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Research Article

The Effect of Shadow Banking on the Systemic Risk in a Dynamic Complex Interbank Network System

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After the financial crisis triggered by the subprime mortgage crisis in the United States in 2008, many scholars believed that the unstable transmission of shadow banking business in the banking system is the main factor causing financial turmoil. This paper proposes a dynamic complex interbank network system model with shadow banking in which the dynamic complex interbank network system differs from the traditional banking network and is formed by the interrelated business between shadow banks and commercial banks to explore the effect of shadow banking on the systemic risk. The results show that the existence of shadow banking will increase the systemic risk, accelerate the speed of bankruptcy of banks, reduce the survival ratio of banks, and increase the strength of central bank assistance. The smaller the number of shadow banks in the system, the higher the degree of credit connection among commercial banks and the smaller the systemic risk.

1. Introduction

The outbreak of the global financial crisis has shown that the occurrence of systemic risk would lead to a tremendous destructive effect on the financial system [1, 2]. Therefore, the research of the systemic risk has drawn more and more attention [3, 4]. In the existing studies of systemic risk, most of them focus on the analysis of the systemic risk that is conducted from the perspective of interbank lending and it is believed that interbank lending relationship has an important impact on the systemic risk [5–7]. The network structure formed by interbank lending as a carrier of risk contagion [8, 9] plays an important role in the systemic risk [6, 7]. Kaufman and Scott [10] argued that the systemic risk will be triggered by risks or possible systemic collapses in the interbank lending market. Allen and Gale [11] studied the effects of a complete market structure and an incomplete market structure on the systemic risk and found that the complete market structure is more stable than the incomplete market structure. Iori and Jafarey [12] found that the homogeneous banking system is more stable than the heterogeneous banking system. Nier et al. [13] pointed out that the impact of banking network concentration on the systemic risk is nonmonotonous. Lenzu and Tedeschi [14] analyzed the impact of different network topologies on the systemic risk and found that the random network structure is more stable than the scale-free network structure. Caccioli et al. [15] showed that the scale-free network has better flexibility, but its systemic risk is significantly higher than other networks. Godlewski et al. [16] argued that the small-world network structure is conducive to enhancing assets connectivity between banks, reducing loan spreads and the systemic risk. Georg et al. [17, 18] stressed that the central bank stabilizes interbank markets in the short run alone and the money-centric network is more stable than the random network. Lux [19] presented that the interbank network shows a "core periphery" structure. The core banks could provide financial support for peripheral banks to prevent systemic risk. Berardi and Tedeschi [20] showed that the banking network presents a centralized structure and the increase in the number of attractive banks will reduce the systemic risk.

The existing studies mainly analyzed the systemic risk caused by the crisis from the perspective of the interbank market and different interbank lending networks. The effect of shadow banking on systemic risk is almost lacking. As defined in Page and Wooder [21], shadow banks are nonbank financial institutions that operate outside the traditional banking regulation system. Shadow banks are not directly regulated by central banks, and they are not included in the safety net. According to Financial Stability Board (FSB) [22], the shadow banking system is a credit intermediary system which is free from the formal banking system and may cause systemic financial risks and regulatory arbitrage risks. The FSB also sets out several classes of shadow banking sectors: (i) sectors susceptible to runs, such as certain mutual funds, credit hedge funds, and real-estate funds; (ii) nonbank lenders dependent on short-term funding, such as finance companies, leasing companies, factoring companies, and consumer-credit companies; (iii) market intermediaries dependent on short-term funding or on the secured funding of client assets, such as broker dealers; (iv) companies facilitating credit creation, such as credit insurance companies, financial guarantors, and monoline insurers; and (v) securitization-based intermediaries. Shadow banking brings prosperity to the financial market, but at the same time, it also brings great vulnerability to the financial system. Therefore, the interest in the impact of shadow banking on financial markets is becoming a growing area within systemic risk literature. Pozsar et al. [23] and Tucker [24] discussed that the size of shadow banking showed a pattern of sudden increase before the outbreak of the global financial crisis and shadow banking was considered as one of the main reasons that could trigger financial systemic risk. Bernanke et al. [25] believed that shadow banking utilizes the balance sheets to provide credit loans similar to commercial banks and uses term conversion to avoid bankruptcy risk, which induces systemic risk. Diamond [26] found that the diversification of shadow banking's portfolio by buying and selling risky loans would result in the accumulation of the systemic risk. Gennaioli et al. [27] used an improved shadow banking model to study the relationship between shadow banking and the systemic risk and discovered if reasonably expected, shadow banking could help withstand the systemic risk and maintain the system stable. Elgin and Oztunali [28] found through a two-sector dynamic general equilibrium model that the relative size of shadow banking sector will affect systemic risk. Colombo et al. [29] constructed a shadow banking model to emphasize that the form of propagation after a crisis shock will reduce the ability of the financial system to resist future shocks, and the level of the systemic risk will increase.

Although the above research concerning the impact of shadow banking on the systemic risk examines the relationship between shadow banking and the systemic risk, it does not reveal the mechanism of systemic risk well, as they neglected the complicated interactions among banks. It is widely believed that the systemic risk mainly originated from the cascading failures of banks due to the complicated interactions among banks. Therefore, the study of the impact of shadow banking on the systemic risk should be integrated with the interbank network system. In view of the above considerations, a dynamic complex interbank network system model with shadow banking is proposed. The dynamic evolution of the systematic risk in the existence and absence of shadow banking is studied in this study; furthermore, the impact of shadow banking on the number of default banks, bank survival rate, ratio of default rate to commercial bank survival rate, and central bank assistance are compared. Moreover, the time course of the systemic risk (dynamic evolutional systemic risk) other than a fixed systemic risk is obtained in this paper, as the calculation of the systemic risk is based on a dynamic interbank network model. This enables us to observe the trend of the systemic risk, making the results of shadow banking effect on the systemic risk more valuable.

2. Model of a Dynamic Complex Interbank Network System with Shadow Banking

2.1. The Structure of Interbank Network with Shadow Banking. A dynamic complex interbank network system with shadow banking is constructed, in which commercial banks and shadow banks form a network including connections to the real economy; here, the real economy represents the rest of economy, namely, the economy outside of banking. The number of agents of commercial banks is denoted by M, and N is the number of agents of shadow banks. Thus, $U = M + N$ is the sum of all the banks in the system. When $N = 0$, the interbank network system can be regarded as the traditional interbank network system. t (t =1, 2, ⋯) is the dynamic evolution time step of the system. At any time t, there are a finite number of banks U. Figure 1 shows the structure of interbank network with shadow banking. Commercial banks are overseen by the central bank. They are operating within the protection net provided by the central bank and receive the central bank's aid like CB_t^j when bank j defaults. According to the definition proposed by Pozsar et al. [23], shadow banks are financial institutions that operate outside of the central bank's regulatory. Thus, there is no need for shadow banks to obey the central bank's regulations (such as legal reserves and investment restrictions). Meanwhile, they cannot receive aid from the central bank.

