2019

Three essays on deposit insurance, initial public offerings, and shadow banks

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Three essays on deposit insurance, initial public offerings, and shadow banks

by

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A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Economics

Program of Study Committee:
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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this dissertation. The Graduate College will ensure this dissertation is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University

Ames, Iowa

2019

DEDICATION

I would like to dedicate this dissertation to my wife Qiulu Xue, without whose support I would not have been able to complete this work. I would also like to thank my friends and family for their loving guidance and financial assistance during the writing of this work.

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ACKNOWLEDGMENTS

I would like to take this opportunity to express my thanks to those who helped me with various aspects of conducting research and the writing of this dissertation. First and foremost, Dr. Oleksandr Zhylyevskyy for his guidance, patience and support throughout this research and the writing of this dissertation. His insights and words of encouragement have often inspired me and renewed my hopes for completing my graduate education. I would also like to thank my committee members for their efforts and contributions to this work. I would additionally like to thank Dr. David M Frankel for his guidance throughout the initial stages of my research career and his collaboration that wrote one chapter in this dissertation. Finally, I would like to thank Dr. Sergio H Lence for his detailed and constructive suggestions for revising my second essay.

ABSTRACT

It is generally argued that deposit insurance weakens depositor discipline and therefore introduces a moral hazard for commercial banks. The traditional theory ignores the role of the regulator in bank run models once deposit insurance is enacted. Chapter 2 proposes a new role that the regulator who can declare a bank legally insolvent will play. The regulator, who may or may not be the deposit insurer, makes decisions on the timing and resolution of failing banks based on the least cost of the deposit insurer in the game. Deposit insurance leads to a loss of depositor discipline. However, regulator discipline is built from least-cost commitment. Moreover, the regulator discipline always has a stronger effect than depositor discipline in preventing banks from speculating. Hence, deposit insurance with least-cost commitment will not bring extra moral hazard issues from the monitoring perspective. Chapter 2 supports the least-cost resolution policy in the United States.

During the Great Recession, liquidity did not flow out of the banking sector but was reallocated internally. Deposits increased, but the volumes of all other short-term debt financing instruments, except for T-Bills, decreased. Commercial banks, which have stable funding sources from deposits, did not render liquidity backup to shadow banks but held the increased deposits as cash on hand. Chapter 3 uses deposits and financial commercial paper outstanding as proxies for commercial and shadow banking financing instruments because they are unique liabilities of commercial and shadow banks, respectively. Using vector autoregressive models, I provide evidence that when liquidity falls in shadow banks, commercial banks experience funding inflows. In normal times, commercial banks render liquidity backup to shadow banks in the following weeks using the increased deposits. However, the dynamic correlation breaks down in crisis times, which may have contributed to the collapse of the shadow banking system during the Great Recession.

Using theoretical and simulation tools, Chapter 4 studies how strategic risk among investors can help explain both underpricing and underreaction in initial public offerings (IPOs). We assume

the post-IPO value of a firm is higher if the IPO raises more capital for the firm. Hence an IPO subscriber faces strategic risk: the value of subscribing depends on the aggregate subscription rate. As this risk is resolved immediately after the IPO, the IPO itself is underpriced. Moreover, since individual investors have limited wealth, a higher offer price raises the risk of undersubscription. Investors respond by demanding a larger discount: the offer price appears to underreact to public news.

CHAPTER 1. INTRODUCTION

Shadow banks, the specialized financial intermediaries that channel funding from lenders to borrowers through a range of securitization and secured funding techniques[1], arguably played a critical role in undermining the whole financial system and bringing about the financial crisis from 2007 to 2008. First, mortgage-backed securities (henceforth, MBSes), especially subprime MBSes, collapsed because of the housing bubble burst during the Great Recession. The unregulated shadow banking system was blamed for taking on or producing excessive credit risks by offering excessive mortgage loans and then securitizing the loans into MBSes. Second, the shadow banking system suffered severe liquidity problems, especially for shadow banks that used MBSes as collateral to raise funds. Somehow, it indirectly affected regulated commercial bank lending during the Great Recession. Fleming (2012) notes that across its many liquidity facilities, the Federal Reserve provided over $1.5 trillion of liquidity support during the crisis. After the Great Recession, the shadow banking system and the subtle distinction between liquidity risks and credit risks become hot topics in both academia and industry. The Dodd-Frank Act and Basel III also cover regulations on the shadow banking system and new liquidity requirements. This dissertation is focused on these topics.

1.1 Deposit Insurance

During the Great Depression, investors responded to the banking crisis by withdrawing deposits from commercial banks and holding the cash on hand. The ratio of deposits to currency plunged

[1]This definition closely follows that of Pozsar et al. (2010). Although there exists plenty of borrowing and lending business within the banking system, lenders and borrowers are outsiders of the banking system in this dissertation unless otherwise stated. Lenders are mainly fixed-income investors who invest in mortgage-backed securities, asset-backed securities, repurchase agreements, commercial paper, money market mutual funds, etc., but not bank deposits or other commercial bank obligations. Investors in mutual funds or hedge funds could be generally considered lenders if the mutual fund or hedge fund invests in the fixed-income products above. Borrowers include (but are not limited to) producers who need funds to produce or consumers who need funds to invest in real estate or purchase automobiles. Borrowers may borrow money from shadow banks directly or from commercial banks, and commercial banks securitize the loans later as fixed-income products. For details, see Section 3.3.

from about 12 to less than 5 between 1929 and 1933 (Schwartz (1963)). In reaction to the substantial cash outflow, commercial banks had to liquidate their assets in fire-sale prices. Hence, the liquidity risk of an entity is actually the refinancing risk when the entity has to roll over its debt. For commercial banks in the Great Depression, they had difficulties in rolling over or refinancing their deposits. Federal Deposit Insurance Corporation (henceforth, FDIC) was introduced during the Great Depression to solve the liquidity problem of commercial banks. Deposit insurance is a government bailout to depositors when financial institutions cannot fulfill the deposit contracts. Diamond and Dybvig (1983) first model the panic-based bank run. The panic-based liquidity risk comes from the consistent beliefs of depositors that others would withdraw their deposits. In such a way, liquidity risks can be separated from credit risks and lead to insolvency of commercial banks. However, credit risks can bring about fundamental-based bank runs as well. Unlike panic-based bank runs proposed by Diamond and Dybvig (1983), fundamental-based bank runs are not totally detrimental to social welfare. They are actually depositor discipline, a threat from depositors if commercial banks take on excessive credit risks.

On one hand, deposit insurance is thought to have a positive role in preventing the panic-based bank runs and stabilize the financial system. On the other hand, deposit insurance may introduce a moral hazard issue. Without deposit insurance, bank managers have a strong incentive to avoid risky loans and other investment because depositors will move their money to safer banks when they feel unsafe about their deposits. The introduction of deposit insurance reduces the depositor discipline (fundamental-based bank runs) that might otherwise penalize banks for risk-taking behavior. Hence, it might even increase the overall fragility of the financial system.

Chapter 2 proposes a new perspective about the role that a regulator who can legally close a bank will play. Banks typically fail after a gradual deterioration of fundamental rather than a single adverse event. Thus, the timing of the closure of a bank directly affects the costs to the deposit insurer[2]. When bank managers take on excessive risks, it increases the present value of expected loss incurred by the deposit insurer because speculations have a higher probability of failure and

[2] In addition to close the bank, the regulator can also make an early intervention to restrict the activities of the bank.

only banks can achieve the excessive return if speculations success. When the regulator, may not be the deposit insurer, makes a commitment to make the decision on the timing of the closure of a bank based on the least present value of expected loss of the deposit insurer, it will punish banks for risk-taking behavior like the depositor discipline. Although deposit insurance weakens the depositor discipline, regulator discipline is built from the least-cost commitment[3]. Moreover, the regulator discipline always has a stronger effect than depositor discipline in preventing banks from speculating. Hence, deposit insurance with least-cost commitment does not bring extra moral hazard issues from the depositor discipline perspective.

The basic model is based on Diamond and Dybvig (1983) and extended with moral hazard of banks like Cooper and Ross (2002). After introducing the lemon project in the model, it gives banks an avenue for moral hazard. The lemon project is so bad that it only has value for the banks. Hence, the lemon project can capture the pure interest conflict between banks and depositors. However, the model in Chapter 2 has two big differences from Cooper and Ross (2002). One is that the capital of banks affects the budget constraint of banks in my model. Hence, as to the capital, my model is relatively more general equilibrium than Cooper and Ross (2002). The other is the assumption of depositor discipline. In Cooper and Ross (2002), when depositors monitor banks, they can make the bank manager choose their favorable risk and investment. In my model, depositor discipline comes from the threat of depositors in a way that depositors withdraw money from their banks to other safer banks if depositors find their banks are likely to expropriate deposits. Flannery (1994) argues that depositors may penalize poor management performance or excessive risk-taking by withdrawing deposits. Hence, my assumption about depositor discipline is more realistic.

Empirically, Iyer et al. (2013) find the regulator has more information about banks' financial positions and depositors actually follow the regulator. After the enactment of the Dodd-Frank Act, we have more reliable rules and regulations on the banking system. We could believe that regulator discipline trumps depositor discipline in monitoring banks. It is worth mentioning that deposit insurance protects depositors but not the commercial bank if a commercial bank fails. Thus,

[3] In some literature, it is called supervisory discipline.

deposit insurance is not like a normal put option for commercial banks on their assets, which is proposed by Merton (1977). The potential moral hazard issue can only come from the weakened depositor discipline. Hence, the introduction of deposit insurance does not bring extra moral hazard issues for commercial banks is the standpoint in Chapter 2.

1.2 Shadow Banking System

Since deposit insurance does not bring extra moral hazard issues for commercial banks, what the influence of the deposit insurance? This is the question that Chapter 3 tries to answer. In terms of the liability side of the balance sheet, deposit insurance separates the debt of the banking system into two parts. One is deposits, which is covered by the deposit insurance[4]. The other is uncovered shadow banking financing instruments[5]. Harvey and Spong (2001) point that growth in traditional deposit funding sources has stagnated at many commercial banks after 1990 and has largely failed to keep up with the growth in bank assets. Hence, commercial banks which face funding difficulties in core deposits have to use funding instruments from shadow banking activities. Because of securitization, many shadow banking activities migrated from commercial banks to become independent unregulated entities and accounted for a large portion of the banking system before the Great Recession. Some of these shadow banks are owned by bank holding companies (henceforth, BHCs), which also hold commercial banks. BHCs are under rigorous regulator discipline, although regulations before the enactment of the Dodd-Frank Act are not fully sound for their shadow banking subsidiaries. The other shadow banks are completely independent of commercial banks or BHCs. Because of loose regulations, independent shadow banks suffered the severest impact during the Great Recession.

Chapter 3 studies the interdependence between shadow banks and commercial banks. They offer similar financial products to investors. The fixed-income products offered by shadow banks have a higher interest rate and risks than deposits. Hence, they are competitors to attract the

[4]Deposits are not fully covered by the FDIC in the United States. The uncovered deposits behave like shadow banking financing instruments in the crisis.

[5]Because only short-term debt has liquidity risks for banks, the shadow banking financing instruments here exclude loans that banks borrow from other entities.

most risk-averse investors[6]. When the market risks increase, investors hold fewer securities issued by shadow banks and more deposits, and vice versa. One example is during the Great Recession, when investors lost confidence in the securities offered by shadow banks and transferred their wealth from shadow banks to commercial banks. Hence, commercial banks have a unique and natural advantage in providing liquidity insurance to shadow banks if they want. Consider a case where investors withdraw funds from shadow banks and deposit them into commercial banks during a period of market stress. If commercial banks lend the same volume of funds to shadow banks and all transactions work efficiently, no liquidity problem comes up in the whole banking system. Money just behaves like "what goes around comes around". Investors still hold the same wealth in the whole banking system if only they keep the same amount of fixed-income investment. Shadow banks cannot raise enough money from investors, but they find an alternative funding source from commercial banks. For commercial banks, deposit inflows serve as a hedge for outflows from new loans given to shadow banks. I give the series of cash flows a name called "Flight-to-Quality" circle (henceforth FTQ circle).

During normal times or periods of moderate market stress, the FTQ circle functions well as commercial banks are willing to lend increased deposits to shadow banks. However, the liquidity backup broke down during the Great Recession, and it could possibly be one of the reasons that caused the collapse of the shadow banking system.

Why is the liquidity backup in the FTQ circle important to the stability of the financial system? My argument is that the liquidity backup from commercial banks to shadow banks is the radical support for the confidence of investors when the financial market suffers the impact of credit risks. The securities offered by shadow banks usually have collateral to protect investors from credit risks, so they were considered to be safe assets before the Great Recession[7]. Based on the shadow banking model of Gennaioli et al. (2013), fixed-income investors are extremely risk-averse. Hence, investors

[6] Compared to the investors who invest in equities, real estate and so on.

[7] It is the reason we usually call them asset-backed or mortgage-backed securities. For repos, investors have even more controls over the collateral than normal collateralized borrowings. Collateral is exempted from the automatic stay, so a party to a repo can unilaterally enforce the termination provisions of the agreement as a result of a bankruptcy filing by the other party. For details, see Section 3.3.

value the risky collateral at a much lower price than the risk-neutral financial intermediaries. The collateral is priced nearly risk-neutral during normal times because of the liquidity offered by banks. Even if investors dislike risks, they can accept collateral at about its risk-neutral price because they believe that they can sell their collateral in a liquid market dominated by risk-neutral banks if defaults happen. When moderate neglected credit risks are revealed in the market, investors ask for more collateral and higher interest rate to offset the credit risks, and the market price of the collateral temporarily decreases because of the underlying fundamental return rates based on the credit risks. However, we are still in a nearly risk-neutral world if the market has sufficient liquidity. Things change when the neglected credit risks are so large that the liquidity backup in the FTQ circle breaks down like it was the case during the Great Recession. The liquidity of the market declined largely due to the fact that commercial banks tighten their credit. Investors lose their confidence and reveal their extreme risk-averse preferences. Collateral is priced with a high risk premium because investors dominate the market this time. Risk-neutral arbitrageurs do not have sufficient funds to turn the market back to the nearly risk-neutral state individually. The market stays a long time with extreme risk-averse pricing before it goes back to risk-neutral again.

Diamond and Dybvig (1983) propose the panic-based liquidity risk for commercial banks, because deposits have no collateral and deposit investors have the incentive to care about the solvency of their commercial banks. However, shadow banking products usually have collateral. Hence, the concern of investors goes to the value of the collateral. In my narrative, liquidity risks come from the change of prevailing preferences in fixed-income markets. In terms of the banking system, we live in a half-covered world. When liquidity backup from commercial banks to shadow banks breaks down, the value of the collateral, which used to be decided by risk-neutral banks, is decided by dominating extremely risk-averse fixed-income investors. Excluding neglected credit risks and bubbles, the preference-based liquidity risks in this chapter can also partly explain the collapse of MBSes during the Great Recession.

1.3 Underpricing in Initial Public Offerings

In Chapter 4, my co-authors, Drs. David M. Frankel and Xiangou Deng, and I investigate underpricing in initial public offerings (henceforth, IPOs). Using theoretical and simulation tools, we study how strategic risk among investors can help explain both underpricing and underreaction in IPOs. We assume the post-IPO value of a firm is higher if the IPO raises more capital for the firm. Hence an IPO subscriber faces strategic risk: the value of subscribing depends on the aggregate subscription rate. As this risk is resolved immediately after the IPO, the IPO itself is underpriced. Moreover, since individual investors have limited wealth, a higher offer price raises the risk of undersubscription. Investors respond by demanding a larger discount: the offer price appears to underreact to public news.

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CHAPTER 2. DEPOSIT INSURANCE WITH LEAST-COST COMMITMENT

Zhongzheng Zhou

2.1 Abstract

It is generally argued that deposit insurance weakens depositor discipline and therefore introduces a moral hazard for commercial banks. The traditional theory ignores the role of the regulator in bank run models once deposit insurance is enacted. This Chapter proposes a new role that the regulator who can declare a bank legally insolvent will play. The regulator, who may or may not be the deposit insurer, makes decisions on the timing and resolution of failing banks based on the least cost of the deposit insurer in the game. Deposit insurance leads to a loss of depositor discipline. However, regulator discipline is built from least-cost commitment. Moreover, the regulator discipline always has a stronger effect than depositor discipline in preventing banks from speculating. Hence, deposit insurance with least-cost commitment will not bring extra moral hazard issues from the monitoring perspective. This Chapter supports the least-cost resolution policy in the United States.

2.2 Introduction

Deposit insurance, a government bailout to depositors when financial institutions cannot fulfill the deposit contracts, has been used for a long time all over the world. The recent Great Recession has led to a new rebate about the advantage and disadvantage of deposit insurance. On one hand, deposit insurance is thought to have a positive role in preventing the panic-based bank runs and stabilize the financial system. On the other hand, deposit insurance may introduce a moral hazard issue. Without deposit insurance, bank managers have a strong incentive to avoid risky loans and other investment because depositors will move their money to safer banks when they feel unsafe about their deposits. The introduction of deposit insurance reduces the depositor discipline that might otherwise penalize banks for risk-taking behavior. Hence, it might even increase the overall fragility of the financial system.

This chapter proposes a new perspective about the role that a regulator who can legally close a bank will play. Banks typically fail after a gradual deterioration of fundamental rather than a single adverse event. Thus, the timing of the closure of a bank directly affects the costs to the deposit insurer[1]. When bank managers take on excessive risks, it increases the present value of expected loss incurred by the deposit insurer because speculations have a higher probability of failure and only banks can achieve the excessive return if speculations success. When the regulator, may not be the deposit insurer, makes a commitment to make the decision on the timing of the closure of a bank based on the least present value of expected loss of the deposit insurer, it will punish banks for risk-taking behavior like the depositor discipline. Although deposit insurance weakens the depositor discipline, regulator discipline is built from the least-cost commitment[2].

The basic model is based on Diamond and Dybvig (1983) and extended with moral hazard of banks like Cooper and Ross (2002). After introducing the lemon project in the model, it gives banks an avenue for moral hazard. The lemon project is so bad that it only has value for the banks. Hence, the lemon project can capture the pure interest conflict between banks and depositors. However, the model of this chapter has two big differences from Cooper and Ross (2002). One is that the capital of banks affects the budget constraint of banks in my model. Hence, as to the capital, my model is relatively more general equilibrium than Cooper and Ross (2002). The other is the assumption of depositor discipline. In Cooper and Ross (2002), when depositors monitor banks, they can make the bank manager choose their favorable risk and investment. In my model, depositor discipline comes from the threat of depositors in a way that depositors withdraw money from their banks to other safer banks if depositors find their banks are likely to expropriate deposits. Calomiris and Kahn

[1]In addition to close the bank, the regulator can also make an early intervention to restrict the activities of the bank.

[2]In some literature, it is called supervisory discipline.

(1991) view deposits as a means for monitoring banker's behavior. Similarly, Diamond and Rajan (2001) also emphasize the governance advantages of demand deposit. Flannery (1994) argues that depositors may penalize poor management performance or excessive risk-taking by withdrawing deposits. Hence, my assumption about depositor discipline is more realistic.

This chapter proceeds as follows. Section 2.3 is the basic model based on Diamond and Dybvig (1983). Section 2.4 extend the basic model based on Cooper and Ross (2002). Section 2.5 gives numerical examples of the model. Section 2.6 contains the empirical evidence. Section 2.7 is the discussion and conclusion. All proofs are contained in the appendix.

2.3 The Basic Model

The basic model is based on Diamond and Dybvig (1983). There are three dates ($t = 0, 1, 2$), a continuum $[0, 1]$ of banks and a continuum $[0, 1]$ of depositors in every bank. Depositors are *ex ante* identical. Each depositor is endowed with one unit at date 0 and nothing thereafter. The preference of each depositor is given by $u(c_1 + \theta c_2)$, where c_1 and c_2 are consumption of date 1 and 2. $\theta \in \{0, 1\}$ is the taste type of the depositor. At the start of date 1, depositors are informed about their taste types. Each depositor has a probability π to be the early type with $\theta = 0$, which means she can obtain utility exclusively from the consumption at date 1, while a probability $1 - \pi$ to be the late type with $\theta = 1$, which means she cares about the sum of consumption at date 1 and date 2. By law of large numbers, π is also the fraction of depositors who are early type and $1 - \pi$ the late type *ex post*. As in the first part of Diamond and Dybvig (1983), in this chapter I assume that π is non-stochastic and known to all agents. The utility function $u(\cdot)$ satisfies $u'(\cdot) > 0$, $u''(\cdot) < 0$, $u(0) = 0$ and relative risk aversion coefficient is greater than one.

There are two technologies available for transferring resources over time, which are listed below.

Date	0	1	2
Storage	-1	1	0
	0	-1	1
Production	-1	1	0
	-1	0	R

First, there is a storage technology, available to both banks and depositors, that yields one unit at next date given one unit invested at the current date. Storage technology has no extra return, but it is a short run investment, which means that at date 1, agents in the model can only use storage technology. Second, there is a production technology, only available to banks, that yields $R > 1$ at date 2 given one unit invested at date 0. The production technology is a long run investment which is not completely liquid. The liquidation of production will yield only one unit at date 1 given one unit invested at date 0. However, at date 0, the storage technology is weakly dominated by the production technology. Hence, the banks will always use the production technology at date 0. Without banks, depositors can only use the storage technology. Early type depositors will consume one unit at date 1, i.e. $c_1 = 1$. Late type depositors are indifferent with any combination of consumption at date 1 and 2 that used up their individual one unit endowment, i.e. $c_1 + c_2 = 1$. For convenience, I assume late depositors will consume $c_2 = 1$.

2.3.1 First Best

Banks are all identical in the model. There is perfect competition among banks, and so they make no profit. I also add the capital (equity) of the banks in my model for the purpose of studying the interest conflict between depositors and banks. Each bank is required to hold a k unit of capital with one unit of liability in demand deposits, and it can absorb one unit deposit at date 0 if the depositors accept the bank's offer. The bank will also invest the capital k through the production technology at date 0. In first best, all banks will offer contracts that maximize the depositors' *ex ante* expected utility subject to the budget constraint only based on the deposit. The first best contract offered by each bank is $\delta^{FB} = (c_1^{FB}, c_2^{FB})$ solving

$$\max_{c_1, c_2} \pi u(c_1) + (1-\pi)u(c_2) \tag{2.1}$$

$$s.t. \qquad 1 = \pi c_1 + \frac{(1-\pi)c_2}{R} \tag{2.2}$$

The properties of utility function make sure that

$$1 < c_1^{FB} < c_2^{FB} < R \tag{2.3}$$

$u''(c) < 0$ implies that $c_1^{FB} < c_2^{FB}$ and relative risk aversion coefficient $-cu''(c)/u'(c) > 1$ implies that $1 < c_1^{FB}$. The depositors will definitely accept the contract because they can only consume $c_1 = c_2 = 1$ without the offer and $u'(c) > 0$. With the contract, the early type depositors will withdraw their money at date 1 with c_1^{FB} and the late type depositors will withdraw their money at date 2 with c_2^{FB}.

The first best outcome is the only equilibrium in the model if and only if $c_1^{FB} \leq 1 + k$. When $1 + k < c_1^{FB}$, there is another bad bank run equilibrium in the model. As in Diamond and Dybvig (1983) model, the late type depositors will withdraw their money at date 1 when they think that all other late type depositors will do so. In this case, the bank will lose all its capital k and be bankrupt at date 1. For late type depositors, waiting cannot give them the consumption c_2^{FB} at date 2 but nothing. If they withdraw their money at date 1, they have the probability of $(1 + k)/c_1^{FB}$ to get the c_1^{FB}, which is based on the sequential service constraint. Sequential service constraint means a bank must service its depositors sequentially, on a first-come, first-served basis.

In this chapter, I will always assume that $1+k < c_1$, which means that capital is not high enough to eliminate the bank runs. However, as to the first best in this chapter, it is the outcome that contract $\delta^{FB} = (c_1^{FB}, c_2^{FB})$ works successfully with the probability of one. With the requirement of minimum capital only, the regulator cannot achieve the first best, because the first best contract is vulnerable to run $(1 + k < c_1^{FB})$.

2.3.2 Second Best

Because $1+k<c_1$, the bank run equilibrium always exists in the model without any other policy intervention from the regulator. Suppose that the bank run equilibrium will happen with the exogenous probability of p and the bank runs will happen in the whole economy (all the banks). It is a sunspots approach that builds the correlated equilibrium in the game as in Cooper and Ross (2002), and Keister (2016). Another way to assign the probability of bank run equilibrium is from global games method. Goldstein and Pauzner (2005) used the global games method to get the unique equilibrium (switching strategies) in Diamond and Dybvig (1983) and the probability of bank run equilibrium is endogenous. Although the global games method can make the probability of bank run equilibrium endogenous, it will complicate the model. As you will see below, the sunspots method in this chapter can capture the spirit in Goldstein and Pauzner (2005).

At date 0, banks also need to raise their capital k from the investors besides one unit of deposit. Investors are not like depositors. They are only late types and can use the production technology at date 0 without banks. For simplicity, I assume that the required expected return R_k at date 2 given one unit invested at date 0 from investors is exogenous and $R_k \geq R$ because investors can always use the production technology without banks to achieve R at date 2 definitely. Investors can always anticipate the bank runs.

2.3.2.1 Unanticipated Bank Run

If depositors cannot anticipate the bank run which is possible because $1+k<c_1$, the second best contract offered by each bank is $\delta^{SBU}=(c_1^{SBU},c_2^{SBU})$ solving

$$\max_{c_1,c_2} \pi u(c_1)+(1-\pi)u(c_2) \tag{2.4}$$

$$s.t. \qquad (1-p)[(1+k-\pi c_1)R-(1-\pi)c_2]=kR_k \tag{2.5}$$

$$1+k<c_1 \tag{2.6}$$

$$c_1<c_2 \tag{2.7}$$

$$\pi u(c_1)+(1-\pi)u(c_2)>u(1) \tag{2.8}$$

The left hand side of equation (2.5) is the expected remaining capital at date 2 after the bank pays all the contract with depositors. It should be greater than or equal to the required expected return from investors (right hand side of equation (2.5)), which is the financing cost of the capital k. Because banks operate in a competitive environment, we have the equality. It also can be written in another way

$$1 - k[\frac{R_k}{(1-p)R} - 1] = \pi c_1 + \frac{(1-\pi)c_2}{R}. \tag{2.9}$$

Because $R_k \geq R$ and $1 - p < 1$, $\frac{R_k}{(1-p)R} - 1$ is greater than zero. Compare the equation (2.9) to equation (2.2), we can find that the capital requirement k decreases the budgets of all banks for deposit contracts because of the high cost of capital even though $R_k = R$ when investors are risk neutral. When $k = 0$, which means no minimum capital requirement, equation (2.9) and equation (2.2) are the same. Hence, we have $\delta^{SBU} = \delta^{FB}$, that is $c_1^{SBU} = c_1^{FB}$ and $c_2^{SBU} = c_2^{FB}$. However, δ^{SBU} is still second best, because in a decentralized economy with only capital requirement ($k = 0$ in this case), bank run equilibrium always exists under the assumption $1 + k < c_1$. When this chapter mention the first best, it is not only the deposit contract offered by the banks, but also means that the contract can work successfully with the probability of one. The first best is the outcome that the regulator wants to achieve.

Inequalities (2.6), (2.7) and (2.8) are not the budget constraint for banks. They are the conditions that second best contrast δ^{SBU} is a equilibrium in the model. Inequality (2.6) is the core assumption in this chapter. When $k = 0$, $c_1^{SBU} = c_1^{FB} > 0$. With the increase of required capital k, banks will have less budget for depositors according to equation (2.9). Hence, c_1^{SBU} and c_2^{SBU} will decrease. Assumption $1 + k < c_1$ makes sure that required capital cannot be too high, otherwise we will have $p = 0$ which means no bank run equilibrium exists. Inequality (2.7) always holds for δ^{SBU} because of the strict concavity of the utility function. It makes sure that late type depositors are willing to wait for date 2. Inequality (2.8) always holds for δ^{SBU} because $c_1^{SBU} > 1 + k > 1$ and $c_2^{SBU} > c_1^{SBU} > 1$. It makes sure that depositors are willing to accept the contract.

2.3.2.2 Anticipated Bank Run

If depositors can anticipate the bank run, the second best contract offered by each bank is $\delta^{SBA} = (c_1^{SBA}, c_2^{SBA})$ solving

$$\max_{c_1,c_2}(1-p)[\pi u(c_1) + (1-\pi)u(c_2)] + pu(c_1)\frac{1+k}{c_1} \tag{2.10}$$

$$s.t. \qquad (1-p)[(1+k-\pi c_1)R - (1-\pi)c_2] = kR_k \tag{2.11}$$

$$1+k < c_1 \tag{2.12}$$

$$c_1 < c_2 \tag{2.13}$$

$$\pi u(c_1) + (1-\pi)u(c_2) > u(1) \tag{2.14}$$

The budget constraint of banks (2.11) is the same as in unanticipated case ((2.5) or (2.9)) because investors can always anticipate the bank run. The *ex ante* utility function of the representative depositor changed because now depositors will consider the utility under the bank run equilibrium.

Proposition 2.3.1. *Let $\delta^{SBU} = (c_1^{SBU}, c_2^{SBU})$ solve (2.4) subject to (2.5) and $\delta^{SBA} = (c_1^{SBA}, c_2^{SBA})$ solve (2.10) subject to (2.11). They have the following relations with feasible exogenous variables $k \geq 0$ and $p > 0$,*

$$\frac{\partial c_1^{SBU}}{\partial k} < 0, \quad \frac{\partial c_1^{SBA}}{\partial k} < 0,$$
$$\frac{\partial c_1^{SBU}}{\partial p} < 0 \ (*), \quad \frac{\partial c_1^{SBA}}{\partial p} < 0.$$

$(*)$ only holds for $k > 0$.

For any given p and k, $c_1^{SBA} < c_1^{SBU} < c_2^{SBU} < c_2^{SBA}$. Feasible parameters k and p should be low enough to make sure $1+k < c_1^{SBA}$.

The proposition states that holding other exogenous variables unchanged, the increase of capital requirement k or the probability of bank run equilibrium p will make banks offer the lower short term interest c_1 in both unanticipated bank run case and anticipated bank run case. For unanticipated bank run case, it is straightforward because banks need to pay high cost to finance the required capital k and the cost will increase if the probability of bank run equilibrium p goes up. Hence, the budget for banks to pay the depositors decreases below one unit according to equation (2.9). The *ex ante* utility function of the representative depositor (2.4) remains the same, so c_1^{SBU} and c_2^{SBU} will decrease. For anticipated bank run case, the budget constraint is the same as former case. However, the *ex ante* utility function of the representative depositor (2.10) will also change with k and p. The concavity of $u(c)$ and $u(0) = 0$ makes sure that c_1^{SBA} will decrease as well.

According to proposition 2.3.1 and analysis above, we know that when $k = 0$, $c_1^{SBA} < c_1^{SBU} = c_1^{FB}$ and $c_1^{FB} > 1$. To make sure the assumption $1 + k < c_1$ satisfied, the probability of bank run equilibrium p should be low enough to get $1 < c_1^{SBA}$ at $k = 0$. With the increase of k, c_1^{SBA} will decrease and get closer to one. However, there always exists the feasible parameter k to make sure $1 + k < c_1^{SBA}$. When $1 + k < c_1^{SBA}$ is satisfied, the second best contracts δ^{SBU} and δ^{SBA} are indeed two equilibria in unanticipated and anticipated bank run cases and they are both vulnerable to run.

The proposition 2.3.1 captures the spirit of Goldstein and Pauzner (2005). Banks will offer short term interest rate c_1 lower than first best when they consider the endogenous probability of bank runs. In the model of Goldstein and Pauzner (2005), the probability of bank run equilibrium p will change with short term interest rate c_1 continuously, and they have positive relation. In this chapter, p is greater than zero and unchanged when $1 + k < c_1$, and zero otherwise, but I only consider the case that $1 + k < c_1$. Although p is exogenous in my model, banks will also offer short term interest rate c_1 lower than first best in two second best cases. As to the required capital of the banks k, proposition 2.3.1 is intuitive in reality that the bank which has high capital offers lower short term interest rate because depositors are willing to believe the banks with the high level of capital.

The analysis above treats capital k as an exogenous variable. The proposition below discusses the incentive of banks to keep the capital.

Proposition 2.3.2. *In the case of the unanticipated bank run, the required capital will decrease the expected utility of depositors. Hence, banks have no incentive to hold capital, and they only keep capital as required. In the case of anticipated bank run, there exists a critical* $R_k^* > R$ *such that* *required capital will decrease the expected utility of depositors if* $R_k > R_k^*$ *and the reverse holds if* $R_k < R_k^*$*. Hence, especially, when* $R_k = R$*, banks will hold capital as much as they can.*

The unanticipated bank run case is straightforward. For the case of the anticipated bank run, banks have a trade-off between the narrow budget and high bank run utility when holding the capital. When $R_k < R_k^*$, holding more capital can increase the utility of depositors. Hence, banks will try to hold capital as much as they can. In this case, the capital requirement can be seen as a cap of all capital in the economy. The assumption $1 + k < c_1^{SBA}$ still holds for this case. As an alternative, it is reasonable to think that R_k will increase with k, it can also explain that why banks will not hold enough capital to eliminate the bank run $1 + k > c_1^{SBA}$. In reality, when the cost of financing capital is low enough, banks will keep excessive capital than the minimum requirement to show the comprehensive ability to deal with the market risks. Although they offer a lower short term interest rate ($\partial c_1 / \partial k < 0$), depositors are still willing to accept the offer from the banks which have the high capital.

