk and indicate some reference for promoting the systemic stability of the banking system.

1. Introduction

The banking system is an indispensable intermediary of financing and it ensures daily activities such as deposits, lending, repayments, etc. A stable banking system is important for the economy. However, systemic risk in the banking system which triggers serious damage to the economy occurs from time to time. Therefore, regulatory intervention in systemic risk has been an urgent problem that should be concerned. Diversification leading to systemic stability used to be regarded as a universal truth, while this theory has struggled to hold up under recent empirical evidence and theoretical scrutiny [1]. On one hand, the crisis of a bank indicates that its interbank loans may not be repaid fully, which harms its counterparties [2–5]. On the other hand, banks may suffer a loss because of the fire sale of common assets [4, 6, 7]. In recent years, a large number of studies have explored the relationship between systemic risk and diversification in both the interbank market and investment market. These studies have enriched the theoretical basis of promoting the stability of the banking system through heterogeneous diversifications. However, further study on the behavioral incentives of diversification decisions is still needed and it will provide a new perspective of supervision inspiration for systemic risk. Motivated by this problem our study is proposed, which might provide the following potential contributions. It fills the research gap of systemic risk in a given environment and provides different regulatory interventions for systemic risk according to different environments. Additionally, it inspires regulatory interventions for systemic risk from the perspective of individual behaviors by analyzing the incentives of diversification both in interbank loans and in external investments.

2. Related Literature

Studies on interbank loans are most concentrated on the interaction between interbank diversification and systemic risk. As shown in the references, an increase in diversification initially increases the contagion of systemic risk but increases the ability to absorb shocks after a threshold value [8–13]. Further study shows that contagion risk is also determined by the individual properties of a bank when the interbank network is highly connected by diversifications [14]. Glasserman and Young [15] pointed out that individual banks with high heterogeneity, leverages, and correlations are most significant for contagion risks. With the increase of heterogeneity, the interbank network will be tiered, which means that a small part of big banks has a large number of interbank loans while most banks only have a small number of linkages. Moreover, the banking system stability will be promoted in a high level of heterogeneity, because "too big to fail" banks will bear more shocks in a highly heterogeneous banking system [16–19]. However, interbank loans among banks are not constant all the time. Empirical studies based on the data from different countries showed that the structure of interbank loans dynamically evolves because of the performance of individual banks [20, 21]. The evolution of interbank loans provides a behavioral perspective for exploring systemic risk [11, 22, 23]. Therefore, systemic risk and dynamic interbank diversification are studied in this paper based on the incentives of individual banks.

Although there have been many studies on contagion risk related to interbank loans, more studies in recent years showed that systemic risk is mainly caused by common investment assets [6, 24–29]. Banks usually sell external investments to supplement liquid assets when in shortages of capital buffers. Subsequently, sales of investments may result in price drops and thus making the loss propagate to other banks with common assets. The common assets are created by investment diversification. According to the portfolio theory, investment diversification will disperse market risk which reduces the individual risk of banks as a result. However, investment diversification is more likely to trigger systemic risk though it is beneficial to individual banks. As a result, contagions of systemic risk will become more serious with the increase in investment diversification [6, 30–35]. As listed, most of the studies on investment diversification and systemic risk are based on the assumption of random investment portfolios, which is inconsistent with the case in the real market. According to the routine, banks usually determine investment portfolios based on risk attitudes to maximize their utilities [17, 36, 37]. Therefore, risk attitude as an incentive for investment diversification is studied in this paper to explore the regulatory intervention of systemic risk prevention.

Some studies have been conducted based on multiple channels including interbank loans and external investment [38–41]. However, most of the results are drawn without considering the dynamic features of the banking system. Bluhm and Krahnen [23] analyzed endogenous systemic risk with multiple channels, while they oversimplified the market environment. Therefore, whether the results are determined by different environments still needs to be validated by the dynamic evolution of systemic risk. Additionally, how the behavioral incentives for interbank loans and external investments affect systemic risk remains unexplored. According to the above problems, this study promotes the work of Aldasoro et al. [37] where systemic risk is endogenously raised and proposes the endogenous banking system. Then we focus on the dynamic evolution of systemic risk in different environments from the perspective of diversification both in the interbank market and in investment market. Through the endogenous mechanism of interbank loans and investment strategies, behavioral incentives of diversification are explored to provide a regulatory reference for preventing systemic risk.

3. The Model

3.1. Initial Balance Sheet. A complex financial system consisting of $N\,(1 \le n \le N)$ banks and $M\,(1 \le m \le M)$ assets is considered, where the balance sheet of a bank includes liquid assets, interbank lending, and external investments on the left side, with deposits, interbank borrowing, and net worth in the right side. The liquid asset, deposit, and net worth of bank i are, respectively, denoted by c_i, d_i, and w_i. The external investment is denoted by $e_i = \sum_{j=1}^{M} e_{ij} p_j$, where e_{ij} indicates the units of asset j held by bank i and p_j is the price of asset j. Interbank lending is denoted by $l_i = \sum_{s=1}^{N} l_{is}$, in which $l_{is} \ge 0$ indicates the cash that bank i lends to bank s. Likewise the interbank borrowing $b_i = \sum_{s=1}^{N} l_{si}$. We define the total asset for bank i as a_i, the following equation is then determined according to the accounting equation:

$$a_i = e_i + l_i + c_i = d_i + b_i + w_i. \quad (1)$$

Therefore, the volume of total assets for all banks in the system is $A = \sum_{i=1}^{N} a_i$.