In the banking system, bank failure is often caused by a lack of liquidity. The liquidity of a bank is mainly related to deposit, financing, investment, and interbank lending. When banks are short of liquidity, they will borrow from each other in the interbank network, which is shown in Figure 1. The directed line segments between banks represent the amounts of borrowing or lending from one bank to another. For example, the arrow from commercial bank M_j points to commercial bank M_k, indicating that commercial bank M_j is the debt bank of commercial bank M_k, and its debt is $b_t^{j,k}$; the arrow from commercial bank M_k points to commercial bank M_i, indicating that commercial bank M_i is commercial bank M_k's creditor bank with a claim of $b_t^{k,i}$. Since shadow banks have the characteristics of independence and information opacity [30], there is a business relationship between shadow banks and commercial banks, while no interbank lending between shadow banks is considered in this paper. For example, $b_t^{j|M,q|N}$ indicates that commercial bank M_j borrows from shadow bank N_q and $b_t^{w|N,j|M}$ indicates that shadow bank N_w borrows from commercial bank M_j. $b_t^{q|N,k|M}$ and $b_t^{k|M,l|N}$ represent the interbank claims and debts between commercial bank M_k and shadow bank N_q and shadow bank N_l, respectively. Similarly, $b_t^{l|N,i|M}$ and $b_t^{i|M,w|N}$ represent the interbank claims and debts between commercial bank M_i and shadow bank N_l and shadow bank N_w, respectively. Moreover, according to the policy restrictions on the relationship between commercial banks and shadow banks, in our model, the interbank lending relationship between a shadow bank and commercial banks will be limited by the number (the number is represented by d, that is, the maximum number of commercial banks that a shadow bank can borrow).

In addition to interbank interactions, in order to be more in line with the real financial state, according to the research of Gong and Page [31], the model proposed in this paper includes connections to the real economy S^n. To simplify the system, this paper divides the state of the real economy into three, that is, $S^n (n = 1,2,3)$. The banking system and real economy feature a two-sided interaction. The state of the real economy influences the banking system by determining the allocation of investment. For each state of the real economy, there is an investment project $K^n (n = 1, 2, 3)$. As shown in Figure 1, a bank selects project K^n to invest in the real economy S^n. The return of the projects K^n is subject to the state of the real economy (detailed in the below section). With reference to Pareto's principle [32], using Pareto's economic model [33] and taking the bank default rate (the ratio of the number of default banks to the total number of banks) as a measure, the three critical values for dividing the real economy are calculated. When the bank default rate is less than 10%, it is in a good economic case S^1, corresponding to the investment project K^1 with low risk and high return; when the bank default rate is between 10% and 20%, it is in a stable economic case S^2, corresponding to the investment project K^2 with medium risk and return; when the bank default rate exceeds 20%, it is in a depressed economic case S^3, corresponding to the investment project K^3 with high risk and low return. The real economy S^n will change with the dynamic evolution of the bank default rate in the system. Banks in the system will default but the number of banks will not increase.

2.2. Traditional Interbank Network System. The traditional interbank network refers to the network formed by the interbank lending of commercial banks. This paper refers to the studies of Iori et al. [12] and Georg et al. [17, 18], and the interbank network is set up as a random network. In a random network, banks are randomly connected and the connectivity relationship is represented by binary matrix J. $J_{i,j}$ is either one or zero. $J_{i,j} = 1$ indicates that there is a credit linkage between bank i and bank j, and $J_{i,j} = 0$ means that there is no relationship. c indicates the probability of a credit linkage between any two banks, i.e., $c \in [0,1]$. At one extreme, $c = 0$ means there is no interbank lending, while $c = 1$ means interbank network's structure is a fully connected structure.

The bank dynamic evolution is based on the banks' balance sheet. Every bank's assets and liabilities in the banking system are dynamically changing at each time step. The balance sheet of each bank in the system evolves dynamically as follows:

$$L_{t-1}^i = A_{t-1}^i + B_{t-1}^i + V_{t-1}^i - \sum_{j=1}^{\tau} I_{t-j}^i, \tag{1}$$

where L_{t-1}^i is the liquidity asset of bank i at time t-1; A_{t-1}^i is the deposit of bank i at time t-1; V_{t-1}^i is the owner's equity of bank i at time t-1; $\sum_{j=1}^{\tau} I_{j-s}^i$ is the total investment of bank i in τ investment periods; and $B_{t-1}^i = \sum_{k=1}^{U} b_{t-1}^{i,k}$ is the total borrowing amount of bank i at time t-1; $b_{t-1}^{i,k} > 0$ if bank i borrows from bank k and $b_{t-1}^{k,i} < 0$ if bank k loans to bank i, where $b_{t-1}^{i,k} = -b_{t-1}^{k,i}$. $b_{t-1}^{i,k} = -b_{t-1}^{k,i} = 0$ if there is no lending relationship between banks.

2.3. Interbank Network System with Shadow Banking. Besides the dynamically changing assets and liabilities of every bank, the interbank lending network also changes dynamically at each time step. It should be noted that there is no interbank lending between shadow banks in this paper. Therefore, the binary matrix J among shadow banks is always set to zero. The balance sheet of banks in the interbank network system with shadow banking is evolved same as equation (1); however, if bank i is a shadow bank, then $B_{t-1}^i = \sum_{k=1}^{d} b_{t-1}^{i|N,k|M}$, indicating the total borrowing amount of shadow bank i at time $t-1$. $b_{t-1}^{i|N,k|M} > 0$ if shadow bank i borrows from commercial bank k and $b_{t-1}^{i|N,k|M} < 0$ if commercial bank k borrows from to shadow bank i, where $b_{t-1}^{i|N,k|M} = -b_{t-1}^{i|N,k|M}$. $b_{t-1}^{i|N,k|M} = -b_{t-1}^{i|N,k|M} = 0$ if there is no lending relationship between shadow bank i and commercial bank k. The sequence of activities in each time is as follows. At the start of each time, each bank inherits the initial liquidity asset. Then, the liquidity asset of banks will change dynamically with the inflow and outflow of funds. The liquidity asset of bank i is updated to