2.3.3 Deposit Insurance

In the basic model, deposit insurance can achieve the first best without any cost like Diamond and Dybvig (1983). At date 0, the regulator sets a deposit insurance policy. The deposit insurance contract stipulates payments to the early and late type depositors as a function of the deposit contract $\delta = (c_1, c_2)$ in the event that banks are unable to make its promised payments. Let the payments to c_1 as $I(c_1)$ and c_2 as $I(c_2)$. If the bank fails at date 1, the depositors, who cannot withdraw c_1 based on the deposit contract from the bank, can get $I(c_1)$ based on the deposit insurance contract from the regulator. Likewise, if the bank fails at date 2, the depositors, who cannot withdraw c_2 based on the deposit contract from the bank, can get $I(c_2)$ based on the deposit insurance contract from the regulator. Importantly, if a bank fails at date 1, the late type depositors cannot get $I(c_2)$ if they want to wait until date 2, but they can definitely get $I(c_1)$ at date 1 if they cannot withdraw c_1 before the failure of the bank. The regulator cannot fail.

If the regulator sets $I(c_1) = c_1^{FB}$ and $I(c_2) = c_2^{FB}$ and $k = 0$, for any deposit contract from banks $\delta = (c_1 \leq c_1^{FB}, c_2 \leq c_2^{FB})$, a late type depositor will always choose to wait even if she believes that all other depositors will withdraw their money at date 1. If the bank fails at date 2, she can get $I(c_2) = c_2^{FB}$, even if the bank fails at date 1 and she is the last one who goes to the bank, she can still get $I(c_1) = c_1^{FB}$. Waiting is a dominant strategy for late type depositors. As to banks, if they offer the contract $\delta = (c_1 \leq c_1^{FB}, c_2 \leq c_2^{FB})$, bank run cannot happen because of the deposit insurance. The competitive environment makes banks to choose $\delta = (c_1 = c_1^{FB}, c_2 = c_2^{FB})$ with no capital requirement. In this case, the probability of bank run p is equal to zero. If $R_k = R$, banks are indifferent to keep any level of capital and with any capital requirement k, competitive banks will still offer the contract $\delta = (c_1 = c_1^{FB}, c_2 = c_2^{FB})$. The first best is achieved. The deposit insurance is only an *ex ante* commitment, it will never be exerted, so it has no real cost.

2.4 The Extended Model

Chapter 2 focuses on the interest conflict between the banks and depositors under an equilibrium which is vulnerable to run. In the above basic model, the banks only have one production technology to choose (although they can also choose the storage technology, it is weakly dominated by the production technology). Hence, the competitive environment will make banks maximize the expected utility function of the representative depositor. No interest conflict between the banks and depositors in the basic model, so deposit insurance works perfectly in the basic model. The extended model is based on Cooper and Ross (2002).

2.4.1 The Lemon Project

To allow the bank an avenue for moral hazard, assume that there is another production technology. The new production technology is also a long run investment but risky. Given one unit invested at date 0, the new technology yields λR at date 2 with the probability v and 0 otherwise. If the new production aborts at date 1, it has a liquidation value of one unit which is the same as the old risk-free production technology. Assume that $\lambda > 0$ and $v\lambda < 1$, so the new risky technology has a higher return if it is successful but nothing otherwise. The risky production technology has a lower expected return than the old risk-free technology. Hence, depositors and investors who avert the risk will prefer the old risk-free technology although depositors cannot use the production technology without the banks. The new risky production technology is called lemon project. At last, assume $v\lambda R > 1$ which means the expected return of the lemon project at date 2 is greater than one. It is reasonable because the lemon project has the liquidation value of one unit at date 1.

Assume that bank managers are risk neutral and they will maximize the capital (equity) of the bank. There still exists interest conflict between bank managers and investors because investors are risk-averse. However, it is not the key point of this chapter. The lemon project has value for the bank managers because it may generate a positive profit in the competitive environment. Consider the extreme case that capital requirement k is zero; the most capital that the banks can lose is zero. If a bank manager only chooses the old technology, the bank will still have zero capital at date 2 after paying all the deposit contract which is the same as the worst case, losing zero capital. However, if she goes to the lemon project, the bank has a positive probability $v(1-p)$ to earn positive capital at date 2 after paying all the deposit contract under the condition that depositors do not monitor the bank. The lemon project has value for the risk-neutral bank managers because of the limited liability of the banks.

Formally, let i denote funds (per unit of deposit and capital) that a bank places in the lemon project. The portfolio choice of a bank is determined from

$$\max_i (1-p)\{v[i\lambda R + (1+k-i-\pi c_1^{SB})R - (1-\pi)c_2^{SB}] + (1-v)\max[(1+k-i-\pi c_1^{SB})R - (1-\pi)c_2^{SB}, 0]\} \tag{2.15}$$

The c_1^{SB} and c_2^{SB} in (2.15) are c_1^{SBU} and c_2^{SBU} in unanticipated bank run case and c_1^{SBA} and c_2^{SBA} in anticipated bank run case. From (2.15), it can be shown that the bank manager will use the all in bet when decides the optimal portfolio i. The bank will place either all of the funds in the lemon project ($i = 1 + k$) or all of the funds in the risk-free production technology ($i = 0$). In addition, assume $R_k < \frac{1+k}{k(1-p)}R$, it makes sure the bank has no capital left if the bank manager chooses $i = 1+k$ and the lemon project fails at date 2 when bank run equilibrium does not happen.

Proposition 2.4.1. *For the portfolio choice from (2.15), the bank manager will choose $i = 0$ if and only if*

$$k \geq k^* = \frac{R(1-p)v(\lambda - 1)}{R(1-p)v(1-\lambda) + R_k(1-v)} \tag{2.16}$$

and $i = 1 + k$ otherwise.

The k^* in equation (2.16) is greater than zero because $\lambda > 1$, $R_k \geq R$ and $v\lambda < 1$. The intuition is straightforward. When the required capital k is large, banks will lose large capital if it fails. Lemon project has no value for the banks when they keep a high level of capital.

2.4.2 Depositor Monitoring

In Cooper and Ross (2002), they assume that after suffering a monitoring cost, depositors can make banks choose the original risk-free production technology. It is unrealistic because when banks go to the lemon project, they always do it secretly and depositors can find the misconduct of banks after the lemon project has already begun. In this chapter, I use another more realistic assumption about the monitoring behavior of depositors in the spirit of Calomiris and Kahn (1991), and Diamond and Rajan (2001). The threat of bank runs solves the agency problems by the fact that depositors who monitor banks will trigger a run if the bank is likely to expropriate depositor funds. In the model setting, at date 0, banks can choose the lemon project or the old risk-free project, and depositors cannot know the choice of banks. At date 1, depositors see the choice of banks. Early type depositors always withdraw their money at date 1 to achieve c_1. Late type depositors decide to trigger a fundamental-based bank run or not if panic-based bank run does not happen. The outcome of the lemon project (success or fail) can only be known at date 2.

The probability of bank run equilibrium p only refers to the panic-based bank run, and it is exogenous. If panic-based bank run does not happen which means the normal deposit contract equilibrium happens with the probability of $1 - p$, the late type depositors may still trigger a fundamental-based bank run if they find banks go to the lemon project and triggering a bank run is better than waiting to the date 2. The panic-based bank run has no relation to the fundamental of banks. It is totally exogenous. Banks that only choose the risk-free project (no fundamental problem) can still suffer a panic-based bank run because $1+k < c_1$. A fundamental-based bank run is endogenous. It is due to the misconduct of banks. Only banks which invest the lemon project would suffer the fundamental-based bank runs. In a word, when depositors (late type only in the model) find that the banks which invest the lemon project, they may withdraw their money from them to the banks that have no fundamental problems if it gives the depositors more utility.

In the model, at date 1, when late type depositors find that their banks go to the lemon project (all in from the above analysis), they will still withdraw their money at date 1 (assume that they have already seen the sunspot that shows no panic-based bank run happens) if and only if

$$u(c_1)\frac{1+k}{c_1} - vu(c_2) \geq 0 \tag{2.17}$$

The first part of inequality (2.17) is the utility that late type depositors can achieve if they trigger a fundamental-based bank run. The second part is the utility of late type depositors if they wait. From the inequality (2.17), let v^{SBU} and v^{SBA} satisfy the equations below

$$u(c_1^{SBU})\frac{1+k}{c_1^{SBU}} - v^{SBU}u(c_2^{SBU}) = 0, \quad u(c_1^{SBA})\frac{1+k}{c_1^{SBA}} - v^{SBA}u(c_2^{SBA}) = 0 \tag{2.18}$$

For the case of unanticipated bank run, if the lemon project has $v \leq v^{SBU}$, the late type depositors will withdraw their money definitely at date 1 when their banks go to the lemon project. Hence, the banks will definitely lose their capital k if they speculate on the lemon project. If the bank managers only choose the risk-free project, they have probability of $1-p$ to leave the Rk capital for the investors at date 2. Hence, banks will not speculate on the lemon project if $v \leq v^{SBU}$ in the case of unanticipated bank run. The interesting thing is that the effect of monitoring behavior from depositors does not depend on the λ of the lemon project. Only the probability of success v of the lemon project is the critical value that whether banks will speculate on it or not. If $v > v^{SBU}$ and the condition on k in equation (2.16) is not satisfied, all banks will go to the lemon project and the deposit contract δ^{SBU} will change to a worse equilibrium. In a word, when condition on k in equation (2.16) is not satisfied, the second best deposit contract $\delta^{SBU} = (c_1^{SBU}, c_2^{SBU})$ is an equilibrium only when $v \leq v^{SBU}$. The same is to the case of anticipated bank run. For the analysis below, assume that $v \leq v^{SBU}$ and $v \leq v^{SBA}$, so δ^{SBU} and δ^{SBA} are always equilibria. In this case, the *ex ante* threat of fundamental-based bank run from (late type) depositors is credible. It works like a *ex ante* commitment to prevent banks from the lemon project.

2.4.3 Deposit Insurance

The deposit insurance in the extended model will cause a moral hazard issue. If the regulator sets the deposit insurance contract $I(c_1) = c_1^{FB}$ and $I(c_2) = c_2^{FB}$ and capital requirement $k = 0$ as before, depositors will not monitor the bank any more. Waiting is always a dominant strategy for late type depositors under such deposit insurance. Hence, all banks will speculate on the lemon project, and the regulator will suffer the cost of deposit insurance $(1-v)(1-\pi)c_2^{FB}$. When fully deposit insurance is introduced, there are no more fundamental-based bank run and panic-based bank run ($p = 0$), the cost of deposit insurance is from the failure of the lemon project. Because the lemon project has a lower expected return than the risk-free project, the benefit from banks is always lower than the cost of deposit insurance.

To solve the problem, Cooper and Ross (2002) proposed the minimum capital requirement. From proposition 2.4.1, let $p = 0$, $R_k = R$ in equation (2.16), we have when $k \geq k^* = [v(\lambda-1)]/(1-\lambda v)$, banks will not speculate on the lemon project under the first best deposit insurance. First best outcome is achieved by using the combination of capital requirement and deposit insurance. Their proposition is correct. However, the capital requirement is too large to be feasible in reality, even for very normal parameters. First, consider a simple numerical example that a lemon project with $v = 0.3$, $\lambda = 3$ and $\lambda v = 0.9 < 1$. The minimum capital requirement should be no less than $k^* = [v(\lambda - 1)]/(1 - \lambda v) = 6$ to prevent banks from speculating the lemon project with only 30% successful rate. $k = 6$ means that with one unit of the deposit in liability, banks need to hold six units of capital in equity. It is ridiculous in reality for any financial institution. Financial institutions often have a high level of financial leverage. According to the newest Basel III, banks need to hold 4.5% tier one capital (equity), i.e. $k = 0.045$. In the next numerical example section, I will stick to the parameter $k = 0.045$. Second, the proposition from Cooper and Ross (2002) is not feasible also because it will violate the core assumption $1 + k < c_1$ in the model. For a lemon project, if $1 + k^* > c_1$, the probability of panic-based bank run p is zero and first best outcome is achievable, why we still need the deposit insurance. The regulator only needs to use the capital requirement policy such that $1 + k = c_1$, and no panic-based bank run will happen. The introduction of deposit insurance only causes the problem of moral hazard from the lemon project and has no benefit at all. Third, the proposition from Cooper and Ross (2002) is based on the assumption $R_k = R$, which is only reasonable when k is low.

2.4.4 The Regulator

In most related literature, the regulator only sets the policy but not a true player in the game. It can be shown that the regulator can play an important role to solve the problem of moral hazard. Assume that a lemon project exists in the economy with $v \le v^{SBU}$ and $v \le v^{SBA}$, so second best deposit contracts δ^{SBU} and δ^{SBA} are equilibria that are vulnerable to panic-based run ($1 + k < c_1$). Also assume that k^* in (2.16) of the lemon project cannot be satisfied under deposit insurance contract $I(c_1) = c_1^{FB}$ and $I(c_2) = c_2^{FB}$ because $1 + k^* > c_1$. It is still possible to achieve the first best outcome without any cost like the basic model. The regulator still sets the deposit insurance contract $I(c_1) = c_1^{FB}$ and $I(c_2) = c_2^{FB}$ as before, but this time it will also minimize its cost. Assume that the regulator also has the right to cease a bank at date 1 if the regulator finds the bank speculates on the lemon project. In reality, the regulator has more information about the bank than depositors. If depositors can know the misconduct of the bank at date 1, the regulator can definitely know it too. In a way, when the regulator ceases a bank at date 1, it plays like the same way that (late type) depositors trigger a fundamental-based bank run. With the introduction of the first best deposit insurance, the *ex ante* threat (commitment) of the fundamental-based bank run from depositors does not exist anymore, but the *ex ante* threat (commitment) from the regulator can be built if the regulator will cease the bank when banks speculate on the lemon project and it is the common knowledge. The deposit insurance transfers the moral hazard risk from depositors to the regulator (insurer), so the regulator has the incentive to monitor the banks instead of depositors. The key point for the mechanism to success is that the insurer who gives the deposit insurance and the regulator who can cease or make an early intervention on banks are the same entity. The regulator, also the insurer, will make a decision on ceasing the bank or not based on the principle of cost minimization.

If the regulator plans to cease the bank at date 1, it has two different methods of resolution. First, the regulator will always pay late type depositors c_2^{FB} at date 2 even the bank is closed at date 1. In this method, the regulator will keep the balance sheet of the failed bank from date 1 to date 2 and it will cost the regulator C to do it[3]. In practice, the ceasing cost depends on the specific types of resolution. If the regulator can find another healthy bank purchases all of the assets of the failed bank and assumes all of the liabilities[4], the ceasing cost is very low for the regulator. However, when no bank is interested in the deposit franchise and an insured-deposit transfer cannot be arranged, the regulator needs to keep the balance sheet of failed banks by itself and the ceasing cost can be very high. I will refer the first method to the un-liquidating method in this chapter. Second, the regulator will pay all depositors c_1^{FB} at date 1 if they cannot get their deposit from the bank. The bank is closed at date 1 and all assets are liquidated. The regulator has no ceasing cost in this case. I will refer the second method to the liquidating method in this chapter. In most cases, the un-liquidating method has a lower cost to the regulator compared to the liquidating method because liquidation is not efficient. However, when the ceasing cost is very high for the regulator, liquidating method can have a lower cost for the regulator. Although the un-liquidating method always has a higher utility for the late type depositors compared to the liquidating method, the regulator will still stick to the least-cost resolution. The deposit insurance with least cost commitment in this chapter not only has the least-cost resolution in practice, the requirement that chooses a method of resolution that minimizes the present value of the costs incurred by the deposit insurer, but also has the least-cost timing of bank closure, the regulator

[3]I will refer C to the ceasing cost later.

[4]This is the purchase-and-assumption transaction, the healthy bank is willing to bid a negative net asset bank because it values the customers of the failed bank or any other charter value.

makes decision on ceasing or not ceasing a bank based on the cost of the deposit insurer. No matter what method the regulator uses to cease a bank, if it did it, the bank would lose all the capitals. The opportunity cost for the regulator to pay one unit at date 1 is R unit at date 2, because the risk-free production technology is available to the regulator and the regulator will always use this technology because it is weakly dominant than storage technology and the lemon project has no value for the regulator.

Formally, assume that the regulator will use the least-cost requirement for the decision on ceasing the bank or not at date 1 and all banks know the commitment. The regulator has the incentive to do it because it is also the insurer. $R_k = R$ must hold for all $k > 0$ because capital requirement will decrease the budget of banks for depositors if $R_k > R$ and first best cannot be achieved. It is a reasonable assumption when k is low because, under the first best deposit insurance, the probability of panic-based bank run p is zero. Investors can definitely achieve R at date 2 given one unit invest in the capital at date 0 (if banks do not speculate on the lemon project) without the risk of panic-based bank run. If $k = 0$, R_k will not affect the budget of banks for depositors. Regulator sets the first best deposit insurance contract $I(c_1) = c_1^{FB}$ and $I(c_2) = c_2^{FB}$ and there are no more fundamental-based bank run and panic-based bank run ($p = 0$). At date 1, when regulator finds that a bank goes to the lemon project (all in from the above analysis), it will have costs below if it uses the un-liquidating method to cease the bank

$$(1 - \pi)c_2 - v\lambda R(1 + k - \pi c_1 - C). \tag{2.19}$$

Assume $C < 1 + k - \pi c_1$ in (2.19), which means the assets of the failed bank always has the positive value at date 2 even considering the ceasing cost. It is reasonable because the regulator can always displace the assets with no cost and just pay the liability $(1 - \pi)c_2$ at date 2. The regulator liquidates $\pi c_1 + C$ assets from the failed bank which speculates on lemon project at date 1 because the expected return ($v\lambda R$) of lemon project is less than the opportunity cost (R). The costs of regulator when it uses the liquidating method to cease the bank is

$$R[c_1 - (1 + k)] \tag{2.20}$$

At date 1, the regulator needs to pay all the depositors c_1^{FB} and she can get $1+k$ from the bank by liquidating the assets of the bank. The payment happens at date 1, so it needs to time the opportunity cost R. According to (2.19) and (2.20), the regulator will choose the un-liquidating method when it plans to cease the bank at date 1 if and only if

$$C \leq \frac{R(c_1-1)-(1-v\lambda)[(1-\pi)c_2+Rk]}{v\lambda R} \tag{2.21}$$

When condition (2.21) is satisfied, the regulator will cease the bank at date 1 if and only if

$$(1-v)(1-\pi)c_2^{FB}-[(1-\pi)c_2-v\lambda R(1+k-\pi c_1-C)] \geq 0 \tag{2.22}$$

The first part of inequality (2.22) is the cost of the regulator if she does not cease the bank at date 1. At date 2, when the lemon project fails, the regulator needs to pay the late type depositors c_2^{FB} and she get nothing from the failed bank. The second part of inequality (2.22) is the cost of the regulator if she ceases the bank at date 1 according to (2.19). Simplify inequality (2.22), we have

$$\lambda \geq \frac{(1-\pi)c_2}{R(k-C)+(1-\pi)c_2} \tag{2.23}$$

From the condition (2.23), we can easily get the next proposition.

Proposition 2.4.2. *If the capital requirement is greater than or equal to the ceasing cost of the failed bank ($k \geq C$), the deposit insurance with least-cost commitment will build the perfect regulator discipline in a way that it prevents banks from any possible lemon project in the extended model.*

In the extended model, deposit insurance eliminates the depositor discipline from monitoring behavior. However, regulatory discipline is built from the least-cost commitment. The proposition 2.4.2 states that if the regulator uses another regulator discipline, capital requirement, and sets $k \geq C$, the combination of capital requirement and least-cost commitment will prevent banks from speculating on any possible lemon project, even for the lemon projects with $v \geq v^{SBU}$ and $v \geq v^{SBA}$ when depositor discipline is not credible. However, if the ceasing cost is too high ($1+C > c_1$), regulator cannot use the combination of capital requirement and least-cost commitment to achieve the perfect depositor discipline. If they can set the capital as high as the ceasing cost, the high capital will eliminate the panic-based bank run ($1+k > c_1$) and deposit insurance is meaningless.

If ceasing cost is high and we have $k < C$, the perfect regulator discipline is not available. How is the regulator discipline when it compares to the depositor discipline? Depositor discipline is not perfect. It is only credible for $v \leq v^{SBU}$ and $v \leq v^{SBA}$ according to the analysis above. Let's consider the worst case of depositor discipline from the least-cost commitment. When ceasing cost is too high, and condition (2.21) is not satisfied. Hence, the regulator will choose to use the liquidating method if it plans to cease the bank at date 1. Formally, when condition (2.21) is not satisfied, the regulator will cease the bank at date 1 if and only if

$$(1-v)(1-\pi)c_2 - R[c_1 - (1+k)] \geq 0 \tag{2.24}$$

Similarly, the first part of inequality (2.24) is the cost of the regulator if she does not cease the bank at date 1. The second part of inequality (2.24) is the cost of the regulator if she ceases the bank at date 1, according to (2.20). Let v^{FB} satisfy the equation below

$$(1-v^{FB})(1-\pi)c_2^{FB} - R[c_1^{FB} - (1+k)] = 0 \tag{2.25}$$

If the lemon project has $v \leq v^{FB}$, the regulator will cease the bank at date 1 when a bank goes to the lemon project even if ceasing cost is very high. In this case, the *ex ante* threat from the regulator is credible. It works like a *ex ante* commitment to prevent banks from the lemon project[5].

Proposition 2.4.3. *Let v^{FB} solves equation (2.25) and v^{SBU}, v^{SBA} solve equation (2.18). They have the following relations*

$$v^{SBU} < v^{FB}, \quad v^{ABU} < v^{FB} \tag{2.26}$$

The commitment from regulator is always stronger than the commitment from depositors to prevent banks from speculating. Hence, the first best deposit insurance with least-cost commitment will not deteriorate interest conflict between banks and depositors from the monitoring perspective.

The conflict of interest between banks and depositors exists in a decentralized economy (no deposit insurance). In the model, because of the asymmetric information and limited liability,

[5]Actually, regulator discipline may prevent banks from lemon project with $v > v^{FB}$, because the liquidating method is only one of the method that regulator can use. If ceasing cost is low, condition (2.21) is satisfied, regulator can do better with un-liquidating method.

banks have the incentive to speculate on the lemon project. The proposition 2.4.3 states that if in the decentralized economy, the commitment of depositor monitoring prevents banks from the lemon project ($v \leq v^{SBU}$ or $v \leq v^{SBA}$), the least-cost commitment from the first best deposit insurance will also prevent banks from the lemon project ($v < v^{FB}$). For lemon project which has ($v > v^{SBU}$ or $v > v^{SBA}$), neither second best deposit contract δ^{SBU} nor δ^{SBA} is an equilibrium any more in the decentralized economy because all banks go to the lemon project. Hence, it is easy to get the next proposition.

Proposition 2.4.4. *In the extended model, if second best deposit contract δ^{SBU} or δ^{SBA} is an equilibrium in the decentralized economy, the deposit insurance $I(c_1) = c_1^{FB}$ and $I(c_2) = c_2^{FB}$ with least-cost commitment can achieve the first best outcome with no cost for any k if $R_k = R$ or $k = 0$ if $R_k > R$.*

The deposit insurance in proposition 2.4.4 can achieve the first best outcome without bringing extra moral hazard because of the least-cost commitment from the regulator. The traditional way treats deposit insurance stable once the policy is enacted. The regulator is not a true player in the game. In my model, the regulator can take actions on ceasing the bank according to the least-cost principal. The effectiveness of proposition 2.4.4 in practice highly depends on how strong the degree of ex ante commitment from the regulator it is. A coherent policy of resolving the failing bank based on the least-cost principal is a strong commitment to preventing banks from speculating the lemon project. If politic interventions on the resolution of banks frequently happened in history, existing banks may take a chance to speculate and test the attitude of the regulator.

In the analysis above, the regulator is also the deposit insurer. It is possible to build a strong commitment when the regulator who makes a decision on the resolution of insolvent banks is different from the deposit insurer. If the regulator claims that she will make a decision on the resolution based on the least-cost of the deposit insurer and all banks believe in the reputation of the regulator, the deposit insurance with least-cost commitment still works. However, it is better to have one entity to do both things. First, the least-cost principal generates the incentive for deposit insurer to diligently monitor the bank instead of depositors. Separated entities may not work efficiently. Second, a unified entity can build a strong commitment that the regulator will stick to the least-cost principal because it is the insurer.

2.5 Numerical Examples

In this section I illustrate the properties of the model with some numerical examples. Assume the depositors' utility function is given by

$$u(c) = \frac{(c+f)^{1-\sigma}}{1-\sigma} - \frac{(f)^{1-\sigma}}{1-\sigma}. \tag{2.27}$$

The function is a modified version of a standard CRRA function with σ being the relative risk aversion coefficient. Parameter f makes sure $u(0) = 0$ is satisfied. For simplicity, parameters are set as follows $\sigma = 2$ and $f = 1$. Parameter $\sigma = 2$ guarantees that the model always has real number solutions. The utility function (2.27) becomes $u(c) = c/(c+1)$. It is easy to check the function satisfies $u'(c) > 0$, $u''(c) < 0$, $u(0) = 0$ and $-cu''(c)/u'(c) > 1$ for $c > 1$.

As to remaining parameters, let $R_k = R = 3$ and $p = 0.02$. I consider the different fraction $1-\pi$ of the late type depositors in next two tables. Table 2.1 shows the case that late type depositors is greater than early type depositors with $\pi = 0.3$. Table 2.2 shows the case that late type depositors is less than early type depositors with $\pi = 0.7$. For each case, I list the outcomes on capital of $k = 0$ and $k = 0.045$. Parameter $k = 0.045$ is based on Basel III.

Table 2.1 Numerical Examples with $\pi = 0.3$

	k	c_1	c_2	$E[u(c)]$	v^*
Unanticipated bank run	0	1.1776	2.7717	0.6766	0.6249
without deposit insurance	0.045	1.1763	2.7694	0.6764	0.6536
Anticipated bank run	0	1.1337	2.8281	0.6724	0.6344
without deposit insurance	0.045	1.1304	2.8285	0.6726	0.6640
First best deposit insurance	0	1.1776	2.7717	0.6766	0.7254
with least cost commitment	0.045	1.1776	2.7717	0.6766	0.7950

Table 2.2 Numerical Examples with $\pi = 0.7$

	k	c_1	c_2	$E[u(c)]$	v^*
Unanticipated bank run	0	1.0614	2.5704	0.5764	0.6738
without deposit insurance	0.045	1.0603	2.5686	0.5762	0.7047
Anticipated bank run	0	1.0553	2.6129	0.5746	0.6728
without deposit insurance	0.045	1.0540	2.6130	0.5748	0.7035
First best deposit insurance	0	1.0614	2.5704	0.5764	0.7612
with least cost commitment	0.045	1.0614	2.5704	0.5764	0.9363

The v^* in the table refers to v^{SBU}, v^{SBA} and v^{FB} in each equilibrium. We can find that $v^{SBU} < v^{FB}$ and $v^{SBU} < v^{FB}$ in two tables as expected. $E[u(c)]$ is the *ex ante* expected utility of the representative depositor. First best outcome always trumps the two second best outcomes of the decentralized economy in all cases. The only exception is the case when $k = 0$, $c_1^{SBU} = c_1^{FB}$ and $c_2^{SBU} = c_2^{FB}$, so the expected utility of first best is the same as that of second best in the case of unanticipated bank run. However, the second best deposit contract δ^{SBU} is still vulnerable to run in this case. Because depositors are naive such that they cannot anticipate the potential bank run, they perceive that they have the same happiness with the first best outcome.

2.6 Empirical Evidence

The key propositions of this chapter come from two aspects. One is that depositor discipline is not very effective. The other is that the regulator has a strong commitment to sticking to the least-cost principal.

2.6.1 Deposit Discipline

The depositor discipline is not effective in the model because the fundamental-based bank run is not efficient for depositors. Only if the lemon project is very bad, the threat from depositors to trigger a fundamental-based bank run is credible for banks. Empirical evidence on the discipline of depositors is mixed. Flannery (1998) contends that depositors are not only concerned about the solvency of banks, but also about the solvency of insurer and willingness of the government to support it. Park and Peristiani (1998) find evidence for market disciplines by depositors. Cook and Spellman (1994) report that rates on small CDs generally vary with banks' financial conditions. However, Jagtiani and Lemieux (2001) find no evidence of market discipline in the CD market.

Bliss and Flannery (2002) note that effective deposit discipline involves two distinct components: the ability of depositors to evaluate a bank's financial position, and to produce or trigger change at the bank management level. Iyer et al. (2013) find that depositors behave differently in a panic-based bank run and a fundamental-based bank run. Hence, depositors have the ability to evaluate the fundamental of banks.

2.6.2 Regulator Discipline

Iyer et al. (2013) also find that fundamental-based bank run resulted by depositors only begin after the central bank audit shows that the bank is already insolvent. It supports the assumption in this chapter that the regulator can definitely find the speculation of the bank if depositors can do it. According to Iyer et al. (2013), the regulator has more information about banks' financial positions, and depositors actually follow the regulator.

The least-cost commitment in the model has two kinds of meanings, least-cost resolution and least-cost timing of closure.

2.6.2.1 Least-Cost Resolution

In the United State, the least-cost resolution refers to the resolution method that minimizes the present value of net losses incurred by the deposit insurer, regardless of other factors. After the passage of FDICIA, which mandated the least-cost requirement, all policy objectives became secondary to cost considerations in determining the resolution method. FDICIA provided fro one exception to least-cost requirement, namely, the systematic risk exception. Before the FDIC can invoke this exception, two-thirds of the FDIC Board Directors and two-thirds of the Board of Governors of the Federal Reserve System must agree that complying with the least-cost requirement would have serious adverse effects on the economic condition or financial stability. Since its creation in FDICIA, the systematic risk exception has never been used. In imposing this rather stringent requirement, banks which are considered to be too big or too important to fail cannot enjoy any additional bailout in the financial crisis.

Outside the United States, a least-cost requirement like one imposed on the FDIC is far from universal. Government bailouts for banks are common in the European Union. Berger and Turk-Ariss (2015) find that market discipline is stronger in the U.S. than the E.U., which is consistent with the conclusion of this chapter.

2.6.2.2 Least-Cost Timing of Closure

Banks typically fail after a gradual deterioration of fundamental rather than a single adverse event. Thus, the timing of the closure of a bank directly affects the costs to the deposit insurer. As a bank approaches failure, uninsured, unsecured liabilities will either flee or attempt to become insured or secured. In addition, bank managers will have an incentive to take on more risk in an attempt to earn sufficient returns to save the bank from failure. Usually, however, these actions result not in high returns to banks but in higher losses to the deposit insurer.

In the United States, FDICIA contains prompt corrective action provisions that formalize the timing of regulatory actions and closure on the basis of capital ratios. Bennett (2001) points out that formalizing early intervention may limit excessive risk-taking.

2.7 Concluding Remarks

This chapter proposes a new role that regulator who can declare a bank legally insolvent will play. It supports the least-cost resolution policy in the United States. The recent Great Recession has led to a new rebate about the least-cost requirement. Many experts in practice suggest that a least-cost requirement that has enough flexibility to allow the deposit insurer to deal with systematic risks may be advantageous. According to this chapter, flexibility means a weaker commitment from the regulator. Regulator discipline may not be strong enough to rebuild the market discipline with the loss of depositor discipline. Moreover, the least-cost commitment in this chapter also includes the least-cost timing of closure.

In addition, this chapter makes a contribution to by constructing a relatively general model based on Diamond and Dybvig (1983) but additionally includes the capital of banks. It gives a new theoretical foundation to evaluate the combination of capital requirement and deposit insurance.

Finally, recent empirical researches about deposit insurance are focused on two things. First, how strong the depositor discipline is without deposit insurance. Second, whether deposit insurance reduces the depositor discipline. This chapter gives a new perspective for empirical researches. Empirical analysis should pay more attention to the behavior of banks and the regulator when deposit insurance is in place.