Interbank linkages can be depicted through the network, in which the points represent banks while edges represent the interbank loans. We suppose that the adjacency matrix B is used to depict the interbank network. If bank s borrows from bank i then $B_{is} = 1$; otherwise $B_{is} = 0$. As a result, the in-degree of bank i can be expressed as the number of banks that lend to it, i.e., $k_i^{in} = \sum_{s=1}^{N} B_{si}$, and the out-degree is $k_i^{\text{out}} = \sum_{s=1}^{N} B_{is}$. As a general rule, banks with a larger lending scale are more likely to have interbank loans in the real financial market. Therefore, the lending scale of a bank can be defined by its in-degree and out-degree proportionally. According to Maeno et al. [39], the interbank loan from bank i to bank s can be expressed as follows:

$$l_{is} = \frac{B_{is}\left(k_i^{\text{out}} k_s^{\text{in}}\right)^r}{\sum_{i=1}^{N} \sum_{s=1}^{N} B_{is}\left(k_i^{\text{out}} k_s^{\text{in}}\right)^r} L. \quad (2)$$

$L = \sum_{i=1}^{N} l_i = \sum_{s=1}^{N} b_s$ is the total interbank loans in the banking system and it is equivalent to the equation $L = \theta A$ if the interbank loan ratio in the banking system is denoted by θ. The parameter $r \ge 0$ determines the heterogeneity of banks in terms of size. In the case of $r = 0$, all banks are homogeneous.

According to the regulations, banks need to reserve some liquid assets proportional to the deposits to ensure the demands for withdrawal and liquidation. If we define the deposit reserve ratio of bank i as α_i and assume that all banks hold liquid assets only to meet the minimum requirement of the deposit reserve ratio, then $c_i = \alpha_i d_i$. Therefore, the external investment of bank i can be determined by the following equation:

$$e_i = \max(b_i - l_i, 0) + \frac{b_i}{L}\left((1-\theta)A - \sum_{i=1}^{N} \alpha d_i - \sum_{i=1}^{N} \max(b_i - l_i, 0)\right). \tag{3}$$

We further assume that all banks have the same initial leverage ratio λ; then the net worth of bank i can be expressed as

$$w_i = \lambda a_i = \lambda(e_i + l_i + c_i). \tag{4}$$

According to (1) and (4), the deposit can be represented by

$$d_i = (1-\lambda)a_i - b_i. \tag{5}$$

Equation (3) is then simplified as follows based on (5):

$$e_i = \max(b_i - l_i, 0) + \frac{b_i}{L}\left((1-\theta-\alpha(1-\lambda))A + \sum_{i=1}^{N} \alpha b_i - \sum_{i=1}^{N} \max(b_i - l_i, 0)\right). \tag{6}$$

Therefore, all items in the balance sheet can be expressed by given parameters.

3.2. The Balance Sheet Update. In general, banks will not sell external investments before maturity unless they are in financial distress. The return on external investments is the prime source of income for banks, while the original funds come from deposits that fluctuate randomly according to the customers. Therefore, banks may have a shortage of liquid assets because of major fluctuations in deposits, in which case interbank borrowing is formed. The interbank borrowing can only be used to meet temporary liquidity and it should be repaid in time. In other words, the terms of interbank loans and deposits are short when compared with external investments. Therefore, the balance sheet update should be divided into two parts, i.e., in the holding period and at maturity.

The simplified bank balance sheet includes liquid assets, interbank lending, investments, deposits, interbank borrowing, and net worth. Given that banks liquidate assets at maturity of external investments, then all balance sheet items should be updated except external investments and net worth. Firstly, banks will face the fluctuation of deposits, which further affects the liquid assets. As a result, the interbank relationship is formed, and then the interbank loans are updated. According to the endogenous mechanism, the balance sheet update in the holding period is as follows.

(1) Deposits. The fluctuation of deposits is one of the primary reasons for liquid assets. We assume that the maximum level of deposits fluctuation is denoted by the parameter $\gamma(\gamma > 0)$; then the deposits fluctuation of bank i is described by the following process:

$$d_i^t = d_i^{t-1} + (-1+2\chi)\gamma d_i^{t-1} = (1-\gamma+2\gamma\chi)d_i^{t-1}, \tag{7}$$

where $\chi \in [0,1]$ follows a uniform distribution.

(2) Liquid assets. At the end of a period, banks should repay the deposit fluctuation and interest through liquid assets. Meanwhile, interbank loans and interest should be liquidated. In addition, the external investment will also affect the liquid assets according to the rule that returns on the investment in each period are classified into liquid assets. Therefore, the liquid assets at time t can be determined as

$$\begin{aligned}\tilde{c}_i^t &= c_i^{t-1} + d_i^t - (1+r_d)d_i^{t-1} \\ &\quad + \left[\omega_i^{t-1} r_i^{t-1} + \left(1-\omega_i^{t-1}\right) r_f\right] e_i^{t-1} \\ &\quad + (1+r_b)\left(l_i^{t-1} - b_i^{t-1}\right).\end{aligned} \tag{8}$$

r_d and r_b denote the interest rate of deposits and interbank loans, respectively, in each period, and ω_i^{t-1} represents the proportion of risky investments in period $t-1$. $r_i^{t-1} = \sum_{j=1}^{M} x_{ij}^{t-1} r_j^{t-1}$ is the return that bank i obtains on its risky assets in period $t-1$, where $x_{ij}^{t-1} \geq 0$ indicates the proportion of asset j held by bank i.