$$L_t^i = L_{t-1}^i + \left(A_t^i - A_{t-1}^i\right) - r_a A_{t-1}^i + \rho \sum_{j=1}^{\tau} I_{t-j}^i + I_{t-\tau}^i, \tag{2}$$

where $r_a A_{t-1}^i$ is the interest paid by the commercial bank to depositors or the interest paid by the shadow bank to financiers and r_a is the deposit interest rate or the financing interest rate; $\rho \sum_{j=1}^{\tau} I_{t-j}^i$ and $I_{t-\tau}^i$ are investment income and the investment recovered at maturity; and ρ is the rate of return on investment of each time. Since the deposit and financing patterns of customers are fluctuating and unpredictable, each bank receives stochastic shocks to its liquidity reserves. Therefore, it is assumed that the deposits or financing A_t^i for the bank i obeys the normal distribution: $A_t^i = |\overline{A} + \overline{A}\delta_A \varepsilon_t|$, $\varepsilon_t \sim N(0,1)$, where $\overline{A}$ is the mean of random deposits of commercial banks or random financing of shadow banks and δ_A is the standard deviation of commercial banks' random deposits or shadow banks' random financing.

If $\mathrm{L}_t^i > 0$, it denotes that bank i has sufficient liquidity. Such bank can undertake dividend payments to

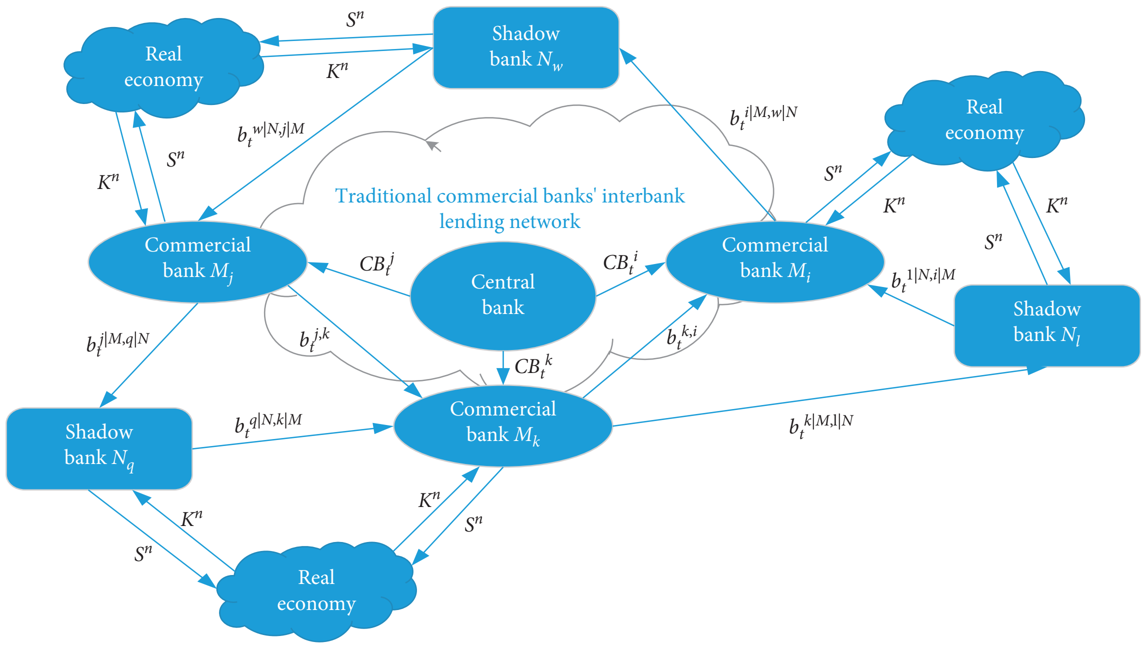

Figure 1: The structure of interbank network with shadow banking.

shareholders. Dividend distribution is different in commercial banks and shadow banks. When bank i is a commercial bank, dividend distribution $D_t^{i|M}$ can be described as follows:

$$D_t^{i|M} = \max\left[0, \min\left[\rho \sum_{j=1}^{\tau} I_{t-j}^i - r_a A_{t-1}^i, L_t^i - R_t^i, L_t^i + \sum_{j=1}^{\tau-1} I_{t-j}^i - (1+\chi) A_t^i\right]\right], \quad (3)$$

where $R_t^i = \beta A_t^i$ is the legal deposit reserve kept by commercial bank i, β is the deposit reserve ratio, and χ is the deposit ratio. When bank i is a shadow bank, dividend distribution $D_t^{i|N}$ is as follows:

$$D_t^{i|N} = max\left[0, \min\left[\chi\left(\rho \sum_{j=1}^{\tau} I_{t-j}^i - r_a A_{t-1}^i\right), L_t^i\right]\right], \quad (4)$$

where χ is the financing ratio; for simplicity, the financing ratio is equal to the deposit ratio in this paper.

After the dividends have been paid, the bank undertakes reinvestment. Corresponding to the real economy S^n, bank i chooses project K^n to reinvest under its available liquidity and investment opportunity. Different projects have different returns on investment. As the value of n increases, the economic condition declines and the return on investment decreases. The return on investment of the project can be expressed as

$$R_o \mid S^n = \begin{cases} 0, & 1 - p_n \\ R_o^{s^n}, & p_n \end{cases} \quad (n = 1, 2, 3), \quad (5)$$

where $R_o^{s^n}$ is the investment return corresponding to project K^n under the state of the real economy S^n. The value of $R_o^{s^n}$ is set according to the existing investment return rate of banks and the loan income rate of finanical companies. p_n is the investment recovery probability corresponding to project K^n, indicating the risk of the project; with the increase of the risk of the project, the investment recovery probability decreases. And the initial value is set by referring to the real bank's nonperforming loan interest ratio. The better the real economy, the lower the risk and the higher the return of investment and the investment recovery probability.

The reinvestment of commercial bank i is $I_t^{i|M}|K^n$, and the reinvestment of shadow bank i is $I_t^{i|N}|K^n$:

$$I_t^{i|M} \mid K^n = \min\left[\max\left[0, L_t^i - D_t^{i|M} - R_t^i\right], \omega_t^i\right], \quad (6)$$

$$I_t^{i|N} \mid K^n = \min\left[\max\left[0, L_t^i - D_t^{i|N}\right], \omega_t^i\right], \quad (7)$$

where ω_t^i is the investment opportunity of bank i. The investment opportunity of bank i at time t is subject to a normal distribution: $\omega_t^i = |\overline{\omega} + \overline{\omega}\delta_\omega \eta_t|, \eta_t \sim N(0,1)$. $\overline{\omega}$ is the average investment opportunity of banks, and δ_ω is the standard deviation of banks' investment opportunity. The difference between the two types of reinvestment is that there is no need for shadow banks to pay the legal deposit reserve to the central bank.

