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Contagion risk in endogenous financial networks

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ABSTRACT

In this paper, we investigate contagion risk in an endogenous financial network, which is characterized by credit relationships connecting downstream and upstream firms, interbank credit relationships and credit relationships connecting firms and banks. The findings suggest that: increasing the number of potential lenders randomly selected can lead to an increase in the number of bank bankruptcies, while the number of firm bankruptcies presents a trend of increase after the decrease; after the intensity of choice parameter rises beyond a threshold, the number of bankruptcies in three sectors (downstream firms, upstream firms and banks) shows a relatively large margin of increase, and keeps at a relatively high level; there exists different trends for bankruptcies in different sectors with the change of the parameter of credits' interest rates.

1. Introduction

Modern financial systems show a complex network structure: banks can conduct credit lending with other banks, firms can be linked with other firms to buy or sell products, and firms can also connect with banks through bank loans. Before the recent financial crisis, the financial network structure is mentioned only infrequently. However, it has now caught the attention of both academics [36] and policy makers [37]. The importance of studying the financial network structure stems from that it can serve as a channel for propagation and amplification of shocks, and has been directly linked to the stability of financial systems.

There is a growing literature on contagion risk in interbank networks. The seminal papers of Allen and Gale [2] and Freixas et al. [14] develop some of the first formal models of contagion risk in interbank networks. The recent financial crisis results in further attention to this line of work. There are many significant studies in this area, such as Nier et al. [30], May and Arinaminpathy [28], Gai et al. [16], Lenzua and Tedeschi [25], Mastromatteo et al. [27], Chen et al. [9], Georg [18], Sachs [34], Chen et al. [10] and González-Avella et al. [20], etc. However, most of the above researches take the interbank network as an exogenous structure. Recently, there are many studies on endogenous networks of banking systems. For instance, Halaj and Kok [21] present the model of network formation under optimizing bank behavior; Bluhm et al. [6] develop a network model whose links are governed by banks' optimizing decisions and by an endogenous tâtonnement market adjustment; Keiserman [24] proposes a simple model in which financial linkages arise endogenously across optimizing banks; Aymanns and Georg [3] model a simple financial system in which banks decide their investment strategy based on a private belief about the state of the world and a social belief formed from observing the actions of peers.

In order to understand the fragility of our economy, scholars have studied the contagion effect among firms from both the aggregate and firm-level perspectives [1,15,22,31]. Some empirical studies show that there is contagion risk among firms [15,22]. In addition, there are many literature studying inter-firm contagion risk from the perspective of network methods. For example, Boissay [7] analyzes how shocks propagate through a trade credit network of firms; Barro and Basso [4] analyze credit contagion in a network of firms with spatial interaction; Gao [17] suggests that inter-firm networks can make firms more resilient to negative shocks, alleviating the total impact of shocks to the economic system; Basole and Bellamy [5] examine the impact of global supply network structure on risk diffusion and supply network health and demonstrate the importance of supply network visibility; Ramírez [32] develops a dynamic model to study how changes in the propagation of idiosyncratic shocks within a inter-firm network affect aggregate output and consumption growth; Golo et al. [19] use Italian firms' trade credit network to test a model of many-to-one contagion of economic growth or economic crisis.

The above studies focus on analyzing interbank contagion risk and inter-firm contagion risk. However, bank-firm credit relation-

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ships can result in contagion risk between banks and firms. Delli Gatti et al. [12] model a network economy with an inside credit (commercial credit) between firms of different productive sectors, and an outside credit (bank credit), and investigate the correlation of bankruptcies among three sectors: downstream firms, upstream firms, and banks. Delli Gatti et al. [11,13] develop a three-sector network economy characterized by credit relationships connecting downstream and upstream firms and credit relationships connecting firms and banks, and focus on the emergence of bankruptcy crises. Miranda and Tabak [29] model a network of firm-bank and bank-bank interrelationships using a unique dataset for the Brazilian economy, and find that distress originating from firms can be propagated through the interbank network. Riccetti et al. [33] build on the network-based financial accelerator model of Delli Gatti et al. [13], and find that if leverage increases, the economy is riskier, with a higher volatility of aggregate production and an increase of firm and bank defaults. Catullo et al. [8] construct an agent based model reproducing an artificial credit network populated by heterogeneous firms and banks, and show that high leverage raises firm default risk and high connectivity may diffuse easily the negative effects of firm and bank failures amplifying the effects of local shocks.

Studying contagion risk in financial networks is very important for the stability of financial systems. But most models of financial networks often suffer from their very own problems. Many financial network models do not include interbank networks or inter-firm networks [8,11,13,29,33]. The study of Delli Gatti et al. [12] includes three lending relationships: downstream and upstream firms obtain credit from banks; downstream firms buy intermediate goods from upstream firms by means of a commercial credit contract; banks obtain credit from other banks, though the financial network is exogenous. To avoid these limits, this paper analyzes contagion risk in endogenous financial networks, which includes interbank networks, inter-firm networks and bank-firm networks.