2.8 Appendix: Proofs

Proof of Proposition 2.3.1

Proof. The budget constraint of banks in two cases ((2.5) and (2.11)) are the same and can be written as

$$c_2 = \frac{R}{1-\pi} - k[\frac{R_k - (1-p)R}{(1-p)(1-\pi)}] - \frac{\pi R}{1-\pi}c_1. \tag{2.28}$$

Because $\delta^{SBU} = (c_1^{SBU}, c_2^{SBU})$ solves (2.4) subject to (2.5), the first order condition is

$$f(c_1^{SBU}, k, p) = u'(c_1^{SBU}) - Ru'(c_2^{SBU}) = 0. \tag{2.29}$$

Use the implicit function theorem and obtain

$$\frac{\partial c_1^{SBU}}{\partial k} = -\frac{\frac{\partial f(c_1^{SBU},k,p)}{\partial k}}{\frac{\partial f(c_1^{SBU},k,p)}{\partial c_1^{SBU}}} = -\frac{Ru''(c_2^{SBU})[\frac{R_k-(1-p)R}{(1-p)(1-\pi)}]}{u''(c_1^{SBU}) + \frac{\pi R^2}{1-\pi}u''(c_2^{SBU})} < 0, \tag{2.30}$$

and

$$\frac{\partial c_1^{SBU}}{\partial p} = -\frac{\frac{\partial f(c_1^{SBU},k,p)}{\partial p}}{\frac{\partial f(c_1^{SBU},k,p)}{\partial c_1^{SBU}}} = -\frac{Ru''(c_2^{SBU})[\frac{kR_k}{(1-p)^2(1-\pi)}]}{u''(c_1^{SBU}) + \frac{\pi R^2}{1-\pi}u''(c_2^{SBU})} < 0. \tag{2.31}$$

The inequality (2.31) holds for $k > 0$. The numerators and denominators in both (2.30) and (2.31) are less than zero because $u''(c) < 0$. As to the case of anticipated bank run, $\delta^{SBA} = (c_1^{SBA}, c_2^{SBA})$

solves (2.10) subject to (2.11). The first order condition is

$$g(c_1^{SBA}, k, p) = (1-p)\pi[u'(c_1^{SBA}) - Ru'(c_2^{SBA})] + p(1+k)[\frac{u'(c_1^{SBA})}{c_1^{SBA}} - \frac{u(c_1^{SBA})}{(c_1^{SBA})^2}] = 0. \tag{2.32}$$

Use the implicit function theorem and obtain

$$\frac{\partial c_1^{SBA}}{\partial k} = -\frac{\frac{\partial g(c_1^{SBA}, k, p)}{\partial k}}{\frac{\partial g(c_1^{SBA}, k, p)}{\partial c_1^{SBA}}}. \tag{2.33}$$

The numerator of equation (2.33) is as follows

$$\frac{\partial g(c_1^{SBA}, k, p)}{\partial k} = (1-p)\pi Ru''(c_2^{SBA})[\frac{R_k - (1-p)R}{(1-p)(1-\pi)}] + p[\frac{u'(c_1^{SBA})}{c_1^{SBA}} - \frac{u(c_1^{SBA})}{(c_1^{SBA})^2}] < 0 \tag{2.34}$$

It is easy to check $(1-p)\pi Ru''(c_2^{SBA})[\frac{R_k-(1-p)R}{(1-p)(1-\pi)}]$ in inequality (2.34) is less than zero because of the concavity of utility function. As to $p[\frac{u'(c_1^{SBA})}{c_1^{SBA}} - \frac{u(c_1^{SBA})}{(c_1^{SBA})^2}]$ in inequality (2.34), we have

$$\begin{aligned} p[\frac{u'(c_1^{SBA})}{c_1^{SBA}} - \frac{u(c_1^{SBA})}{(c_1^{SBA})^2}] &= p\frac{u'(c_1^{SBA})c_1^{SBA} - u(c_1^{SBA})}{(c_1^{SBA})^2} \\ &= p\frac{u'(c_1^{SBA})c_1^{SBA} - [u(0) + u'(\xi)c_1^{SBA}]}{(c_1^{SBA})^2} \\ &= p\frac{u'(c_1^{SBA})c_1^{SBA} - u'(\xi)c_1^{SBA}}{(c_1^{SBA})^2} < 0 \end{aligned}$$

where $\xi \in (0, c_1^{SBA})$. Because $u''(c) < 0$ and $\xi < c_1^{SBA}$, $p[\frac{u'(c_1^{SBA})}{c_1^{SBA}} - \frac{u(c_1^{SBA})}{(c_1^{SBA})^2}]$ is also less than zero. Thus, the inequality (2.34) holds. The denominator of equation (2.33) is also negative according to the second order condition, so $\frac{\partial c_1^{SBA}}{\partial k}$ is negative. Similarly,

$$\frac{\partial c_1^{SBA}}{\partial p} = -\frac{\frac{\partial g(c_1^{SBA}, k, p)}{\partial p}}{\frac{\partial g(c_1^{SBA}, k, p)}{\partial c_1^{SBA}}} \tag{2.35}$$

The numerator of equation (2.35) is as follows

$$\begin{aligned} \frac{\partial g(c_1^{SBA}, k, p)}{\partial p} &= -\pi[u'(c_1^{SBA}) - Ru'(c_2^{SBA})] + \\ Ru''(c_2^{SBA})[\frac{\pi k R_k}{(1-p)(1-\pi)}] &+ (1+k)[\frac{u'(c_1^{SBA})}{c_1^{SBA}} - \frac{u(c_1^{SBA})}{(c_1^{SBA})^2}] \end{aligned} \tag{2.36}$$

The second part $Ru''(c_2^{SBA})[\frac{\pi k R_k}{(1-p)(1-\pi)}]$ and third part $(1+k)[\frac{u'(c_1^{SBA})}{c_1^{SBA}} - \frac{u(c_1^{SBA})}{(c_1^{SBA})^2}]$ on the right hand side of equation (2.36) are less than zero as shown before. As to the first part, using equation (2.32) we have

$$-\pi[u'(c_1^{SBA}) - Ru'(c_2^{SBA})] = \frac{p(1+k)}{1-p}[\frac{u'(c_1^{SBA})}{c_1^{SBA}} - \frac{u(c_1^{SBA})}{(c_1^{SBA})^2}] < 0 \tag{2.37}$$

Hence, the numerator of equation (2.35) is negative. The denominator of equation (2.35) is also negative according to the second order condition, so $\frac{\partial c_1^{SBA}}{\partial p}$ is negative.

The difference between δ^{SBU} and δ^{SBA} only comes from the *ex ante* expected utility of representative depositor. In the case of anticipated bank run, depositors will consider the utility when bank run equilibrium happens. The utility of bank run equilibrium has negative relation with short term interest rate c_1 as shown below,

$$d[u(c_1)\frac{1+k}{c_1}]/dc_1 = (1+k)[\frac{u'(c_1)}{c_1} - \frac{u(c_1)}{(c_1)^2}] < 0 \tag{2.38}$$

Hence, we have $c_1^{SBA} < c_1^{SBU}$. Because of the same budget constraint (2.28), the long term interest rate should have reverse relation $c_2^{SBA} > c_2^{SBU}$. At last, according to equation (2.29), we have $c_1^{SBU} < c_2^{SBU}$. □

Proof of Proposition 2.3.2

Proof. In the case of unanticipated bank run, let value function $V(k)$ satisfy

$$V(k) = \max_{c_1,c_2} \pi u(c_1) + (1-\pi)u(c_2) \tag{2.39}$$

subject to the budget constraint of equation (2.28). Use the envelope theorem and obtain

$$V'(k) = -(1-\pi)u'(c_2^{SBU})[\frac{R_k - (1-p)R}{(1-p)(1-\pi)}] = -u'(c_2^{SBU})[\frac{R_k - (1-p)R}{(1-p)}] < 0. \tag{2.40}$$

Hence, the required capital will decrease the expected utility of depositors. Banks have no incentive to hold capital and they only keep capital as required.

In the case of anticipated bank run, similarly, let value function $U(k)$ satisfy

$$U(k) = \max_{c_1,c_2}(1-p)[\pi u(c_1) + (1-\pi)u(c_2)] + pu(c_1)\frac{1+k}{c_1} \tag{2.41}$$

subject to the budget constraint of equation (2.28). Use the envelope theorem and obtain

$$U'(k) = -(1-p)(1-\pi)u'(c_2^{SBA})[\frac{R_k-(1-p)R}{(1-p)(1-\pi)}] + p\frac{u(c_1^{SBA})}{c_1^{SBA}}$$
$$= p[\frac{u(c_1^{SBA})}{c_1^{SBA}} - Ru'(c_2^{SBA})] + u'(c_2^{SBA})[R-R_k] \quad (2.42)$$

From the first order condition of equation (2.32), we have

$$u'(c_1^{SBA}) - Ru'(c_2^{SBA}) = -\frac{p(1+k)}{\pi(1-p)}[\frac{u'(c_1^{SBA})}{c_1^{SBA}} - \frac{u(c_1^{SBA})}{(c_1^{SBA})^2}] > 0 \quad (2.43)$$

Hence, the first part of equation (2.42) is positive as follows

$$p[\frac{u(c_1^{SBA})}{c_1^{SBA}} - Ru'(c_2^{SBA})] > p[u'(c_1^{SBA}) - Ru'(c_2^{SBA})] > 0 \quad (2.44)$$

The second part of equation (2.42) is zero when $R_k = R$, so $U'(k) > 0$ and banks will hold capital as much as they can. From equation (2.42), we can also derive the R_k^* as follows

$$R_k^* = \frac{p}{u'(c_2^{SBA})}[\frac{u(c_1^{SBA})}{c_1^{SBA}} - Ru'(c_2^{SBA})] + R \quad (2.45)$$

It is easy to check that $U'(k) > 0$ if $R_k < R_k^*$ and $U'(k) < 0$ if $R_k > R_k^*$. □

Proof of Proposition 2.4.1

Proof. Rewrite the portfolio choice of bank in (2.15) here

$$\max_i (1-p)\{v[i\lambda R + (1+k-i-\pi c_1^{SB})R - (1-\pi)c_2^{SB}] +$$
$$(1-v)\max[(1+k-i-\pi c_1^{SB})R - (1-\pi)c_2^{SB}, 0]\}. \quad (2.46)$$

Using the budget constraint (2.28), (2.46) becomes

$$\max_i (1-p)\{v[i\lambda R + \frac{kR_k}{(1-p)} - iR] + (1-v)\max[\frac{kR_k}{(1-p)} - iR, 0]\} \quad (2.47)$$

Consider i' satisfies

$$\frac{kR_k}{(1-p)} - i'R = 0. \quad (2.48)$$

For $i > i'$, the objective function is increasing with i. Moreover, for $i < i'$, the objective function is decreasing with i. Hence, i will be set to 0 or $1 + k$ since any interior choice of i is dominated by one of these extremes. The profits of the bank are higher at $i = 0$ than at $i = 1 + k$ if and only if

$$kR_k \geq (1-p)v[(1+k)R(\lambda-1) + \frac{kR_k}{(1-p)}] \tag{2.49}$$

given the assumption $R_k < \frac{1+k}{k(1-p)}R$. From (2.49), it is easy to derive

$$k^* = \frac{R(1-p)v(\lambda-1)}{R(1-p)v(1-\lambda) + R_k(1-v)} \tag{2.50}$$

□

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CHAPTER 3. LIQUIDITY BACKUP FROM COMMERCIAL BANKS TO SHADOW BANKS

Zhongzheng Zhou

3.1 Abstract

During the Great Recession, liquidity did not flow out of the banking sector but was reallocated internally. Deposits increased, but the volumes of all other short-term debt financing instruments, except for T-Bills, decreased. Commercial banks, which have stable funding sources from deposits, did not render liquidity backup to shadow banks but held the increased deposits as cash on hand. This Chapter uses deposits and financial commercial paper outstanding as proxies for commercial and shadow banking financing instruments because they are unique liabilities of commercial and shadow banks, respectively. Using vector autoregressive models, I provide evidence that when liquidity falls in shadow banks, commercial banks experience funding inflows. In normal times, commercial banks render liquidity backup to shadow banks in the following weeks using the increased deposits. However, the dynamic correlation breaks down in crisis times, which may have contributed to the collapse of the shadow banking system during the Great Recession.

3.2 Introduction

Shadow banks, the specialized financial intermediaries that channel funding from lenders to borrowers through a range of securitization and secured funding techniques[1], arguably played a

[1] This definition closely follows that of Pozsar et al. (2010). Although there exists plenty of borrowing and lending business within the banking system, lenders and borrowers are outsiders of the banking system in this chapter unless otherwise stated. Lenders are mainly fixed-income investors who invest in mortgage-backed securities, asset-backed securities, repurchase agreements, commercial paper, money market mutual funds, etc., but not bank deposits or other commercial bank obligations. Investors in mutual funds or hedge funds could be generally considered lenders if the mutual fund or hedge fund invests in the fixed-income products above. Borrowers include (but are not limited to) producers who need funds to produce or consumers who need funds to invest in real estate or purchase automobiles.

critical role in undermining the whole financial system and bringing about the financial crisis from 2007 to 2008. In terms of the liability side of the balance sheet, unlike regulated commercial banks which are mainly and uniquely funded by deposits, shadow banks are primarily funded by issuing fixed-income securities in wholesale money markets. During the Great Depression, investors responded to the banking crisis by withdrawing deposits from commercial banks and holding the cash on hand. The ratio of deposits to currency plunged from about 12 to less than 5 between 1929 and 1933 (Schwartz (1963)). Hence, most old school studies about bank runs are highly focused on commercial banks. When there is a substantial and rapid decrease in deposits, commercial banks suffer high pressure in liquidity risks, and in the worst cases, asset liquidation in fire-sale price could happen. During the Great Recession, shadow banks suffered a similar experience to commercial banks in the Great Depression. The funds of shadow banks plunged because of the collapse of wholesale money markets. Shadow banks expected they could continuously issue fixed-income securities to raise money like deposits of commercial banks. However, investors lost confidence in the wholesale money markets, making it difficult for shadow banks to reissue their securities as they matured. As a result, the funds of shadow banks dried up when the outstanding levels of the fixed-income securities they issued shrank rapidly. The refinancing risks become the severe liquidity risks in a way that shadow banks had to find alternative channels to raise funds or liquidate their assets. After 2008, most of the literature concentrates on the collapse of two important fixed-income products: repurchase agreements (henceforth repos) and asset-backed commercial paper (henceforth ABCP)[2]. Gorton and Metrick (2012) document a systematic run on one segment of bilateral repo markets. Both repo spreads and repo haircuts jumped up during the Great Recession. Copeland et al. (2014) point that the run on the tri-party repo market is more like the one in traditional commercial banks, which means the run is concentrated on some specific

Borrowers may borrow money from shadow banks directly or from commercial banks, and commercial banks securitize the loans later as fixed-income products. For details, see Section 3.3.

[2]Other studies are concerned with runs on money market mutual funds. In this chapter, I treat money market funds as investors like Krishnamurthy et al. (2014) because money market funds are the main investors in repos and commercial paper. In addition, little money flows from money market funds directly to outside borrowers. Hence, it is better to see money market funds as outside lenders but not shadow banks to avoid double counting errors. For details, see Section 3.3.

shadow banks (e.g. Lehman Brothers) but not system-wide. Acharya et al. (2013) analyze the collapse of ABCP markets in 2008 and conclude that most losses of ABCP conduits are undertaken by the sponsors (large financial institutes) but not outside investors. Although shadow banks faced severe funds shortage during the Great Recession, commercial banks had a distinct experience this time. Deposits increased dramatically as investors sought a safe haven for their money.

This chapter studies the interdependence between shadow banks and commercial banks. They offer similar financial products to investors. The fixed-income products offered by shadow banks have a higher interest rate and risks than deposits. Hence, they are competitors to attract the most risk-averse investors[3]. When the market risks increase, investors hold fewer securities issued by shadow banks and more deposits, and vice versa. One example is during the Great Recession, when investors lost confidence in the securities offered by shadow banks and transferred their wealth from shadow banks to commercial banks. Hence, commercial banks have a unique and natural advantage in providing liquidity insurance to shadow banks if they want. Consider a case where investors withdraw funds from shadow banks and deposit them into commercial banks during a period of market stress. If commercial banks lend the same volume of funds to shadow banks and all transactions work efficiently, no liquidity problem comes up in the whole banking system. Money just behaves like "what goes around comes around". Investors still hold the same wealth in the whole banking system if only they keep the same amount of fixed-income investment. Shadow banks cannot raise enough money from investors, but they find an alternative funding source from commercial banks. For commercial banks, deposit inflows serve as a hedge for outflows from new loans given to shadow banks. I give the series of cash flows a name called "Flight-to-Quality" circle (henceforth FTQ circle) which is illustrated in Figure 3.1.

The FTQ circle consists of blue links ②, ③ and ④. The blue links ② and ③ represent the fact that securities issued by shadow banks and deposits are substitutes. The blue link ④ happens later and is the key to the success of the FTQ circle. It represents that commercial banks lend increased deposits from the link ③ to shadow banks. The FTQ circle is not totally new and it follows the spirit

[3] Compared to the investors who invest in equities, real estate and so on.

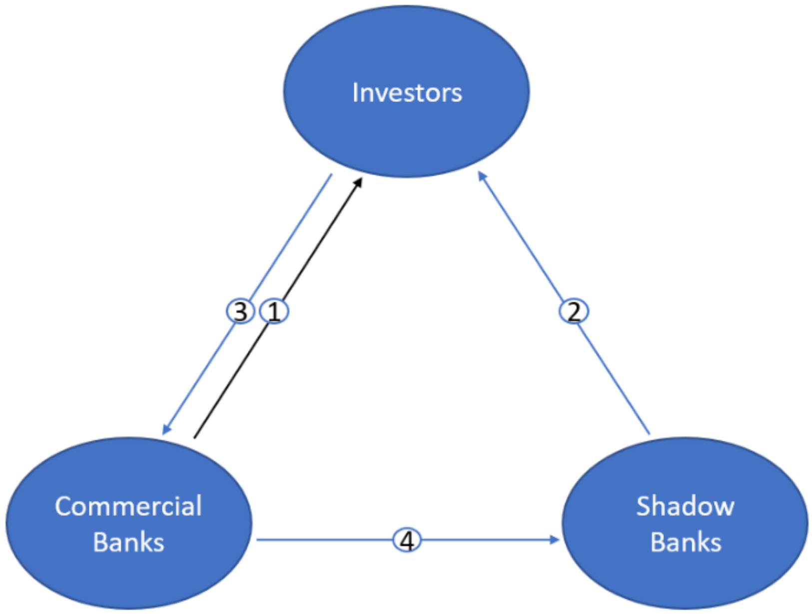

Figure 3.1 Flight-to-Quality Circle

of Kashyap et al. (2002), and Gatev and Strahan (2006). They study the interdependence between commercial banks and large corporations that issue non-financial commercial paper (henceforth, CP) to raise money. During the periods of market stress, large corporations cannot issue enough non-financial CP in the wholesale money market, so they resort to commercial banks as the last lender by taking down the backup line of the non-financial CP (like the link ④).

In this chapter, I argue that the FTQ circle is vulnerable to resist strong market impact and it only works when the link ④ happens. During normal times or periods of moderate market stress, the FTQ circle functions well as commercial banks are willing to lend increased deposits to shadow banks through the link ④. However, the link ④ broke down during the Great Recession and it could possibly be one of the reasons that caused the collapse of the shadow banking system[4].

Why is the link ④ in the FTQ circle important to the stability of the financial system? My argument is that the liquidity backup from commercial banks to shadow banks is the radical support

[4]According to the forecast model in this chapter based on financial CP, the link ④ broke down from Sep. 2007 to Apr. 2009. For details, see Section 3.5.

for the confidence of investors when the financial market suffers the impact of credit risks. The securities offered by shadow banks usually have collateral to protect investors from credit risks, so they were considered to be safe assets before the Great Recession[5]. Based on the shadow banking model of Gennaioli et al. (2013), fixed-income investors are extremely risk-averse. Hence, investors value the risky collateral at a much lower price than the risk-neutral financial intermediaries. The collateral is priced nearly risk-neutral during normal times because of the liquidity offered by banks. Even if investors dislike risks, they can accept collateral at about its risk-neutral price because they believe that they can sell their collateral in a liquid market dominated by risk-neutral banks if defaults happen. When moderate neglected credit risks are revealed in the market, investors ask for more collateral and higher interest rate to offset the credit risks, and the market price of the collateral temporarily decreases because of the underlying fundamental return rates based on the credit risks. However, we are still in a nearly risk-neutral world if the market has sufficient liquidity. Things change when the neglected credit risks are so large that the link ④ in the FTQ circle breaks down like it was the case during the Great Recession. The liquidity of the market declined largely due to the fact that commercial banks tighten their credit. Investors lose their confidence and reveal their extreme risk-averse preferences. Collateral is priced with a high risk premium because investors dominate the market this time. Risk-neutral arbitrageurs do not have sufficient funds to turn the market back to the nearly risk-neutral state individually. The market stays a long time with extreme risk-averse pricing before it goes back to risk-neutral again.

My research differs from the existing literature in that it studies the liquidity risks based on concurrent and dynamic correlations between commercial banks and shadow banks (the FTQ circle). Studies before the Great Recession are mostly focused on runs on commercial banks, which is the black link ① in Figure 3.1. By contrast, when crises occur today, we observe increases in deposits, which are the blue link ③ in Figure 3.1[6]. The introduction of deposit insurance could

[5]It is the reason we usually call them asset-backed or mortgage-backed securities. For repos, investors have even more controls over the collateral than normal collateralized borrowings. Collateral is exempted from the automatic stay, so a party to a repo can unilaterally enforce the termination provisions of the agreement as a result of a bankruptcy filing by the other party. For details, see Section 3.3.

[6]Not only during the Great Recession. According to Gatev and Strahan (2006), the deposits increased when the market suffered liquidity shocks from 1988 to 2002.

probably explain the reverse cash flows in the links ① and ③. I also find that (uncovered) large time deposits behave more like the securities offered by shadow banks. Studies after the Great Recession are mostly focused on runs on shadow banks, which is the blue link ② in Figure 3.1. There also exists some literature that studies how runs on shadow banks (the link ②) can undermine the regulated commercial banking system because they are closely related in reality. However, no study proposes the runs that come from the breakdown of the link ④ in the FTQ circle.

Although there exists a large number of independent shadow banks, commercial banks and shadow banks are organizationally connected in two different frames. First, commercial banks themselves are not pure. Commercial banks are funded not only by deposits, but also through shadow banking channels. For example, repos are typical fixed-income products offered by shadow banks (mostly dealer banks) to raise money. However, commercial banks can also use them for financing like deposits. The amount funded by repo as a percentage of total assets of commercial banks from April 1, 2008, to February 29, 2009, was 63 basis points (mean) and the median was 2.7% (Afonso et al. (2010)). It is very small but still exists. Harvey and Spong (2001) point that growth in traditional deposit funding sources has stagnated at many commercial banks after 1990 and has largely failed to keep up with the growth in bank assets. Hence, commercial banks which face funding difficulties in core deposits have to use funding instruments from shadow banking activities. Obviously, the runs on shadow banking activities can influence the commercial banks directly in such a way. Second, commercial banks and shadow banks can have the same parent company. In the United States, commercial banks are held by bank holding companies (henceforth, BHCs), which can have shadow banking subsidiaries. Copeland (2012) points out that shadow banking subsidiaries of BHCs have been increasing over time and represent a quantitatively important share of the BHCs' total earnings. For example, ABCP conduits are special purpose vehicles sponsored by large financial institutions, which are mostly BHCs[7]. In January 2007, commercial banks (BHCs) accounted for $903 billion or 74.8% of ABCP outstanding. Among

[7] A special purpose vehicles or entity is a subsidiary of a company which is protected from the parent company's financial risk. Hence, the bankruptcy of the parent company would not jeopardize the subsidiary. In the context of ABCP, investors do not need to worry about the failure risks of the sponsoring BHC.

them, the largest BHC sponsoring ABCP conduits in the United States was Citigroup, with 16 conduits and $92.6 billion of ABCP outstanding. According to Acharya et al. (2013), regulatory arbitrage was an important motive that BHCs set up ABCP conduits. ABCP conduits are off-balance sheet financing for commercial banks. Although BHCs need to satisfy capital requirements based on consolidated balance sheets, they could enjoy reduced regulatory capital if guarantees (they provide to ABCP conduits in order to protect outside investors[8]) were skillfully structured before the Great Recession[9]. Admittedly, there are regulations that require BHCs to prioritize the interests of their commercial banks. During periods of market stress, it is difficult to believe that BHCs can stand by while their shadow banking subsidiaries are getting in trouble. Hence, the runs on shadow banking subsidiaries can influence the commercial banks indirectly in such a way. Actually, Acharya et al. (2013) find that most losses of ABCP conduits are undertaken by the commercial banks instead of outside investors during the Great Recession.

Because the probable problem of endogeneity lies in the real world as I stated in the last paragraph, empirical counterparts identified to the FTQ circle need to avoid the conflict of interest based on the organizational relations. In this chapter, I use the volume of deposits but not total liabilities or total assets of commercial banks as the proxy for commercial banks in the FTQ circle because of its purity. Only commercial banks can legally issue deposits to raise funds and it is the essential difference between commercial banks and shadow banks. A decrease in deposits means commercial banks can only raise fewer funds from the investors and it is the failure of refinancing of deposits. Although commercial banks can also issue some kinds of shadow banking instruments to raise funds, they are usually not allowed to issue financial CP. Hence, I use financial CP outstanding as the proxy for shadow banks in the FTQ circle given that only shadow banks can legally issue financial CP to raise funds. A decrease in financial CP outstanding means shadow banks can only

[8] Almost all sponsors provide guarantees to outside investors in ABCP conduits. ABCP has not only backed assets which play a role like collateral but also guarantees from the sponsors. Hence, they were considered safe investment even for the extreme risk-averse investors before the Great Recession. For details, see Section 3.3.

[9] In June 2009, the Financial Accounting Standard Board (FASB) announced the Statements of Financial Accounting Standards (FAS) 166 and 167, amending existing accounting rules for the consolidation of securitization transactions. The United States banking agencies clarified in September 2009 that depository institutions (commercial banks) would have to hold normal regulatory capital against consolidated securitization transactions and ABCP conduits.

raise fewer funds from the investors and it is the failure of refinancing of financial CP. Albeit BHCs may use shadow banking subsidiaries to issue financial CP and pass the proceeds downstream into commercial banks, the main issuers of financial CP are independent shadow banks (foreign financial institutions, captive finance companies, and dealer banks) and they are competitors to commercial banks as illustrated in the FTQ circle.

In the analysis at the industry level, I use weekly time series data regarding total deposits of domestically chartered commercial banks and total financial CP issued in the domestic market to estimate a series of vector autoregressions (henceforth, VARs). The change of deposits and that of financial CP outstanding are concurrently negatively correlated all the time. They are substitutes for fixed-income investors, and the blue links ② and ③ in the FTQ circle demonstrate the concurrent correlation. In normal times, there is a dynamic correlation between deposits and financial CP outstanding. An increase in deposits leads to an increase in financial CP outstanding in 1 to 3 weeks. Considering financial CP with an average maturity of about 30 days, it is enough time for shadow banks to rebuild liquidity. However, the dynamic correlation as shown by the blue link ④ in the FTQ circle disappears in times of market stress. In addition to the Great Recession, the liquidity backup from the dynamic correlation also broke down from 2010 to 2011 (the peak of the European sovereign debt crisis), and in the second half of 2014 (the oil prices crash). Given that a large number of issuers of financial CP are foreign financial institutions headquartered in Europe, we can easily expect that domestic commercial banks aborted the liquidity backup for them during the peak of the European sovereign debt crisis in 2010 and 2011. In 2014, after the period of the shale oil boom in the united states, the oil price slumped by more than 50% since peaking in June. There is no doubt that large oil and gas companies suffered severe impact because of the price crash. Their captive finance companies (subsidiaries), the issuers of financial CP, were therefore considered too risky to receive liquidity funds by commercial banks.

For BHCs, we can see them as mixtures of commercial banks and shadow banks. There indeed existed some commercial banks that suffer a severe liquidity impact during the Great Recession. However, the shortage of liquidity does not come from the deposits, but from the shadow banking activities in which the commercial banks are involved. When liquidity dried up during the Great Recession, commercial banks that relied more heavily on core deposit and equity capital financing could continue to lend compared to other banks (Cornett et al. (2011)). For the example stated above, Citigroup set up most ABCP conduits and we know it was insolvent in 2008 even if it had received funds from the Troubled Asset Relief Program (henceforth, TARP). In February 2009, the *New York Times* reported the following:

> "It would seem obvious that helping banks, not holding companies, would be the most direct way to stimulate bank lending. But when TARP purchased preferred stock and warrants, it bought them from holding companies, not their bank subsidiaries. While TARP has been generous with bank holding companies, these companies have not been so generous with their banks. Four large holding companies (JP Morgan, Citigroup, Bank of America and Wells Fargo) initially received a total of $90 billion in TARP money in the fall, but by the end of 2008 they had contributed less than $15 billion in equity capital to their subsidiary banks[10]."

Thus BHCs had larger liquidity problems in their shadow banking subsidiaries than in their commercial banks. It is worth mentioning that although commercial banks can also face liquidity problems if their deposits increase by less than the reduction in shadow banking securities they issue, they still have much milder funding problems than independent shadow banks.

The two decades in the run-up to the Great Recession saw the emergence of a large number of independent shadow banks. Some economists call the phenomenon dis-intermediation[11]. However, after the Great Recession, we saw the trend toward consolidation of independent shadow banks in BHCs. Some economists call the migration of independent shadow banks into BHCs re-intermediation. Cetorelli (2012) shows that, by 2011, BHCs controlled about 38% of assets of the largest insurance companies, 41% of total money market mutual fund (henceforth, MMMF) assets, and 93% of the assets of the largest brokers and dealers. Because BHCs have much higher reg-

[10] See "The Bailout Is Robbing the Banks," John C. Coates and David S. Scharfstein, *New York Times*, February 17, 2009.

[11] For dis-intermediation, only commercial banks are considered intermediaries.

ulation cost and limitations compared to the independent shadow banks, many economists think the re-intermediation is a paradox and expect more securitization-related activities will migrate from BHCs to independently run shadow banks over time[12]. The theory in this chapter can partly explain the re-intermediation paradox after the Great Recession. First, commercial banks are virtual winners in the Great Recession compared to the independent shadow banks because they have stable funding sources from deposits. The finding of Cetorelli (2012) is direct evidence that how favorably BHCs thrive after the Great Recession. Hence, they had the ability to acquire independent shadow banks during or after the Great Recession. Second, in addition to that ability, BHCs also had the incentive to do so according to the FTQ circle. There are synergies for a BHC to hold commercial banks and shadow banks together. Commercial banks serve as a hedge for shadow banks as the consolidation internalizes the FTQ circle[13]. If the synergies from liquidity management are greater than the regulation cost, we can see the re-intermediation. Last but not least, the internalized FTQ circle can only hedge the liquidity risks in the fixed-income market, but cannot eliminate them. When market credit risks are large enough, the core deposits of commercial banks could be insufficient to hedge the shadow banking subsidiaries that BHCs hold. Call the case of Citigroup during the Great Recession. Nowadays, commercial banks play fewer roles in BHCs when they own more shadow banking subsidiaries. We need to care about not only the capital adequacy but also the core deposits adequacy. Fortunately, liquidity requirements of BHCs have been introduced in recent years[14].

The chapter proceeds as follows. Section 3.3 provides some background of shadow banks and a literature review. In Section 3.4, I estimate VAR models to provide empirical evidence that the FTQ circle exists in normal times, but the blue link ④ broke down during the Great Recession. Total data set is separated into three time periods: pre-crisis, crisis and post-crisis in advance.

[12]The re-intermediation is not totally market-oriented. For example, Goldman Sachs and Morgan Stanley received government bailouts during the Great Recession. In return, they transited into BHCs to abide by more regulations in 2008, even if they did not hold any commercial bank back then.

[13]The synergy shares the same spirit of Kashyap et al. (2002). In their study, that commercial banks take deposits and lend via commitments together can generate synergies in liquidity management between the two activities because both require banks to hold large balances of liquid assets. The increase in deposits can serve as a hedge for the take-down of commitments during the crisis times.

[14]Liquidity Coverage Ratio (LCR) comes into full effect in 2019. Net Stable Funding Ratio (NSFR) was introduced in 2018.

Because the split points that isolate the Great Recession period from the total data time span are chosen arbitrarily, I let the data itself reveal the exact times that the blue link ④ in the FTQ circle broke down in Section 3.5. If the dynamic correlation between deposits and financial CP outstanding via the blue link ④ exists, past deposits can help improve the prediction of future financial CP outstanding. Using one-step forward-chaining cross-validation, I find that including past deposits in the model can significantly increase the accuracy of prediction of financial CP outstanding measured by the mean squared error except for the times during the Great Recession, the peak of the European sovereign debt crisis, and the 2014 oil price crash. Section 3.6 contains the discussion and conclusions.

3.3 Shadow Banks and the Great Recession

Where does the liquidity risk of an entity come from? It comes from the refinancing risk when the entity has to roll over its debt. If an entity has borrowed money from others, it has to pay back the principal and interest when the loan matures. Most entities plan to keep a stable capital structure in the long term. They can issue long-term debt to achieve the goal, or issue short-term debt and reissue it when it matures, doing this over and over until they reach the same long-term goal. If an entity cannot reissue new debt when the old debt matures, it will experience a passive but obligatory cash outflow. The cash outflow has more liquidity risks if it is unexpected. For example, a non-financial company may raise funds for a 5-year investment by rolling over 3-month non-financial CP or repeatedly getting 3-month loans from commercial banks. If it can successfully roll over its debt 20 times, it seems as if the company issued 5-year debt for the investment. However, if a credit crunch happens within 5 years, in which CP investors are not willing to repurchase the security or commercial banks contract their credit, the company has to find alternative funding sources, or in the worst case, liquidate the investment. In a way, we observe investors[15] withdraw their money from the company, which has been being lent to the company as debt investment.

[15] When a commercial bank lends a loan to a company, it is also a debt investor for the company.

Commercial banks are different from normal companies in corporate finance because they have a unique funding source from deposits. The principle of liquidity risks is totally the same if we see deposits as the debt of commercial banks. A second example is a commercial bank issuing 3-month time deposits over and over to raise funds. Some investors may not repurchase the new time deposits when the old ones mature; some investors may continue their time deposits; and there are some new investors who begin to make time deposits. If the total deposits that investors keep holding remain relatively steady, the commercial bank will have no liquidity risk. However, if investors are no longer willing to make the time deposits they have been making, we observe investors withdraw their money from the commercial banks. Hence, as a matter of fact, runs on a commercial bank are the bank cannot roll over its deposits.

Generally speaking, the shorter the maturity of the debt, the greater the potential liquidity risk of the entity because the entity has to roll over its debt more times. The exception is transaction deposits, also known as demand deposits. Transaction deposits have infinitely short maturities given that investors can withdraw them at any time. In other words, commercial banks have to reissue transaction deposits every second and the investors actually repurchase the deposits every second. For normal debt financing, it would have the highest refinancing risks and potential liquidity risks for the issuing entity, due to the extremely short maturity. However, transaction deposits together with small time deposits are called core deposits[16] which are considered the most stable funding source of commercial banks. When liquidity dried up during the Great Recession, commercial banks that relied more heavily on core deposit and equity capital financing could continue to lend compared to other banks (Cornett et al. (2011)).