After completing the above dividend distribution and reinvestment, if bank i's liquidity asset $L_t^i \geq 0$, it can continue interbank lending. Conversely, if $L_t^i < 0$, bank i becomes a member of defaulted set F at time step t. When defaulted bank i is a commercial bank, even if it is unable to borrow enough money to restore its liquidity, it can go back to the banking system because it will be bailed out by the central bank. The form of the assistance of the central bank will be described as follows:

$$CB_t^i = \begin{cases} R_t^i - L_t^i, & R_t^i > L_t^i, \\ 0, & \text{otherwise}. \end{cases} \quad (8)$$

When $R_t^i > L_t^i$, the central bank's assistance amount to commercial bank i is $R_t^i - L_t^i$. After getting the assistance of the central bank, commercial bank i's debts update to 0 ($B_t^i = 0$) and go into the next time step. Otherwise, the commercial bank i pays legal deposit reserve by itself and evolves to the next time step. Protected by the central bank, commercial banks only default and do not go bankrupt.

Alternatively, if a bank experiencing negative liquidity is a shadow bank i (i.e., $L_t^i<0$), it will be cleared by the central bank. Following Eisenberg and Noe [34], this paper assumes that shadow banks with insufficient liquidity to cover their debts pay their debts proportionally. The debt repayment is calculated as follows:

$$PB_t^{i|N,k|M} = \begin{cases} V_t^{i|N} * \dfrac{b_t^{i|N,k|M}}{\sum_{k=1}^{d} b_t^{i|N,k|M}}, & \text{if } b_t^{i|N,k|M} > 0 \\ & \text{and } V_t^{i|N} > 0, \\ 0, & \text{otherwise}, \end{cases} \quad (9)$$

where $V_t^{i|N}$ represents the owner's equity of shadow bank i, $b_t^{i|N,k|M}$ is the loan amount of commercial bank k to shadow bank i, and $\sum_{k=1}^{d} b_t^{i|N,k|M}$ is the total amount of shadow bank i borrowed from no more than d commercial banks. d is the number of commercial banks that is borrowed by shadow bank i. Then, the shadow bank i's debts update to 0, and it becomes a member of bankrupt set D.

2.4. Dynamic Process Algorithm of Interbank Network System with Shadow Banking. In the interbank network system with shadow banking, banks conduct interbank lending when their liquidity is insufficient, including interbank lending among commercial banks and business relationship between commercial banks and shadow banks. The dynamic process algorithm of the interbank network with shadow banking is shown in Figure 2, which is divided into the following 4 steps:

Step 1: at time $t = 1$, the initial real economy S^n is set to S^1, and the initial calculation of the initial deposit of the commercial banks, the initial financing of the shadow bank, and each parameter and variable is, respectively, performed.

Step 2: the real economy S^n is determined and the asset liquidity L_t of each bank at time t is calculated. According to the number of default banks at time t-1, the bank default rate is calculated to determine the real economy S^n in time t, and the value of relevant parameters is determined by S^n. Then, the liquidity of the survival bank at time t is calculated, the banks with sufficient liquidity ($L_t > 0$) carry out dividend distribution D_t and reinvestment I_t, and the banks that lack liquidity ($L_t \leq 0$) enter into Step 3 and start interbank lending.

Step 3: according to the liquidity of each bank in Step 2, the bank with liquidity $L_t > 0$ is the creditor bank and the bank with liquidity $L_t \leq 0$ is the debt bank. The debt bank and the creditor bank establish a connection through a random network and conduct interbank lending according to the liquidity of the banks. If the debt bank j can borrow sufficient funds from the creditor banks to repay the previous loan and interest, i.e., $L_t^j - (1 + r_b)B_{t-1}^j \geq 0$ (r_b is the interbank lending rate), bank j enters the next time step; if the debt bank j cannot borrow sufficient funds to repay the previous loan and interest, i.e., $L_t^j - (1 + r_b)B_{t-1}^j < 0$, the debt bank j becomes a member of defaulted set F and gets into Step 4.

Step 4: the insolvent default debt bank is bailed out or cleared. If the default bank j is a shadow bank, it will partially repay the debt according to its owner's equity and then get into the bankruptcy set D; if the default bank j is a commercial bank, the central bank will aid it to make its liquidity meet the legal deposit reserve. The debts of banks, which are bailed out or cleared, update to 0 ($B_t^j = 0$).

3. Simulation and Analysis

The interbank network system with shadow banking constructed in this paper can simulate the real dynamic evolutionary process of the interbank network system. The bank's balance sheet is dynamically evolved, such as liquidity L, owner's equity V, deposit A, and investment I. Related indicators will change dynamically over time t. By observing the dynamic evolution process of the interbank network system, the impact of shadow banking on the systemic risk is studied. Due to the heterogeneity of banks, banks in the interbank network will be exposed to risks owing to different operating conditions and business strategies, resulting in a series of, and even large-scale, chain failure. The systemic risk of the interbank network is not only affected by the banks' own factors (internal factors) but also by shadow banking (external factors). To objectively reflect the effect of shadow banking on the banking system and measure the systemic risk of the banking network, the average number of default banks in the $[t+1, t+T]$ time zone was normalized, and the calculated value was recorded as $Risk(t)$. It is calculated as follows:

$$\text{Risk}(t) = \frac{1}{TR_e} \sum_{i=1}^{R_e} \sum_{j=t+1}^{t+T} \frac{C_j^i}{S_j^i}, \quad (10)$$

where the T is the time interval, and the average proportion of default banks in the future T time (that is, the average probability of default banks) can indicate the systemic risk of the system at a certain moment. This paper sets $T = 10$. R_e is the time number of the simulation, C_j^i is the number of banks that default at time j in the ith simulation, and S_j^i is the number of banks that survived at time j in the ith simulation.