(3) Interbank loans. As mentioned earlier, interbank linkages are determined by the shortage of liquid assets. Therefore, banks can be divided into two categories, obligor banks ($c_i^t \leq \alpha d_i^t$) and creditor banks ($c_i^t > \alpha d_i^t$), according to the liquid assets in (8). Obligor banks that are in shortage of liquid assets need to borrow money through the interbank market, and creditor banks that have excess liquidity can lend money to the banks in need. According to a stylized fact, obligor banks usually prefer creditor banks that have more liquidity to issue loan applications. We further assume that all loan applications are equivalent. If the creditor bank has enough excess liquidity, it will satisfy the loan application of all obligor banks. Otherwise, the money will be allocated in turn according to the borrowing order until there is no excess liquidity. According to the above mechanism, counterparties are determined endogenously. Thereafter, the liquid assets of all banks are updated according to the interbank loans, which are determined in (9) for obligor banks,

$$c_i^t = \tilde{c}_i^t + \sum_{j=1}^{N} l_{ji}, \tag{9}$$

and in (10) for creditor banks,

$$c_i^t = \tilde{c}_i^t - \sum_{j=1}^{N} l_{ij}. \tag{10}$$

Banks will liquidate assets at the maturity of external investments according to the movement of asset prices. Accordingly, external investments and net worth in the balance sheet are updated. Then it will determine whether banks are bankrupt as well as investment strategies for the next period. The repayment of interbank borrowings and deposits is also considered in the liquidation, and after that, the liquid assets are reupdated. Then banks determine external investments in the next period according to their liquid assets and risk attitudes. The dividend is paid at the last by liquid assets exceeding the deposit reserve. The next period continues to circulate from the fluctuation of deposits when the balance sheet has finished the above updates. According to the endogenous mechanism, the balance sheet updates at maturity are shown as follows.

(1) External investments. At the initial time of a period, banks will determine the volumes of investments and the proportion of risk-free assets or risky assets by the combination of risk attitudes and the utility function. Therefore, the return on external investments can be divided into fixed income and floating income. Fixed income is calculated at the risk-free interest rate, and the determination of floating income depends mainly on the movement of asset prices. Overall, the movement of the asset price in the financial market conforms to the lognormal distribution. Therefore, the movement of asset price can be defined as follows:

$$p^t = p^{t-1} \exp\left[\left(r_f - \frac{1}{2}\sigma^2\right)\Delta t + \sigma\sqrt{\Delta t}\, z_t\right], \tag{11}$$

where r_f represents the return of risk-free investment and σ represents the volatility of asset prices in each period. z_t is the standard normal distribution. According to (11), the return of risky asset investment j is calculated by $r_j^t = \ln(p_j^t/p_j^{t-1})$.

(2) Net worth. It should be determined which banks failed according to the negative net worth at maturity. If asset prices are still determined by (11), the net worth of bank i can be represented as

$$\begin{aligned} w_i^t = {} & c_i^{t-1} - (1+r_d)d_i^{t-1} \\ & + \left[\omega_i^{t-1}\sum_{j=1}^{M} x_{ij}^{t-1} p_j^t + \left(1-\omega_i^{t-1}\right)\left(1+r_f\right)\right]e_i^{t-1} \\ & + (1+r_b)\left(l_i^{t-1} - b_i^{t-1}\right). \end{aligned} \tag{12}$$

The asset prices and the interbank loans in (12) separately denoted by p_j^t and l_j^{t-1} are temporary variables. Therefore, the net worth will be updated until there are no failures in the system.

(3) Liquid assets. The survived banks will liquidate the interbank loans and external investments according to the equilibrium payments and equilibrium prices when failed banks are liquidated and all money is classified into liquid assets. Afterward, the liquid assets can be expressed as

$$\begin{aligned} \tilde{c}_i^t = {} & c_i^{t-1} + d_i^t - (1+r_d)d_i^{t-1} \\ & + \left[\omega_i^{t-1}\sum_{j=1}^{M} x_{ij}^{t-1} \tilde{p}_j + \left(1-\omega_i^{t-1}\right)\left(1+r_f\right)\right]e_i^{t-1} \\ & + (1+r_b)\left(\sum_{s=1}^{N} \pi_{is}\tilde{q}_s - b_i^{t-1}\right). \end{aligned} \tag{13}$$

where $\tilde{p}$ and $\tilde{q}$, respectively, represent the equilibrium prices and equilibrium payments when no bank fails in the system and $\pi_{is} = l_{is}/b_s$ indicates the relative loan of bank s to bank i.

(4) External investments. Banks will start new external investments after the liquidation in the last period to earn continuous returns. Strategies should be determined in advance of the external investments. Individual banks may show different risk attitudes because of the heterogeneity. Therefore, investment strategies can be determined by the utility function. According to Georg [17], the CRRA utility function is used to determine the optimal proportion of risky assets which is shown as follows:

$$\omega_i^t = \min\left\{\mu_i^t \eta_i^{-1}\left(\sigma_i^t\right)^{-2}, 1\right\}^+, \tag{14}$$

where μ_i^t and σ_i^t, respectively, represent the expected return and volatility of risky investment at the time t, and η_i is the relative risk aversion coefficient, which measures the risk attitude of the bank. Thereafter, the optimal volume of external investments is determined by the equation

$$\tilde{e}_i^t = r_c^{-1/\eta_i}\left[1 + \omega_i^t\mu_i^t - \frac{1}{2}\eta_i\left(\omega_i^t\sigma_i^t\right)^2\right]^{1-\eta_i/\eta_i}, \tag{15}$$

where r_c represents the financing cost. As mentioned earlier, interbank borrowing is only used for temporary liquidity instead of external investment. Therefore, it is reasonable to assume that the financing cost r_c equals the interest rate of deposits r_d in terms of the fact that the funds of external investment originate from deposits.

Although the optimal volumes of external investments are determined, not all banks have enough liquid assets to meet them. If all liquid assets beyond deposit reserves can be assigned by the bank, the real volume of external investments is

$$e_i^t = \min\left\{\tilde{c}_i^t - \alpha d_i^t, \tilde{e}_i^t\right\}. \tag{16}$$

(5) Dividend. The liquid assets will be renewed after all gains or losses are liquidated and new investment strategies are determined. Banks can be divided into two types according to the update on liquid assets. The first type of bank has no excess liquid assets except the deposit reserves. Another type of bank still has excess liquid assets after deducting deposit reserves, interbank loans, and new external investments. For the former type of bank, the remaining liquid assets will be used for dividends limited to the deposit reserve and the initial net worth. After the dividend is paid, the liquid asset of bank i is updated to

$$c_i^t = \max\left\{\alpha d_i^t, d_i^t - e_i^t + w_i^0\right\}. \tag{17}$$

3.3. Liquidation Mechanism. The liquidation of failed banks within the investment period does not have the problem of equilibrium payments of interbank loans, but it is necessary to repay the loans to their counterparties in the current period. As mentioned above, surviving banks will not liquidate external investments until maturity although devaluations are raised by failed banks. As a result, there is no equilibrium in asset prices too. The drops in external investments caused by sales of failed banks are reflected in the changes in liquid assets.