Shadow banks also have their special kinds of debt financing instruments. The debt financing instruments are not only liabilities of shadow banks, but also the assets of investors. In plain words, investors no longer purchase the debt financing instruments which they used to purchase. In addition to the special funding instruments, shadow banks and commercial banks also have higher financial leverage compared to normal companies. Commercial banks usually have 10 times

[16]Except for large time deposits, other deposits are core deposits.

leverage. Because of loose regulations, shadow banks can have much higher leverage. For example, independent primary dealer banks before the Great Recession usually had from 20 to 30 times leverage[17]. If an entity cannot roll over its debt, it may experience more liquidity risks if it has higher leverage. Because the debt issued by shadow banks plunged during the Great Recession, some literature also calls this phenomenon "deleveraging". When literature uses the term "deleveraging", it considers the decrease in debt comes from the supply side (shadow banks)[18]. The special mechanisms in shadow banks could make them have to reduce or liquidate a large asset holdings with only a little decrease of funding[19]. By contrast, the leverage of the commercial banking sector increased over the crisis because of the stable funding sources from deposits (He et al. (2010)).

In addition to funding and leverage, the liquidity risks of an entity also depend on its liquid assets holdings. The more the liquid asset an entity has, the smaller the liquidation cost it suffers. For example, reducing cash assets holdings in response to a decrease in debt has no liquidation cost. Moreover, strictly speaking, the refinancing risks depend on the average remaining maturity of debt but not the average maturity of the debt. For example, in 2007, a company funded by 10-year bonds or loans with only 1 year left had more potential liquidity risks than another company funded by 5-year bonds or loans with 4 years left. Hence, we need detailed data regarding all items on and off the balance sheet of a commercial bank or shadow bank to measure its potential liquidity risks. Berger and Bouwman (2009) propose a measure called Liquidity Creation (henceforth, LC) for commercial banks. LC of a commercial bank is defined as the liquidity of liabilities minus the liquidity of assets. A commercial bank has large LC if it holds more long-term loans (illiquid) and is funded heavily by short-term time deposits or transaction deposits (liquid). LC is not precise to measure liquidity risks in two aspects. First, the liquidity of liabilities is not equivalent to the instability of them during crisis times. As stated above, core deposits could be highly liquid and short-term, but they are the most stable funding sources of commercial banks. Second, the

[17] No independent primary dealer bank exists after the Great Recession. Goldman Sachs and Morgan Stanley transited into BHCs even if they did not hold any commercial bank back then. Lehman Brothers failed. Merrill Lynch and Bear Stearns were acquired by Bank of America and J.P. Morgan Chase.

[18] By contrast, when literature uses the term "runs", it considers the reduction in debt comes from the demand side (investors).

[19] For example, rehypothecation of collateral and haircuts of repos.

liquidity of assets could change significantly during crisis times. Before the Great Recession, most short-term fixed-income products issued by shadow banks were considered highly liquid assets by investors[20], but they collapsed over the crisis and investors had large liquidation cost to sell them. Bai et al. (2018) construct a measure called Liquidity Mismatch Index (henceforth, LMI) to evaluate the liquidity risks of BHCs. LMI fixes the problems of LC by giving liquidity risk weights to all assets, liabilities and off-balance sheet items. It is like the risk-based capital and assets in capital requirements. However, the liquidity risk weights in LMI are not fixed but matched to the market prices.

In this chapter, I use weekly time series data regarding the commercial banking sector and the shadow banking sector to perform the analysis at the industry level, so it is impossible and unnecessary to evaluate liquidity risks of any particular bank. I only consider liquidity risks from the liability side when I evaluate the liquidity risks of commercial and shadow banking sectors. By definition, commercial banks are different from shadow banks in liabilities. Hence, I define deposits as the only commercial banking financing instrument to capture the essential difference between commercial banks and shadow banks. All other short-term debt financing channels except for treasury bills are shadow banking financing instruments[21]. Although it is possible to sum all liquid assets in the commercial banking sector, it may not help improve the measure of liquidity risks in the sector. We cannot simply add up the liquid assets of each entity to get the liquid buffer of the whole sector. Moreover, liquidity risks stem from the liability side. Thus, we can reasonably think that a decrease in deposits means commercial banks are facing liquidity risks, and a decrease in shadow banking financing instruments means shadow banks are facing liquidity risks[22].

Although this chapter only uses financial CP as the proxy for shadow banking financing in formal regressions, it is beneficial to check total U.S. short-term debt financing instruments, also known as money market financing instruments, and therefore build a big picture. Table 3.1 shows annual (2003-2018) main debt financing instruments with maturity less than 1 year except for

[20] Here, investors could be commercial banks or shadow banks.

[21] Long-term debt financing is related to solvency problems but not liquidity risks.

[22] Although commercial banks also use shadow banking financing instruments to raise funds and BHCs may have shadow banking subsidiaries, their funds are mainly from commercial banking financing instruments (deposits).

deposits. Because deposits are the only commercial banking financing instrument and they are most stable funding sources in crisis times, I list the total deposits in Table 3.1 which include long-term time deposits and transaction deposits. Apart from deposits and treasury bills (henceforth T-Bills), which are issued by the government, agency debentures, CP, and repos are typical shadow banking financing instruments[23]. Although repos in Table 3.1 only contain tri-party repos, and I estimate data for them before 2008 and data for agency debentures with tenor less than 1 year before 2006 because of unavailability, the data in Table 3.1 is precise enough to give a big picture[24].

All of the instruments had an increasing trend from 2003 to 2007. In 2007, the volume of total shadow banking financing instruments, the sum of CP, repos and agency debentures, almost equaled that of total deposits. CP and repos outstanding decreased from 2007 to 2009. The peak of agency debentures was $1.124 trillion outstanding in 2008, and the volume fell to $652 billion in 2009, since runs on government-sponsored enterprises (henceforth, GSEs), the issuer of agency debentures, happened in the last quarter of 2008 and agency debentures in Table 3.1 use the last quarter value in each year as the annual data[25]. Although the volume of all shadow banking financing instruments decreased during the Great Recession, deposits increased as we expected, especially from 2008 to 2009. It is worth mentioning that T-Bills increased from $1 trillion in 2007 to $1.861 trillion in 2008. There were many government bailouts during the Great Recession, so the government needed to raise funds from investors and lent them to financial institutions. For example, Krishnamurthy et al. (2014) find MMMFs, which are the main investors in repos, stopped accepting private asset-backed securities as collateral in the tri-party repo market during the crisis. T-Bills were the most preferred (or sometimes only) collateral that investors were willing to accept. The government helped dealer banks to exchange their collateral with T-Bills so that they could

[23] Although corporate CP, which belongs to CP, is issued by large non-financial corporations. We can generally see them as shadow banks with lower leverage.

[24] According to the Securities Industry and Financial Markets Association (SIFMA), in early 2007, total U.S. short-term debt financing accounted for approximately $5 trillion. CP was the largest instrument in this market with more than $1.97 trillion outstanding. The second-largest instrument was T-Bills, which accounted for $940 billion outstanding. Other important short-term debt instruments were time deposits and repos. In their statistics, they only consider short-term deposits and net tri-party repos without general collateral financing (GCF) trades. It is the reason that they have much fewer deposits and repos than that in my data. The main instruments listed in Table 3.1 covered most of the short-term debt financing market back then.

[25] Actually, repos also peaked in 2008 if we use higher frequency data. Repos outstanding in Table 3.1 is the annual average value of daily data.

still issue repos over the crisis. Hence, the volume of shadow banking financing instruments should have been much lower if there had been no bailout. Investors only trusted the government during the crisis. Only the government and deposits covered by the government could raise more funds. After the Great Recession, deposits keep increasing but shadow banking financing instruments remain at a relatively low and constant level. Nowadays, compared to the size of total deposits, the size of shadow banking financing instruments listed in Table 3.1 is no longer large. Do we live in a safer banking sector with more sufficient deposits? No. Many emerging shadow banks use new shadow banking financing instruments that are not listed in Table 3.1. In addition, potential liquidity risks may transfer directly into mutual funds and hedge funds. I will discuss this in the section of concluding remarks.

Now, let's take a look at the demand side: investors. Few individual investors invest in shadow banking financing instruments directly. One of the main investors is MMMFs. According to regulations, MMMFs can only invest in short-term fixed-income products, so the instruments in Table 3.1 cover almost all of the products in the portfolio of MMMFs. MMMFs are also typical shadow banks, and they experienced runs during the Great Recession. The product issued by MMMFs to raise funds is also called the MMMF[26]. After Lehman Brothers' bankruptcy, some MMMF investors withdrew their money from their MMMFs when they realized their MMMFs were holding financial CP and repos issued by Lehman Brothers. MMMFs had to liquidate some of their assets listed in Table 3.1 and they also adjusted their portfolios. They reduced their holdings of CP and repos, and expanded that of T-Bills, agency debentures, and deposits. If I treat MMMFs as another shadow banking financing instrument, it will double count the money that flows from outside into the shadow banking system. MMMFs are investors in the FTQ circle. They withdrew their money from shadow banks and put it into commercial banks like the blue links ② and ③ in the FTQ circle during the Great Recession. In addition to MMMFs, general mutual funds and hedge funds may also invest small parts of their funds into shadow banking financing instruments. Large corporations can purchase shadow banking financing instruments to manage their liquidity

[26]For funds, the money they raise is not like debt or equity. For details, see the section of concluding remarks.

assets. Hence, individual investors can indirectly invest in shadow banking products by holding MMMFs (mainly), mutual funds and equity of large non-financial companies.

Table 3.2 shows the liquid financial assets of individual investors and their share of total[27]. According to their share of the total, equity and mutual funds bottomed out and all fixed-income assets peaked in 2008. It may be partly caused by the larger decline in the market value of equity compared to that of fixed-income securities. Anyway, the market value of all fixed-income assets increased from 2007 to 2008, which demonstrates that individual investors did not transfer their funds from fixed-income investments to the other investments during the Great Recession. Individual investors increased their holdings of MMMFs over the crisis, so in total, institution investors could be the main trigger of runs on MMMFs[28]. The jump in the value of corporate bonds from \$1.195 trillion in 2007 to \$2.150 trillion in 2008 is more likely from the supply side. Corporations had difficulties issuing short-term CP and getting loans from commercial banks over the crisis, so they resorted to issuing long-term bonds. Owing to the high interest rate, individual investors were willing to keep more bonds for corporations that still have good fundamentals.

3.3.1 Shadow Banks

In this subsection, I concisely introduce the typical shadow banks discussed in this chapter. Because this chapter studies the liquidity risks of shadow banks, the introduction is organized by the order of shadow banking financing instruments in Table 3.1. Shadow banks, the entities, are mentioned as issuers when each instrument is introduced.

Shadow banks first come from the securitization. When a traditional commercial bank makes a loan to a borrower, it keeps the loan as an asset on its balance sheet. If a commercial bank securitizes its loans and sells them to investors, a shadow bank emerges. To sell its securitized loans, the commercial bank will set up a special purpose vehicle (henceforth, SPV), a bankruptcy remotely subsidiary, to issue the securities. The SPV securities issuer is a shadow bank. Investors

[27]The term "liquid" is not equal to "short-term". For example, corporate bonds are long-term debt instruments but considered liquid financial assets by individual investors.

[28]Runs stopped on September 19, 2008, three days after it started, when the U.S. government announced that it would provide deposit insurance to investments in MMMFs.

are willing to buy the securities from the SPV but not the commercial bank because the failure of the commercial bank will not affect the SPV and the securities. For the commercial bank, it gets money from selling its loans and it can lend the money again. For the SPV, if it can sell the securities with no debt from investors, then it has no liquidity risks. It is a process of dis-intermediation. Security investors will receive the payment from the borrower directly and it seems as if investors lend their money to the borrower. In most cases, the securities have collateral in case borrowers default. If the collateral is real estate, the securities are mortgage-backed securities (henceforth, MBSes). For the other collateral, they are asset-backed securities (henceforth, ABSes).

Table 3.3 shows the ABSes and MBSes outstanding in the United States from 2003 to 2018. Agency MBSes are issued by GSEs such as Ginnie Mae, Fannie Mae or Freddie Mac. They should not be confused with agency debentures. Agency debentures are the debt of GSEs, so they are financing instruments for GSEs. However, GSEs issue agency MBSes for business and they are not debt. Shadow banks usually prefer to have more funds to issue MBSes or ABSes. Hence, they use the shadow banking financing instruments listed in Table 3.1 to raise funds. For examples, GSEs issue agency debentures to raise funds. One the asset side, shadow banks hold MBSes and ABSes before they can sell them or use them as collateral to raise more funds such as repos. When shadow banking financing instruments collapsed during the Great Recession, shadow banks had to liquidate their holdings of securitized assets. By contrast, commercial banks increased securitized assets holdings because they had stable funding sources (He et al. (2010)). Because of the liquidation, the market value of ABSes and MBSes plunged over the crisis. Agency MBSes were saved by the U.S. Federal Reserve's $1.25 trillion program to purchase agency MBSes, which commenced on January 5, 2009, and was completed on March 31, 2010. Nowadays, Agency MBSes account for $8.089 trillion in total $11.06 trillion securitized assets maybe because investors believe a government bailout will happen again when a crisis arrives.

3.3.1.1 Commercial Paper

Commercial paper includes ABCP, financial CP and corporate CP[29]. The maturity of CP is usually between 1 and 90 days with an average at about 30 days, although it can legally be up to 270 days. ABCP is relatively new compared to financial CP and corporate CP. It is issued by ABCP conduits which are SPVs sponsored by large financial institutions. The assets of ABCP conduits are collateral of ABCP and they are usually long-term MBSes and ABSes. Given the normal term structure of interest rates, ABCP conduits can earn profits by holding long-term securitized assets and issuing short-term ABCP as debt. The sponsoring financial institutions are mainly commercial banks and they usually provide guarantees to ABCP investors in case ABCP conduits default. In January 2007, commercial banks (BHCs) accounted for $903 billion or 74.8% of ABCP outstanding. According to Acharya et al. (2013), regulatory arbitrage was another important motive that BHCs set up ABCP conduits. ABCP conduits are off-balance sheet financing for commercial banks. Although BHCs need to satisfy capital requirements based on consolidated balance sheets, they could enjoy reduced regulatory capital if guarantees were skillfully structured before the Great Recession. Most losses of ABCP conduits were undertaken by the commercial banks instead of ABCP investors during the Great Recession. In June 2009, the Financial Accounting Standard Board (FASB) announced the Statements of Financial Accounting Standards (FAS) 166 and 167, amending existing accounting rules for the consolidation of securitization transactions. The United States banking agencies clarified in September 2009 that depository institutions (commercial banks) would have to hold normal regulatory capital against consolidated securitization transactions and ABCP conduits. Hence, we can see that the ABCP outstanding continues to decline after 2009 in Table 3.4.

Corporate CP is issued by large non-financial corporations. It has no collateral, so only corporations with good reputations can issue it. Compared to long-term bonds, corporate CP has fewer issue costs. It also usually has a backup (credit) line from commercial banks in case corporations cannot reissue their CP in crisis times. Besides seeking loans from commercial banks, corporations

[29] For a more detailed introduction about CP during the Great Recession, see Kacperczyk and Schnabl (2010).

can also issue long-term bonds to replace the CP that they have difficulties reissuing. For example, CP is an important source of financing for Coca Cola, representing about 30% of their liabilities in 2007. During the Great Recession, Coca Cola switched to alternative long-term financing, mostly as a response to the reality that it could not reissue enough CP anymore. On March 3, 2009, Coca Cola announced that it had sold $0.9 billion of five-year and $1.35 billion of ten-year notes to repay its maturing CP. In table 3.2, we can see individual investors held much more corporate bonds during the Great Recession (2008).

Financial CP is issued by large financial institutions. It also has no collateral. The main issuers of financial CP are foreign financial institutions, accounting for $455 billion of total $772 billion financial CP outstanding in 2007. Foreign financial institutions usually set up U.S. subsidiaries to issue financial CP in the U.S. market. Other main issuers of financial CP are captive finance companies. Captive finance companies are financial subsidiaries of manufacturers, with the purpose of providing financing for the manufacturer. Others are shadow banks in the U.S. banking sector. They could be commercial bank-related or independent. Commercial banks cannot legally issue financial CP directly, but their BHCs can set up shadow banking subsidiaries to issue it. As an example of independent shadow banks, Lehman Brothers was a main issuer of financial CP and its bankruptcy triggered the following run on the financial CP market. Hence, most issuers of financial CP are independent shadow banks and it is the reason why I choose financial CP as the proxy for shadow banking financing instruments.

3.3.1.2 Tri-Party Repos

Repurchase Agreements have a similar process like collateralized borrowings, but investors have more controls over the collateral. The collateral is exempted from the automatic stay, so an investor in a repo can unilaterally enforce the termination provisions of the agreement as a result of a bankruptcy filing by the counter-party. Hence, investors have fewer risks when purchasing repos than when lending covered by collateral. In the tri-party repo market, a third party called a clearing bank acts as an intermediary and alleviates the administrative burden between two parties engaging in a repo. Dealers issue repos in the tri-party repo market using their securitized asset holdings as collateral. The largest dealers are primary dealers. Primary dealers are dealer banks that are authorized to trade directly with the New York Fed. Most tri-party repos are overnight.

General collateral financing (GCF) in Table 3.5 are repos that trade between dealer banks. Because the FTQ circle model in this chapter only considers the funds that flow from outside into the shadow banking system, net repos outstanding without GCF should be used in my study. Unfortunately, data before 2010 is unavailable.

3.3.1.3 Agency Debentures

Agency debentures are agency debt issued by GSEs. GSEs includes Fannie Mae, Freddie Mac, Farm Credit, Federal Home Loan Bank, Farmer Mac, and Tennessee Valley Authority. Agency debentures have no collateral, but GSEs have implicit government backup. From Table 3.6 we can see that short-term debt plunged, but the long-term debt remained relatively stable during the Great Recession[30].

3.3.2 The Great Recession

In this section, I review how CP outstanding and deposits changed over the Great Recession. Figure 3.2 shows the weekly CP outstanding, total deposits and cash at commercial banks from Dec. 12, 2001, through Nov. 29, 2017. The gray-shaded area in Figure 3.2 is the time period of the Great Recession. We can see the CP market had two prominent collapses during the Great Recession. I label them as ABCP market collapse and Lehman's Bankruptcy. The increase in deposits accompanied by the ABCP market collapse was not significant. Only a fraction of funds flew from ABCP into deposits directly. The others flew into financial CP, corporate CP, repos, etc. According to Figure 3.3, the ABCP market collapse happened on August 9, 2007. Financial CP and corporate CP still increased after the ABCP market collapse. The financial CP market collapse happened after the bankruptcy of Lehman Brothers on September 15, 2008, because Lehman

[30]The peak of short-term agency debentures was \$1.124 trillion outstanding in 2008, and the volume fell to \$652 billion in 2009, since runs on GSEs, the issuer of agency debentures, happened in the last quarter of 2008. Agency debentures in Table 3.6 use the last quarter value in each year as annual data.

Figure 3.2 Deposits and Cash at Commercial Banks, and CP Outstanding

The figure shows the weekly total deposits and cash at commercial banks, and CP Outstanding from Dec. 12, 2001, through Nov. 29, 2017. The gray-shaded area is the time period of the Great Recession (from Aug. 1, 2007, to Jun. 24, 2009). The ABCP market collapse was Aug. 9, 2007. Lehman's bankruptcy was Sep. 15, 2008. Source: Federal Reserve's H.8 statistical release and CP release.

Brothers was a main issuer of financial CP. No prominent collapse happened in corporate CP market like other two CP markets during the Great Recession. The bankruptcy of Lehman Brothers also triggered runs on the repo market and MMMFs. Lehman Brothers was a primary dealer bank in the tri-party repo market, and after knowing the portfolio of MMMFs had financial CP and repos from Lehman Brothers, MMMFs investors also withdrew their money from MMMFs. Hence, we observe an unprecedented steep jump in deposits accompanied by the bankruptcy of Lehman

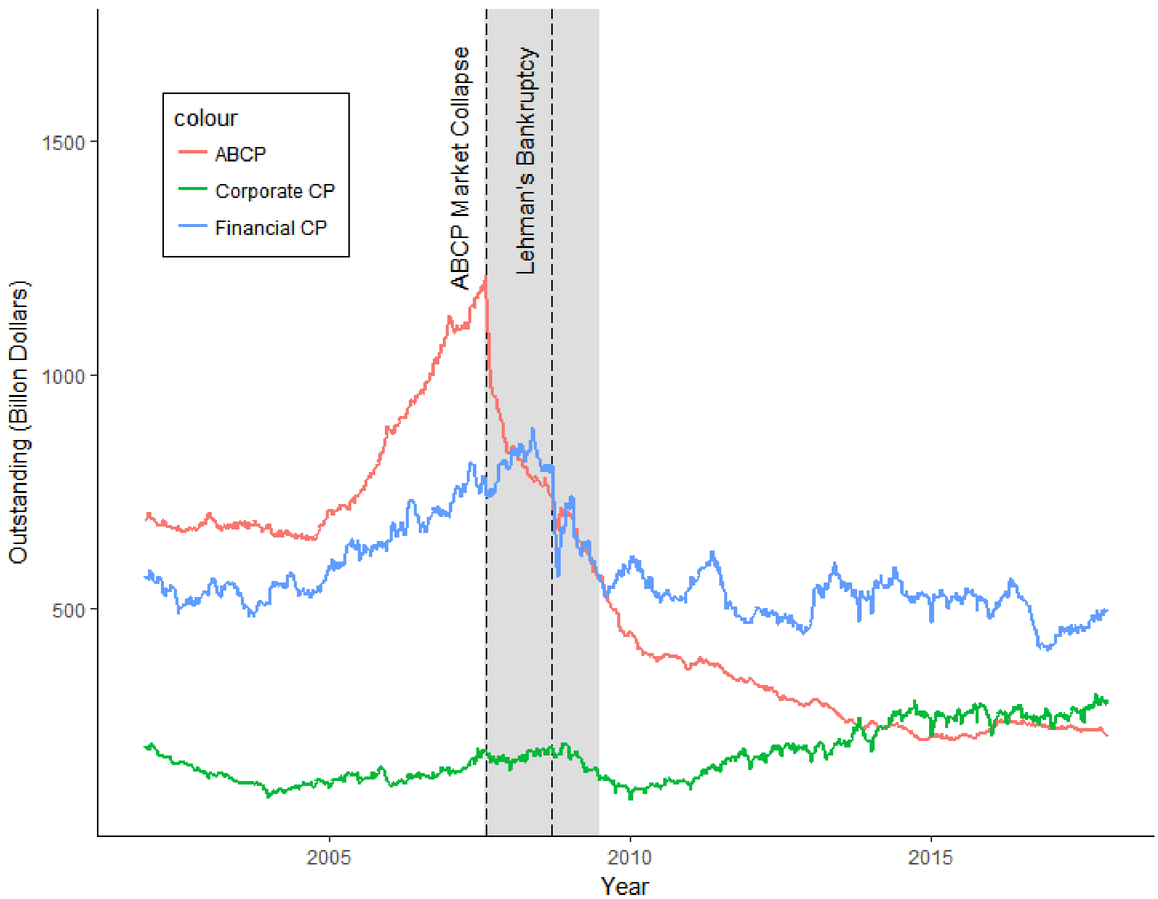

Figure 3.3 ABCP, Financial CP, and Corporate CP Outstanding

The figure shows ABCP, Financial CP and Corporate CP Outstanding from Dec. 12, 2001, through Nov. 29, 2017. The gray-shaded area is the time period of the Great Recession (from Aug. 1, 2007, to Jun. 24, 2009). The ABCP market collapse was Aug. 9, 2007. Lehman's bankruptcy was Sep. 15, 2008. Source: Federal Reserve's CP release.

Brothers. Investors transferred their funds from shadow banks (CP and repos) to commercial banks (deposits).

From Figure 3.2, the cash[31] holdings of commercial banks shows that commercial banks had a relatively constant cash level before Lehman's bankruptcy. Commercial banks always tried to keep their cash at the level although their deposits continuously increased. The cash target did not change even after the ABCP market collapse. It means commercial banks still did not keep the increment of deposits as extra cash on hand after the beginning of the Great Recession. Things

[31] Cash includes reserves.

changed after Lehman's bankruptcy. Commercial banks kept almost all the increment of deposits as extra cash on hand. Hence, the liquidity backup from commercial banks to shadow banks likely broke down after Lehman's bankruptcy.

It is worth mentioning that CP outstanding should have been much lower if unprecedented government bailouts did not happen during the Great Recession. Runs on MMMFs stopped on September 19, 2008, three days after it started, when the U.S. government announced that it would provide deposit insurance to investments in MMMFs. Although the MMMF outstanding stopped dropping, MMMFs still adjusted their portfolios by holding more T-Bills and deposits, and less CP and repos. For the first time ever, the Federal Reserve decided to purchase CP directly like investors. By early January 2009, the Federal Reserve was the single largest purchaser of CP and owned CP worth $357 billion, or 22.4% of the market, through a variety of lending facilities.

3.4 Empirical Evidence: the FTQ Circle

From Section 3.3, we know that investors withdraw funds from commercial banks or shadow banks is actually the decrease in commercial or shadow banking financing instruments. Hence, to test the FTQ circle empirically, we first need to find empirical proxies for commercial and shadow banking financing instruments. For commercial banking financing instruments, it is easy because deposits are the only ones. For shadow banking financing instruments, we need to find an empirical counter-party that only shadow banks can issue to raise funds, and what is more, the issuing shadow banks are independent. It is especially difficult given that BHCs controlled much more shadow banks after the Great Recession. This chapter chooses financial CP outstanding as the proxy for shadow banking financing instruments because only shadow banks can legally issue financial CP and main issuers are independent foreign financial institutions.

According to Figure 3.4, foreign financial institutions have accounted for an increasing share of financial CP outstanding over time. The financial CP outstanding issued by U.S.-owned financial institutions falls from more than 60% in 2002 to less than 20% in 2017. Although I do not collect data regarding how much financial CP outstanding issued by U.S. financial institutions are from

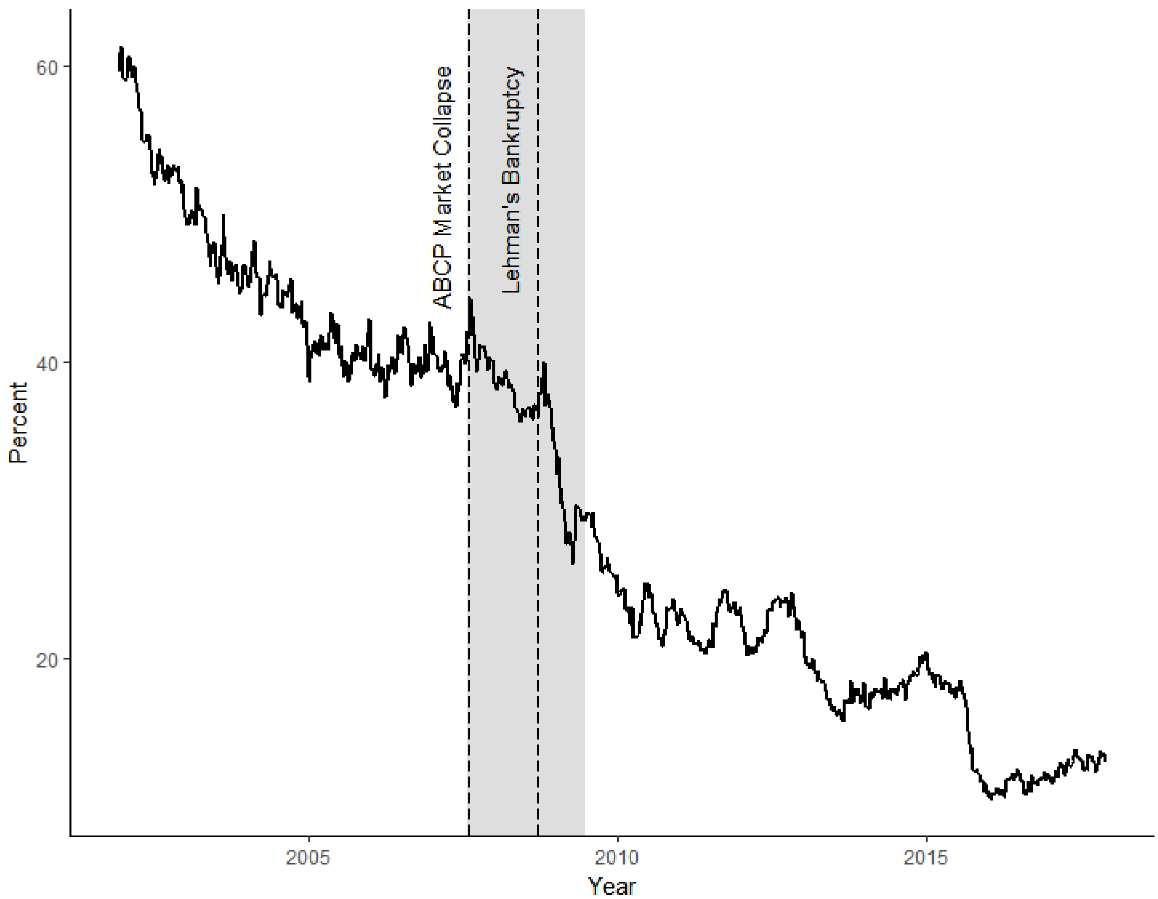

Figure 3.4 The Percentage of Financial CP Outstanding from U.S. Financial Institutions

The figure shows the percentage of financial CP outstanding that is issued by the U.S. owned financial institutions from Dec. 12, 2001, through Nov. 29, 2017. The gray-shaded area is the time period of the Great Recession (from Aug. 1, 2007, to Jun. 24, 2009). The ABCP market collapse was Aug. 9, 2007. Lehman's bankruptcy was Sep. 15, 2008. Source: Federal Reserve's CP release.

independent shadow banks, the volume is not small, especially before the Great Recession. Captive finance companies, subsidiaries of non-financial large corporations, are main financial CP U.S. issuers. They are independent shadow banks. In addition, before the Great Recession, independent dealer banks such as Lehman Brothers were also main financial CP issuers. Hence, most financial CP issuers have no relation with U.S. BHCs and they are competitors by offering similar fixed-income products for investors in the FTQ circle. Deposits have lower interest rates and fewer risks than financial CP. Although there always exists some financial CP issued by shadow banking subsidiaries of BHCs, it is just like the large time deposits in total deposits[32]. They do not change qualitative results in empirical tests.

Another difficulty in empirical tests comes from the frequency of data. In principle, the blue links ②, ③, and ④ in the FTQ circle occur in sequence. In reality, few investors hold plenty of cash on hand for some days, and most money transfers in investors' portfolios are executed electronically and instantaneously, so it is difficult to observe the time-lag between the links ② and ③. Given weekly data used in this chapter, we can think the substitution of deposits for financial CP happens within each week when investors are more risk-sensitive. Hence, the negative correlation between the change of deposits and that of financial CP outstanding is weekly concurrent. The interest of this chapter is not the time-lag between the links ② and ③ but the observation of subsequent liquidity backup from commercial banks to shadow banks. According to the FTQ circle, I need high-frequency data to observe the link ④ that happens later after an increase in deposits, but not too late for shadow banks to rebuild the liquidity. Given that the highest frequency observation I could get from the data is weekly, the shadow banking financing instruments I pick to test should have the average maturity above at least one week. Repos are not feasible because they are mostly overnight. The link ④ in the FTQ circle may happen in a day. The liquidity backup from commercial banks in a week may be too late for repos. However, financial CP has the average maturity as about 30 days. Hence, the weekly data is enough to observe the link ④ in the FTQ circle if it really exists. In addition, the timely liquidity backup is effective for shadow banks to rebuild the liquidity.

After choosing the empirical proxies, we can simplify the FTQ circle into two hypotheses that we need to test.

- **Hypothesis 1**: In each week, there exists a concurrent correlation between the change of deposits and that of financial CP outstanding all the time. The concurrent correlation is negative as shown by the links ② and ③ in the FTQ circle.

[32]The large time deposits outstanding decreased over the Great Recession like shadow banking financing instruments because they are uncovered.

- **Hypothesis 2**: In normal times, there exists a dynamic correlation between deposits and financial CP outstanding inter-weekly. An increase in deposits leads to an increase in financial CP outstanding in the following several weeks as shown by the link ④ in the FTQ circle. In crisis times, the dynamic correlation breaks down.

3.4.1 Methods and Data

I collect my data regarding commercial banks from the Federal Reserve's H.8 statistical release. Although data from the Call Reports contain much more detailed information about commercial banks than H.8 data, the latter does offer the available highest frequency (weekly) look at commercial banks. I choose the H.8 data regarding all domestically chartered commercial banks from December 12, 2001, to November 29, 2017. Weekly data about financial CP are collected from Federal Reserve's CP release and matched to the H.8 data.

I separate my entire times series data into three windows: pre-crisis, crisis, and post-crisis. The cutoff dates to split the period of the Great Recession are chosen arbitrarily. I choose August 1, 2007, one week before the ABCP market collapse, as the beginning of the crisis and June 24, 2009, as the end of the crisis. In such a way, I have 100 data points for the crisis, and the financial CP collapse is about in the middle of the crisis[33]. To test two hypotheses based on the FTQ circle, I estimate a series of VARs, each using the data in the window pre-crisis, crisis, and post-crisis[34].

Because both time series of deposits and financial CP outstanding are non-stationary in all the three windows and they are not co-integrated, I normalize them as follows:

$$g_{\mathrm{De},t} = \ln(\frac{\mathrm{Deposit}_t}{\mathrm{Deposit}_{t-1}}) * 100; \quad g_{\mathrm{CP},t} = \ln(\frac{\mathrm{Financial\ CP}_t}{\mathrm{Financial\ CP}_{t-1}}) * 100.$$

[33]There exists a tradeoff in choosing the window crisis. If the chosen crisis is too short, observations in the crisis may be too few to get significant regression coefficients. If the chosen crisis is too long, it may include excessive noise. According to the nonprofit National Bureau of Economic Research (the official arbiter of U.S. recessions), the Great Recession in the U.S. began in December 2007 and ended in June 2009. My choice begins four months before the official one so that it can include the ABCP market collapse. Qualitative results in this chapter do not change if I use the official time window.