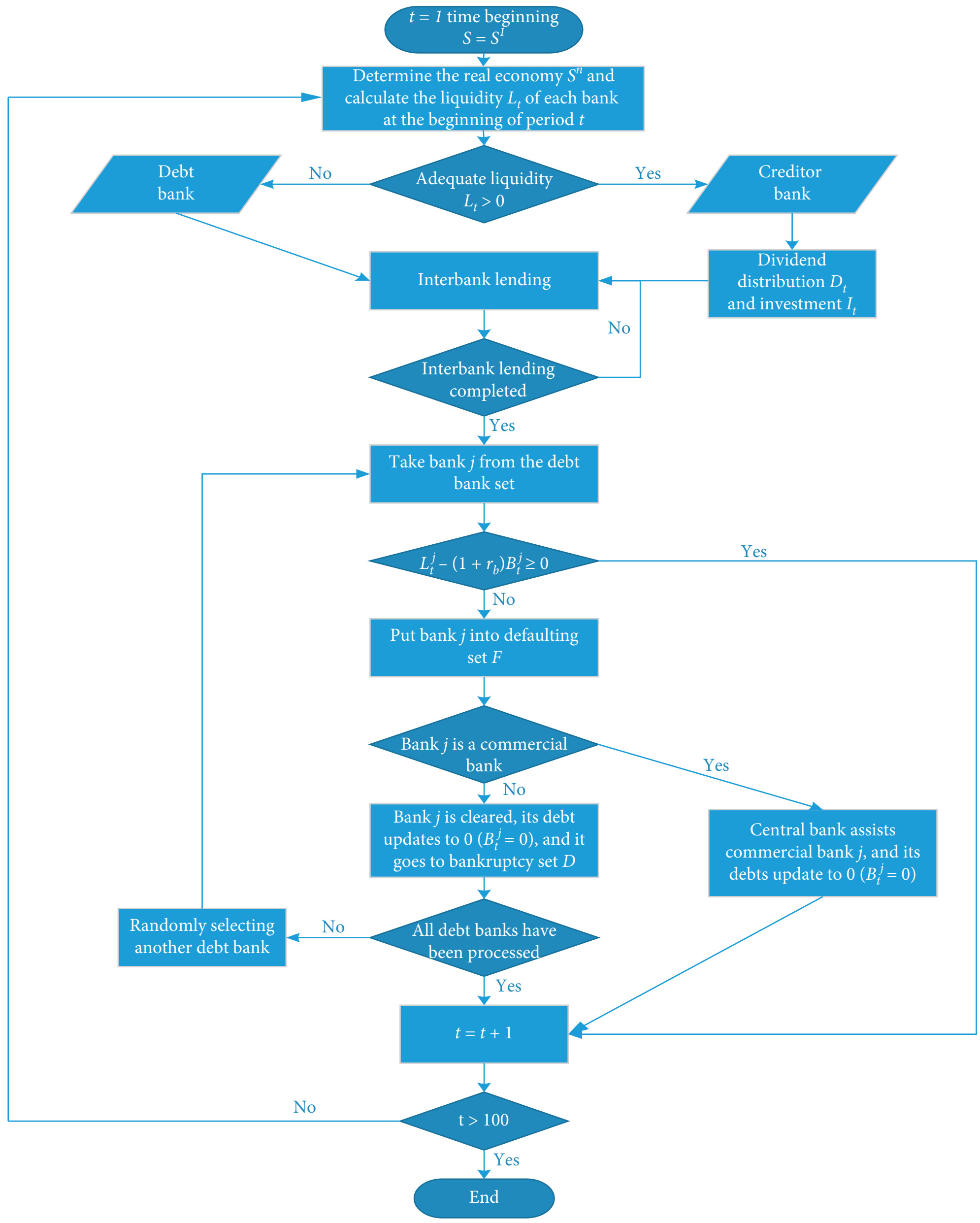

Figure 2: Dynamic process algorithm of the interbank system with shadow banking.

400 banks were selected as research objects (sufficient to reflect the characteristics of the banking network system), including 100 commercial banks (M=100) and 300 shadow banks (N=300), and the maximum simulation time step was set to $t = 100$ (the simulated 100-step system has approached stability).

3.1. The Impact of Shadow Banking on the Systemic Risk. Figure 3 plots the systemic risk of the interbank network with the existence of shadow banking and no shadow banking over time. It can be seen from Figure 3 that in any case, the systemic risk exists from the beginning of the simulation, which is related to the heterogeneity of the banks. Different banks have different operating activities, which lead to the initial risk of the banking system. It is further found that although there is a systemic risk in the banking system with no shadow banking, its value fluctuates only within a small range close to 0 and is relatively stable. However, the systemic risk of the system with shadow banking has been relatively high and fluctuating, which indicates that shadow banking is affected by the high-risk characteristics of its own business activities, which will bring significant systemic risk impact to the banking system. With the extension of time steps, the systemic risk has shown a downward trend. This may be due to the bankruptcy of the shadow bank, which caused the termination of the interbank lending between the shadow bank and the commercial bank. At the same time, the banking system can self-regulate digestive risks, which is also an important reason to resist

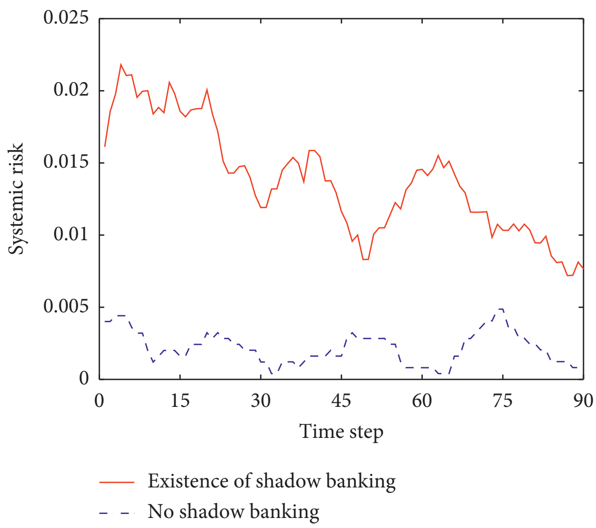

FIGURE 3: The impact of the existence of shadow banking on the systemic risk (the parameters are set as follows: $r_a = 0.0035$, $r_b = 0.023$, $\beta = 0.15$, $\chi = 0.3$, $\sigma_A = 0.3$, $\sigma_\omega = 0.03$, $c = 0.03$, $\overline{A} = 1000$, $\overline{\omega} = \overline{I} = 500$, $\rho = 0.045$, $\tau = 3$, $d = 3$, $R_o^{s^1} = 0.07$, $R_o^{s^2} = 0.03$, $R_o^{s^3} = 0.01$, $p_1 = 0.95$, $p_2 = 0.5$, $p_3 = 0.3$, $U = 400$, $M = 400$, and $N = 0$ for the case of no shadow banking and $M = 100$ and $N = 300$ for the case of existence of shadow banking).

external shock and maintain the stability of the banking system.

