An Iterative Approach to Reduce Systemic Risk among Financial Institutes

Xiang-Shen Ye* Ruo-Bing Xue** Jian-Jun Gao*** Xi-Ren Cao****

* Department of Automation, Shanghai Jiao Tong University, Shanghai 200240, China (e-mail: yesys@sjtu.edu.cn)
** Department of Automation, Shanghai Jiao Tong University, Shanghai 200240, China (e-mail: xue_rubing@outlook.com)
*** School of Information Management and Engineering, Shanghai University of Finance and Economics, Shanghai, 200433, China (e-mail: gao.jianjun@shufe.edu.cn)
**** Department of Automation, Shanghai Jiao Tong University, Shanghai 200240, China, and Institute of Advanced Study, Hong Kong University of Science and Technology (e-mail: xrcao@sjtu.edu.cn or eecao@ust.hk)

Abstract: Financial institutions are interconnected by holding debt claims against each other. The interconnection is a key contributing factor to the past worldwide financial crisis. A default bank may cause its creditors to default, and the risk may be further propagated to up-stream institutes. We study how the mechanism of default liquidation affects the total wealth of the financial system and curbs the risk contagion. We formulate this problem as a nonlinear optimization problem with equilibrium constraints and propose an optimal liquidation policy to minimize the system’s loss without changing the partition of default and non-default banks. We show that the optimization problem resembles a Markov decision problem (MDP) and therefore we can apply the direct-comparison based optimization approach to solve this problem. We derive an iteration algorithm which combines both the policy iteration and the gradient based approach. Our work provides a new direction in curbing the risk contagion in financial networks; and it illustrates the advantages of the direct-comparison based approach, which originated in the field of discrete event dynamic system, in nonlinear optimization problems.

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1. INTRODUCTION

The paper is motivated by two recent developments in financial engineering and performance optimization. First, it is known that financial institutions link with each other through borrowing-and-lending activities among themselves or holding marketable securities against each other (Chen et al. [2014]). Since the 2007-2009 credit crisis in the US and the European sovereignty debt crisis, it has been increasingly clear that the interconnection could pose potential threats to the stability of the financial system. For example, a default bank may cause its creditors to default, and the risk may be further propagated to up-stream institutes. During default liquidation, how to curb such risk contagion among financial networks becomes extremely important. In this paper, We show that this issue can be modeled as an optimization problem.

The problem formulated above has a large dimension and many highly nonlinear constraints, and we need to develop an efficient algorithm for an optimal solution. On this side, a direct-comparison based approach has been developed in the past years to the optimization of nonlinear problems and has been successfully applied to many problems, such as optimization of singular controlled diffusion processes (Ni and Fang [2013]), MDP with long-run average criterion (Cao [2007, 2015]) and variance criterion (Xia [2016]), and nonlinear performance with probability distortion (Cao and Wan [2017]). In this paper, we show that the special features of the financial risk contagion problem make it possible to be solved by the direct-comparison based approach, leading to some new insights to the problem.

To study the rationale for the risk contagion effect, much of the literature is devoted to analyze the structure of the financial network, e.g., Catanzaro and Buchanan [2013] propose complex networks as a tool to avert the financial crisis. It is shown that network connections can have both a positive effect by diversifying risk and a negative effect by adding spreading channels for risk (Haldane [2009], Summer [2013]). In the literature, Rochet and Tirole
[1996], Allen and Gale [2000], and Leitner [2005], focus on how the risk-sharing mechanism can transmit the systemic crisis when a global shortage for liquidity happens. Other papers pour attention into the contagious effect of asset price, such as Holmstrom and Tirole [2000], Allen and Gale [2004], and Brunnermeier and Pedersen [2007].

According to Yellen’s speech at the American Economic Association (Yellen [2013]), in response to the financial crisis and the weaknesses it revealed, governments around the globe are acting to improve financial stability and reduce the risks posed by a highly interconnected financial system. It is natural to expect the central bank (CB) to take a more active role in curbing contagion and controlling systemic risk. Dasgupta [2004] and Castiglionesi [2007] have already argued the necessity of a CB in systemic risk.

In this paper, we propose another possible role that the CB may take in curbing contagion: arbitrating the liquidation among banks in the system during the economic crisis and providing required compensation to achieve fairness. In the literature, it’s often assumed that all claimant nodes are paid off in proportion to the size of their claims on bank assets, such as Eisenberg and Noe [2001] and Chen et al. [2014]. We show that by allowing different liquidation schemes we may reduce the system’s loss without changing the partition of default and non-default banks. However, this may violate the fairness of the prorated scheme, and government/CB arbitration and compensation are needed; this echoes Yellen’s speech (Yellen [2013]) and is consistent with others’ work on the roles of governments and CBs (Dasgupta [2004], Castiglionesi [2007]).