[34]Since I have time series data, and VAR models can identify the concurrent correlation and dynamic correlation for time series data with endogenous variables, I use the VAR models to identify the two hypotheses. Another way to identify the breakdown of liquidity backup during the Great Recession is to use a time dummy variable for the Great Recession. For the dummy variable method, I have to ignore the probable problem of endogeneity between deposits and financial CP outstanding. In addition, only Hypothesis 2 can be identified by the dummy variable. For details, see Section 3.7.

Time series of $g_{\mathrm{De},t}$ and $g_{\mathrm{CP},t}$ are actually weekly growth rates and they are stationary in all the three windows[35]. Table 3.7 shows the summary statistics for time series of $g_{\mathrm{De},t}$ and $g_{\mathrm{CP},t}$. We can see the mean of the percentage change in deposits is highest in the crisis as 0.188, but the standard deviation does not increase from the pre-crisis to the crisis. Hence, deposits have a stable high growth rate in the crisis. By contrast, the growth rate of financial CP outstanding has the lowest mean and the highest volatility in the crisis.

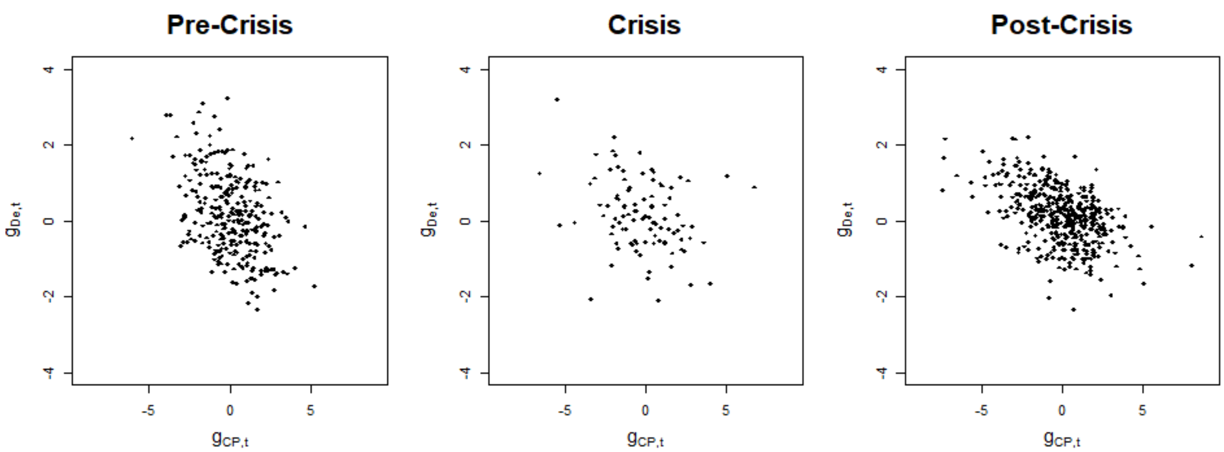

Figure 3.5 Concurrent Scatter Plots for Weekly Growth Rates of Deposits and Financial CP

From Figure 3.5 and Table 3.8, we can see time series of $g_{\mathrm{De},t}$ and $g_{\mathrm{CP},t}$ have negative correlation coefficients all the time. However, it is not sufficient to justify Hypothesis 1 because there may exist an endogeneity problem between the growth rate of deposits and that of financial CP outstanding. To solve the possible endogeneity problem, I use VAR models that include two endogenous variables ($g_{\mathrm{De},t}$ and $g_{\mathrm{CP},t}$). I always choose the lag order as 4 in my VAR models because lag 4 means 4 weeks, and given that the average maturity of financial CP is 30 days, the liquidity backup after

[35] In some literature, the growth rate of deposits is defined by $g_{\mathrm{De},t} = 100 * (\mathrm{Deposit}_t - \mathrm{Deposit}_{t-1})/\mathrm{Deposit}_{t-1}$. For the small absolute value of $r_{\mathrm{De},t} = \mathrm{Deposit}_t/\mathrm{Deposit}_{t-1}$, the two definitions are very close, because $\ln(1+r_{\mathrm{De},t}) \approx r_{\mathrm{De},t}$. In this chapter, I always use log-difference to calcultate growth rates, since it is symmetry, and consistent with the forecast model in Section 3.5. Qualitative results in this chapter do not change if I use the alternative definition.

4 weeks may not be effective in helping even if it exists[36]. The fitted VAR(4) model I estimate in each time window has the following formula:

$$\begin{bmatrix} g_{\mathrm{De},t} \\ g_{\mathrm{CP},t} \end{bmatrix} = \begin{bmatrix} \phi_1^0 \\ \phi_2^0 \end{bmatrix} + \begin{bmatrix} \phi_{11}^1 & \phi_{12}^1 \\ \phi_{21}^1 & \phi_{22}^1 \end{bmatrix} \begin{bmatrix} g_{\mathrm{De},t-1} \\ g_{\mathrm{CP},t-1} \end{bmatrix} + \begin{bmatrix} \phi_{11}^2 & \phi_{12}^2 \\ \phi_{21}^2 & \phi_{22}^2 \end{bmatrix} \begin{bmatrix} g_{\mathrm{De},t-2} \\ g_{\mathrm{CP},t-2} \end{bmatrix} + \begin{bmatrix} \phi_{11}^3 & \phi_{12}^3 \\ \phi_{21}^3 & \phi_{22}^3 \end{bmatrix} \begin{bmatrix} g_{\mathrm{De},t-3} \\ g_{\mathrm{CP},t-3} \end{bmatrix} + \begin{bmatrix} \phi_{11}^4 & \phi_{12}^4 \\ \phi_{21}^4 & \phi_{22}^4 \end{bmatrix} \begin{bmatrix} g_{\mathrm{De},t-4} \\ g_{\mathrm{CP},t-4} \end{bmatrix} + \begin{bmatrix} a_{1t} \\ a_{2t} \end{bmatrix}.$$

Here, residuals $\begin{bmatrix} a_{1t} \\ a_{2t} \end{bmatrix}$ are a sequence of serially uncorrelated vectors with mean zero and covariance matrix $\Sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{bmatrix}$ if the VAR(4) model is correctly fitted. We can calculate the correlation coefficient between residuals a_{1t} and a_{2t} using $\rho_{12} = \sigma_{12}/\sqrt{\sigma_{11} * \sigma_{22}}$. If Hypothesis 1 is true, then ρ_{12} is negative in all three time windows. To justify Hypothesis 2, we expect to find that some of ϕ_{21}^1, ϕ_{21}^2, ϕ_{21}^3 and ϕ_{21}^4 are significantly positive in the pre-crisis and the post-crisis, but not significant in the crisis.

3.4.2 Results

Table 3.9 summarizes the VAR(4) results in all the three time windows. Let's first look at the residuals $a_t = (a_{1t}, a_{2t})$. If the VAR(4) model is correctly fitted in any time window, residuals a_t should have no autocorrelation and no heteroskedasticity. In the pre-crisis, the p-value of Ljung-Box test based on 10 lags of a_t is 0.014, so we can reject the null hypothesis that residuals a_t have no autocorrelation at 5% significance level. However, because commercial banks have an incentive to exaggerate their deposits when they report their financial statements quarterly, including seasonal dummy variables (from lag 1 to lag 13) can raise adjusted R^2 in equation $g_{\mathrm{CP},t}$ from 0.133 up to 0.213 and that in equation $g_{\mathrm{De},t}$ from 0.389 to 0.540. The p-value of Ljung-Box test based on 10 lags of a_t jumps up from 0.014 to 0.243. In addition, the p-value of Ljung-Box test based on 10 lags of

[36] According to information criteria (AIC and BIC), lag order 3 or 4 is usually optimal in the pre-crisis and the post-crisis, but lag order 1 or 2 is optimal in the crisis.

standardized residuals $\tilde{a}_t = a_t/\sigma_t$ rises from 0.087 to 0.270. Hence, considering seasonal effects, the fitted model has no autocorrelation and no heteroskedasticity in the pre-crisis[37]. The VAR(4) may also be correctly fitted in the crisis given large enough p-values of Ljung-Box tests based on a_t and $\tilde{a}_t$. By contrast, the residuals a_t are not well-behaved in the post-crisis. There may exist missing variables that should be included in the model. Another possible reason is the model structure has changed for the time span of the post-crisis. The post-crisis has 440 data points across more than 8 years. I treat it as normal times in this section, but the dynamic correlation between deposits and financial CP outstanding still breaks down in some periods of the post-crisis[38]. Anyway, no crisis after 2009 is as prominent as the Great Recession. Hence, in this section, I ignore the possible structural change in the post-crisis. The correlation coefficients between a_{1t} and a_{2t} are -0.301, -0.356 and -0.475 in the three time windows. They further demonstrate that Hypothesis 1 is true all the time though they are larger than what we get in Table 3.8. The change of deposits and the change of financial CP outstanding are concurrently negatively correlated.

In the pre-crisis, except for the intercept, only coefficients of the growth rate of deposits are significant. For equation $g_{\mathrm{CP},t}$, the coefficients of $g_{\mathrm{De},t-1}$, $g_{\mathrm{De},t-2}$ and $g_{\mathrm{De},t-3}$ are significantly positive. Hence, an increase in deposits leads to an increase in financial CP outstanding in the following one to three weeks, and shadow banks have enough time to rebuild the liquidity. It is worth mentioning that the dynamic correlation is unidirectional. The change of financial CP is affected by the past movements of the change of deposits. However, past movements of the change of financial CP outstanding do not significantly affect the change of deposits, even though the two series have substantial concurrent negative correlation. From the Granger causality tests, we can also see that the change of deposits Granger causes that of financial CP outstanding, but the change of latter does not Granger cause that of deposits. Hence, commercial banks dominate the market in the pre-crisis.

[37]The estimation results of VAR(4) models with seasonal dummy variables are given if request. Qualitative results do not change.

[38]For details, see Section 3.5.

In the crisis, no coefficient is significant at all. Actually, according to the F-test of the whole model (not reported in Table 3.9), two equations about $g_{\text{CP},t}$ and $g_{\text{De},t}$ are not significant. Hence, no dynamic correlation between deposits and financial CP outstanding exists. The liquidity backup shown by the link ④ in the FTQ circle breaks down.

In the post-crisis, the dynamic correlation between deposits and financial CP outstanding emerges again. For equation $g_{\text{CP},t}$, the coefficient of $g_{\text{De},t-2}$ is significantly positive. Hence, an increase in deposits leads to an increase in financial CP outstanding in the following two weeks. The dynamic correlation is not unidirectional anymore although the significant coefficients of the change of financial CP outstanding on the change of deposits are relatively small (-0.069 and -0.031).

In summary, Hypothesis 2 is also supported by the results of VAR(4) models.

3.4.3 Other Variables of Commercial Banks

In this subsection, I estimate VAR(4) models for some other variables of commercial banks and financial CP outstanding. On the liability side, besides deposits, large time deposits are also an interesting variable. They are uncovered by deposit insurance. During the Great Recession, the volume of large time deposits decreased like financial CP. Thus, I expect the concurrent negative correlation between large time deposits and financial CP outstanding still exists but weaker than deposits, given that commercial banks and independent shadow banks are competitors. However, commercial banks are not willing to use the increase in large time deposits as the liquidity backup to shadow banks because of the high risks. The dynamic correlation between large time deposits and financial CP outstanding does not exist all the time. On the asset side, I estimate VAR(4) models for cash, liquid assets and (total) assets with financial CP outstanding respectively[39]. When investors make deposits from commercial banks, on one hand, deposits are the debt of commercial banks. On the other hand, deposits are the cash of commercial banks if they keep the cash on hand. If I replace deposits with cash in the VAR(4) models, I should have the same qualitative

[39]Liquid assets include cash and securities.

results as Table 3.9. It means in a week, when there is an increase in deposits, commercial banks would keep the deposits as cash on hand but not lend them. In the following weeks, the cash goes to shadow banks if no crisis happens. If within one week, cash does not increase when there is an increase in deposits, my story is not valid even though the fact of two hypotheses exists in deposits. I calculate the growth rates as follows:

$$g_{\text{LTDe},t} = \ln(\frac{\text{Large Time Deposit}_t}{\text{Large Time Deposit}_{t-1}}) * 100; \quad g_{\text{Cash},t} = \frac{\text{Cash}_t}{\text{Cash}_{t-1}} * 100;$$

$$g_{\text{LAsset},t} = \ln(\frac{\text{Liquid Asset}_t}{\text{Liquid Asset}_{t-1}}) * 100; \quad g_{\text{Asset},t} = \frac{\text{Asset}_t}{\text{Asset}_{t-1}} * 100;$$

Table 3.10 shows the regression results for large time deposits. As we expected, the concurrent correlation between the change of large time deposits and that of financial CP outstanding is still negative all the time, although they are weaker than the case of deposits. The dynamic correlation is more subtle. In the crisis, an increase in large time deposits can even lead to a decrease in financial CP outstanding. It could be the liquidity spirals (Brunnermeier and Pedersen (2008)). In normal times, we can see the change of commercial banks' attitudes towards large time deposits. In the pre-crisis, liquidity backup from large time deposits happens in two or three weeks, but in the post-crisis, it only happens in four weeks. Commercial banks are more prudent to offer liquidity backup that comes from the increase in large time deposits. After the Great Recession, commercial banks realize that large time deposits possess more liquidity risks than they thought before.

From Table 3.11 and Table 3.12, we can see the results for cash and liquid assets are similar to the case of deposits in normal times. Regression results (not reported in the chapter) also show that the change of cash and that of deposits have strong positive concurrent correlation within one week. Hence, within one week, commercial banks keep most increment of deposits as cash on hand. Things change in the crisis. Not only $g_{\text{Cash},t}$ and $g_{\text{LAsset},t}$ do not Granger cause $g_{\text{CP},t}$, but also absolute values of correlation coefficients of residuals are relatively small with -0.081 from residuals of $g_{\text{Cash},t}$ and $g_{\text{CP},t}$, and -0.064 from residuals of $g_{\text{LAsset},t}$ and $g_{\text{CP},t}$. For (total) assets, the correlation coefficient of residuals of $g_{\text{Asset},t}$ and $g_{\text{CP},t}$ is -0.292, and it is nearly as low as the case of deposits. Within one week, which is a relatively short term, when there is a decrease in financial

CP outstanding, there is an increase in deposits, and total assets also have to keep up with the corresponding change of deposits because of the accounting equation. However, commercial banks may no longer keep the increase in deposits as cash or liquid asset on hand within one week given the relatively insignificant concurrent correlations shown before.

3.4.4 Robustness Tests

To simplify the analysis, I only include two endogenous variables in VAR(4) models before. Although the residuals are well-behaved, potentially omitted variables are worth further studies in case I ignore some possible crucial relations. In this subsection, I estimate VAR(4) models with three endogenous variables: the growth rate of deposits ($g_{\mathrm{De},t}$), the growth rate of financial CP outstanding ($g_{\mathrm{CP},t}$) and one of the potentially omitted variables. The potentially omitted variables considered in this chapter are about interest rates. If deposits and financial CP outstanding are sales quantities of commercial and shadow banking financing products, interest rates are prices. Because different commercial banks have different interest rates, and there are different kinds of deposits, it is difficult to find a proxy for interest rates of total deposits. I first consider the 3-month T-Bill rate as the potentially omitted variable. T-Bills are similar to covered deposits in that they are default risk-free fixed-income products. If commercial banks match the interest rates of their deposits against the T-Bill rate, an increase in the T-Bill rate could lead to an increase in deposits. In weekly data, T-Bills and deposits are more likely substitutes. Hence, I expect an increase in the T-Bill rate to lead to a decrease in deposits. Next, the spread (Paper-TBill) between the 3-month AA-rated financial CP rate and the 3-month T-Bill rate could possibly explain the change of financial CP outstanding. An increase in the Paper-TBill spread means not only a higher return rate but also higher liquidity and potential credit risks in the investment of financial CP. If investors perceive the return more than risks, then a positive concurrent or dynamic correlation may exist between the change of spread and $g_{\mathrm{CP},t}$. In the other case, if the large spread is offered by shadow banks when they have difficulties in rolling over their debt, then it reflects more about the liquidity and potential credit risks.

In addition to the T-Bill rate and the Paper-TBill spread, risks in the whole banking sector are also crucial to the transfer of funds between deposits and financial CP. Intuitively, when the risks increase, investors prefer to invest more in deposits and less in financial CP, and vice versa. In most of the literature, the spread (a.k.a. TED spread) between the 3-month London inter-bank offered (henceforth, Libor) rate and the 3-month T-Bill rate is used as the proxy for the risks. In this chapter, I further subdivide the TED spread into two parts: (1) the spread (Libor-OIS) between the 3-month Libor rate and the 3-month overnight indexed swap (henceforth, OIS) rate which is a proxy for credit risks; (2) the spread (OIS-TBill) between 3-month OIS rate and the 3-month T-Bill rate which is a proxy for liquidity risks.

In order to save space, I first report Granger and Instantaneous causality tests for VAR(4)s that include one more potentially omitted variable respectively in Table 3.14. If an omitted variable indeed significantly influences $g_{\text{De},t}$ and $g_{\text{CP},t}$, I report detailed results of regressions including the variable next. Statistics and p-values (in parentheses) testing the null that the variable on the left side does not Granger or instantaneously cause the other two variables are shown in Table 3.14[40]. The Granger causality tests check the significance of dynamic correlations, and the Instantaneous causality tests check that of concurrent correlations. From Table 3.14, we can see the concurrent correlation between the growth rate of deposits and the growth rate of financial CP outstanding in Hypothesis 1 always exists, even if I include one of the potentially omitted variables in the VAR(4) models[41]. Besides, the dynamic correlation between the growth rate of deposits and the growth rate of financial CP outstanding exists in normal times but breaks down in the crisis like Hypothesis 2 after I consider the potentially omitted variables.

Except for the Libor-OIS spread, no potentially omitted variable has significant dynamic or concurrent correlations with $g_{\text{De},t}$ and $g_{\text{CP},t}$ in normal times, but they are indeed worth being included in the models when the crisis happens. In normal times, the prices of deposits and

[40] I also test the effective federal funds rate, which is a proxy for the interest rate of deposits, to see if it is a potentially omitted variable. However, it is insignificant all the time and has almost no effect on deposits and financial CP outstanding. I drop it to save space.

[41] In this chapter, I use first differences but not log-difference growth rates for all interest rates because some interest rates are negative. Qualitative results do not change if I first add a constant value to interest rates and then transform them into log-difference growth rates.

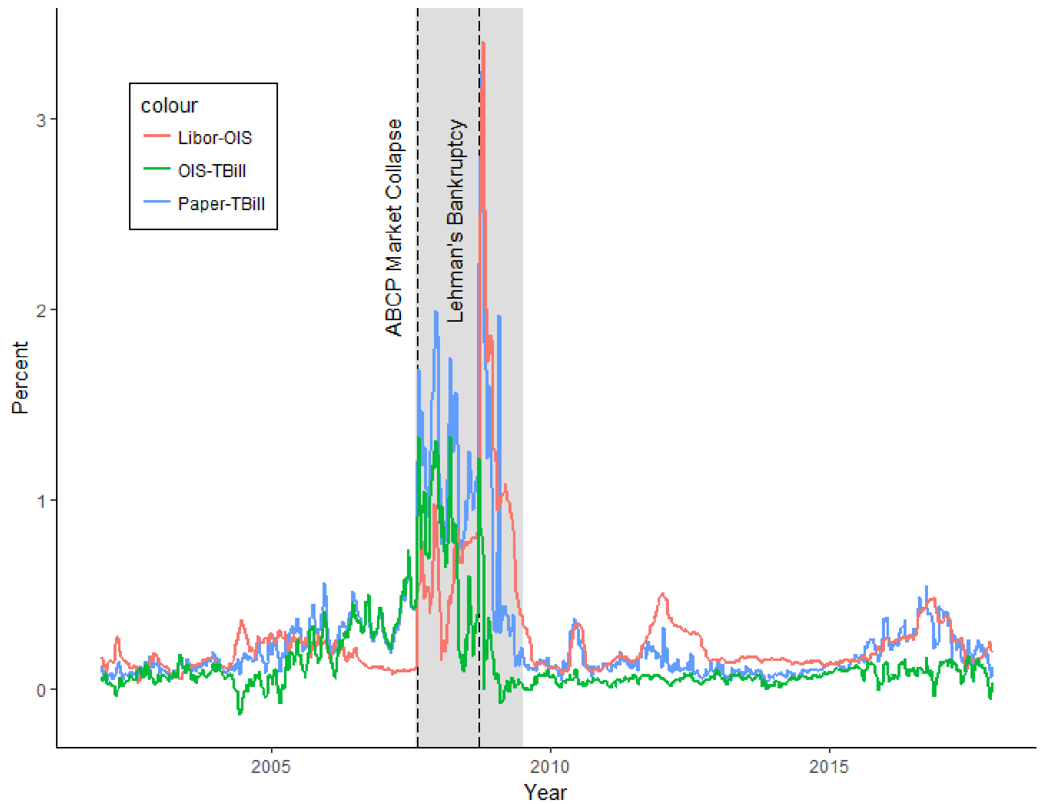

Figure 3.6 The Spreads

The figure shows the spreads from Dec. 12, 2001, through Nov. 29, 2017. Paper-TBill: the spread between the 3-month AA-rated financial CP rates and the 3-month T-Bill rates. Libor-OIS: the spread between the 3-month London inter-bank offered rates and the 3-month overnight indexed swap rates. OIS-TBill: the spread between the 3-month overnight indexed swap rates and the 3-month T-Bill rates. The gray-shaded area is the time period of the Great Recession (from Aug. 1, 2007, to Jun. 24, 2009). The ABCP market collapse was Aug. 9, 2007. Lehman's bankruptcy was Sep. 15, 2008. Source: Federal Reserve's CP release, Bloomberg, U.S. Treasury.

financial CP, and the liquidity risks in the banking sector are totally endogenously decided by $g_{\mathrm{De},t}$ and $g_{\mathrm{CP},t}$. The credit risks in the banking sector (Libor-OIS spread) have significant dynamic explanatory power in the pre-crisis, but the power disappears in the post-crisis. By contrast, the potentially omitted variables are exogenously decided in the crisis. From Figure 3.6, we can see that spreads widen in the crisis, and it is very likely unexpected to commercial banks and shadow banks. Hence, all potentially omitted variables have explanatory power in the crisis.

Table 3.15 shows the estimation results of VAR(4) that includes the Libor-OIS spread in the pre-crisis. As we expected, an increase in the credit risks of the banking sector leads to an increase in deposits and a decrease in financial CP outstanding in two weeks. The results of VAR(4)s include each potentially omitted variable in the crisis are reported in Table 3.16, 3.17, 3.18, and 3.19 respectively. During the Great Recession, $g_{\text{De},t}$ and $\Delta_{\text{T-Bill},t}$ are concurrently negatively correlated, and an increase in T-Bill rates leads to an increase in financial CP outstanding and a decrease in deposits, since deposits and T-Bills are substitutes. $g_{\text{CP},t}$ and $\Delta_{\text{Paper-TBill},t}$ are concurrently negatively correlated, and an increase in Paper-TBill spread leads to a decrease in financial CP outstanding. It proves that in the crisis, shadow banks have difficulties to reissue their financial CP even if they offer high additional interest rates. Investors perceive the high additional return of financial CP as high risks. Finally, investors transfer their funds from financial CP to deposits when the banking sector has increases in credit risks (Libor-OIS spread) and liquidity risks (OIS-TBill spread) in the crisis. As to concurrent correlations, $\Delta_{\text{Libor-OIS},t}$ is negatively correlated with $g_{\text{CP},t}$ and positively correlated with $g_{\text{De},t}$, but $\Delta_{\text{OIS-TBill},t}$ is only positively correlated with $g_{\text{De},t}$. Hence, investors do not think liquidity risks have an instant negative influence on financial CP like credit risks.

3.5 The Forecast Model: When Liquidity Backup Breaks Down

In Section 3.4, I mark out the time window of the Great Recession as the crisis in advance. The VAR(4) model for $g_{\text{De},t}$ and $g_{\text{CP},t}$ is not significant in the crisis. Although the crisis set has 100 data points, it still could be too small to have significant results. In this section, I do not presume the crisis times but let the data reveal them according to the FTQ circle. If my FTQ circle model is correct, when the liquidity backup of the blue link ④ breaks down, it is the time that markets have a crisis. How to find the specific time that the liquidity backup from commercial banks to shadow banks breaks down? The dynamic correlation between $g_{\text{De},t}$ and $g_{\text{CP},t}$ stemming from the blue link ④ can help improve the prediction of future financial CP outstanding in normal times. An increase in deposits leads to an increase in financial CP outstanding. Hence, to predict future financial

CP outstanding, including the past value of deposits is more accurate than using the past value of financial CP outstanding alone. If including the past value of deposits cannot substantially increase the accuracy of the prediction of financial CP outstanding, it means the dynamic correlation breaks down, and it is the crisis time. I expect that the data will reveal the liquidity backup breaks down during the most time of the Great Recession beforehand, or the FTQ circle model may be wrong.

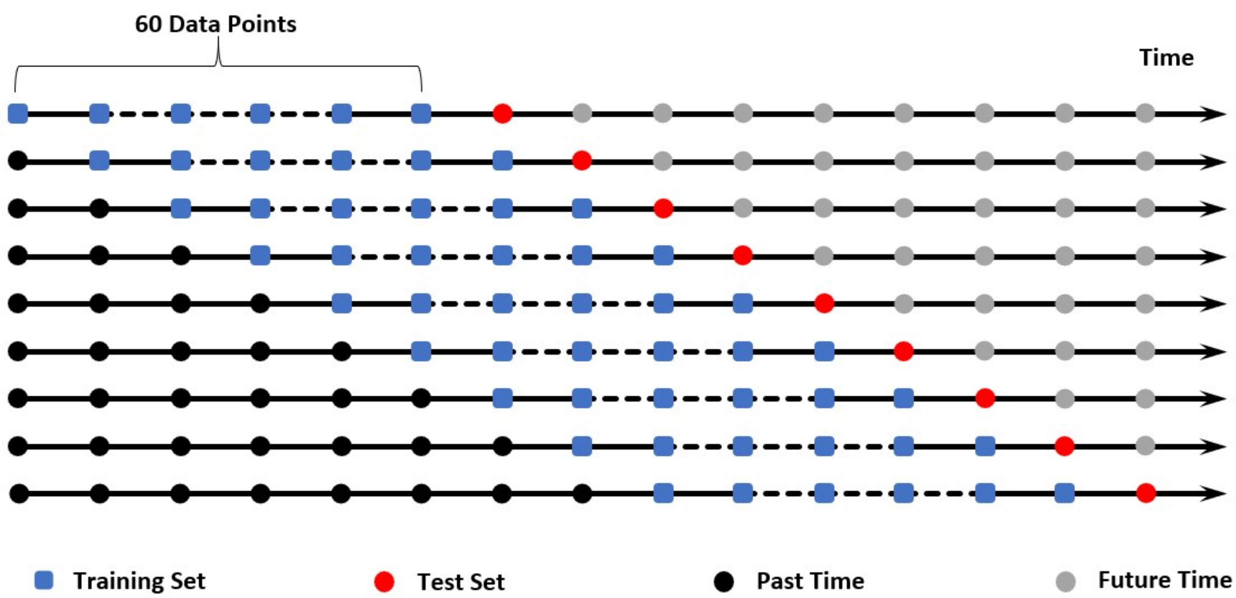

Figure 3.7 One-Step Forward-Chaining Cross-Validation

The time span I use to make predictions is longer than that I use to estimate the VAR(4) models in Section 3.4. I collect weekly data regarding deposits and financial CP outstanding from January 3, 2001, to January 16, 2019. Totally, there are 942 observations. Figure 3.7 shows the one-step forward-chaining cross-validation method I use to compare the prediction accuracy of different models. Each training set (blue squares) has 60 data points, and the corresponding test set (red circle) is the next observation after the training set. Hence, each model has to be estimated in total 882 training sets respectively, and the 882 fitted models are used to predict the 882 test sets. Finally, we have time series of 882 squared errors from the difference between the true value and the predicted value in test sets for each model, and they are the measure to judge the prediction accuracy of different models.

I set the size of training sets as fixed 60 data points even if there exist more historical data when we predict relatively recent test sets. Although including more data points in training sets can help estimate the yearly seasonality, the time series of squared errors will have a decreasing trend because more recent test sets have more data points in their corresponding training sets. To give a fair condition for each group of the training set and test set, I assume the 60 weeks Markov property. Given 60 weeks in each training set, I ignore the yearly seasonality. However, it does not undermine the analysis in this section because the goal of this section is not to find a model that can best predict weekly financial CP outstanding but justify including past deposits can improve the prediction in normal times.

For univariate models with only financial CP outstanding, a simple random walk with drift model regarding the log value can give a good prediction according to the mean squared error (henceforth, MSE) in test sets. Hence, the univariate model I use to predict financial CP outstanding is:

$$\text{Univariate Model:} \quad \ln(\text{Financial CP}_{t+1}) = d + \ln(\text{Financial CP}_t) + \epsilon_t$$

where ϵ_t is a normal i.i.d. error and financial CP outstanding is in million dollars. It is the same as we usually assume the price of a stock follows the geometric Brownian motion. Complicated univariate models like ARIMA-GARCH models or artificial neural networks models cannot substantially reduce the MSE. The multivariate model including deposits I use to predict financial CP outstanding is:

$$\text{Multivariate Model:} \quad \begin{cases} \ln(\text{Financial CP}_{t+1}) = d_1 + \ln(\text{Financial CP}_t) + \epsilon_{1t} + \\ \beta[\ln(\widehat{\text{Deposits}}_{t+1}) - \ln(\text{Deposits}_t)] \\ (1-\gamma_1 L^{13})[\ln(\text{Deposits}_{t+1}) - \ln(\text{Deposits}_t)] = d_2 + (1-\gamma_2 L^{13})\epsilon_{2t} \end{cases}$$

where ϵ_{1t} and ϵ_{2t} are normal i.i.d. errors, and deposits and financial CP outstanding are in million dollars. Compared to the univariate model, financial CP outstanding depends on not only the drift and its value in last week but also the predicted deposits ($\widehat{\text{Deposits}}_{t+1}$). The predicted deposits ($\widehat{\text{Deposits}}_{t+1}$) are estimated by a seasonal random walk with drift model. The quarterly (13 weeks) seasonality exists in deposits because commercial banks tend to exaggerate their deposits when they report their financial statements every quarter[42]. It is the reason I cannot use the VAR model to predict financial CP outstanding. Even seasonal VAR models cannot capture the seasonality in deposits like the univariate seasonal model for deposits. Admittedly, the seasonal random walk with drift model is not the best model to predict deposits. However, to achieve the goal in this section, it is enough and straightforward. I only need to test if including deposits and keeping all other things unchanged in the univariate model of financial CP outstanding can improve the prediction accuracy in normal times.

Figure 3.8 shows 40 weeks moving averages of squared errors for univariate and multivariate models. To make the MSE more readable, the squared error in Figure 3.8 is calculated as follows:

$$\text{Squared Error} = (\ln(\text{Financial CP}) - \ln(\widehat{\text{Financial CP}}))^2 * 10000$$

where financial CP outstanding from test sets is in million dollars. Except for the four gray-shaded columns, the multivariate model has fewer MSEs than the univariate model as we expected, which means there exists a dynamic correlation between deposits and financial CP outstanding. The liquidity backup was broken from September 2007 to April 2009 first time as shown by the first gray column. It is almost the generally accepted time period of the Great Recession. The second and third gray columns are from January 2010 to April 2010 and from September 2010 to May 2011, respectively. We know the European sovereign debt crisis peaked between 2010 to 2011. Foreign financial institutions account for more than 75% of total financial CP outstanding after 2010 (Figure 3.4), and most of them are headquartered in Europe, so it is not hard to understand that U.S. commercial banks stop the liquidity backup from increased deposits to European financial institutions during the European debt crisis. According to my forecast model, there exists a mitigation gap between the second and third gray columns. Further studies need to check if the crisis truly mitigates between April 2010 to September 2010. The last gray column in Figure 3.8

[42] Financial CP outstanding does not have quarterly seasonality alone.

is between June 2014 to November 2014. Crude oil prices (Brent or WTI) plunged more than 50% in this period. The more detailed reasons behind the breakdown of liquidity backup are still worth further studies.

The model in this section is not for the financial crisis forecast. Commercial banks change their strategies about the change of deposits when they realize a crisis is coming. Somehow, they can forecast the arrival of a potential crisis using their risk management models. In addition, the breakdown of liquidity backup does not necessarily result in the collapse of financial CP. We only observe the prominent collapse following the Lehman's Bankruptcy. Liquidity backup is a guarantee for investors' confidence. When it breaks down, a trigger such as a large impact of credit risks may set off the collapse of financial CP.