3.2. The Impact of Shadow Banking on the Cumulative Number of Default Banks, Bank Survival Rate, Ratio of Bank Default Rate to Commercial Bank Survival Rate, and the Amount of Central Bank Assistance in the Banking System . To effectively describe the specific performance of the impact of the existence of shadow banking on the systemic risk of banks, we calculated the cumulative number of default banks, bank survival rate, ratio of bank default rate to commercial bank survival rate, and the amount of central bank assistance in the banking system through simulation. Figure 4(a) shows the impact of the existence of shadow banking on the cumulative number of default banks in the system. It can be found that the cumulative number of default banks in the banking system with shadow banking is significantly higher than that of the banking system with no shadow banking, and the difference between the two is multiplied as the time step is extended. When the time step reaches 100, the cumulative number of default banks in the banking system with no shadow banking is stable at 6, while that in the banking system with shadow banking is as high as 20. The existence of shadow banking can significantly increase the number of default banks within the system. The emergence of default banks under the existence of shadow banking is mainly due to the decline in liquidity of the system caused by the interbank lending between shadow banks and commercial banks. Table 1 shows the liquidity of the system under the existence of shadow banking and no shadow banking at evolutionary time. Under the influence of business activities such as investment, the existence of shadow banking aggravates the interbank lending between shadow banks and commercial banks, resulting in a significant decline in the liquidity of the system. Debt banks cannot repay their debts on time, resulting in an increase in the number of default banks.

Figure 4(b) shows the impact of the existence of shadow banking on changes in bank survival ratio in the system. It can be seen that the bank survival ratio in the banking system with no shadow banking decreased with the extension of the time step, but the decline was relatively small, and the fluctuation was stable and finally stayed at around 0.92. This shows that the banking system with no shadow banking is generally stable. However, the bank survival ratio in the banking system with shadow banking has shown a notable decline from the beginning. As the time step is extended, the rate of decline has not slowed down, and there is still a significant downward trend until 100 steps. It shows that the existence of shadow banking significantly reduces the number of surviving banks in the system, undermines the stability of the banking system, has a big shock on the banking system, and increases the possibility of inducing systemic risk in the banking system. The condition of commercial banks in the banking system can directly reflect the stability of the banking system, and it is meaningful to calculate the ratio of the bank default rate to the survival rate of commercial banks. Figure 4(c) depicts the impact of the existence of shadow banking on the ratio of bank default rate to commercial bank survival rate. With the introduction of shadow banking, the contagion risk induced by shadow banking results in the decline of commercial bank survival ratio and the increase of bank default rate; the ratio of default rate to commercial bank survival rate is significantly higher than that in the case with no shadow banking, and ultimately, the stability of the banking system is damaged. Figure 4(d) shows the impact of the existence of shadow banking on the change in the amount of central bank assistance. The central bank assistance to commercial banks can be clearly observed from about 60 steps as shown in the figure. The existence of shadow banking has significantly aggravated the central bank assistance to commercial banks. This once again emphasizes the interbank lending between shadow banks and commercial banks will greatly reduce the liquidity of the system (as shown in Table 1). The bankruptcy of the shadow banks will cause commercial banks to fall into a liquidity dilemma because they cannot recover the loan funds on time. Eventually, commercial banks closed down. The ability of the system to withstand risks is reduced, causing systemic risk.

3.3. The Impact of Changes in Correlation Indicators between Shadow Banks and Commercial Banks on Systemic Risk of Banks. In the case of a finite number of banks in the system, that is, $U = 400$, the combination of the number of shadow banks and commercial banks will affect the scope of the lending between them, and the liquidity of the system will change and thus affect the systemic risk. Figure 5 shows the systemic risk curve under the number combination of three