However, both payments and prices are dynamics for the liquidation of failed banks at maturity. Therefore, the realized payment of bank i in equilibrium is

$$q_i^t = \min\left\{ (1+r_b)b_i^t, c_i^t - (1+r_d)d_i^t + \left[\omega_i^t \sum_{j=1}^{M} x_{ij}^t p_j^t + \left(1-\omega_i^t\right)\left(1+r_f\right)\right] e_i^t + (1+r_b)\sum_{s=1}^{N} \pi_{is}^t q_s^t \right\}^+, \tag{18}$$

where $\pi_{is} = l_{is}/b_s$ means the relative loan. The asset price in equilibrium is given by the inverse demand function according to Cifuentes et al. [42].

$$p_j^t = \exp\left(-\beta \sum_{i\in F}^{N} s_i^t\right). \tag{19}$$

The parameter β measures the sensitivity of asset prices, s_i represents the fraction of assets sold by the failed bank i to the total volumes of the assets, and F is the set of all failed banks. We define $\tilde{p}$ as the equilibrium asset prices and $\tilde{q}$ as the equilibrium payments when there are no more bankrupt banks in the system; then $\tilde{p}$ and $\tilde{q}$ can be calculated by fixed point iterations and their existence and uniqueness of them have been proved by Feinstein [43].

4. Results and Discussions

4.1. Parameterization. A simulated financial system is considered in which the number of banks is $N = 100$ and the total assets is $A = 100$ with a heterogeneity parameter $r = 5$. The balance sheet of banks at the initial time is set according to the real financial market and regulations, where the interbank loan ratio is $\theta = 0.1$, the leverage ratio is $\lambda = 0.1$, and the deposit reserve ratio $\alpha$and the maximum level of deposits fluctuation γ are both 0.2. In addition, the deposit interest rate, risk-free interest rate, and interbank interest rate are $r_d = 0.02$, $r_f = 0.03$, and $r_b = 0.04$, respectively. The average connectivity of the interbank network is $\mu_1 = 0.1$; i.e., the average number of counterparties is 10.

The number of external assets is $M = 20$ and the benchmark diversification of investments is $\mu_2 = 0.5$ which means the average number of external assets held by each bank is equal to the maximum. At the beginning of each period, the prices of all assets are initialized to $p^0 = 1$. The maturity of external investments is $T = 10$, and the fluctuation of asset prices follows a normal distribution with the mean $r_f = 0.05$ and variance $\sigma = 0.2$. We follow a stylized assumption that $\beta = 1$ according to Caccioli et al. [6]. At the initial time, banks invest in the same proportion of risky assets, i.e., $\omega^0 = 0.5$. The risk aversion $\eta \in (1, 10)$ is uniformly distributed.

The average number of failed banks is taken as the measure of systemic risk. The model evolves 200 periods in an experiment and simulations are repeated 1000 times as the results to increase the robustness. Since the financial system is dynamically evolving, failed banks should be removed from the system after liquidation and the same number of new banks is introduced. It is assumed that the size of new banks is the same as that of failed banks to ensure the stability of the banking system.

4.2. Interbank Loans and Systemic Risk. Interbank loans are mainly determined by the number of interbank counterparties, namely, interbank diversification. The effect of interbank diversification on systemic risk is shown in Figure 1, where bankruptcy is only caused by liquidity shortages. The result indicates that an increased number of interbank counterparties generally prevents systemic risk. It is more effective in the initial stage since the increased number of interbank counterparties provides more liquidity assesses for obligor banks to meet liquidity shortages and thus mitigates the bankruptcy of obligor banks. However, with the continuous increase of interbank diversification when obligor banks have sufficient interbank borrowings to meet liquidity shortages, it will provide a channel for contagion risks when creditor banks bankrupt. Therefore, the increase in the number of interbank counterparties will not prevent systemic risk in the later stage. This result is further verified by the histogram in Figure 2, which, respectively, shows the count of bankrupt banks in all periods at a low level and high level of interbank diversification. Notably, the count is logarithmic. We can see that the increased number of interbank counterparties reduces the possibility of moderate systemic risk but increases the possibility of serious systemic risk. In other words, the excessive number of interbank counterparties is out of effect and harms the stability of the banking system. This result implies important systemic risk supervision by reducing interbank diversification in the environment of a sufficient liquidity supplement. At the same time, banks with a high level of interbank diversification should be strictly supervised.

Although the number of interbank counterparties prevents systemic risk caused by liquidity shortage, the result in Figure 3 shows that systemic risk is steadily promoted with the increase of interbank diversification if the investment shock is considered. It highlights the financial accelerator

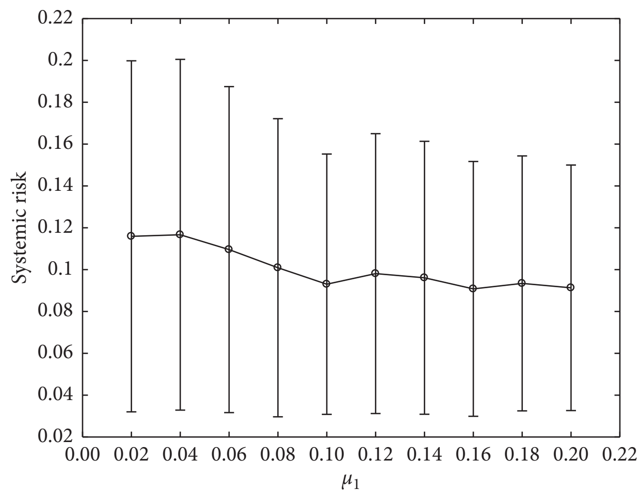

Figure 1: Interbank diversification in liquidity shortage period.