3.6 Concluding Remarks

During the Great Recession, not all funds flew out from the banking system. Deposits increased, but the volumes of all other short-term financing instruments decreased. Commercial banks that relied more heavily on core deposit and equity capital financing could still lend and purchase securitized assets compared to other banks. After the bankruptcy of Lehman Brothers, commercial banks kept the unprecedentedly large increase in deposits as cash on hand, which could be crucial liquidity backup for shadow banks (see Table 3.2). This may have been due to the counter-party risks or the newly introduced policy by the Federal Reserve to pay interest on bank reserves. Or sometimes, commercial banks would rather squeeze their credit and acquire securitized assets at fire-sale price liquidated by shadow banks than offer liquidity backup to high risky counter-parties (Acharya et al. (2010)). Although there were unprecedented government bailouts after Lehman's bankruptcy, securitized assets have already been priced at extremely risk-averse preference from fixed-income investors. Using their securitized assets as collateral, shadow banks cannot raise enough funds compared to times when securitized assets are in nearly risk-neutral pricing. No liquidity can arbitrage securitized assets back to nearly risk-neutral pricing, and even if any, it takes a too long time to go back, and survival could be a problem.

After the Great Recession, BHCs were potential winners and owned more and more shadow banking subsidiaries. Although the number of independent shadow banks decreased, we have the internal FTQ circle in BHCs. BHCs can enjoy the synergy by holding commercial banks and shadow banks together. However, deposits may not be enough for some BHCs to survive in the next crisis. Funds will transfer from some BHCs to others, and regulations should be able to stimulate BHCs with rich liquidity to help BHCs in trouble but not stand by and profit from the trouble. This chapter also proposes that regulations should focus on not only sufficient capital, but also sufficient core deposits.

Nowadays, new kinds of shadow banks spring up. It is important to differentiate between pure dis-intermediation and banking activities. For example, peer-to-peer lending is pure dis-intermediation if the lending platform only channels funds from lenders to borrowers, and all risks transfer from borrowers to lenders. However, lending platforms usually have their own liquidity management and sometimes offer guarantees to investors for protection. The credit risk retention can stimulate platforms to monitor borrowers, but it also brings about the liquidity risks given that lending platforms are not pure platforms anymore. Another example of new rising shadow banks is the mortgage lending company. Some mortgage lenders are ultimately funded by agency MBSes. During the Great Recession, agency MBSes were saved by government bailouts. Agency MBS investors may expect the implicit bailouts will happen again, so agency MBSes dominate the securitized asset market today (Table 3.3). If agency MBSes suffer runs in the future, mortgage lenders that rely on the agency MBS financing will suffer liquidity problems too. Even if the government saves the agency MBSes again, taxpayers will undertake the final cost.

The FTQ circle model in this chapter also has implications for international finance. When a country raises capital internationally, it can still have sufficient capital when normal fluctuation in the economy of the country happens. The capital outflow is offset by the inflow from the liquidity backup. However, when a severe crisis happens inside the country, the liquidity problem may break out. In reality, European financial institutions issue financial CP in the United States, and the liquidity backup broke down during the European debt crisis.

Finally, there is one caveat: this chapter only considers the liquidity risks and therefore, the liability side of financial institutions. Most financial institutions failed in the Great Recession because of their holdings of MBSes, especially subprime MBSes. When the prices of their assets (mostly MBSes) declined, financial institutions could be insolvent even with no liquidity problem. The neglected credit risks and bubbles in prices of collateral (mostly real estate) largely account for the price decline of securitized assets. Liquidity risks also play a role in explaining the price decline. As the story in this chapter, when the liquidity backup from commercial banks broke down, shadow banks could not roll over their debt and had to liquidate their securitized assets. The liquidation leads to the further price decline of MBSes. Excluding the neglected credit risks and bubbles, MBSes are priced from nearly risk-neutral to extremely risk-averse valuation because extremely risk-averse investors dominate the markets. It is hard to say that the failed financial institutions hold a large number of MBSes intentionally or they cannot resell the MBSes they issued or underwrote. From a risk-neutral perspective, their holdings of MBSes may be correct, but they cannot survive into the time when markets are full of liquidity and dominated by nearly risk-neutral arbitragers again.

3.7 Supplementary Analyses

Since I have time series data, and VAR models can identify the concurrent correlation and dynamic correlation for time series data with endogenous variables, I use the VAR models to identify the two hypotheses about deposits and financial CP outstanding in most parts of this chapter. In this section, I use a time dummy variable for the Great Recession to identify the breakdown of liquidity backup during the Great Recession, i.e., Hypothesis 2. For this method, I have to ignore the probable problem of endogeneity between deposits and financial CP outstanding. In addition, Hypothesis 1 cannot be identified by the time dummy variable.

Each column in Table 3.20 reports a linear regression of the same dependent variable: the growth rate of financial CP outstanding at date t ($g_{\mathrm{CP},t}$) but different independent variables. C_{t-1} is the time dummy variable, which equals one if the time $t-1$ happens in the Great Recession.

If Hypothesis 2 truly exists, I expect to find significantly positive coefficients of lag terms of the growth rate of deposits, i.e. $g_{\mathrm{De},t-1}$, $g_{\mathrm{De},t-2}$, or $g_{\mathrm{De},t-3}$, which means an increase in deposits leads to an increase in financial CP outstanding. Meanwhile, some interaction terms between lag terms of the growth rate of deposits and the time dummy variable, i.e. $g_{\mathrm{De},t-1} * C_{t-1}$, $g_{\mathrm{De},t-2} * C_{t-1}$, or $g_{\mathrm{De},t-3} * C_{t-1}$, are significantly negative. Hence, it demonstrates that liquidity backup from commercial banks to shadow banks was weak during the Great Recession compared to other times.

Compared to Model (1), Model (3), and Model (5), Model (2), Model (4), and Model (6) allow autoregressive effects for the growth rate of financial CP outstanding by including lag terms of $g_{\mathrm{CP},t}$ in the independent variables. Model (1) and Model (2) are basic models with only first-order lag terms. The signs of coefficients of $g_{\mathrm{De},t-1}$ and $g_{\mathrm{De},t-1} * C_{t-1}$ are as expected, but they are not significant. The R^2s are very low compared to the VAR models, so it seems that Model (1) and Model (2) are not correctly fitted.

Model (3) and Model (4) have up to third-order lag terms. As I expected, they have significantly positive coefficients of lag terms of the growth rate of deposits, i.e. $g_{\mathrm{De},t-1}$, $g_{\mathrm{De},t-2}$, and $g_{\mathrm{De},t-3}$, and significantly negative interaction terms between lag terms of the growth rate of deposits and the time dummy variable, i.e. $g_{\mathrm{De},t-1} * C_{t-1}$, $g_{\mathrm{De},t-2} * C_{t-1}$, and $g_{\mathrm{De},t-3} * C_{t-1}$. Hence, one week time-lag is not enough to depict liquidity backup from commercial banks to shadow banks.

For models in the last two columns of Table 3.20, I further elaborate Model (3) and Model (4) by including two variables about risks in the banking system. First, the weekly change in the spread between the 3-month London inter-bank offered rate and the 3-month overnight indexed swap rate ($\Delta_{\text{Libor-OIS},t}$), which is a proxy for credit risks. Second, the weekly change in the spread between the 3-month overnight indexed swap rate and the 3-month T-Bill rate ($\Delta_{\text{OIS-TBill},t}$), which is a proxy for liquidity risks. Model (5) and Model (6) still have significant coefficients on lag terms of the growth rate of deposits and one interaction term between the growth rate of deposits and the time dummy variable. In addition, the coefficient of $\Delta_{\text{Libor-OIS},t-1} * g_{\mathrm{De},t-1}$ is significantly negative, which means when credit risks in the banking system are large, if there is an increase in deposits, commercial banks offer significantly less liquidity backup to shadow banks in the next week. Intuitively, when facing large credit risks in the banking system, commercial banks would rather keep the increase in deposits on hand than offer liquidity backup to high risky counter-parties. It is worth mentioning that the coefficient of $\Delta_{\text{Libor-OIS},t-1}$ is not significant, which means credit risks themselves have no direct correlation with the change of financial CP outstanding. Moreover, liquidity risks have nothing to do with the willingness of commercial banks to offer liquidity backup.

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Table 3.1 Annual U.S. Main Short-Term Debt Financing Instruments ($ billions)

Year	Commercial Paper	Repurchase Agreements	Treasury Bills	Deposits	Agency Debentures
2003	1,341	1,244	929	4,095	445
2004	1,334	1,518	1,001	4,428	566
2005	1,529	1,838	961	4,817	485
2006	1,806	2,106	941	5,181	518
2007	2,005	2,427	1,000	5,477	832
2008	1,739	2,239	1,861	5,889	1,124
2009	1,303	1,728	1,793	6,548	652
2010	1,074	1,717	1,773	6,742	567
2011	1,081	1,871	1,521	7,208	517
2012	993	2,064	1,629	7,944	460
2013	1,034	1,932	1,592	8,490	533
2014	1,047	1,781	1,458	9,047	636
2015	1,028	1,801	1,514	9,657	718
2016	1,020	1,788	1,818	10,244	552
2017	996	1,958	1,956	10,752	529
2018	1,088	2,103	2,340	11,170	544

This table reports annual (2003-2018) main debt financing instruments with maturity less than 1 year, a.k.a. money market financing instruments, except for deposits. Deposits are total deposits of domestically chartered commercial banks including long-term time deposits and transaction deposits. They are the annual average value of weekly data obtained from the Federal Reserve's H.8 statistical release. Commercial Paper outstanding is the annual average value of weekly data obtained from the Federal Reserve's CP release. Repurchase Agreements are only tri-party repos. Their annual average collateral value is calculated by daily data obtained from the Federal Reserve Bank of New York. The data before 2008 about repos is estimated by the author because of a lack of data availability. Treasury bills outstanding is the year-end value of monthly data obtained from the U.S. Treasury. Agency debentures outstanding is the year-end value of quarterly data obtained from Securities Industry and Financial Markets Association (SIFMA). The data about agency debentures before 2006 is estimated by the author because of a lack of data availability.

Table 3.2 Annual U.S. Household Liquid Financial Assets ($ billions, Percent)

Year	Equity	Deposits	Mutual Funds	Treasury & Agency	Municipal Bonds	MMMF	Corporate Bonds	Total
2003	6,973	4,524	2,674	762	626	909	670	17,111
	40.8%	26.4%	15.5%	4.5%	3.7%	5.3%	3.9%	100%
2004	7,640	4,941	3,074	884	1,514	878	601	19,531
	39.1%	25.3%	15.7%	4.5%	7.7%	4.5%	3.1%	100%
2005	8,307	5,311	3,299	866	1,630	926	810	21,150
	39.3%	25.1%	15.6%	4.1%	7.7%	4.4%	3.8%	100%
2006	10,220	5,789	3,858	815	1,687	1,097	831	24,297
	42.1%	23.8%	15.9%	3.4%	6.9%	4.5%	3.4%	100%
2007	10,075	6,210	4,343	919	1,777	1,343	1,195	25,862
	39.0%	24.0%	16.8%	3.6%	6.9%	5.2%	4.6%	100%
2008	5,601	6,660	2,795	1,140	1,916	1,577	2,150	21,839
	25.6%	30.5%	12.8%	5.2%	8.8%	7.2%	9.8%	100%
2009	7,338	6,798	3,875	1,154	1,994	1,306	1,706	24,171
	30.4%	28.1%	16.0%	4.8%	8.2%	5.4%	7.1%	100%
2010	8,704	6,937	4,503	1,352	2,073	1,121	1,332	26,021
	33.5%	26.7%	17.3%	5.2%	8.0%	4.3%	5.1%	100%
2011	8,191	7,605	4,489	960	1,969	1,103	1,325	25,643
	31.9%	29.7%	17.5%	3.7%	7.7%	4.3%	5.2%	100%
2012	9,496	8,114	5,331	1,113	1,830	1,119	1,091	28,094
	33.8%	28.9%	19.0%	4.0%	6.5%	4.0%	3.9%	100%
2013	12,649	8,480	6,340	1,410	1,839	1,120	1,087	32,925
	38.4%	25.8%	19.3%	4.3%	5.6%	3.4%	3.3%	100%
2014	14,314	9,063	6,829	1,060	1,696	1,033	1,090	35,085
	40.8%	25.8%	19.5%	3.0%	4.8%	2.9%	3.1%	100%
2015	13,837	9,563	6,758	1,680	1,642	1,044	1,144	35,668
	38.8%	26.8%	18.9%	4.7%	4.6%	2.9%	3.2%	100%
2016	15,209	10,187	7,251	1,847	1,673	1,023	846	38,036
	40.0%	26.8%	19.1%	4.9%	4.4%	2.7%	2.2%	100%
2017	17,877	10,331	8,685	1,882	1,570	1,054	456	41,855
	42.7%	24.7%	20.7%	4.5%	3.7%	2.5%	1.1%	100%

Households include nonprofit organizations. Liquid financial assets exclude such illiquid assets as pension fund reserves, equity in the non-corporate business, etc. Source: Federal Reserve Flow of Funds, L.101.

Table 3.3 Annual U.S. Asset-Backed and Mortgage-Related Securities Outstanding ($ billions)

Year	ABSes	Non-Agency MBSes	Agency MBSes	Total
2003	995	1,366	4,349	6,710
2004	1,100	1,896	4,405	7,402
2005	1,281	2,556	4,662	8,499
2006	1,657	3,299	5,091	10,047
2007	1,964	3,585	5,801	11,349
2008	1,830	3,188	6,279	11,297
2009	1,712	2,716	6,636	11,065
2010	1,508	2,424	6,835	10,766
2011	1,359	2,128	6,948	10,434
2012	1,280	1,878	6,960	10,118
2013	1,286	1,703	7,040	10,028
2014	1,349	1,623	7,219	10,191
2015	1,384	1,528	7,367	10,278
2016	1,397	1,385	7,638	10,420
2017	1,469	1,299	8,005	10,773
2018	1,677	1,294	8,089	11,060

Source: Securities Industry and Financial Markets Association (SIFMA).

Table 3.4 Annual U.S. Commercial Paper Outstanding ($ billions)

Date	ABCP	Financial CP	Corporate CP	Total
2003	680	528	134	1,341
2004	663	550	121	1,334
2005	763	623	142	1,529
2006	970	693	142	1,806
2007	1,059	772	175	2,005
2008	764	783	192	1,739
2009	558	597	148	1,303
2010	403	547	125	1,074
2011	370	543	167	1,081
2012	317	479	197	993
2013	275	544	216	1,034
2014	242	540	265	1,047
2015	231	522	275	1,028
2016	255	492	273	1,020
2017	242	468	285	996
2018	238	548	301	1,088

Source: Federal Reserve's H.8 statistical release.

Table 3.5 Annual U.S. Tri-Party Repos Outstanding ($ billions)

Year	Tri-Party Repos	GCF	Net Tri-Party Repos
2010	1,717	333	1,384
2011	1,871	306	1,565
2012	2,064	293	1,772
2013	1,932	257	1,675
2014	1,781	202	1,579
2015	1,801	221	1,580
2016	1,788	179	1,609
2017	1,958	123	1,835
2018	2,103	134	1,969

Source: Federal Reserve Bank of New York.

Table 3.6 Annual U.S. Agency Debentures Outstanding ($ billions)

Year	Short-Term	Long-Term	Total
2006	518	2,114	2,632
2007	832	2,074	2,906
2008	1,124	2,085	3,208
2009	652	2,074	2,726
2010	567	1,971	2,538
2011	517	1,810	2,327
2012	460	1,636	2,096
2013	533	1,525	2,058
2014	636	1,393	2,029
2015	718	1,278	1,995
2016	552	1,420	1,972
2017	529	1,406	1,935
2018	544	1,322	1,865

Source: Securities Industry and Financial Markets Association (SIFMA).

Table 3.7 Summary Statistics for Weekly Growth Rates of Deposits and Financial CP (Percent)

Window	Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Pre-Crisis	$g_{\mathrm{De},t}$	294	0.132	1.062	−2.327	−0.595	0.864	3.241
	$g_{\mathrm{CP},t}$	294	0.113	1.638	−6.023	−0.900	1.228	5.234
Crisis	$g_{\mathrm{De},t}$	100	0.188	1.019	−2.094	−0.513	0.883	4.227
	$g_{\mathrm{CP},t}$	100	−0.313	2.824	−11.769	−1.691	1.169	10.456
Post-Crisis	$g_{\mathrm{De},t}$	440	0.118	0.745	−2.340	−0.392	0.631	2.216
	$g_{\mathrm{CP},t}$	440	−0.031	2.148	−7.396	−1.330	1.403	11.980

Table 3.8 Concurrent Correlation Coefficients for Weekly Growth Rates of Deposits and Financial CP and t-Test

Window	Pre-Crisis	Crisis	Post-Crisis
Correlation Coefficient	−0.445	−0.276	−0.502
t-Value	−8.498	−2.847	−12.140
df	292	98	438
p-Value	5.0E-16	0.003	2.2E-16

Table 3.9 VAR(4)s for Weekly Growth Rates of Deposits and Financial CP

	Pre-Crisis		*Crisis*		*Post-Crisis*	
	$g_{\mathrm{CP},t}$	$g_{\mathrm{De},t}$	$g_{\mathrm{CP},t}$	$g_{\mathrm{De},t}$	$g_{\mathrm{CP},t}$	$g_{\mathrm{De},t}$
$g_{\mathrm{CP},t-1}$	0.028	−0.048	0.170	0.047	−0.166**	0.012
	(0.062)	(0.034)	(0.113)	(0.039)	(0.054)	(0.016)
$g_{\mathrm{De},t-1}$	0.567***	−0.603***	−0.225	−0.093	−0.154	−0.191***
	(0.114)	(0.062)	(0.325)	(0.113)	(0.183)	(0.053)
$g_{\mathrm{CP},t-2}$	0.115	−0.042	0.097	−0.050	0.104	−0.069***
	(0.062)	(0.034)	(0.114)	(0.040)	(0.055)	(0.016)
$g_{\mathrm{De},t-2}$	0.709***	−0.468***	−0.616	0.026	0.751***	−0.439***
	(0.122)	(0.067)	(0.323)	(0.112)	(0.175)	(0.050)
$g_{\mathrm{CP},t-3}$	0.044	−0.017	−0.105	0.004	−0.029	0.007
	(0.062)	(0.034)	(0.114)	(0.040)	(0.056)	(0.016)
$g_{\mathrm{De},t-3}$	0.554***	−0.525***	−0.105	−0.164	0.342	−0.336***
	(0.128)	(0.069)	(0.327)	(0.114)	(0.180)	(0.052)
$g_{\mathrm{CP},t-4}$	0.021	−0.048	0.039	0.024	0.149**	−0.031*
	(0.062)	(0.034)	(0.110)	(0.038)	(0.054)	(0.016)
$g_{\mathrm{De},t-4}$	0.117	−0.033	0.277	0.190	0.197	0.197***
	(0.122)	(0.066)	(0.319)	(0.111)	(0.183)	(0.053)
const	−0.172	0.367***	−0.078	0.195	−0.153	0.207***
	(0.105)	(0.057)	(0.318)	(0.111)	(0.115)	(0.033)
Observations	290	290	96	96	436	436
R^2	0.157	0.406	0.122	0.156	0.104	0.378
Adjusted R^2	0.133	0.389	0.042	0.078	0.087	0.367
Σ	2.347	−0.385	7.843	−0.972	4.228	−0.577
	−0.385	0.696	−0.972	0.949	−0.577	0.350
ρ	1	−0.301	1	−0.356	1	−0.475
	−0.301	1	−0.356	1	−0.475	1
Granger Causality	0.171	1.5E-09	0.595	0.303	1.4E-05	2.3E-05
a_t Ljung-Box $Q_2(10)$	0.014		0.686		2.8E-05	
$\tilde{a}_t$ Ljung-Box $Q_2(10)$	0.087		0.118		2.2E-05	

Note: *p<0.05; **p<0.01; ***p<0.001

Granger Causality is the p-value of excluding the variable. a_t Ljung-Box test is a portmanteau test for autocorrelation in residuals. $\tilde{a}_t = a_t/\sigma_t$ are standardized residuals. $\tilde{a}_t$ Ljung-Box test is a portmanteau test for heteroskedasticity in residuals.

Table 3.10 VAR(4)s for Weekly Growth Rates of Large Time Deposits and Financial CP

	Pre-Crisis		*Crisis*		*Post-Crisis*	
	$g_{\mathrm{CP},t}$	$g_{\mathrm{LTDe},t}$	$g_{\mathrm{CP},t}$	$g_{\mathrm{LTDe},t}$	$g_{\mathrm{CP},t}$	$g_{\mathrm{LTDe},t}$
$g_{\mathrm{CP},t-1}$	0.009	−0.013	0.245*	−0.045	−0.147**	0.037*
	(0.061)	(0.039)	(0.109)	(0.050)	(0.048)	(0.017)
$g_{\mathrm{LTDe},t-1}$	0.144	−0.183**	0.242	0.115	−0.247	0.083
	(0.094)	(0.060)	(0.244)	(0.112)	(0.138)	(0.049)
$g_{\mathrm{CP},t-2}$	0.043	0.031	0.083	−0.005	−0.016	−0.004
	(0.060)	(0.038)	(0.108)	(0.049)	(0.049)	(0.017)
$g_{\mathrm{LTDe},t-2}$	0.236*	−0.157*	−0.660**	0.410***	0.221	0.067
	(0.094)	(0.061)	(0.235)	(0.108)	(0.138)	(0.049)
$g_{\mathrm{CP},t-3}$	−0.036	0.031	−0.193	0.012	−0.078	−0.012
	(0.060)	(0.038)	(0.107)	(0.049)	(0.049)	(0.017)
$g_{\mathrm{LTDe},t-3}$	0.219*	−0.150*	−0.327	−0.249*	0.003	0.050
	(0.095)	(0.061)	(0.238)	(0.109)	(0.138)	(0.049)
$g_{\mathrm{CP},t-4}$	0.014	−0.023	0.078	0.038	0.141**	−0.022
	(0.060)	(0.039)	(0.107)	(0.049)	(0.048)	(0.017)
$g_{\mathrm{LTDe},t-4}$	−0.202*	0.172**	0.583*	0.088	0.277*	0.077
	(0.095)	(0.061)	(0.247)	(0.113)	(0.137)	(0.049)
const	0.036	0.244***	−0.198	0.017	−0.016	−0.018
	(0.104)	(0.067)	(0.280)	(0.128)	(0.101)	(0.036)
Observations	290	290	96	96	436	436
R^2	0.075	0.127	0.179	0.260	0.068	0.041
Adjusted R^2	0.049	0.102	0.103	0.192	0.050	0.023
Σ	2.575	−0.321	7.338	−1.102	4.397	−0.247
	−0.321	1.061	−1.102	1.542	−0.247	0.551
ρ	1	−0.194	1	−0.328	1	−0.159
	−0.194	1	−0.328	1	−0.159	1

Note: $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Table 3.11 VAR(4)s for Weekly Growth Rates of Cash and Financial CP

	Pre-Crisis		*Crisis*		*Post-Crisis*	
	$g_{\text{CP},t}$	$g_{\text{Cash},t}$	$g_{\text{CP},t}$	$g_{\text{Cash},t}$	$g_{\text{CP},t}$	$g_{\text{Cash},t}$
$g_{\text{CP},t-1}$	0.009	0.009	0.227*	0.173	−0.140**	0.047
	(0.059)	(0.203)	(0.106)	(0.304)	(0.050)	(0.093)
$g_{\text{Cash},t-1}$	0.062***	−0.826***	0.010	−0.356***	−0.033	−0.277***
	(0.017)	(0.058)	(0.036)	(0.104)	(0.027)	(0.050)
$g_{\text{CP},t-2}$	−0.001	0.314	0.135	0.044	0.021	0.043
	(0.058)	(0.201)	(0.106)	(0.306)	(0.050)	(0.094)
$g_{\text{Cash},t-2}$	0.067***	−0.505***	−0.058	0.073	0.074**	−0.214***
	(0.020)	(0.067)	(0.038)	(0.109)	(0.027)	(0.050)
$g_{\text{CP},t-3}$	−0.038	−0.411*	−0.141	−0.309	−0.091	0.319***
	(0.059)	(0.203)	(0.106)	(0.305)	(0.050)	(0.093)
$g_{\text{Cash},t-3}$	0.100***	−0.586***	−0.013	0.042	−0.020	−0.147**
	(0.019)	(0.067)	(0.038)	(0.109)	(0.027)	(0.051)
$g_{\text{CP},t-4}$	0.090	−0.684***	0.047	−0.632*	0.126*	−0.072
	(0.059)	(0.204)	(0.105)	(0.303)	(0.050)	(0.093)
$g_{\text{Cash},t-4}$	0.068***	−0.248***	0.062	0.157	−0.011	0.095
	(0.017)	(0.058)	(0.036)	(0.104)	(0.026)	(0.049)
const	0.114	−0.066	−0.193	0.942	−0.026	0.270
	(0.093)	(0.321)	(0.304)	(0.877)	(0.101)	(0.188)
Observations	290	290	96	96	436	436
R^2	0.110	0.513	0.128	0.233	0.079	0.167
Adjusted R^2	0.085	0.500	0.048	0.163	0.061	0.151
Σ	2.478	−1.137	7.790	−1.806	4.345	−2.206
	−1.137	29.342	−1.806	64.612	−2.206	15.189
ρ	1	−0.133	1	−0.081	1	−0.272
	−0.133	1	−0.081	1	−0.272	1

Note: *p<0.05; **p<0.01; ***p<0.001

Table 3.12 VAR(4)s for Weekly Growth Rates of Liquid Assets and Financial CP

	Pre-Crisis		*Crisis*		*Post-Crisis*	
	$g_{\text{CP},t}$	$g_{\text{LAsset},t}$	$g_{\text{CP},t}$	$g_{\text{LAsset},t}$	$g_{\text{CP},t}$	$g_{\text{LAsset},t}$
$g_{\text{CP},t-1}$	0.015	0.072	0.253*	0.004	−0.140**	0.032
	(0.060)	(0.065)	(0.106)	(0.091)	(0.050)	(0.037)
$g_{\text{LAsset},t-1}$	0.108	−0.531***	0.205	−0.271*	−0.067	−0.279***
	(0.055)	(0.060)	(0.121)	(0.104)	(0.070)	(0.051)
$g_{\text{CP},t-2}$	−0.018	0.130*	0.135	0.001	0.037	−0.006
	(0.059)	(0.064)	(0.107)	(0.092)	(0.051)	(0.037)
$g_{\text{LAsset},t-2}$	0.082	−0.312***	−0.170	0.097	0.225**	−0.261***
	(0.059)	(0.064)	(0.121)	(0.104)	(0.070)	(0.051)
$g_{\text{CP},t-3}$	−0.032	−0.075	−0.167	−0.244**	−0.094	0.118**
	(0.060)	(0.065)	(0.106)	(0.092)	(0.050)	(0.037)
$g_{\text{LAsset},t-3}$	0.262***	−0.388***	−0.086	0.035	−0.029	−0.162**
	(0.059)	(0.064)	(0.120)	(0.103)	(0.071)	(0.051)
$g_{\text{CP},t-4}$	0.043	−0.044	0.093	−0.153	0.126*	−0.034
	(0.060)	(0.065)	(0.107)	(0.092)	(0.050)	(0.037)
$g_{\text{LAsset},t-4}$	0.099	−0.011	0.184	0.185	−0.018	0.073
	(0.056)	(0.061)	(0.119)	(0.102)	(0.068)	(0.049)
const	0.064	0.172	−0.231	0.243	−0.042	0.258***
	(0.096)	(0.104)	(0.299)	(0.258)	(0.104)	(0.075)
Observations	290	290	96	96	436	436
R^2	0.084	0.329	0.151	0.212	0.082	0.178
Adjusted R^2	0.058	0.310	0.073	0.139	0.064	0.162
Σ	2.552	−0.409	7.590	−0.415	4.331	−0.959
	−0.409	3.003	−0.415	5.622	−0.959	2.284
ρ	1	−0.148	1	−0.064	1	−0.305
	−0.148	1	−0.064	1	−0.305	1

Note: *p<0.05; **p<0.01; ***p<0.001

Table 3.13 VAR(4)s for Weekly Growth Rates of Assets and Financial CP

	Pre-Crisis		*Crisis*		*Post-Crisis*	
	$g_{\text{CP},t}$	$g_{\text{Asset},t}$	$g_{\text{CP},t}$	$g_{\text{Asset},t}$	$g_{\text{CP},t}$	$g_{\text{Asset},t}$
$g_{\text{CP},t-1}$	0.003	0.010	0.216*	0.012	−0.154**	0.014
	(0.061)	(0.023)	(0.106)	(0.028)	(0.052)	(0.012)
$g_{\text{Asset},t-1}$	0.419*	−0.412***	−0.049	−0.095	−0.426	−0.223***
	(0.165)	(0.061)	(0.416)	(0.111)	(0.224)	(0.051)
$g_{\text{CP},t-2}$	0.012	0.027	0.098	−0.003	0.064	−0.024*
	(0.061)	(0.023)	(0.107)	(0.029)	(0.052)	(0.012)
$g_{\text{Asset},t-2}$	0.515**	−0.195**	−1.111**	0.295**	0.889***	−0.295***
	(0.173)	(0.064)	(0.417)	(0.111)	(0.219)	(0.050)
$g_{\text{CP},t-3}$	−0.040	0.029	−0.129	−0.002	−0.072	0.025*
	(0.061)	(0.023)	(0.106)	(0.028)	(0.052)	(0.012)
$g_{\text{Asset},t-3}$	0.583***	−0.267***	−0.023	0.060	0.130	−0.274***
	(0.173)	(0.064)	(0.423)	(0.113)	(0.222)	(0.050)
$g_{\text{CP},t-4}$	0.036	−0.018	0.103	−0.0002	0.153**	−0.021
	(0.061)	(0.023)	(0.104)	(0.028)	(0.051)	(0.011)
$g_{\text{Asset},t-4}$	0.178	0.053	1.228**	0.100	0.191	0.165**
	(0.166)	(0.061)	(0.419)	(0.112)	(0.222)	(0.050)
const	−0.141	0.266***	−0.196	0.092	−0.076	0.119***
	(0.118)	(0.044)	(0.304)	(0.081)	(0.107)	(0.024)
Observations	290	290	96	96	436	436
R^2	0.067	0.243	0.189	0.133	0.108	0.268
Adjusted R^2	0.040	0.222	0.115	0.053	0.091	0.254
Σ	2.598	−0.229	7.244	−0.566	4.208	−0.360
	−0.229	0.357	−0.566	0.518	−0.360	0.216
ρ	1	−0.238	1	−0.292	1	−0.378
	−0.238	1	−0.292	1	−0.378	1

Note: $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Table 3.14 Robustness Tests for Omitted Variables

	Potentially Omitted	*Pre-Crisis*		*Crisis*		*Post-Crisis*	
	Variable (top row)	Granger	Instant	Granger	Instant	Granger	Instant
(1)	$\Delta_{\text{T-Bill},t}$	0.753	0.858	**2.397**	5.234	1.558	4.074
		(0.645)	(0.651)	(0.017)	(0.073)	(0.133)	(0.130)
	$g_{\text{De},t}$	**6.893**	**23.799**	1.339	**13.540**	**3.437**	**82.149**
		(8.3E-09)	(6.8E-06)	(0.225)	(0.001)	(0.001)	(2.2E-16)
(2)	$\Delta_{\text{Paper-TBill},t}$	0.630	0.843	**2.444**	**10.507**	0.264	0.006
		(0.753)	(0.656)	(0.015)	(0.005)	(0.977)	(0.997)
	$g_{\text{De},t}$	**8.057**	**24.525**	1.113	**8.040**	**4.157**	**80.412**
		(1.6E-10)	(4.7E-06)	(0.355)	(0.018)	(6.4E-05)	(2.2E-16)
(3)	$\Delta_{\text{Libor-OIS},t}$	**2.751**	1.860	**2.806**	**15.928**	0.579	3.384
		(0.005)	(0.395)	(0.005)	(3.5E-04)	(0.796)	(0.184)
	$g_{\text{De},t}$	**6.694**	**20.659**	0.756	**18.705**	**3.752**	**82.330**
		(1.6E-08)	(3.3E-05)	(0.642)	(8.7E-05)	(2.4E-04)	(2.2E-16)
(4)	$\Delta_{\text{OIS-TBill},t}$	1.132	1.034	**3.169**	3.655	0.757	1.902
		(0.339)	(0.596)	(0.002)	(0.161)	(0.641)	(0.386)
	$g_{\text{De},t}$	**7.220**	**24.069**	1.397	**10.098**	**3.562**	**81.879**
		(2.8E-09)	(5.9E-06)	(0.198)	(0.006)	(4.3E-04)	(2.2E-16)

Granger and Instantaneous causality tests for VAR(4)s with three endogenous variables: the growth rate of deposits ($g_{\text{De},t}$), the growth rate of financial CP outstanding ($g_{\text{CP},t}$) and one of the potentially omitted variables. The potential omitted variables are (1) $\Delta_{\text{T-Bill},t}$: the weekly change in the 3-month T-Bill rate; (2) $\Delta_{\text{Paper-TBill},t}$: the weekly change in the spread between the 3-month AA-rated financial CP rate and the 3-month T-Bill rate; (3) $\Delta_{\text{Libor-OIS},t}$: the weekly change in the spread between the 3-month London inter-bank offered rate and the 3-month overnight indexed swap rate; (4) $\Delta_{\text{OIS-TBill},t}$: the weekly change in the spread between the 3-month overnight indexed swap rate and the 3-month T-Bill rate. The table reports the F-Test statistics and p-values (in parentheses) testing the null that the variable on the left side does not Granger cause the other two variables in Granger columns. In addition, it also reports the χ^2 statistics and p-values (in parentheses) testing the null that the variable on the left side does not instantaneously cause the other two variables in Instant columns. All statistics that are significant at the 5% significance level are in bold.

