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Guarantee network model and risk contagion

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ABSTRACT

In this paper, we construct a dynamic guarantee network model. Based on the constructed model, the dynamic evolution of risk contagion is researched by means of simulation methods. The risk contagion research is carried out from three aspects:guarantee mechanism, partner selection mechanism, and production parameter. The research shows that: (1) Firm size distribution takes on a power-law tail. (2) Guarantee network provides a channel for risk contagion and aggravates risk contagion among firms. (3) The type of partner selection mechanism has an impact on risk contagion. Risk cognation in the net worth mechanism is more serious in comparison to the random mechanism. (4) Risk contagion among firms is the increasing function of the production parameter φ.

1. Introduction

With the continuous development of the economy, correlations among economic subjects are increasing in proximity, numbers, and complexity. Some economic subjects' defaults may result in the defaults of other economic subjects through direct or indirect financial correlations among them. This phenomenon is termed as domino effect or risk contagion. Due to the serious effects of the recent financial crisis, many scholars have begun to study financial risk contagion from different aspects. For example, Rodriguez [1], Wen et al. [2] and Han et al. [3] use the copula approach to measure financial contagion, while Syllignakis and Kouretas [4] apply a dynamic correlation model to research financial contagion in the Central and Eastern European markets. Furthermore, Pais and Stork [5] use extreme value theory to measure contagion risks, while Upper [6] assesses the danger of contagion in interbank markets based on counterfactual simulations. Asgharian and Nossman [7] develop a stochastic volatility model with jumps in returns and volatility to analyze the risk spillover. Chen et al. [8] establish an entropy spatial model of credit risk contagion in the credit risk transfer market. Gallegati [9] and Ranta [10] use a wavelet-based approach to test financial market contagion. Moreover, a strand of meaningful research is worthy of being mentioned. The negative effect resulting from some agents' defaults spread in a way similar to the spread of infectious diseases through the social network. Therefore, the category of research on dynamics of infectious diseases transmission [11–15] provides some references for the study of financial risk contagion and research in this aspect is emerging [16,17].

With the continuous development of network theory, it is often used as a tool for studying complex phenomena. Due to the complexity of risk contagion and higher correlations among subjects, the network is also logically used in the study of financial risks. Economic subjects and financial correlations among them form financial correlation networks, such as credit networks, guarantee networks, and equity networks. Essentially, the financial crisis has also shown that financial correlation networks provide channels for risk contagion, and the network formed by economic subjects and financial links has to be taken into account when researching risk cognation [18]. Considering this, there is a growing number of literatures that research financial risk contagion from network perspective in recent years [19–23]. Due to the widespread existence of credit correlations, the credit network attracts scholars' attention. Gatti et al. [24] construct a model using credit links connecting (a) downstream and upstream firms and (b) firms and banks, and identify that a bankruptcy avalanche may occur when a shock hits a significant group of agents in a credit network. Lenzu and Tedeschi [19] research systemic risk on different network topologies and the research shows a higher vulnerability of the power-law network in comparison to the random one. Georg [25] establishes an interbank credit network model with a central bank and identifies that money-center networks are more stable in comparison to random networks by means of simulation methods. Thurner and Poledna [26] show that the network structure has an impact on cascade sizes of defaulting banks and higher connectivity refers to larger cascades. Catullo et al. [27] point out the

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extent of risk contagion is related to the network structure and agent's leverage ratio. Li and Sui [28] research risk contagion in endogenous credit networks. Catullo et al. [29] establish an agent-based model reproducing an artificial credit network that evolves endogenously, and research early warning indicators for crises. It is obvious that increasing research on risk contagion based on credit networks is emerging. However, we can identify that research on guarantee correlations connected closely to credit correlations is limited. In practice, firms are usually required to provide a guarantee when they want to obtain credit from banks for the purpose of risk control. After considering the guarantee mechanism, the shock resulting from certain firms' defaults is transmitted to the corresponding banks through credit links on one hand, and leads to a shock to firms that provide guarantees to these defaulted firms through guarantee links on the other hand. If these affected firms (guarantors) cannot afford the transmitted shock, they default too. The stated process is repeated until the shock is absorbed by the networks. The guarantee network provides another channel for risk contagion. Moreover, Zhang et al. [30] and Xu and Zhou [31] show that guarantee links indeed provide channels for risk contagion. Another strand of research by Milgo [32] and Flatnes et al. [33] considers the joint liability lending mechanism. In such a joint liability lending mechanism, group members guarantee each other. Some members' defaults may be involuntary due to other members' defaults, and this shows the existence of risk contagion. However, from existing research, we can observe that research on risk contagion related to the guarantee network is not sufficient. It is necessary to research the impact of the guarantee network on risk contagion. Considering this, this paper researches the establishment of the guarantee network model and then analyzes the dynamic evolution of risk contagion.

The contributions of this paper are the following. We first construct a dynamic guarantee network model. We then research firm size distribution by means of simulation methods. We also research the impacts of the guarantee mechanism and partner selection mechanism on risk contagion among firms. We finally research the impact of firm behavior parameter φ on risk contagion among firms. This paper supplements existing research on risk contagion based on credit networks.

The remainder of this paper is organized as follows. In Section 2, a dynamic guarantee network model is established. In Section 3, we present simulation results. Section 4 concludes the paper and offers suggestions for future research.