Closest to our work is Delli Gatti et al. [12]. However, our paper is different from theirs in network formation. The network formation in this paper is endogenous, while that in Delli Gatti et al. [12] is exogenous. In addition, the business actions of banks and firms in this paper are closer to reality than that in Delli Gatti et al. [12]. We take investment activities for banks and firms and dividend for banks into consideration, but they do not consider these factors. When modeling business actions of banks and firms, we combine the studies of Iori et al. [23], Delli Gatti [11,13,18,26]. But there are some differences between this work and theirs. Similar to the study of Iori [23], we describe business actions of banks. However, the risk investment in the present model is considered through risk preference of banks, but Iori does not consider this factor. In this paper, interbank credit lending relationships are established by partner selection mechanism, while they are exogenously determined in the study of Li [26]. Comparing with the studies of Delli Gatti [11,13], we set double constraints for firms' production, introduce investments, dividend payments and deposit fluctuation to describe the behavior of the related agents, and allow multi-period debt structures. Our model is also different from the study of Georg [18]. For example, we take into consideration multi-period debt structures and dividend payments in our model, but Georg does not consider these factors.

The rest of the paper is organized as follows. Section 2 describes the basic model in detail. Section 3 presents the results of numerical simulations. And the conclusion is drawn in Section 4.

2. The model

We investigate an economy with three sectors: downstream firms, upstream firms and banks, where downstream (D hereafter) firms produce consumption goods, while upstream (U hereafter) firms supply intermediate inputs to D firms, and banks extend credit to firms and other banks. The operation of the economy is regarded to be in discrete time, which is denoted by t, $t = 0, 1, 2, \cdots$. D firms are labeled by the index $i = 1, 2, ..., I$, U firms are labeled by the index $j = 1, 2, ..., J$, and banks are labeled by the index $z = 1, 2, ..., Z$. In this paper, we describe business actions of agents combining the studies of Iori et al. [23], Delli Gatti et al. [11,13], Li [26] and Georg [18]. We analyze three kinds of credit relationships: D and U firms obtain credit from banks; D firms buy intermediate goods from U firms by means of a commercial credit contract; banks obtain interbank credits from other banks, which are established by the partner selection mechanism in the study of Delli Gatti et al. [13]. Initially, at time $t = 0$, the financial network is random. But from $t = 1$, in every period each borrower selects randomly a number of potential lenders (a fraction M of the total potential lenders) and observe their interest rates. Potential lender x' sets the following interest rate on loans to the borrower x:

$$r^{x}_{x't} = \alpha A^{-\alpha}_{x't} + \alpha (l_{xt})^{\alpha}, \tag{1}$$

where $\alpha > 0$, $A_{x't}$ is the net worth of agent x' and l_{xt} is the leverage of agent x. Leverage is the ratio of credit extended to an agent to its net worth. Higher leverage of the borrower means higher counterparty risk, and that therefore interest rate increases with leverage. When the lender's net worth is too high, the interest rate goes down. And more borrowers will be attracted by the lender and more loans will be extended. We assume that the borrower sticks to the current lender if the previous lender's interest rate, r_{old}, is smaller than or equal to the minimum interest rate set by the observed potential new lenders, r_{new}. If this is not the case, the probability P_s of switching to a new lender is equal to $1 - e^{\lambda(r_{new} - r_{old})/r_{new}}$ if $r_{new} < r_{old}$, otherwise $P_s = 0$, where $\lambda > 0$ is an intensity of choice parameter.

2.1. Firms

In this paper, we follow the study of Delli Gatti et al. [11,13], and set the level of production of the ith D firm at time t, Y_{it}, be read as Eq. (2).

$$Y_{it} = \varphi A^{\beta}_{it}, \tag{2}$$

where $\varphi > 1$, $0 < \beta < 1$. This equation represents the financially constrained output function. In order to calculate the labor and intermediate goods requirement of each D firm, for simplicity we assume that the production function of each D firm is of the Leontief type, namely, $Y_{it} = \min\{N_{it}/\delta_d, Q_{it}/\gamma\}$, where $\delta_d > 0$, $\gamma > 0$, N_i is employment and Q_i are intermediate inputs. And then, we can obtain the labor and intermediate goods requirement functions are as $N_{it} = \delta_d Y_{it}$ and $Q_{it} = \gamma Y_{it}$ respectively. The ith D firm sends the order with the amount Q_{it} to U firms based on the above partner selection mechanism. For the jth U firm, if its total amount of the orders received from D firms is less than its level of production $Y_{jt} = \varphi A^{\beta}_{jt}$, all its customers' demands for intermediate goods can be satisfied. Otherwise, the U firm satisfies its customers in sequence according to the rank of the D firms' net worth from high to low until all its output is completely allocated. If the ith D firm does not obtain the amount Q_{it} of intermediate goods, it contacts other U firms for the remaining intermediate goods according to the same rule until its demand for intermediate goods is totally satisfied or there are no more intermediate goods to be allocated.

Therefore, the real outputs of D and U firms can be expressed as follows:

$$Y^{real}_{it} = \sum_{j \in \Psi_{it}} Q^{i}_{jt} / \gamma, \tag{3}$$