The above problem can be modeled as a performance optimization problem. The solution space may have multi regions, i.e., different partitions of default and non-default banks. In this paper, we want to find an optimal solution in one of the regions. Fortunately, we solve this problem through an approach originally developed for the optimization of discrete event dynamic systems (Cao [2007]), called the direct-comparison based approach. The approach is based on a performance difference formula (PDF), which provides the details in the difference of the performance of the system under any two policies. The approach is intuitively clear, and it can provide new insights, leading to new results to many problems (Ni and Fang [2013], Cao [2007, 2015], Xia [2016], Cao and Wan [2017]).

In this paper, we apply this approach to the risk contagion problem and develop an algorithm that combines policy iteration with performance gradient; numerical examples indicate a big improvement in financial loss. Our work casts new insights to the problem, extends the Eisenberg-Noe model and obtains optimal liquidation scheme in curbing the risk contagion.

The rest of the paper is structured as follows. In Section 2, we review the Eisenberg-Noe model and some other related works, and we formulate our problem. In Section 3, we apply the direct-comparison based approach and propose an policy iteration-gradient combined algorithm for the optimal liquidation scheme to minimize the system’s loss in one region. In Section 4, we provide two numerical examples showing the improvement in system’s loss. Finally, Section 5 concludes the paper.

2. PROBLEM FORMULATION

2.1 A brief review

Our work is based on the structural framework for contagion in financial networks proposed in Eisenberg and Noe [2001]. This model illustrates how shocks to individual agents can be propagated through interbank networks, and it was followed by many subsequent works, such as Liu and Staum [2010], Chen et al. [2014], and Glasserman and Young [2015].

In the model, there are $n$ banks with interconnected balance sheets. The interconnection of the banks is represented via an $n \times n$ liability matrix $L := (L_{i,j})$, where $L_{i,j}$ denotes the nominal obligation of bank $i$ to bank $j$. Naturally, $L_{i,j} \geq 0$ for $i \neq j$ and $L_{i,i} = 0$. Every bank may also have some liabilities to creditors outside the network, denoted as a row vector $b = (b_i)$, $b_i \geq 0$. (Vectors in the form of $(b_i)$ are row vectors.) We denote the liability vector as $l := (l_i)$, $l_i := b_i + \sum_{j \neq i} L_{i,j}$, and set $r_{i,j} := L_{i,j}/l_i$ to denote the relative liability, and let $R := (r_{i,j})$. We assume that there is only one seniority for the liability. We use a vector $\alpha := (\alpha_i)$, $\alpha_i \geq 0$, to represent the values of exogenous assets of the banks. Then the total asset of bank $i$ is $\alpha_i + \sum_{j \neq i} L_{j,i}$.

A bank is defined to be in default if its total liability exceeds its total assets. It’s often assumed that bank default will not change the prices outside the network, i.e., $\alpha$ is independent of defaults.

Let $P := (p_{i,j})$ be the liquidation matrix, meaning that in this scheme bank $i$ pays bank $j \neq i$ proportionally to $p_{i,j}$, $j \neq i$, $i = 1, 2, \ldots, N$. More precisely, let $x_i$ be the total debt that bank $i$ pays to others, and $x = (x_i)$ is called the a clearing payment vector. Then bank $i$ pays bank $j$ with $x_i p_{i,j}$. In normal situation, $P = R$, i.e., debts are paid proportionally to the relative liabilities, which is called a pro rata scheme. Next, $x$ and $P$ satisfy the following conditions:

(a) Limited Liability. \( \forall i = 1, \ldots, n, \)
\[
x_i \leq \alpha_i + \sum_{j=1}^{n} x_j p_{j,i}.\]

(b) Absolute Priority. \( \forall i = 1, \ldots, n, \) either liabilities are paid in full $x_i = l_i$, or all value is paid to creditors, that is
\[
x_i = \alpha_i + \sum_{j=1}^{n} x_j p_{j,i}.\]

Putting them into a matrix form as the fixed-point characterization, we have
\[
x = \min[l, \alpha + x P].
\]

On the basis of fixed-point arguments, Eisenberg and Noe [2001] discusses the existence and uniqueness of the clearing vector. It is proved that, for each realization of $\alpha$, a clearing vector exists. Furthermore, the clearing vector is unique under some mild regularity conditions. As an example, if we assume that every bank has positive external liability, i.e., $b_i > 0$ for all $i$ like what Glasserman and Young [2015] does, then the substochastic matrix $P$ has all the row sums strictly less than 1. Thus there exists
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