2. The model

In this paper, we model an artificial firm system with the guarantee mechanism populated by N firms. Each firm is indexed by i, $\hat{i}$, or i' ($i, \hat{i}, i' = 1, 2, \cdots, N$). A firm's production behavior follows the model described in Gatti et al. (2010). Firms organize production and investment in each simulation step. When there are financing gaps, they request the bank market for liquidity. In order to reduce credit risk, the bank requires firm i to provide the corresponding amount of guarantee for its bank borrowing. In practice, there are several types of guarantee modes. For the purpose of researching risk contagion from the network perspective, the guarantee in this paper is defined as an agreement pursuant to which a guarantor and a creditor (the bank) agree that the guarantor shall perform the obligation or bear the liability according to the agreement, when the debtor fails to perform the corresponding obligation. In this case, when firm i defaults, in addition to the default, its guarantors' net worth is eroded. This situation may lead to a new round of firm bankruptcies. In the following section, we construct a model to research the stated risk contagion resulting from the guarantee mechanism.

2.1. Behavior description

In each simulation step, firm i determines its financially constrained output expressed as follows: $Y_{it} = \varphi A_{it}^{\beta}$, where $\varphi > 1$, $0 < \beta < 1$, and A_{it} is the net worth [24]. Following Gatti et al. (2010), firm i produces goods using labor as the only input and the Leontief production function is adopted as follows: $Y_{it} = N_{it}/\delta$, where N_{it} represents the amount of labor and $\delta > 0$. Therefore, the amount of labor corresponding to the financially constrained output can be written as follows: $N_{it} = \delta Y_{it} = \delta\varphi A_{it}^{\beta}$.

At time t, firm i makes a new investment given as follows: $I_{it} = \left|\hat{I}_{it} + \sigma_1\eta_t\right|$, where $\hat{I}_{it} \sim \left|\mathrm{N}(\mu_f, \sigma_f)\right|$ and $\eta_t \sim N(0,\ 1)$ [34]. The new investment continues for τ periods and will obtain a random return $\rho_{it+\tau}$ ($\rho_{it+\tau} \sim \mathrm{N}(\bar{\mu}_f, \bar{\sigma}_f)$) after τ periods [26].

Firm i organizes the production and makes investments. When firm i experiences financing gaps, it requests the bank for liquidity. Firm i measures the financing gap (FG_{it}) according to the following formula:

$$FG_{it} = wN_{it} + \sum_{s=1}^{n-1} B_{it-s}r + B_{it-(n-1)} + I_{it+1} + I_{a[\tilde{L}_{it}]}\tilde{L}_{it} - \hat{\mu}_{it}Y_{it} - I_{it-(\tau-1)}\left(1+\hat{\rho}\right) - (1 + I_{a[\tilde{L}_{it}]})\tilde{L}_{it} \tag{1}$$

where w refers to the price of labor; B_{it} denotes firm i's bank borrowing lasting for n periods at time t; r is the corresponding interest rate charged by the bank; $\tilde{L}_{it}$ represents firm i's intra-period cash; $I_{a[\bullet]}$ is the indicative function, and when $\tilde{L}_{it} < 0$, $I_{a[\bullet]} = -1$, otherwise, $I_{a[\bullet]} = 0$; $\hat{\rho}$ is the expected investment return; $\hat{\mu}_{it}$ refers to the expected price of the final good, which is equal to the average of historical prices.

When $FG_{it} > 0$, firm i borrows money from the bank market, and the bank borrowing B_{it} equals FG_{it}. In this case, for the purpose of reducing the bad debt ratio, the bank requires firm i to provide a corresponding guarantee for bank borrowing B_{it} and the amount of the guarantee should cover the bank borrowing B_{it}. Therefore, firm i attempts to obtain the guarantee from other firms. Firm i first requests for a guarantee from firms that it supplies the guarantee to. In this situation, when there is more than one firm, firm i first selects the firm that obtains the largest amount of guarantee. If firm i cannot obtain sufficient guarantees from the firms stated above, it randomly chooses another firm to seek the remaining amount of guarantee until its demand for guarantees is totally satisfied or there are no more firms that can supply the extra amount of guarantee. To avoid heavy concentrated risk, firm $\hat{i}$ can only supply a limited amount of guarantee which is proportional to its net worth, given by the following equation:

$$G_{\hat{i}t}^{max} = \varpi A_{\hat{i}t} - \sum_{s=1}^{n-1} \sum_{i \in \tilde{\Phi}_{\hat{i}t-s}^{c}} C_{i\hat{i}}^{B_{it-s}}$$

where ϖ is the amplification factor of the guarantee; $\tilde{\Phi}_{\hat{i}t}^{c}$ denotes the set of firms obtaining the guarantee from firm $\hat{i}$ at time t; and $C_{i\hat{i}}^{B_{it}}$ refers to the guarantee obtained by firm i from firm $\hat{i}$ for the bank borrowing B_{it}. Suppose $R_{\hat{i}t}^{eq}$ represent the guarantee requests received by firm $\hat{i}$, which can be expressed as follows:

$$R_{\hat{i}t}^{eq} = \sum_{i \in \hat{\Phi}_{\hat{i}t}^{c}} \bar{C}_{i\hat{i}}^{B_{it}} \tag{2}$$

where $\hat{\Phi}_{\hat{i}t}^{c}$ refers to the set of firms who send guarantee requests to firm $\hat{i}$ at time t; $\bar{C}_{i\hat{i}}^{B_{it}}$ denotes the guarantee request sent by firm i to firm $\hat{i}$ for the bank borrowing B_{it}. When $G_{\hat{i}t}^{\max}$ is sufficiently large ($G_{\hat{i}t}^{\max} \geq R_{\hat{i}t}^{eq}$), all firms that seek guarantees from firm $\hat{i}$ will obtain sufficient guarantees. If it is not true, then firm $\hat{i}$ satisfies firms'