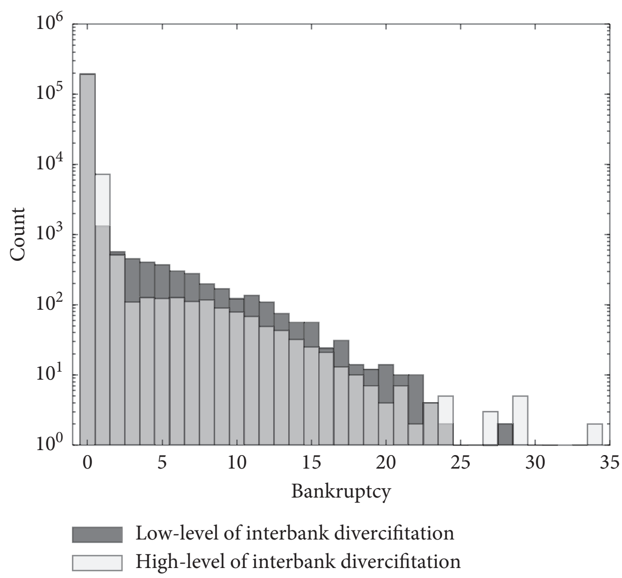

Figure 2: Bankruptcies of different interbank diversification.

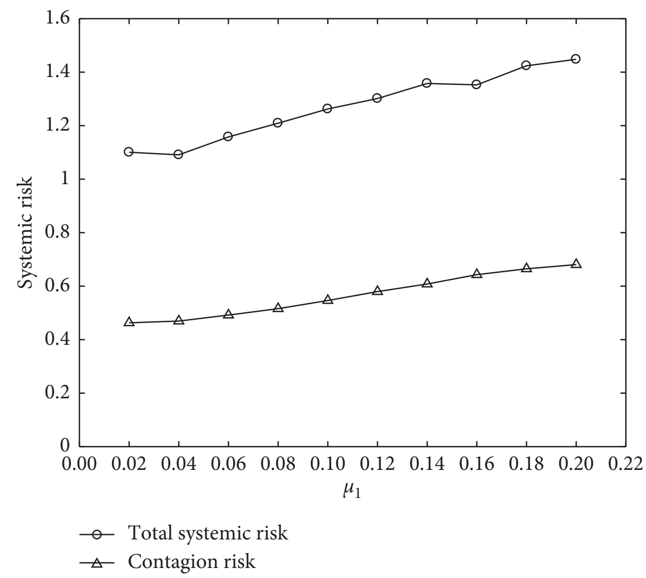

Figure 3: Interbank diversification in the investment shock period.

effect of fire sales. When bankrupt banks liquidate their external investments, fire sales of external investments deteriorate the balance sheets of other banks which hold common assets and then form a financial disaster. As shown in Figure 3, the increased systemic risk is mainly contributed by contagion risks, which indicates that interbank counterparties not only provide channels for direct contagion risks but also provide channels for indirect contagion risks through fire sales. This conclusion is inconsistent with classical results which propose that interbank diversification promotes contagion risks from the beginning and disperses contagion risks after the threshold. However, evidence from the endogenous banking system, which contains multiple channels both in the interbank market and in investment market, indicates different effects of interbank diversification on systemic risk in different environments. That is, the increased number of interbank counterparties mitigates bankruptcies of individual banks when in liquidity shortages while endangering systemic stability in the environment of investment shock. Therefore, the regulatory intervention should be dynamically adjusted according to the financial environment, which implements interbank diversification easing in the environment of liquidity shortage and strengthens the supervision in the environment of investment shock.

Systemic risk is not only related to debtor banks in the interbank market but also determined by the decision of creditor banks. According to the endogenous model, we further explore the effects of creditor banks on systemic risk in terms of the behavioral incentive that determines interbank lending in order of liquidity gaps or total assets. Since systemic risk has different features when faced with liquidity shortage and investment shock, Figure 4 shows the different cases where only liquidity shortage is considered in the left panel, and both liquidity shortage and investment shock are considered in the right panel. The results indicate that creditor banks determine interbank lending orders according to the scale of total assets which is more helpful to the systemic stability of the banking system. It highlights the advantages of big banks in preventing the contagions of systemic risk, exactly as the "too big to fail" policy shows. It indicates a macroprudential regulatory intervention that big banks should be given more priority to meet liquidity shortages.

Empirical evidence shows that the scale of banks in terms of total assets usually follows a power-law distribution, where the big banks hold most of the assets and a large number of small banks hold only a few assets. However, different markets also have heterogeneity, which could be distinguished by the power-law exponent. The structural heterogeneity of different markets is studied in Figures 5 and 6, where systemic risk is, respectively, simulated in the environment of liquidity shortage and investment shock. From the perspective of a liquidity shortage, the result shows that heterogeneous big banks are helpful to reduce systemic risk. Big banks usually have more chances to provide interbank lending and more