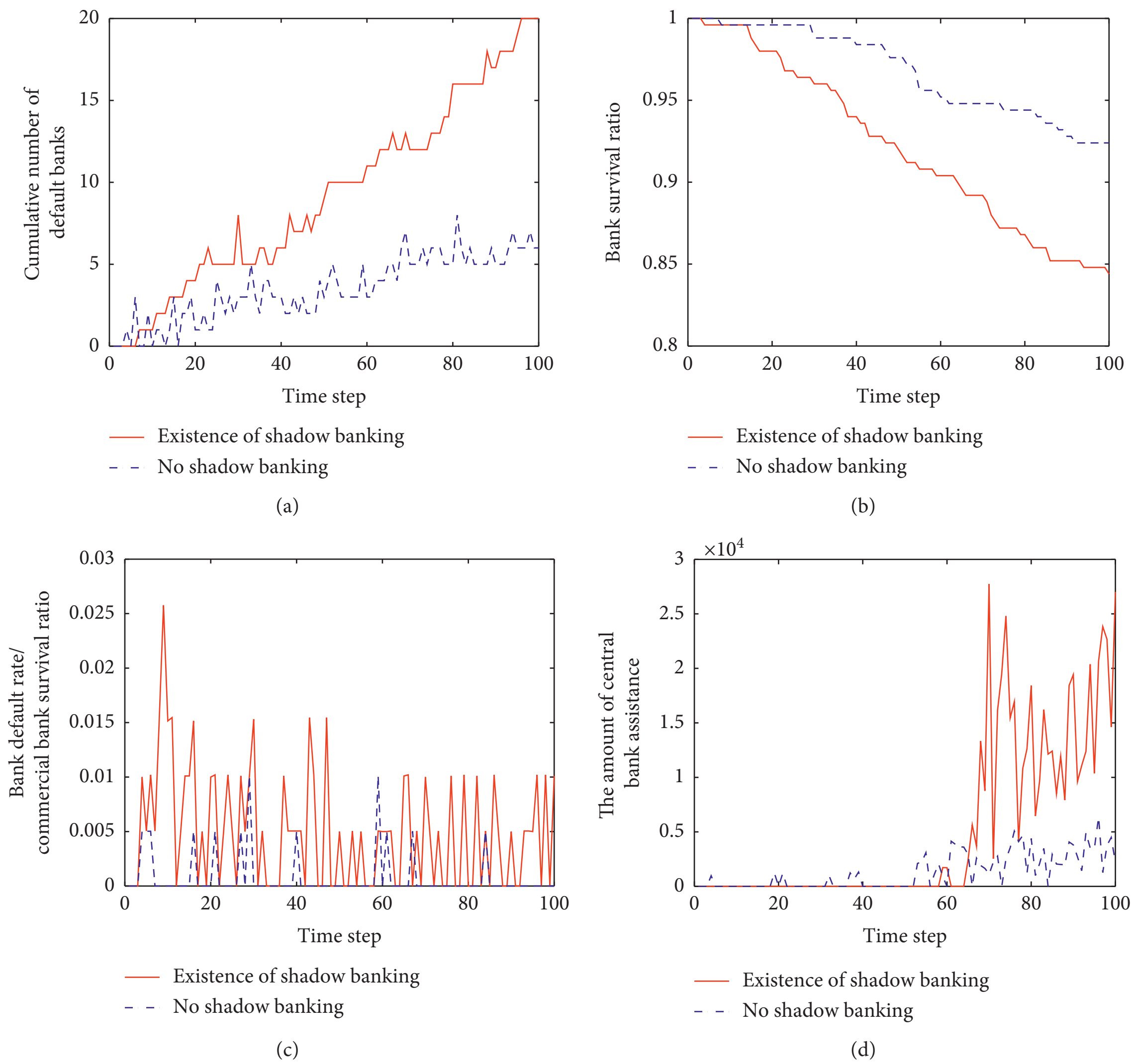

Figure 4: (a) The impact of the existence of shadow banking on the cumulative number of default banks in the banking system. (b) The impact of the existence of shadow banking on changes in bank survival ratio in the banking system. (c) The impact of the existence of shadow banking on the ratio of bank default rate to commercial bank survival rate. (d) The impact of the existence of shadow banking on the changes in the amount of central bank assistance (the parameter settings are the same as in Figure 3).

Table 1: The liquidity of the system under the existence of shadow banking and no shadow banking at evolutionary time.

	Time step			
	20	40	60	80
Existence of shadow banking	70319.3	74651.0	73180.7	72943.4
No shadow banking	73994.4	72397.3	75185.8	81082.3

types of shadow banks and commercial banks (M: N=100 : 300, M: $N=200:200$, and M: $N=300:100$). It can be seen that as the number of shadow banks in the system decreases from 300 to 100 and the number of commercial banks increases from 100 to 300, the systemic risk gradually decreases and tends to be stable, and the possibility of bank default in the system is also reduced. It shows that the more the number of shadow banks in the banking system compared to the number of commercial banks, the greater the risk impact of the system. The high number of shadow banks will reduce the maintenance role of the regulatory authorities and the central bank on the stability of the banking system, bring a large and uncertain risk impact to the banking system, weaken the ability of the banking system to deal with risks, and accelerate bank failure.

Iori et al. [12] and Georg [18] studied traditional banking network systems and pointed out that the higher the credit connection between banks, the lower the systemic risk. To further examine the impact of shadow banking on the systemic risk, Figure 6 plots the systemic risk changes under different credit connections (c=0.01, $c=0.03$, and $c=0.05$) between shadow banks and commercial banks. The result is similar to the traditional view. Under the structure of the interbank network with shadow banking, the higher the credit connection between shadow banks and commercial banks, the lower and more stable the systemic risk. This

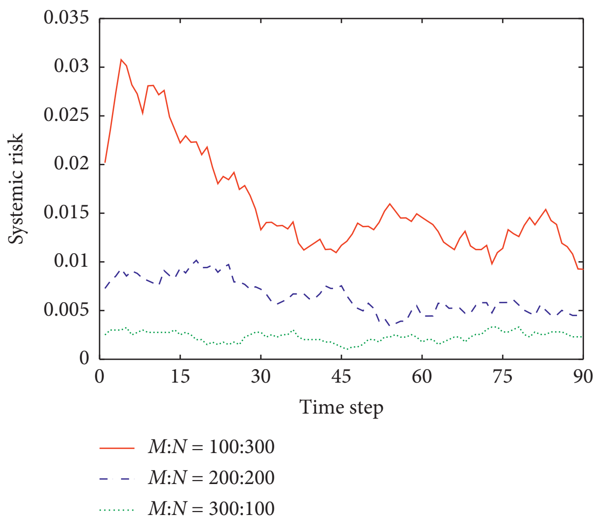

Figure 5: The impact of the change in the number combination between the shadow banks and the commercial banks on the systemic risk curve (the parameter setting is the same as in Figure 3 except for M and N).

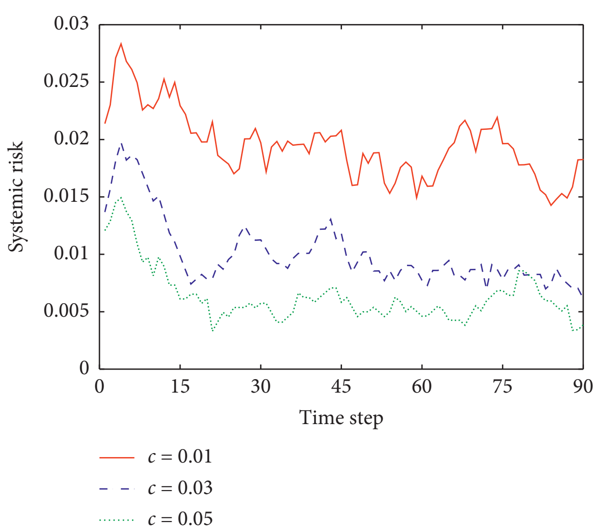

Figure 6: The impact of changes in credit connection between shadow banks and commercial banks on systemic risk curves (the parameter setting is the same as in Figure 3 except $M = 100$, $N = 300$, and c).

illustrates that with the increase of the credit connection between shadow banks and commercial banks, the possibility of interbank lending between shadow banking and commercial banks is increased. The existence of shadow banking shares part of the systemic risk, improves the stability of the banking system, and reduces the possibility of bankruptcy.

4. Conclusions

The growth of shadow banking has led to fundamental changes in the global financial architecture. As an important part of the contemporary complex financial system, shadow banking is considered to be one of the important reasons for causing systemic risk. In order to better explain the effect of shadow banking on systemic risk, a dynamic complex interbank network model with shadow banking is constructed in this paper. Based on the traditional banking network model, the model used the relationship between shadow banks and commercial banks to form a banking system network and analyzed the impact of shadow banking on the systemic risk. In addition, the banks' balance sheet and the interbank lending network are dynamically evolved in this model, which is closer to real bank operations and depicts the specific impact of shadow banking on systemic risk from a microlevel. Through numerical simulation, we have obtained a series of conclusions as follows:

(i) Compared with the traditional banking network system, the existence of shadow banking does affect the systemic risk.

(ii) The existence of shadow banking will have an impact on the stability of the banking system, resulting in an increase in the number of default banks in the system, a decline in bank survival rates, and an increase in the number of central bank assistance. The liquidity of funds within the system is reduced, which increases the occurrence of systemic risk.

(iii) When the number of shadow banks is greater than the number of commercial banks, the systemic risk will be enormous. However, higher credit connection between shadow banks and commercial banks will reduce the systemic risk.