Table 3.15 VAR(4) Includes the Libor-OIS Spread in the Pre-Crisis

	Pre-Crisis		
	$g_{\mathrm{CP},t}$	$g_{\mathrm{De},t}$	$\Delta_{\text{Libor-OIS},t}$
$g_{\mathrm{CP},t-1}$	0.019	−0.035	−0.001
	(0.063)	(0.034)	(0.001)
$g_{\mathrm{De},t-1}$	0.593***	−0.635***	−0.003*
	(0.116)	(0.062)	(0.001)
$\Delta_{\text{Libor-OIS},t-1}$	−3.271	2.329	0.299***
	(5.293)	(2.840)	(0.058)
$g_{\mathrm{CP},t-2}$	0.092	−0.027	0.0001
	(0.063)	(0.034)	(0.001)
$g_{\mathrm{De},t-2}$	0.717***	−0.493***	−0.001
	(0.127)	(0.068)	(0.001)
$\Delta_{\text{Libor-OIS},t-2}$	−13.449*	8.093**	−0.039
	(5.486)	(2.944)	(0.061)
$g_{\mathrm{CP},t-3}$	0.029	−0.005	0.0001
	(0.062)	(0.033)	(0.001)
$g_{\mathrm{De},t-3}$	0.539***	−0.527***	0.001
	(0.132)	(0.071)	(0.001)
$\Delta_{\text{Libor-OIS},t-3}$	2.372	4.006	−0.165**
	(5.566)	(2.987)	(0.061)
$g_{\mathrm{CP},t-4}$	0.025	−0.047	0.001*
	(0.062)	(0.033)	(0.001)
$g_{\mathrm{De},t-4}$	0.123	−0.035	0.001
	(0.123)	(0.066)	(0.001)
$\Delta_{\text{Libor-OIS},t-4}$	−5.027	1.455	−0.133*
	(5.360)	(2.876)	(0.059)
const	−0.176	0.375***	0.00004
	(0.106)	(0.057)	(0.001)
Observations	290	290	290
R^2	0.183	0.441	0.217
Adjusted R^2	0.148	0.417	0.183
	1	−0.275	−0.072
ρ	−0.275	1	−0.015
	−0.072	−0.015	1
Note:			*p<0.05; **p<0.01; ***p<0.001

Table 3.16 VAR(4) Includes the T-Bill Rate in the Crisis

	Crisis		
	$g_{\text{CP},t}$	$g_{\text{De},t}$	$\Delta_{\text{T-Bill},t}$
$g_{\text{CP},t-1}$	0.166	0.054	−0.014
	(0.114)	(0.039)	(0.009)
$g_{\text{De},t-1}$	−0.376	−0.102	−0.017
	(0.343)	(0.116)	(0.026)
$\Delta_{\text{T-Bill},t-1}$	0.591	0.416	−0.057
	(1.424)	(0.481)	(0.107)
$g_{\text{CP},t-2}$	0.139	−0.035	−0.008
	(0.116)	(0.039)	(0.009)
$g_{\text{De},t-2}$	−0.424	−0.047	−0.057*
	(0.340)	(0.115)	(0.025)
$\Delta_{\text{T-Bill},t-2}$	3.532*	−1.351**	−0.153
	(1.393)	(0.471)	(0.104)
$g_{\text{CP},t-3}$	−0.094	0.002	−0.005
	(0.114)	(0.038)	(0.009)
$g_{\text{De},t-3}$	−0.063	−0.145	−0.005
	(0.332)	(0.112)	(0.025)
$\Delta_{\text{T-Bill},t-3}$	−1.413	−0.463	0.052
	(1.453)	(0.491)	(0.109)
$g_{\text{CP},t-4}$	0.063	0.003	0.004
	(0.110)	(0.037)	(0.008)
$g_{\text{De},t-4}$	0.420	0.104	−0.022
	(0.323)	(0.109)	(0.024)
$\Delta_{\text{T-Bill},t-4}$	0.187	−0.947	−0.083
	(1.473)	(0.498)	(0.110)
const	0.029	0.110	−0.033
	(0.326)	(0.110)	(0.024)
Observations	96	96	96
R^2	0.196	0.270	0.127
Adjusted R^2	0.079	0.165	0.0003
	1	−0.337	0.026
ρ	−0.337	1	−0.233
	0.026	−0.233	1

Note: $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Table 3.17 VAR(4) Includes the Paper-TBill Spread in the Crisis

	Crisis		
	$g_{\text{CP},t}$	$g_{\text{De},t}$	$\Delta_{\text{Paper-TBill},t}$
$g_{\text{CP},t-1}$	0.004	0.087*	0.020
	(0.118)	(0.044)	(0.015)
$g_{\text{De},t-1}$	−0.104	−0.111	0.064
	(0.306)	(0.113)	(0.039)
$\Delta_{\text{Paper-TBill},t-1}$	−2.324*	0.657	−0.068
	(0.895)	(0.332)	(0.114)
$g_{\text{CP},t-2}$	0.048	−0.041	−0.008
	(0.120)	(0.045)	(0.015)
$g_{\text{De},t-2}$	−0.496	−0.012	0.049
	(0.306)	(0.113)	(0.039)
$\Delta_{\text{Paper-TBill},t-2}$	−3.034**	0.470	−0.055
	(0.899)	(0.333)	(0.114)
$g_{\text{CP},t-3}$	−0.077	0.008	0.032*
	(0.114)	(0.042)	(0.014)
$g_{\text{De},t-3}$	−0.024	−0.183	0.014
	(0.306)	(0.113)	(0.039)
$\Delta_{\text{Paper-TBill},t-3}$	−1.163	0.286	0.108
	(0.947)	(0.352)	(0.120)
$g_{\text{CP},t-4}$	0.135	0.006	−0.002
	(0.110)	(0.041)	(0.014)
$g_{\text{De},t-4}$	0.436	0.168	0.027
	(0.300)	(0.111)	(0.038)
$\Delta_{\text{Paper-TBill},t-4}$	0.690	0.087	−0.023
	(0.914)	(0.339)	(0.116)
const	−0.236	0.234*	−0.034
	(0.302)	(0.112)	(0.038)
Observations	96	96	96
R^2	0.276	0.208	0.130
Adjusted R^2	0.171	0.093	0.004
	1	−0.301	−0.349
ρ	−0.301	1	0.077
	−0.349	0.077	1

Note: *p<0.05; **p<0.01; ***p<0.001

Table 3.18 VAR(4) Includes the Libor-OIS Spread in the Crisis

	Crisis		
	$g_{\text{CP},t}$	$g_{\text{De},t}$	$\Delta_{\text{Libor-OIS},t}$
$g_{\text{CP},t-1}$	0.081	0.051	−0.016*
	(0.111)	(0.041)	(0.007)
$g_{\text{De},t-1}$	0.371	−0.225	0.003
	(0.336)	(0.125)	(0.020)
$\Delta_{\text{Libor-OIS},t-1}$	−6.873**	1.754*	0.462***
	(2.065)	(0.770)	(0.122)
$g_{\text{CP},t-2}$	−0.020	−0.023	0.00001
	(0.119)	(0.044)	(0.007)
$g_{\text{De},t-2}$	−0.128	−0.033	0.008
	(0.337)	(0.126)	(0.020)
$\Delta_{\text{Libor-OIS},t-2}$	−2.745	−0.087	0.025
	(2.214)	(0.825)	(0.131)
$g_{\text{CP},t-3}$	−0.121	0.007	0.009
	(0.119)	(0.044)	(0.007)
$g_{\text{De},t-3}$	−0.171	−0.135	−0.001
	(0.332)	(0.124)	(0.020)
$\Delta_{\text{Libor-OIS},t-3}$	3.360	−0.962	−0.220
	(2.206)	(0.822)	(0.130)
$g_{\text{CP},t-4}$	0.212	−0.008	0.001
	(0.115)	(0.043)	(0.007)
$g_{\text{De},t-4}$	0.270	0.174	0.028
	(0.312)	(0.116)	(0.018)
$\Delta_{\text{Libor-OIS},t-4}$	0.716	0.578	−0.053
	(1.952)	(0.728)	(0.115)
const	−0.304	0.234*	−0.009
	(0.311)	(0.116)	(0.018)
Observations	96	96	96
R^2	0.291	0.217	0.415
Adjusted R^2	0.189	0.104	0.330
	1	−0.294	−0.186
ρ	−0.294	1	0.442
	−0.186	0.442	1

Note: $^*p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Table 3.19 VAR(4) Includes the OIS-TBill Spread in the Crisis

	Crisis		
	$g_{\text{CP},t}$	$g_{\text{De},t}$	$\Delta_{\text{OIS-TBill},t}$
$g_{\text{CP},t-1}$	0.123	0.076*	0.009
	(0.112)	(0.038)	(0.007)
$g_{\text{De},t-1}$	−0.251	−0.117	0.005
	(0.333)	(0.113)	(0.020)
$\Delta_{\text{OIS-TBill},t-1}$	−2.346	−0.379	−0.103
	(1.689)	(0.576)	(0.103)
$g_{\text{CP},t-2}$	0.108	−0.026	0.009
	(0.115)	(0.039)	(0.007)
$g_{\text{De},t-2}$	−0.385	−0.037	0.046*
	(0.329)	(0.112)	(0.020)
$\Delta_{\text{OIS-TBill},t-2}$	−5.386**	1.901**	−0.142
	(1.664)	(0.567)	(0.102)
$g_{\text{CP},t-3}$	−0.081	0.004	0.005
	(0.113)	(0.038)	(0.007)
$g_{\text{De},t-3}$	−0.076	−0.124	−0.017
	(0.321)	(0.109)	(0.020)
$\Delta_{\text{OIS-TBill},t-3}$	−0.231	0.952	0.099
	(1.768)	(0.603)	(0.108)
$g_{\text{CP},t-4}$	0.128	−0.008	−0.0002
	(0.109)	(0.037)	(0.007)
$g_{\text{De},t-4}$	0.465	0.106	−0.003
	(0.310)	(0.106)	(0.019)
$\Delta_{\text{OIS-TBill},t-4}$	−1.938	1.238*	−0.118
	(1.784)	(0.608)	(0.109)
const	−0.197	0.243*	−0.015
	(0.308)	(0.105)	(0.019)
Observations	96	96	96
R^2	0.239	0.297	0.173
Adjusted R^2	0.129	0.196	0.053
	1	−0.290	−0.057
ρ	−0.290	1	0.199
	−0.057	0.199	1

Note: *p<0.05; **p<0.01; ***p<0.001

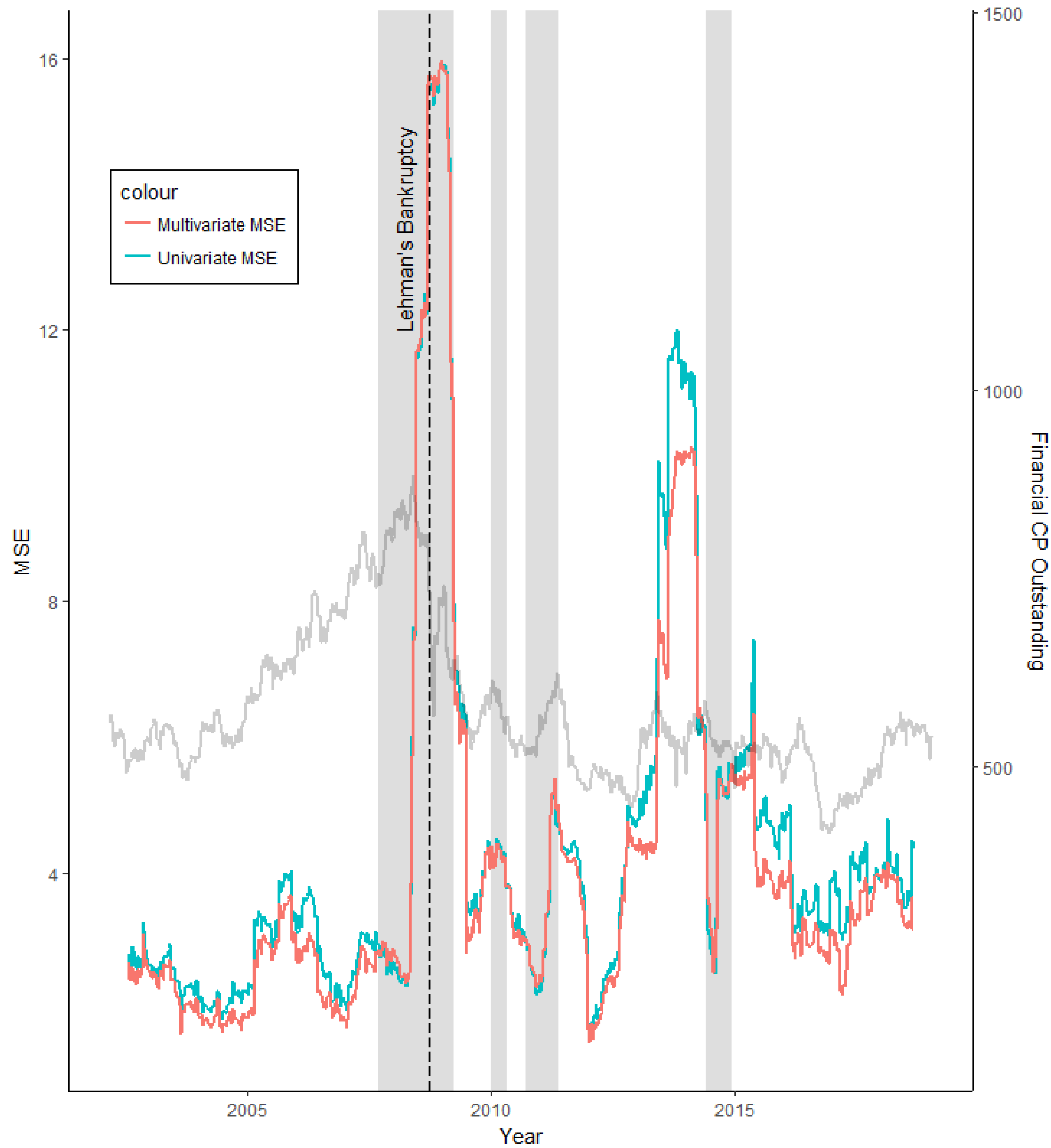

Figure 3.8 40 Weeks Moving Averages of Squared Errors for Univariate and Multivariate Models

The figure shows 40 weeks moving averages of squared errors for univariate and multivariate models. The gray-shaded areas are the time periods when the multivariate MSE is larger the univariate MSE and therefore, the possible crisis times. The first gray column is from Sep. 2007 to Apr. 2009 (the Great Recession). The second and third gray columns are from Jan. 2010 to Apr. 2010 and from Sep. 2010 to May 2011, respectively (the European debt crisis). The fourth gray column is from Jun. 2014 to Nov. 2014 (2014 Oil price crash). Lehman's bankruptcy was Sep. 15, 2008. The gray line in the background is financial CP outstanding (billion dollars) for reference only.

Table 3.20 Identifying the Breakdown of Liquidity Backup during the Great Recession by Using a Dummy Variable

	Dependent variable:					
	$g_{\text{CP},t}$					
	(1)	(2)	(3)	(4)	(5)	(6)
$g_{\text{De},t-1}$	0.116	0.094	0.334***	0.309**	0.564***	0.541***
	(0.087)	(0.095)	(0.090)	(0.098)	(0.112)	(0.116)
$g_{\text{CP},t-1}$		−0.022		−0.033		−0.036
		(0.038)		(0.038)		(0.037)
$g_{\text{CP},t-2}$				0.108**		0.113**
				(0.037)		(0.037)
$g_{\text{CP},t-3}$				−0.032		−0.032
				(0.037)		(0.037)
$g_{\text{De},t-2}$			0.560***	0.670***	0.572***	0.688***
			(0.092)	(0.101)	(0.092)	(0.100)
$g_{\text{De},t-3}$			0.462***	0.455***	0.462***	0.458***
			(0.090)	(0.098)	(0.089)	(0.098)
$\Delta_{\text{Libor-OIS},t-1}$					0.287	0.346
					(0.256)	(0.260)
$\Delta_{\text{OIS-TBill},t-1}$					0.222	0.221
					(0.342)	(0.341)
$g_{\text{De},t-1} * C_{t-1}$	−0.320	−0.316	−0.648**	−0.687**	0.462	0.429
	(0.220)	(0.220)	(0.220)	(0.219)	(0.393)	(0.393)
$g_{\text{De},t-2} * C_{t-1}$			−1.368***	−1.397***	−1.405***	−1.455***
			(0.224)	(0.223)	(0.241)	(0.242)
$g_{\text{De},t-3} * C_{t-1}$			−0.665**	−0.653**	−0.409	−0.410
			(0.221)	(0.223)	(0.250)	(0.251)
$\Delta_{\text{Libor-OIS},t-1} * g_{\text{De},t-1}$					−1.128***	−1.142***
					(0.246)	(0.245)
$\Delta_{\text{OIS-TBill},t-1} * g_{\text{De},t-1}$					−0.139	−0.151
					(0.408)	(0.407)
Constant	−0.023	−0.021	−0.130	−0.139	−0.243*	−0.267*
	(0.073)	(0.073)	(0.074)	(0.074)	(0.106)	(0.107)
Observations	833	833	831	831	831	831
R^2	0.003	0.004	0.076	0.087	0.100	0.113
Adjusted R^2	0.001	0.0002	0.069	0.077	0.089	0.099
Note:						*p<0.05; **p<0.01; ***p<0.001

Each column in this table reports a linear regression of the same dependent variable: the growth rate of financial CP outstanding at date t ($g_{\text{CP},t}$ = Financial CP_t/Financial CP_{t-1}) but different independent variables. The sample is weekly time series data from December 12, 2001, to November 29, 2017. Independent variables include: the growth rate of deposits in all domestically chartered commercial banks ($g_{\text{De},t}$ = $\text{Deposits}_t/\text{Deposits}_{t-1}$), the time dummy variable, which equals one if the time t happens in the Great Recession (from Aug. 1, 2007, to Jun. 24, 2009) (C_t), the weekly change in the spread between the 3-month London inter-bank offered rate and the 3-month overnight indexed swap rate ($\Delta_{\text{Libor-OIS},t}$), and the weekly change in the spread between the 3-month overnight indexed swap rate and the 3-month T-Bill rate ($\Delta_{\text{OIS-TBill},t}$).

CHAPTER 4. UNDERPRICING AND UNDERREACTION IN INITIAL PUBLIC OFFERINGS: THE ROLE OF STRATEGIC RISK

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4.1 Abstract

Using theoretical and simulation tools, we study how strategic risk among investors can help explain both underpricing and underreaction in initial public offerings (IPOs). We assume the post-IPO value of a firm is higher if the IPO raises more capital for the firm. Hence an IPO subscriber faces strategic risk: the value of subscribing depends on the aggregate subscription rate. As this risk is resolved immediately after the IPO, the IPO itself is underpriced. Moreover, since individual investors have limited wealth, a higher offer price raises the risk of undersubscription. Investors respond by demanding a larger discount: the offer price appears to underreact to public news.

4.2 Introduction

Initial public offering (IPO) is an important milestone for entrepreneurial firms. The proceeds from IPOs can help to finance the future growth of firms and make them more liquid through stock market trading. The IPO also provides a way for trading the company's shares, enabling its existing shareholders to diversify their investments and to crystallize their capital gains from backing the company. The act of the IPO itself helps improve the reputation of the company, and the attendant publicity may bring indirect benefits, such as attracting more talented managers and lowering the cost of funding the company's operations and investments.

An important aspect of the IPO process is the underpricing of newly issued shares, representing a discount from its fair market price measured by the difference between the closing price on the first day of trading and the IPO offer price. IPO underpricing is one of the best-documented empirical findings in finance and the underpricing phenomenon is persistent over time and across countries. Logue (1973) and Ibbotson (1975) documented that when companies go public, the shares they sell tend to be underpriced, in that the share price jumps substantially on the first day of trading. Boehmer and Ljungqvist (2004) provide evidence of underpricing in the United States from 1960 to 2003, in main countries of Europe from 1990 to 2003 and in main countries of Asia-Pacific and Latin America from 1990 to 2001. To be specific, in the United States, there are $8,249$ IPOs from 1980 to 2016. The average first-day return for the IPOs is 17.9% (equally-weighted average return) and the aggregate amount of "money left on the table" is $155.14 billion, where the "money left on the table" is defined as the first-day price gain multiplied by the number of shares sold. Compared with the total proceeds of IPOs ($839.65 billion), 18.5% of firms' potential proceeds has been left to the investors. Figure 4.1 displays the mean first-day return and "money left on the table" for IPOs in the United States from 1980-2016. Such "money left on the table" constitutes a substantial opportunity cost of going public for issuing firms. However, owners and managers seem unconcerned about situations of underpricing. In a survey of chief financial officers (CFOs) that took their firms public, Krigman et al. (2001) find that CFOs of virtually all of the most underpriced firms are highly satisfied with the performance of their lead IPO underwriters.

Why are the firms willing to sacrifice such a great amount of money in the process of IPOs? In this chapter, we present an explanation for this underpricing phenomenon by examining the strategic risk in IPOs. The concept of strategic risk comes from the global games literature. Generally, we consider a situation in which payoffs from agents strategies depend on an uncertain state of the world about which agents obtain very informative but noisy signals. Because agents do not have the same assessments of the state of the world, this creates strategic uncertainty in

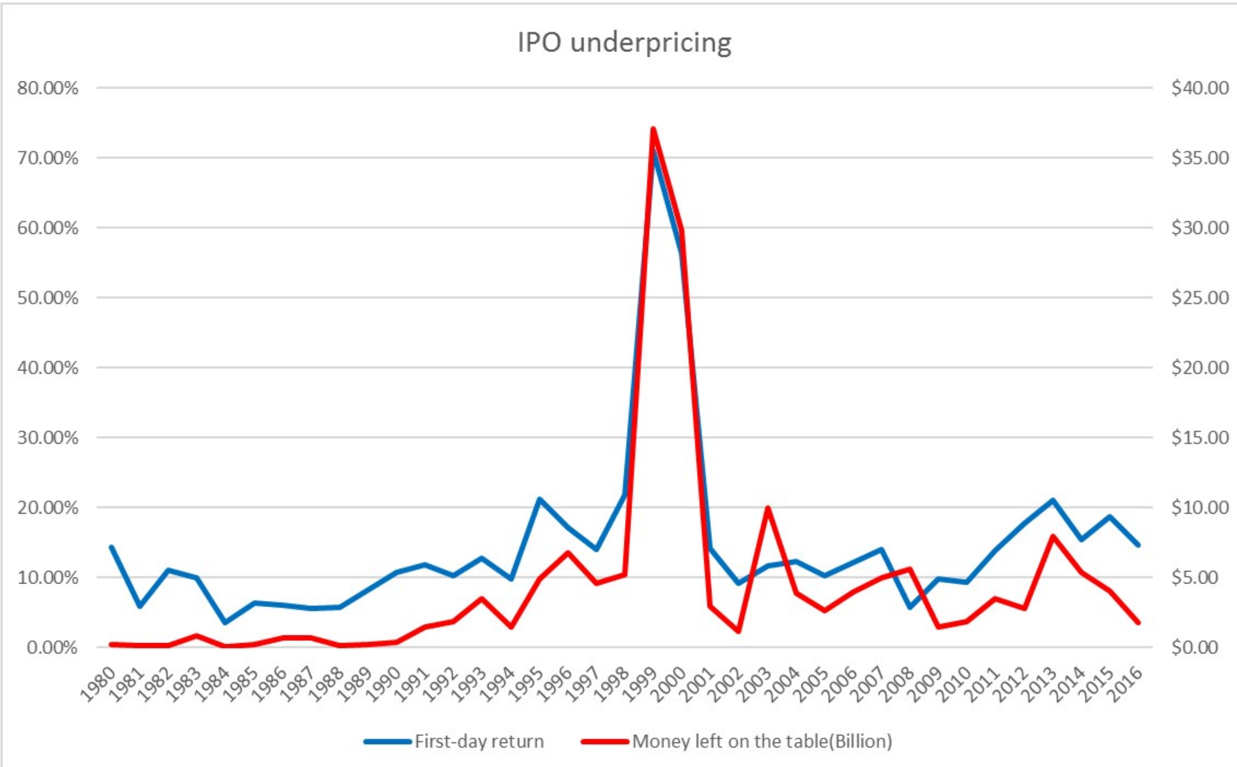

Figure 4.1 IPO Underpricing in the U.S.

equilibrium. The risk comes from this kind of uncertainty is called strategic risk. Strategic risk is widely examined in researches on global games[1].

However, strategic risk is seldom examined in the literature on IPOs. In our setting, shares sold in an IPO are more valuable if the firm reaps more revenue from the IPO. There are two motivations for this assumption. Trivially, a firm can use its IPO proceeds productively, which lets it pay higher dividends in the future. In addition, Stoughton et al. (2001) suggest that the success of a firm's IPO acts as a quality signal to the firm's small stakeholders, who may choose whether or not to do business with the firm or to adopt the firm's platform. Such stakeholders may include customers, suppliers, makers of ancillary products such as software and replacement parts, and potential future investors. For the firm to survive and thrive, such stakeholders must

[1] For example, see Carlsson and Van Damme (1993), Morris and Shin (1998), and Chassang and Miquel (2010)

be willing to do business with it. Importantly, this informational effect may be large even if a firm seeks relatively little capital in its IPO. With the assumption that liquidating dividend is increasing in IPO proceeds, investors in an IPO face strategic risk: the value of the shares depends on the IPO's success, which depends on other investors' decisions to subscribe.

We will show in a global games setting that the strategic risk leads to underpricing. Intuitively, an agent's reservation price is the price at which she is just willing to subscribe to the IPO. But if, given her information about the IPO, she is indeed just willing to subscribe, then she knows that some others are likely to have received slightly more negative information than her own and thus will choose not to subscribe. Hence, her reservation price reflects a positive probability of undersubscription, which - if it occurs - will lower the firm's value. Once the IPO concludes and the subscription rate is known, this strategic risk disappears. Accordingly, shares trade at a higher price in the aftermarket[2].

Strategic risk can generate underreaction as well. The term underreaction describes the well-documented fact that the final offer price does not fully react to favorable information received in the process of pricing the IPO, which indicates that the price revision over the course of bookbuilding and the first-day underpricing return are positively correlated[3]. Intuitively, when good news tells the firm that the IPO is more attractive to investors, the firm can raise the IPO price. But since individual investors have limited wealth, a higher offer price raises the risk of undersubscription. Hence the risk of undersubscription is now greater: investors face even more strategic risk. Thus, this price revision worsens underpricing, which appears in the data as underreaction.

Besides, our empirical result shows that underpricing is positively correlated with oversubscription, our model can also give an explanation for this. Intuitively, since firm sees only a noisy signal of fundamentals. Being concerned with the risk of undersubscription, when the firm observes a bad

[2]Underpricing in this model does not require risk aversion. Rather, it occurs because the firm must charge a low share price in order to induce the agents to subscribe in the presence of undersubscription risk. Indeed, our model assumes risk-neutrality; under risk aversion, the underpricing would be worse.

[3]For example, see Hanley (1993), Edelen and Kadlec (2005), Bradley and Jordan (2002), and Lowry and Schwert (2004)

signal and is overly pessimistic, it will lower its offer price to attract more investor to subscribe. Therefore, there is more underpricing and more oversubscription.

Historically, there are four main kinds of explanations for IPO underpricing. The first kind of explanation for underpricing claims that it is due to winner's curse [4]: when the firm's growth prospects are high, informed investors will subscribe, shrinking the stock available to retail investors. Since retail investors face a winner's curse, they are not willing to pay the firm the true value of its shares. This kind of explanation shows how underpricing happens. However, it did not explain the underraction phenomenon and the positive relationship between oversubscription and underpricing. The second explanation of underpricing is the signal of firm quality[5]. If companies have better information about the present value or risk of their future cash flows than do investors, underpricing may be used to signal the companys "true" high value. This is clearly costly, but if successful, signaling may allow the issuer to return to the market to sell equity on better prices at a later date. This explanation does not explain for the underreaction phenomenon and the relationship between oversubscription and underpricing, either.

The third explanation for underpricing is moral hazard[6]. Intuitively, a firm conducts an IPO through a third party underwriter. The underwriting has an incentive to reward itself or top clients with underpriced shares. This theory can also be used to explain underreaction in IPOs. However, this theory does not take the subscription rate into account. The fourth explanation is information revelation theories. Benveniste and Spindt (1989), Benveniste and Wilhelm (1990), and Spatt and Srivastava (1991) show that if some investors are better informed than either the company or other investors, the underwriter has the incentive to design a mechanism through the process of bookbuilding which will induce investors to reveal their information truthfully by making it in their best interest to do so. To ensure truth-telling, the allocations have to involve underpriced stock. In this explanation, IPO underpricing serves as the cost of extracting the informed investors private information. Bookbuilding allows firms to extract positive information and raise the offer

[4] For example, see Rock (1986)

[5] For example, see Allen and Faulhaber (1989), Grinblatt and Hwang (1989), and Welch (1989)

[6] See Baron and Holmström (1980), and Baron and Holmström (1980)

price in response even though the price will rise further in the after-market because some money has to be left on the table. Thus the price revision over the course of bookbuilding and the first-day underpricing return are positively correlated. This setting can also explain the phenomenon of IPO underreaction. But it does not take the subscription into account, either.

This chapter differs from the related literature in the following ways. First, unlike the theory of winner's curse and signaling, our model can explain the phenomenon of underpricing and underreaction at the same time. Although the theory of moral hazard and information revelation can also explain the underreaction, they did not take the subscription into account, which ignores the relationship between underpricing and oversubscription. Our theory can explain all these three phenomena. Second, different from the explanation of winner's curse, information revealing and signaling, there is no need for us to assume that there is an information gap (some investors are informed and some are uninformed) among investors. In fact, we can show that even when the investors share the same information, underpricing may still exist in our setting. Third, unlike the explanations which referred to moral hazard and psychological reasons, Chapter 4 assumes that all agents engaged in the IPO process are fully rational. With the assumption that moral hazard caused the underpricing, Baron and Holmström (1980), and Baron (1982) construct a screening model where the uninformed party offers a menu, from which the informed party selects the one that is optimal given her unobserved type in the roadshow process. However, this kind of road show commitment is not widely observed in reality. Chapter 4 gets rid of this commitment and tends to be more realistic. Fourth, Chapter 4 takes the endogeneity of stock value into consideration, which has seldom been examined before in the studies of IPOs. IPO revenue can be used to finance the firm's investment, and a successful IPO will help to improve the firm's reputation. So the firm's value, and hence the stock value, may be affected by the IPO process itself. However, few research on IPOs has examined this effect. Chapter 4 seeks to fill this gap.

4.3 The Model

There is a fixed measure $m > 0$ of agents, each endowed with one unit of capital. There is also a single firm with a worthwhile project. All participants are risk-neutral and fully rational. The firm is assumed already to have initiated the process of an IPO, paid all filing fees, etc.

All participants first see a public signal y of an exogenous stochastic state $\theta \sim N\left(y, \tau^2\right)$.[7] The state θ can be thought of as the unobserved quality of the firm's project. We regard the public signal y as being revealed during the firm's road show. On seeing y, the firm decides whether to go forward with the IPO or to withdraw it.

If the firm goes forward and raises k units of capital in the IPO, its final value is $e^{\theta} f(k)$ where f is a differentiable and strictly increasing function that satisfies

$$\iota \overset{d}{=} f(0) > 0 \text{ and } \Omega \overset{d}{=} \max_{k \in [0,m]} \frac{f'(k)}{f(k)} \in (0, \infty). \tag{4.1}$$

If the firm withdraws the IPO, its final value is $e^{\theta} f(c)$ where $c > 0$ is a known constant. Interpreting c literally, it equals the fixed cost of carrying out the IPO versus withdrawing it. However it can also capture the equivalent, in terms of lost capital, of the damage from an IPO that spectacularly fails versus one that is quietly withdrawn in the face of of "adverse market conditions".

Assume henceforth that the firm decides to go forward with the IPO. It then announces a number $s \in [0, 1]$ of shares that are offered for sale, as well as a price $p \geq 0$ per share. Rather than working with s directly, it is more convenient to assume the firm chooses a price p and a capital target $t = ps \in [0, p]$; the number of shares s is then given by t/p. We will assume, without loss of generality, that the capital target t does not exceed the aggregate capital m of the agents as the firm cannot raise more than m units of capital.

After the firm announces p and t, each agent $i \in [0, m]$ then sees a private signal $x_i = \theta + \varepsilon_i$ of the state θ, where $\varepsilon_i \sim N\left(0, \sigma^2\right)$, $\sigma > 0$ is a scalar, and θ and the ε_i's are all mutually independent.

[7] This can be obtained most simply if θ is uniformly distributed on the whole real line and y equals the public signal $\theta + \nu$ where $\nu \sim N\left(0, \tau^2\right)$ is independent of θ. In section 4.3.1.1, we present an alternative derivation in which the prior distribution of θ is normal.

The agents then decide simultaneously whether or not to subscribe: to offer to buy up to $1/p$ shares at the price p.[8] Figure 4.2 shows the time line of the IPO model.