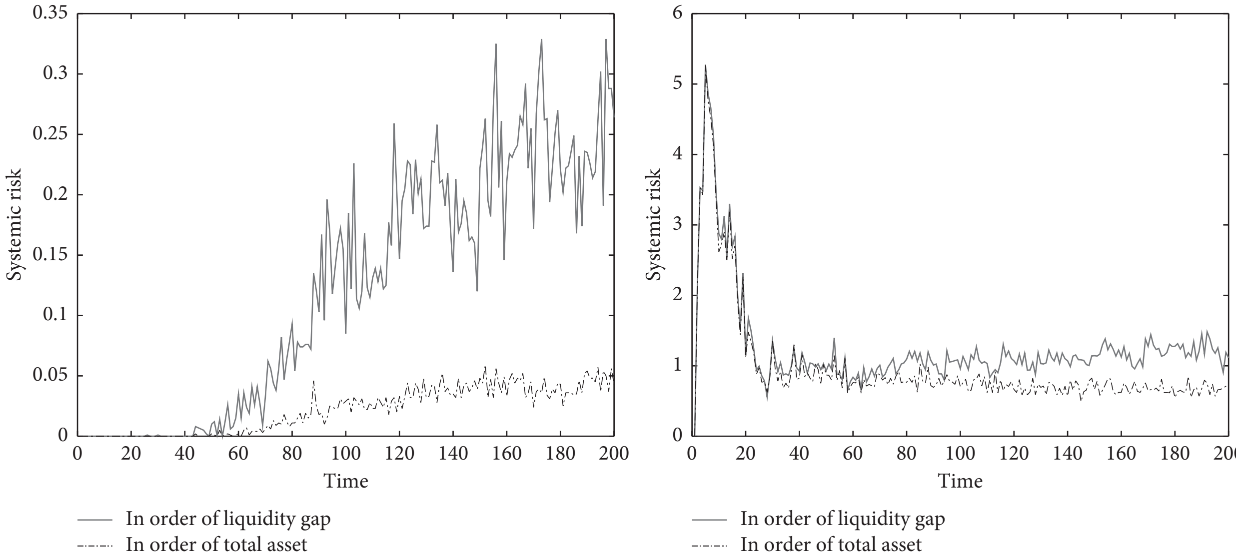

Figure 4: Interbank lending decision and systemic risk.

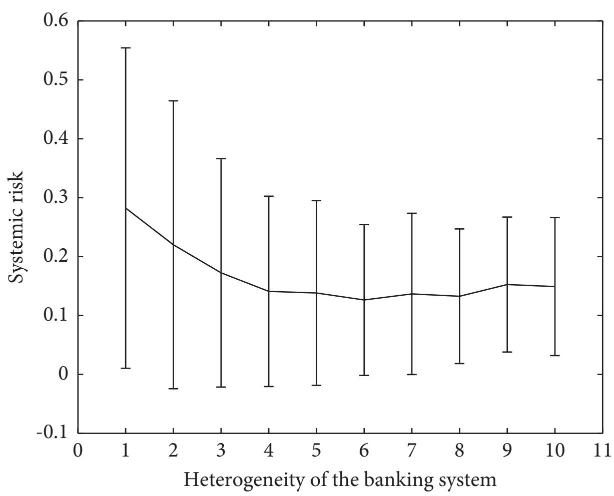

Figure 5: Structural heterogeneity in liquidity shortage period.

capital buffer to suffer losses from the debtor banks, so systemic stability is improved as long as there is no bankruptcy for big banks. However, if the investment shock is considered, the advantage of heterogeneous big banks is weakened, and it even promotes systemic risk after a threshold. It means that the bankruptcy of big banks promoted by investment shocks will destroy the whole banking system. Therefore, the scale of big banks determines systemic stability. The banking system with an intermediate scale of big banks is optimal, while too many big banks and only a few big banks will both harm systemic stability. This conclusion has a valuable regulatory reference that the system stability will be improved by adapting the scale of big banks for the banking system.

4.3. Investment Strategy and Systemic Risk. Investment strategy measured by diversification is the other factor that determines systemic risk. The effect of investment diversification is explored in Figure 7. The result shows that investment diversification initially reduces systemic risk while it does not work with continuous increases. To explore this result, Figure 8, respectively, compares the count of bankruptcies at a low level and high level of investment diversification. It shows that although a high level of investment diversification reduces the moderate systemic risk, the serious systemic risk increases at the same time. It means investment diversification provides more possibilities for serious systemic risk by providing more channels for contagion risks. The results indicate accommodative investment diversification to reduce systemic risk in the booming market. However, banks with a high level of investment diversification should be strictly regulated during the recession to prevent serious contagions since that excessive investment diversification is ineffective.

Evidence shows that investment diversification provides more channels for contagion risks. Therefore, how to disperse contagion risks in a given level of investment diversification is critical for supervision. Figure 9 demonstrates the effect of investment portfolio overlaps on systemic risk in a given level of investment diversification. Given that the number of investment assets held by banks is fixed, the result shows that systemic risk is reduced by providing more types of assets. Moreover, the count of bankruptcies in Figure 10 indicates that the increased types of investment assets not only reduce the moderate systemic risk but also disperse the serious systemic risk. This result highlights the advantages of reducing investment portfolio overlaps in dispersing systemic risk. It provides regulatory incentives for preventing systemic risk from the perspective of increasing heterogeneous types of assets.

The investment strategy of banks is usually motivated by a risk attitude. The advantage of the endogenous model is exploring the relationship between risk attitude and systemic risk and then providing a reference for systemic risk

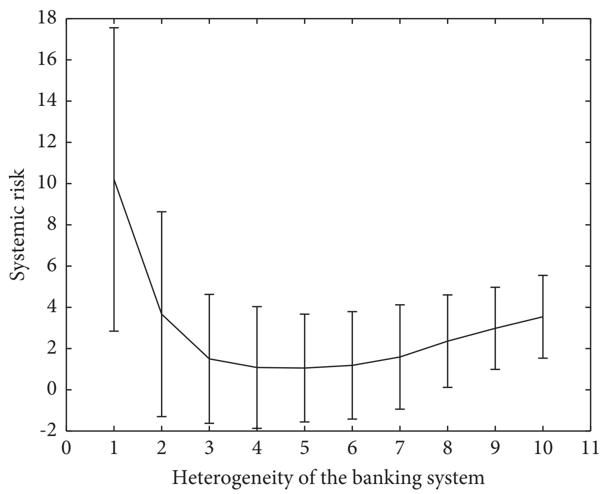

Figure 6: Structural heterogeneity in investment shock period.