The aforementioned conclusions not only have practical significance for quantitative research on the systemic risk but also have important reference value for preventing financial risks. In addition, the definition of shadow banking is different and the banking system is relatively complex. Therefore, there are still many problems that can be discussed in future work, for example, government policy interference factors under macroeconomic conditions should be considered [35], a more in-depth network structure of interbank lending [36](not only random network) should be constructed, and the real-world interbank lending network should be estimated by using real data.

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 that they have no conflicts of interest.

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References

[1] Y. Jin and Z. Zeng, "Banking risk and macroeconomic fluctuations," *Journal of Banking & Finance*, vol. 48, pp. 350–360, 2014.

[2] S. Poledna, J. L. Molina-Borboa, S. Martínez-Jaramillo, M. van der Leij, and S. Thurner, "The multi-layer network nature of systemic risk and its implications for the costs of financial crises," *Journal of Financial Stability*, vol. 20, pp. 70–81, 2015.

[3] A. R. Neveu, "A survey of network-based analysis and systemic risk measurement," *Journal of Economic Interaction and Coordination*, vol. 1, pp. 1–41, 2016.

[4] M. Pollak and Y. Guan, "Partially overlapping ownership and contagion in financial networks," *Complexity*, vol. 2017, Article ID 9895632, 16 pages, 2017.

[5] W. Silva, H. Kimura, and V. A. Sobreiro, "An analysis of the literature on systemic financial risk: a survey," *Journal of Financial Stability*, vol. 28, pp. 91–114, 2016.

[6] M. Kanno, "Assessing systemic risk using interbank exposures in the global banking system," *Journal of Financial Stability*, vol. 20, pp. 105–130, 2015.

[7] T. Schuler and L. Corrado, "Interbank market failure and macro-prudential policies," *Journal of Financial Stability*, vol. 33, pp. 133–149, 2016.

[8] F. Castiglionesi, "Financial contagion and the role of the central bank," *Journal of Banking & Finance*, vol. 31, no. 1, pp. 81–101, 2007.

[9] A. Hasman and M. Samartín, "Information acquisition and financial contagion," *Journal of Banking & Finance*, vol. 32, no. 10, pp. 2136–2147, 2008.

[10] G. G. Kaufman and K. E. Scott, "What is systemic risk, and do bank regulators retard or contribute to it?" *Independent Review*, vol. 7, no. 3, pp. 371–391, 2003.

[11] F. Allen and D. Gale, "Financial contagion," *Journal of Political Economy*, vol. 108, no. 1, pp. 1–33, 2000.

[12] 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.

[13] 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.

[14] 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.

[15] F. Caccioli, T. A. Catanach, and J. D. Farmer, "Heterogeneity, correlations and financial contagion," *Advances in Complex Systems*, vol. 15, Article ID 1250058, 2012.

[16] C. J. Godlewski, B. Sanditov, and T. Burger-Helmchen, "Bank lending networks, experience, reputation, and borrowing costs: empirical evidence from the French syndicated lending market," *Journal of Business Finance and Accounting*, vol. 39, no. 1-2, pp. 113–140, 2012.

[17] C. P. Georg and J. Poschmann, *Systemic Risk in a Network Model of Interbank Markets with Central Bank Activity*, Jena Economic Research Papers, 2010.

[18] 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.

[19] T. Lux, "Emergence of a core-periphery structure in a simple dynamic model of the interbank market," *Journal of Economic Dynamics and Control*, vol. 52, pp. A11–A23, 2015.

[20] S. Berardi and G. Tedeschi, "From banks' strategies to financial (in)stability," *International Review of Economics & Finance*, vol. 47, pp. 255–272, 2017.

[21] J. H. F. Page and M. Wooders, "Networks and Stability," in *Computational Complexity*, R. Meyers, Ed., pp. 6024–6048, Springer, New York, NY, USA, 2012.

[22] Financial Stability Board, *Global Shadow Banking Monitoring Report 2015*, Financial Stability Board, Basel, Switzerland, 2015.

[23] Z. Pozsar, T. Adrian, A. Ashcraft et al., *Shadow Banking Federal Reserve Bank of New York*, Staff Reports, vol. 105, no. 458, pp. 447–457, New York, NY, USA, 2010.

[24] P. Tucker, "Shadow banking, financing markets and financial stability," in *Proceedings of the Remarks at a Bernie Gerald Cantor Partners Seminar*, vol. 21, Oxford University Press, London, UK, January 2010.

[25] B. S. Bernanke, C. C Bertaut, L. Demarco et al., "International capital flows and the returns to safe assets in the United States, 2003–2007," *FRB International Finance Discussion Paper*, vol. 1014, 2011.

[26] D. W. Diamond, "Financial intermediation and delegated monitoring," *The Review of Economic Studies*, vol. 51, no. 3, pp. 393–414, 1984.

[27] N. Gennaioli, A. Shleifer, and R. W. Vishny, "A model of shadow banking," *The Journal of Finance*, vol. 68, no. 4, pp. 1331–1363, 2013.

[28] C. Elgin and O. Oztunali, "Shadow economies around the world: model based. estimates," *Bogazici University Department of Economics working Papers*, vol. 5, no. 2012, pp. 1–48, 2012.

[29] E. Colombo, L. Onnis, and P. Tirelli, "Shadow economies at times of banking crises: empirics and theory," *Journal of Banking & Finance*, vol. 62, no. 9, pp. 180–190, 2016.

[30] T. V. Dang, G. Gorton, and B. Holmstrom, *Opacity and the Optimality of Debt for Liquidity Provision*, Manuscript Yale University, New Haven, CT, USA, 2009.

[31] R. Gong and F. H. Page, "Shadow banks and systemic risks," *SSRN Electronic Journal*, 2015.

[32] J. M. Juran, "Pareto, lorenz, Bernoulli, juran and others," *Industrial Quality Control*, vol. 25, no. 10, 1960.

[33] F. Basile, "Great management ideas can work for you," *Indianapolis Business Journal*, vol. 16, no. 1, pp. 53-54, 1996.

[34] L. Eisenberg and T. H. Noe, "Systemic risk in financial systems," *Management Science*, vol. 47, no. 2, pp. 236–249, 2001.

[35] A. R. Admati, P. M. DeMarzo, M. F. Hellwig, and P. Pfleiderer, "The leverage ratchet effect," *The Journal of Finance*, vol. 73, no. 1, pp. 145–198, 2018.

[36] S. Gabrieli, "The microstructure of the money market before and after the financial crisis: a network perspective," *SSRN Electronic Journal*, vol. 9, no. 181, 2011.