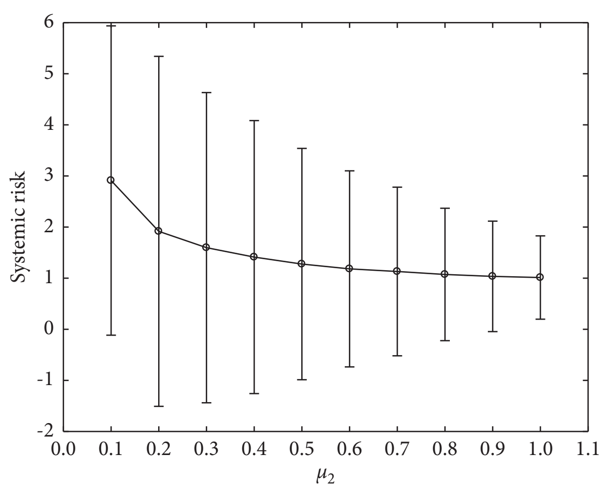

Figure 7: Investment diversification and systemic risk.

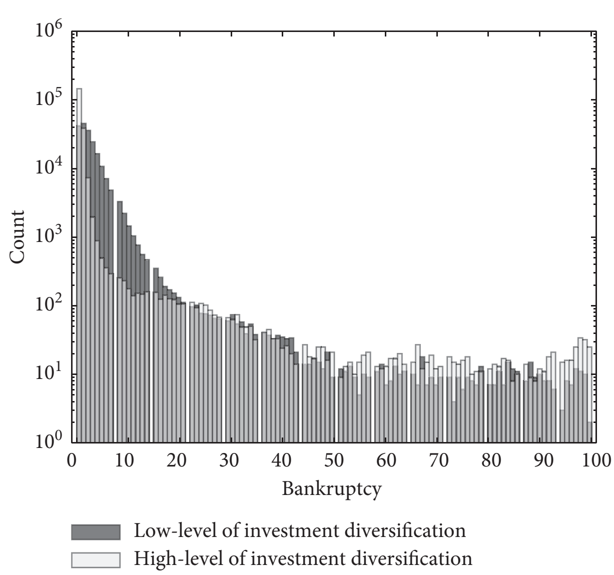

Figure 8: Bankruptcies of different investment diversification.

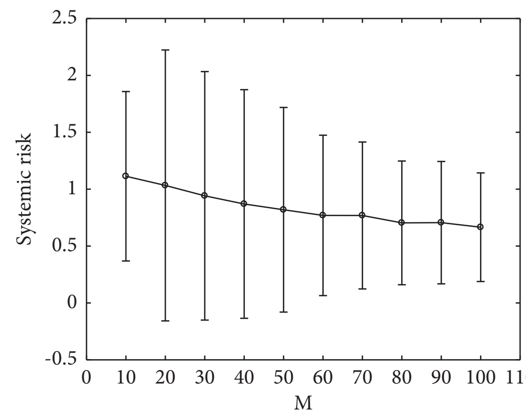

Figure 9: Investment asset types and systemic risk.

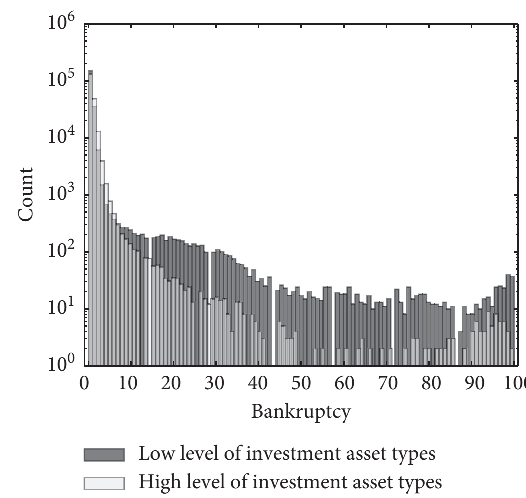

Figure 10: Bankruptcies of investment asset types.

prevention according to the behavioral incentives of investment strategies. The risk aversion as a direct indicator of risk attitude is explored in Figure 11. The systemic risk contribution shows a downward trend with the increased risk aversion since both investment shocks and contagion risks decrease with the low proportion of risky assets. Further study in Figure 12 depicts how the matching of risk aversion and leverage ratio affects the systemic risk contribution of individual banks. We find that a more matching degree of risk attitude and leverage ratio helps to prevent the systemic risk contribution of individual banks. This result provides an implication for regulatory intervention that risk attitude should match the leverage ratio for individual banks.

The price elasticity (or market depth) of assets held by banks is also an important measure of risk attitude. Therefore, systemic risk contribution also depends on the price elasticity of assets held by banks. Figure 13 depicts the weighted external investments of banks by the heterogeneous price elasticity and systemic risk contribution of individual banks. It shows a positive correlation between the price elasticity of individual banks and systemic risk contribution which means that the higher asset price elasticity promotes contagion risks. Therefore, the price elasticity of

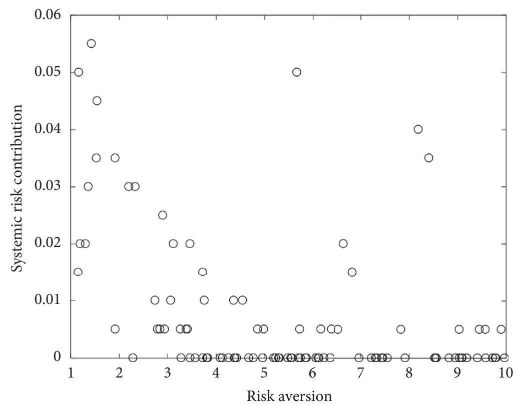

Figure 11: Risk aversion and systemic risk.

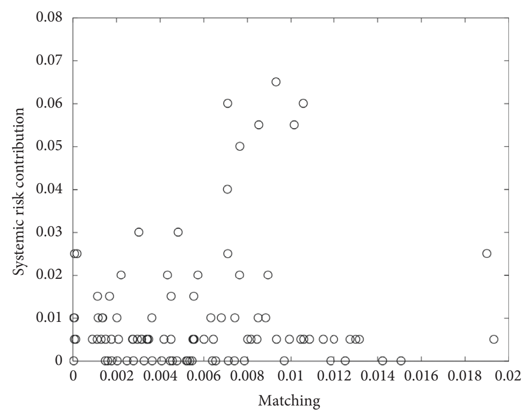

Figure 12: Matching of risk aversion and leverage ratio.

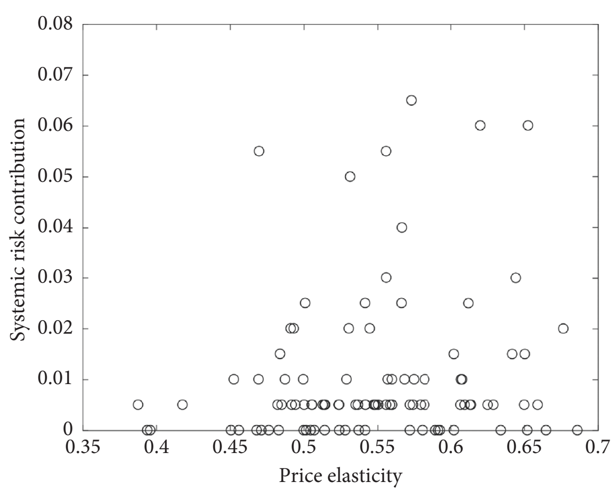

Figure 13: Price elasticity and systemic risk.

assets should also be considered when determining investment strategies. The result also indicates that the supervision of assets with high price elasticity should be concerned. Furthermore, Figure 14 demonstrates that a more matching degree of risk attitude and leverage ratio helps to prevent systemic risk contribution of individual banks and promotes the banking system stability.

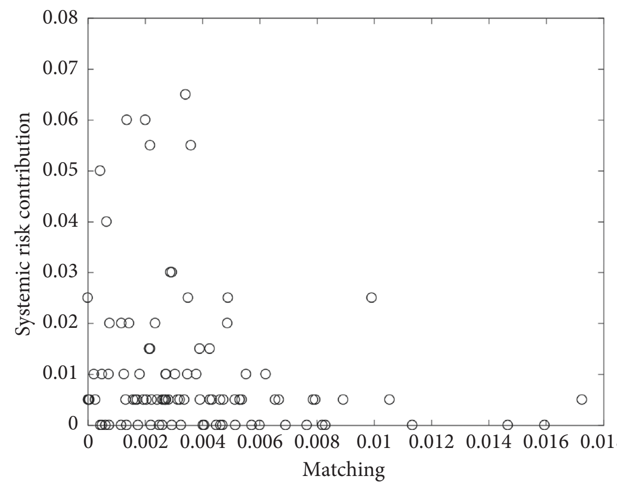

Figure 14: Matching of price elasticity and leverage ratio.

5. Conclusions

The empirical results have shown that systemic risk is noticeably affected by the diversification of interbank loans and investment strategies. However, a further problem of how different diversifications are endogenously motivated still needs analysis. It is critical for systemic risk supervision. Therefore, a dynamic endogenous model is proposed in our study to explore the behavioral incentives of diversification, where interbank loans and investment strategies are, respectively, determined by the liquidity shortage and risk attitude. Based on the model, the evolution of systemic risk is explored, as well as the effect of diversification incentives. The results may provide references for regulatory intervention to prevent systemic risk in the banking system.

In summary, the study highlights the following results. On one hand, evidence from the interbank market finds that the increased number of interbank counterparties disperses systemic risk caused by liquidity shortage, while it promotes contagions when faced with investment shocks. Therefore, the effectiveness of interbank diversification in preventing systemic risk depends on the market environment. Given contagion risks, incentives of interbank diversification indicate that big banks play a more important role in promoting systemic stability. As a result, big banks should be provided with priority to meet liquidity shortages. It also shows that the banking system with an intermediate scale of big banks is optimal, while too many big banks and only a few big banks both harm systemic stability. On the other hand, evidence from the investment market finds that although a high level of investment diversification reduces the possibility of moderate systemic risk, serious systemic risk is also promoted with the increased channels for contagions. However, the increased contagion risks could be dispersed by reducing the investment portfolio overlaps. The incentive of investment diversification shows that risk attitude has a great effect on systemic risk. The systemic risk could be effectively reduced when risk attitudes match leverage ratios for individual banks.

These results demonstrate the dynamic effect of interbank loans and external investments on systemic risk and fill the gap of behavioral supervision for systemic risk by exploring behavioral incentives of diversification in the interbank market and investment market. It indicates the following regulatory intervention for preventing systemic risk. Firstly, regulatory policies should be dynamically adjusted according to the financial environment, which implements interbank diversification easing when in liquidity shortages and strengthens the supervision of banks with a high level of interbank diversification or investment diversification during the recession. It should also ensure that the number of big banks is consistent with the banking system to improve systemic stability. According to the principle of "too big to fail," big banks should be provided with priority to meet the liquidity shortages. Finally, risk attitude whether consistent with the leverage ratio for individual banks should be taken as a regulatory intervention for systemic risk prevention. The above results are completely determined by the endogenous self-regulation of the banking system without considering the interventions of the central bank. It is the main limitation of our study and also the direction of further study in the future.

Data Availability

Data are available on request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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