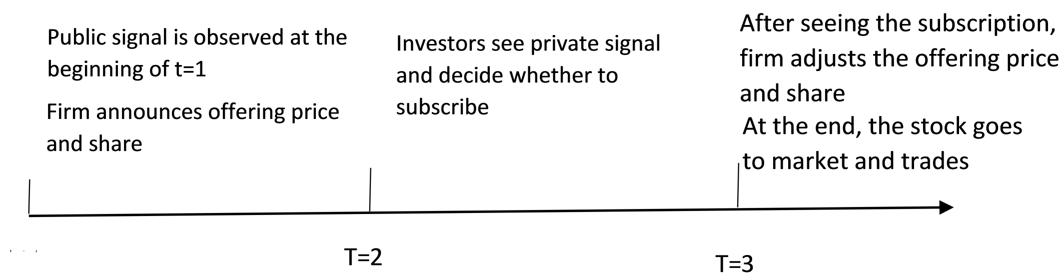

Figure 4.2 Timeline of the IPO Model

Let $\ell \in [0, m]$ be the measure of agents who subscribe or, equivalently, the amount of capital bid by the agents (as each has one unit). If ℓ does not exceed the capital target t, each subscriber transfers her capital to the firm in return for $1/p$ shares. If instead ℓ exceeds t, the IPO is rationed: each subscriber transfers $t/\ell < 1$ units of capital in return in return for $t/(\ell p) < 1/p$ shares while the firm raises t units of capital. An agent's sole alternative investment is a risk-free asset that pays a zero net return. Hence, an agent's net realized payoff from subscribing is

$$\pi_p^t(\theta, \ell) = \begin{cases} \frac{1}{p}\left[e^{\theta} f(\ell) - p\right] & \text{if} \quad \ell \leq t \\ \frac{t}{p\ell}\left[e^{\theta} f(t) - p\right] & \text{if} \quad \ell \in [t, m] \end{cases} \tag{4.2}$$

while the firm's realized payoff is

$$\Pi_p^t(\theta, \ell) = \left(1 - \frac{\min\{t, \ell\}}{p}\right) e^{\theta} f(\min\{t, \ell\}).$$

An implication is that the firm's maximum payoff from a capital target $t < c$ is less than its payoff, $e^{\theta} f(c)$, from withdrawing the IPO. Thus, if the firm carries out the IPO, it will choose a capital target

$$t \in [c, m]. \tag{4.3}$$

[8]An agent cannot offer to buy more shares since she has only one unit of capital to invest. We say "offer to buy" because demand for shares can exceed supply, in which case the IPO is rationed. (See below.)

The following standard result from probability theory will be used without proof.

Proposition 4.3.1. *Suppose we have a variable $\theta \sim N(y, V_\theta)$ to estimate. We observe the variables $x_j = \theta + \varepsilon_j$ for $j = 1, ..., J$, where each $\varepsilon_j \sim N(0, V_j)$ is independent of every $\varepsilon_{j'}$ and of θ. Define the precision of variable j to be $w_j = 1/V_j$. Define $x_0 = y$, $V_0 = V_\theta$, and $w_0 = 1/V_0$. Then the posterior distribution of θ is*

$$\theta^{posterior} \sim N\left(\frac{\sum_{j=0}^{J} w_j x_j}{\sum_{j=0}^{J} w_j}, \frac{1}{\sum_{j=0}^{J} w_j}\right) \tag{4.4}$$

By Proposition 4.3.1, conditional on the public signal y and the private signal x_i, the state θ is normal with mean

$$\overline{\theta}_{x_i} = \frac{\frac{y}{\tau^2} + \frac{x_i}{\sigma^2}}{\tau^{-2} + \sigma^{-2}} = \frac{\sigma^2 y + \tau^2 x_i}{\sigma^2 + \tau^2} \tag{4.5}$$

and variance S^2 where

$$S = \frac{\sigma\tau}{\sqrt{\sigma^2 + \tau^2}}. \tag{4.6}$$

A threshold equilibrium is one in which an agent i invests if and only if her posterior mean $\overline{\theta}_{x_i}$ is not less than some threshold κ, which may depend on the public signal y and the firm's choices t and p.[9] In such an equilibrium, the measure who invest for given θ and κ is

$$\begin{aligned} \ell &= \ell^{\kappa}_{\theta,y} \overset{d}{=} m \Pr\left(\overline{\theta}_{x_j} \geq \kappa | \theta\right) = m \Pr\left(\overline{\theta}_{x_j} \geq \kappa | \theta\right) \\ &= m \Pr\left(\frac{\varepsilon_j}{\sigma} \geq \frac{\sigma^2(\kappa - y) + \tau^2(\kappa - \theta)}{\tau^2 \sigma} \middle| \theta\right) \\ &= m\left[1 - \Phi\left(\frac{\sigma^2(\kappa - y) + \tau^2(\kappa - \theta)}{\tau^2 \sigma}\right)\right] \end{aligned} \tag{4.7}$$

by the law of large numbers. Hence, if an agent has posterior mean $\overline{\theta}$ and thinks that each other agent uses the threshold κ, her relative payoff from subscribing is

$$\pi^{t*}_p\left(\overline{\theta}, \kappa\right) = \int_{\theta=-\infty}^{+\infty} \pi^t_p\left(\theta, \ell^{\kappa}_{\theta,y}\right) d\Phi\left(\frac{\theta - \overline{\theta}}{S}\right). \tag{4.8}$$

We will assume two conditions that jointly imply the existence of a unique threshold equilibrium. First, the private noise σ is not too small:

$$\sigma > h\left(\Phi^{-1}\left(1 - \frac{c}{m}\right)\right) \tag{4.9}$$

[9] Below we give sufficient conditions for the existence of a unique threshold equilibrium.

where $h(z) = \frac{\Phi'(z)}{1-\Phi(z)}$ denotes the standard normal hazard function. Second, the public noise is not too small relative to the private noise:

$$\frac{\tau^2}{\sigma} > \max\left\{\frac{m\Omega}{\sqrt{2\pi}}, h\left(\Phi^{-1}\left(1 - \frac{c}{m}\right)\right)\right\}. \tag{4.10}$$

Our main result is as follows. It shows that there is a unique threshold equilibrium where agents will only invest if their posterior judgement for the mean state $\overline{\theta}_{x_i}$ exceeds the threshold at which the relative payoff from subscribing is zero. Intuitively, if an agent gets a high private signal which indicates that the state is good, he will then expect a good performance of the firm. From his point of view, he believes that other agents also tend to observe a high private signal which encourage them to expect a good state. Since good state means higher firm value, agents are more likely to subscribe. So, in this way, given other agents are adopting threshold strategies (investing if they believes that the posterior state mean is higher than a threshold), an agent will also adopt the threshold strategy to get a positive expected payoff if he has a high enough posterior mean state. At the threshold, the expected payoff should be zero: if the expected payoff is negative, agents will not subscribe; if the expected payoff is positive, agents are then willing to subscribe at a lower posterior mean state.

Theorem 4.3.1. *Assume (4.9) and (4.10). For any choices p and t of the firm, the agents have a unique threshold equilibrium, where the subscription threshold κ is the unique solution to* $\pi_{p,y}^{t*}(\kappa, \kappa) = 0$.

Proof. Follows directly from Claims 4.6.1, 4.6.2, and 4.6.3. See Appendix. □

4.3.1 Simulations - A Toolkit

We now show how to simulate the large-noise model. We begin with some preliminaries.

4.3.1.1 Making y Stochastic

We have assumed that the state θ is normal with constant mean y. Hence the firm will (for generic parameters) have a unique optimal IPO price p. In order to obtain a *distribution* of IPO prices (and thus of price revisions), the mean y must instead be stochastic. We accomplish this by modelling the prior distribution $N\left(y, \tau^2\right)$ as itself a posterior distribution that results from seeing a public signal of θ which can be interpreted as information that arises from the road show. The mean y then varies with the realization of this public signal. In short, we will be able to assume that y is normal with zero mean and an arbitrary variance $V > 0$ and that, conditional on y, the state θ has the distribution $N\left(y, \tau^2\right)$ where τ must be chosen to satisfy (4.10).

To see why, let us now suppose that the true prior distribution of the state θ is $N\left(0, V_\theta\right)$.[10] Before anyone acts, all participants see a public signal $Z = \theta + \eta$ of the state, where the signal noise $\eta \sim N\left(0, V_\eta\right)$ is independent of θ. By the usual formula for the sum of two independent normal variables, unconditional on θ, the public signal Z is normal with mean $E\left[Z\right] = 0$ and variance $Var\left(Z\right) = V_\theta + V_\eta$. And by Proposition 4.3.1, given Z, the state θ is normally distributed with posterior mean $y = E\left[\theta|Z\right] = \frac{0/V_\theta + Z/V_\eta}{1/V_\theta + 1/V_\eta} = \frac{V_\theta}{V_\theta + V_\eta} Z$ and variance

$$\tau^2 = Var\left(\theta|Z\right) = \frac{1}{1/V_\theta + 1/V_\eta} = \frac{V_\theta V_\eta}{V_\theta + V_\eta}. \tag{4.11}$$

Moreover, when viewed as a random variable (as it is a function of the random variable Z), the posterior expected value $y = E\left[\theta|Z\right]$ of the state θ is itself normally distributed with mean

$$E\left[y\right] = E\left[E\left[\theta|Z\right]\right] = \frac{V_\theta}{V_\theta + V_\eta} E\left[Z\right] = 0$$

and variance

$$V = Var\left(E\left[\theta|Z\right]\right) = Var\left(\frac{V_\theta}{V_\theta + V_\eta} Z\right) = \left(\frac{V_\theta}{V_\theta + V_\eta}\right)^2 Var\left(Z\right) = \frac{V_\theta^2}{V_\theta + V_\eta}. \tag{4.12}$$

4.3.1.2 Bounds on p and t

For each realization y, the we must compute the firm's optimal price p and capital target t. The simplest (but not most efficient) way is by grid search. However, the grid must be finite. Thus,

[10] The zero mean is a normalization: if the mean μ is nonzero, we can replace θ and the firm value function $f\left(\right)$ with $\theta - \mu$ and $e^\mu f\left(\right)$, respectively.

we require upper and lower bounds on each variable. The bounds on t are simple: t must lie in $[c, m]$. And conditional on t, the price p cannot be less than t; else the number $s = t/p$ of shares will exceed one.

It remains to compute an upper bound on p. The idea of the bound is that if the price is too high, the IPO will raise little capital with high probability, so the IPO is not worth its cost c. The bound $\overline{p}_y$, which is increasing in the public signal y, is as follows.

Claim 4.3.2. *Given a parameter y, a firm that does an IPO will never choose a price p that exceeds the bound*

$$\overline{p}_y = f(m)\left(\frac{\tau}{\sqrt{2\pi}}\frac{f(m)-f(c)}{f(c/2)-f(c)}\right)^{\frac{\tau^3}{\sigma^2+\tau^2}} \exp\left(\begin{array}{c} y+\frac{\tau^3}{2}\frac{\tau^2+\tau+1}{\sigma^2+\tau^2}+\frac{S^2}{2} \\ +\frac{\sigma\tau^2}{\sigma^2+\tau^2}\Phi^{-1}\left(1-\frac{c}{2m}\right) \end{array}\right). \quad (4.13)$$

Proof of Claim 4.3.2. See Appendix.

4.4 The Simulation

In this section, we will do a simulation to the theoretic model and compare the simulation result to the empirical data.

4.4.1 Methodology for the Simulation

We now show how to simulate the model. The procedure is thus as follows. One first chooses parameters $m > 0$, $c \in (0, m)$, and $V > 0$. One then chooses a function f; for simplicity, we restrict to the two-parameter family $f(k) = (a+k)^b$ where $a, b > 0$. Once a and b are selected, equation (4.1) pins down the parameters $\iota = a^b$ and $\Omega = \max_{k\in[0,m]} \frac{f'(k)}{f(k)} = \max_{k\in[0,m]} \frac{b(a+k)^{b-1}}{(a+k)^b} = \frac{b}{a}$. Finally, one chooses parameters σ and τ satisfying (4.9) and (4.10). There thus are seven parameters: $(m, c, V, a, b, \sigma, \tau)$.

In order to draw realizations y from the distribution $N(0, V)$ we fix some large positive n and, for each $i = 1, ..., n-1$, let $y_i = V\Phi^{-1}(i/n)$. As this implies $\Phi(y_i/V) = i/n$, each y_i is that y which occurs at exactly the (i/n)th percentile in the distribution $N(0, V)$. One thus can treat each y_i as occurring with equal probability $(n-1)^{-1}$. That is, letting $y_i^n = y_i$,

$$\Phi\left(\frac{y_{i+1}^n}{V}\right) - \Phi\left(\frac{y_i^n}{V}\right) = \frac{i+1}{n} - \frac{i}{n} = \frac{1}{n},$$

whence for any integrable function $g(y)$,

$$\begin{aligned}\int_{y=-\infty}^{\infty} g(y)\, d\Phi\left(\frac{y}{V}\right) &= \lim_{n\to\infty} \sum_{i=1}^{n-1} g(y_i^n)\left[\Phi\left(\frac{y_{i+1}^n}{V}\right) - \Phi\left(\frac{y_i^n}{V}\right)\right] \\ &= \lim_{n\to\infty}\left[\frac{1}{n}\sum_{i=1}^{n-1} g(y_i^n)\right].\end{aligned}$$

For each y_i in $(y_i)_{i=1}^{n-1}$, one then computes the equilibrium threshold κ_{p,y_i}^t (the threshold κ that satisfies $\pi_{p,y_i}^{t*}(\kappa,\kappa) = 0$)[11] for each target $t \in [c, m]$ and price $p \in \left[t, \overline{p}_{y_i}\right]$ in a fine grid. One then searches this grid for the target t and price p that jointly maximize the IPO payoff

$$\Pi(t, p, y_i) = \int_{\theta=-\infty}^{+\infty} \left(1 - \frac{\ell_{p,y_i}^t(\theta) \wedge t}{p}\right) e^{\theta} f\left(\ell_{p,y_i}^t(\theta) \wedge t\right) d\Phi\left(\frac{\theta - y_i}{\tau}\right) \tag{4.14}$$

where "$\wedge$" denotes the pairwise minimum and $\ell_{p,y}^t(\theta)$ denotes the subscription rate $\ell_{\theta,y}^{\kappa_{p,y}^t}$ that results from the equilibrium threshold $\kappa_{p,y}^t$ when the state is θ, the public signal is y, and the firm's choices are (p, t).[12]. Let us denote the optimal choices as t_i and p_i, and let $\Pi(y_i)$ denote the firm's maximized IPO payoff $\Pi(t_i, p_i, y_i)$. Let I be the set of indices i for which the firm's optimal IPO payoff $\Pi(y_i)$ exceeds its payoff $\Pi_0(y_i) = \int_{\theta=-\infty}^{+\infty} e^{\theta} f(c)\, d\Phi\left(\frac{\theta - y_i}{\tau}\right)$ from withdrawing the IPO. As the firm will carry out the IPO if and only if i lies in I, computed moments should thus be restricted to i in I.

For each i in I, the distribution of the state θ is $N\left(y_i, \tau^2\right)$. We simulate this distribution as follows: for each $j = 1, ..., n-1$, we let $\theta_i^j = y_i + \tau\Phi^{-1}(j/n)$, whence $\Phi\left(\frac{\theta_i^j - y_i}{\tau}\right) = \frac{j}{n}$ so that θ_i^j is the realization that is at the (j/n)th percentile of a $N\left(y_i, \tau^2\right)$ random variable. For each y_i, we thus assign each θ_i^j the same probability weight $(n-1)^{-1}$. For each θ_i^j, the final (end of trading day) value of a share is $p_i^j \overset{d}{=} e^{\theta_i^j} f\left(\ell_i^j \wedge t_i\right)$ where $\wedge$ denotes pairwise minimum and ℓ_i^j denotes

---

[11] By (4.15) and (4.16), κ lies in $\left[\ln\left(\frac{p}{f(m)}\right) - \frac{S^2}{2}, \ln\left(\frac{pm}{c\iota}\right) - \frac{S^2}{2}\right]$. Hence, to find $\kappa_{p,y}^t$ one can perform a bisection search on this finite interval.

[12] The function $\ell_{\theta,y}^{\kappa}$ is defined in (4.7).

the subscription rate $\ell^{\kappa}_{\theta,y}$ that arises from the parameters $\theta = \theta^j_i$ and $y = y_i$ and the subscription threshold $\kappa_i = k^{t_i}_{p_i,y_i}$.[13]

Finally, in order to compute price revisions we require an initial filing price p_0, which is chosen prior to observing y. We will assume for simplicity that the filing price is chosen to minimize the mean squared pricing error $\frac{1}{|I|}\sum_{i\in I}(p_{y_i} - p_0)^2$ conditional on the IPO going through.[14] Hence, p_0 is computed as the mean $\frac{1}{|I|}\sum_{i\in I} p_{y_i}$ of the final IPO prices p_{y_i} over all public signals y_i for which the firm chooses to carry out IPO. The quantities of interest are then computed as follows for each pair (i, j) such that i is in I:

1. Price Revision: $R_i = \frac{p_i - p_0}{p_0}$.
2. Underpricing: $U^j_i = \frac{p^j_i - p_i}{p_i}$.
3. Oversubscription: $O^j_i = \ell^j_i / t_i$.

4.4.2 The Sample Data

The sample we would like to study consists of firms completing an initial public offering between January 2007 to December 2015 in United States and India. In United States, the data of subscription in IPO are not available as in many other countries. Fortunately, we have found that the data of subscription are publicly available in India. So, we add the data of India to our study. The data of United States comes from Thomson Financial's Securities Data Company (SDC) database. The data of India comes from National Stock Exchange (NSE), Bombay Stock Exchange (BSE) and Chittorgarh Infotech, a company which specialized in providing financial information in India[15]. We exclude unit offers, closed-end funds (including REITs), financial institutions, ADRs of companies already listed in their home countries, limited partnerships, and penny stocks (IPOs

[13] A formula for $\ell^{\kappa}_{\theta,y}$ appears in equation (4.7).

[14] It seems reasonable that large price revisions have a reputation cost for the firm's underwriter. If this cost is quadratic, we obtain the given formula for p_0.

[15] The data are collected from the following websites. National Stock Exchange(NSE): https://www.nseindia.com/products/content/equities/ipos/historical_ipo.htm, Bombay Stock Exchange(BSE): https://www.bseindia.com/markets/PublicIssues/IPOIssues_new.aspx?expandable=3&id=2&Type=P, and Chittorgarh Infotech: http://www.chittorgarh.com/ipo/reports/ipo_report_listing_day_gain.asp

with offer prices below five dollars). In addition, we only consider the native companies which is different from most former empirical studies.

A brief description of the data is in Table 4.1. In the sample, there are 935 IPOs for United States and 297 IPOs for India. We can see that the mean and median of initial return for the U.S. and India are quite close and they are quite larger than 0 (about 16% $\sim$ 17%), which suggests the existence of underpricing in the IPOs in both United States and India. The means of initial return are much higher than the medians, which suggests that the distributions skew to the right. The mean of price revision is negative in the U.S., while is positive in India. But both are relatively small in absolute value. Besidesthe medians of price revision are quite near 0 for both countries. For the oversubscription variable in India, we can see that the IPOs in India are generally oversubscribed (most of the oversubscription values are greater than 1).

Table 4.1 Summary Statistics for Sample data

	Underpricing		*Price Revision*		*Oversubscription*
	U.S.	India	U.S.	India	India
Mean	0.161	0.1683	−0.0287	0.0263	19.5102
Standard Error	0.009	0.0244	0.0051	0.0035	1.6943
Median	0.0833	0.086	0	0.037	4.51
Standard Deviation	0.2766	0.4197	0.156	0.0611	29.1998
Sample Variance	0.0765	0.1761	0.0243	0.0037	852.6258
Kurtosis	8.9803	4.4852	0.4542	38.0987	4.6685
Skewness	2.3456	1.5728	−0.4775	−4.6714	2.1224
Range	2.5664	3.1067	1.1045	0.6616	160.12
Minimum	−0.3964	−0.6892	−0.65	−0.5707	0.44
Maximum	2.17	2.4175	0.4545	0.0909	160.56
Count	935	297	935	297	297

Table 4.2 describes the correlations between the key variables in the U.S. and India. We can see that the IPOs in both U.S. and India tend to display the characteristic of underreaction: the price revision is positively correlated with underpricing. This is one of the most important results indicated from our theoretic model and it is also consistent with previous studies. Intuitively, good

Table 4.2 Correlation Coefficients for Sample data

Nation	Statistics	*Underpricing*	*Price Revision*	*Oversubscription*
US	*Underpricing*	1	0.4683	
	Price Revision	0.4683	1	
India	*Underpricing*	1	0.0971	0.5106
	Price Revision	0.0971	1	0.0713
	Oversubscription	0.5106	0.0713	1

news about the state variable lead firms to raise IPO price, which induces a higher price revision. Since agents' wealth is limited, the risk of undersubscription is now greater: investors face greater strategic risk. This leads to a higher underpricing, which appears in the data as underreaction. Also, we can see that underpricing is positively correlated with oversubscription rate.

4.4.3 Simulation Results

Based on the theoretic model, the simulation data are generated by setting default parameters value as follows: $\sigma = 1$; $\tau = 1$; $m = 2$; $a = 1$; $b = 1.1$; $c = 1$; $\alpha = 1$. We generate 99 public signals y and 999 economic states θ from their normal distributions which are described in Section 4.4.1. In the simulation, 21 IPOs are conducted. Therefore, we have $21 * 99 = 20979$ data points in the simulation. The key variables in the simulation are described in Table 4.3. We can see that the data display underpricing in the simulation.

Table 4.4 displays the correlations between the key variables in the simulation. We can see that the correlation coefficient between underpricing and price revision is 0.128, which indicates the existance of underreaction. This is consistent with the empirical results in India and the U.S. and the value of the simulated correlation coefficient between underpricing and price revision is quite similar to the value in India (0.097). The correlation coefficient between underpricing and oversubscription is 0.6. It shows that there exists a very strong positive relation between underpricing and oversubscription. This is also consistent with the empirical result in India and the values of the simulated correlation coefficient between underpricing and oversubscription are close to that in

India. Therefore, our simulation tends to be consistent with the empirical results for the correlations among underpricing, price revision and oversubscription. In this way, we provide a simulation result which generates underpricing and underreaction from the strategic risk of undersubscription, which lends additional support to our hypothesis that underpricing and underreaction are caused by the risk of undersubscription.

Table 4.3 Summary Statistics for Simulation data

	Underpricing	*Price Revision*	*Oversubscription*
Mean	0	0.9546	0.6656
Standard Error	0.0021	0.0188	0.0019
Median	−0.0994	0.0495	0.7325
Standard Deviation	0.3104	2.7258	0.2762
Sample Variance	0.0964	7.4299	0.0763
Kurtosis	1.1766	24.4785	−0.7322
Skewness	1.3685	3.9308	−0.6379
Range	1.1873	39.9483	0.9986
Minimum	−0.3025	−0.9854	0.0014
Maximum	0.8848	38.963	1
Count	20979	20979	20979

Table 4.4 Correlation Coefficients for Simulation data

Statistics	*Underpricing*	*Price Revision*	*Oversubscription*
Underpricing	1	0.1284	0.2926
Price Revision	0.1284	1	0.6023
Oversubscription	0.2926	0.6023	1

4.5 Conclusion

This chapter examines how strategic risk among investors can help explain both underpricing and underreaction in initial public offerings (IPOs). The strategic risk we studied comes from the assumption that the post-IPO value of a firm can be higher if the IPO raises more capital for the firm. With this assumption, the value of subscribing depends on the aggregate subscription rate. As this risk is resolved immediately after the IPO, the IPO itself is underpriced. Moreover, since individual investors have limited wealth, a higher offer price raises the risk of undersubscription. Investors respond by demanding a larger discount: the offer price appears to underreact to public news.

In this chapter, we first use a theoretic model in a global game setting to display the strategic risk of undersubscription in IPO and show how the undersubscription risk can lead to underpricing and underreaction. Then, we conduct a simulation for the model and compare the simulated results to the empirical results in India and the U.S. The simulation results tend to be consistent with the empirical results, which lends further support for our hypothesis that the strategic risk of undersubscription can be used to explain underpricing and underreaciton.

This chapter provides a new insight for understanding the underpricing and underreaction in IPOs. Our results suggest that undersubscription risk can be an important concern for investors who plan to participate in IPOs. Also, the introduction of the endogeneity of firm value in the stock market in our analysis may shed new light on the studies of IPOs. These results can also be useful for policy makers in the stock market.

4.6 Appendix: Proofs and Technical Results

We first show that there are dominance regions: that it is strictly dominant (not) to subscribe when a player's posterior mean $\overline{\theta}$ is sufficiently high (low). This result does not assume (4.9) or (4.10).

Claim 4.6.1. *For p and s satisfying $t = ps > 0$:*

$$\text{for all } \overline{\theta} < \ln\left(\frac{p}{f(m)}\right) - \frac{S^2}{2},\ \pi_p^{t*}\left(\overline{\theta}, \kappa\right) < 0 \text{ for any } \kappa; \tag{4.15}$$

$$\text{for all } \overline{\theta} > \ln\left(\frac{pm}{c\iota}\right) - \frac{S^2}{2},\ \pi_p^{t*}\left(\overline{\theta}, \kappa\right) > 0 \text{ for any } \kappa. \tag{4.16}$$

Proof. Since $t = ps \geq c > 0$, we must have $p > 0$ and $s > 0$. By (4.2),

$$p * \pi_p^t(\theta, \ell) \in \begin{cases} \left[e^\theta \iota - p, e^\theta f(t) - p\right] & \text{if} \quad \ell \leq t \\ \left[\frac{t}{m}\left[e^\theta f(t) - p\right], e^\theta f(t) - p\right] & \text{if} \quad \ell \in [t, m] \end{cases}$$

Combining these cases and using $t \geq c$ and $f(t) \geq \iota$, we obtain, for all ℓ,

$$\pi_p^t(\theta, \ell) \in \left[\frac{e^\theta}{p}\frac{c\iota}{m} - 1, \frac{e^\theta}{p} f(m) - 1\right]$$

which, using $\int_{\theta=-\infty}^{+\infty} e^\theta d\Phi\left(\frac{\theta - \overline{\theta}}{S}\right) = e^{\overline{\theta} + S^2/2}$ and (4.8), implies

$$\pi_p^{t*}\left(\overline{\theta}, \kappa\right) \in \left[\frac{e^{\overline{\theta}+S^2/2}}{p}\frac{c\iota}{m} - 1, \frac{e^{\overline{\theta}+S^2/2}}{p} f(m) - 1\right],$$

from which the claim immediately follows. □

We next show that if a player believes that others are playing a threshold strategy, then an increase in her posterior mean $\overline{\theta}$ strengthens her own incentive to subscribe.

Claim 4.6.2. *Assume (4.9) and suppose that some player i believes that each other player j will play threshold strategy with threshold κ (i.e., subscribe if and only if $\overline{\theta}_{x_j} > \kappa$). Then player i's relative payoff $\pi_p^{t*}\left(\overline{\theta}, \kappa\right)$ from subscribing is increasing in her posterior mean $\overline{\theta}$.*

Proof. For any ε, let $\overline{\theta}' = \overline{\theta} + \varepsilon$. By the change of variables $\theta' = \theta - \varepsilon$ (whence $\frac{\theta' - \overline{\theta}}{S} = \frac{\theta - \overline{\theta}'}{S}$), we have

$$\begin{aligned} \pi_p^{t*}\left(\overline{\theta}', \kappa\right) &= \int_{\theta=-\infty}^{+\infty} \pi_p^t\left(\theta, \ell_{\theta,y}^\kappa\right) d\Phi\left(\frac{\theta - \overline{\theta}'}{S}\right) \\ &= \int_{\theta'=-\infty}^{+\infty} \pi_p^t\left(\theta' + \varepsilon, \ell_{\theta+\varepsilon,y}^\kappa\right) d\Phi\left(\frac{\theta' - \overline{\theta}}{S}\right) \end{aligned}$$

and thus, renaming θ' to θ,

$$\pi_p^{t*}\left(\overline{\theta}', \kappa\right) - \pi_p^{t*}\left(\overline{\theta}, \kappa\right) = \int_{\theta=-\infty}^{+\infty} \left[\pi_p^t\left(\theta + \varepsilon, \ell_{\theta+\varepsilon,y}^\kappa\right) - \pi_p^t\left(\theta, \ell_{\theta,y}^\kappa\right)\right] d\Phi\left(\frac{\theta - \overline{\theta}}{S}\right)$$

whence

$$\frac{d}{d\overline{\theta}}\pi_p^{t*}\left(\overline{\theta}, \kappa\right) = \int_{\theta=-\infty}^{+\infty} \left[\frac{d}{d\theta}\pi_p^t\left(\theta, \ell_{\theta,y}^\kappa\right)\right] d\Phi\left(\frac{\theta - \overline{\theta}}{S}\right). \tag{4.17}$$

We now evaluate the integrand. By (4.2),

$$\frac{d}{d\theta}\pi_p^t\left(\theta,\ell_{\theta,y}^{\kappa}\right)=\begin{cases}\underline{\Gamma}_{p,y}^t\left(\theta,\kappa\right) & \text{if} \quad \ell_{\theta,y}^{\kappa}\leq t\\ \overline{\Gamma}_{p,y}^t\left(\theta,\kappa\right) & \text{if} \quad \ell_{\theta,y}^{\kappa}\geq t\end{cases}$$

where $\underline{\Gamma}_{p,y}^t\left(\theta,\kappa\right)=\frac{e^{\theta}}{p}\left[f\left(\ell_{\theta,y}^{\kappa}\right)+f'\left(\ell_{\theta,y}^{\kappa}\right)\frac{\partial}{\partial\theta}\ell_{\theta,y}^{\kappa}\right]$ is positive and

$$\begin{aligned}\overline{\Gamma}_{p,y}^t\left(\theta,\kappa\right) &= \frac{e^{\theta}}{p}\left[\frac{t}{\ell_{\theta,y}^{\kappa}}f\left(t\right)-\frac{t}{\left(\ell_{\theta,y}^{\kappa}\right)^2}\left[f\left(t\right)-e^{-\theta}p\right]\frac{\partial}{\partial\theta}\ell_{\theta,y}^{\kappa}\right]\\ &= \frac{e^{\theta}}{p}\frac{t}{\ell_{\theta,y}^{\kappa}}\left(\frac{f\left(t\right)}{\sigma}\left(\sigma-\frac{\sigma}{\ell_{\theta,y}^{\kappa}}\frac{\partial}{\partial\theta}\ell_{\theta,y}^{\kappa}\right)+e^{-\theta}p\frac{1}{\ell_{\theta,y}^{\kappa}}\frac{\partial}{\partial\theta}\ell_{\theta,y}^{\kappa}\right).\end{aligned}$$

To ensure that $\overline{\Gamma}_{p,y}^t\left(\theta,\kappa\right)$ is also positive, it thus suffices to check that whenever $\ell_{\theta,y}^{\kappa}\geq t$, we have

$$\sigma>\frac{\sigma}{\ell_{\theta,y}^{\kappa}}\frac{\partial}{\partial\theta}\ell_{\theta,y}^{\kappa}=\sigma\frac{m}{\ell_{\theta,y}^{\kappa}}\frac{\partial}{\partial\theta}\left(\frac{\ell_{\theta,y}^{\kappa}}{m}\right)=h\left(z_{\theta,y}^{\kappa}\right)\tag{4.18}$$

by (4.7), where

$$z_{\theta,y}^{\kappa}=\frac{\sigma^2\left(\kappa-y\right)+\tau^2\left(\kappa-\theta\right)}{\tau^2\sigma}=\Phi^{-1}\left(1-\frac{\ell_{\theta,y}^{\kappa}}{m}\right).\tag{4.19}$$

But by (4.7) and since h is increasing, $\ell_{\theta,y}^{\kappa}\geq t$ implies that $h\left(z_{\theta,y}^{\kappa}\right)$ does not exceed $h\left(\Phi^{-1}\left(1-\frac{t}{m}\right)\right)$ which, in turn, is not greater than $h\left(\Phi^{-1}\left(1-\frac{c}{m}\right)\right)$ as $t\geq c$. By (4.9), then, (4.18) holds whenever $\ell_{\theta,y}^{\kappa}\geq t$. □

By Claim 4.6.2, a finite threshold κ is an equilibrium if and only if a player's relative payoff from subscribing $\pi_p^{t*}\left(\overline{\theta},\kappa\right)$ is zero when her posterior mean $\overline{\theta}$ equals the threshold κ: if and only if

$$\pi_{p,y}^{t*}\left(\kappa,\kappa\right)=\int_{\theta=-\infty}^{+\infty}\pi_p^t\left(\theta,\ell_{\theta,y}^{\kappa}\right)d\Phi\left(\frac{\theta-\kappa}{S}\right)\tag{4.20}$$

equals zero. Claim 4.6.1 implies that $\pi_{p,y}^{t*}\left(\kappa,\kappa\right)$ is positive (negative) for sufficiently high (low) thresholds κ. The next claim states that under (4.10), $\pi_{p,y}^{t*}\left(\kappa,\kappa\right)$ is continuous and increasing in κ.

Claim 4.6.3. *1. $\pi_{p,y}^{t*}\left(\kappa,\kappa\right)$ is continuous in κ. 2. Assume (4.10). Then $\pi_{p,y}^{t*}\left(\kappa,\kappa\right)$ is strictly increasing in κ wherever $\pi_{p,y}^{t*}\left(\kappa,\kappa\right)$ is zero.*

Proof. Part 1. Obvious as $\pi_{p,y}^{t*}(\kappa,\kappa)$ is defined in terms of continuous functions. Part 2. For any ε, let $\kappa' = \kappa + \varepsilon$. By the change of variables $\theta' = \theta - \varepsilon$ (whence $\frac{\theta'-\kappa}{S} = \frac{\theta-\kappa'}{S}$), we have

$$\begin{aligned}\pi_{p,y}^{t*}(\kappa',\kappa') &= \int_{\theta=-\infty}^{+\infty} \pi_p^t\left(\theta, \ell_{\theta,y}^{\kappa'}\right) d\Phi\left(\frac{\theta-\kappa'}{S}\right)\\ &= \int_{\theta'=-\infty}^{+\infty} \pi_p^t\left(\theta'+\varepsilon, \ell_{\theta'+\varepsilon,y}^{\kappa+\varepsilon}\right) d\Phi\left(\frac{\theta'-\kappa}{S}\right)\end{aligned}$$

and thus, renaming θ' to θ,

$$\pi_{p,y}^{t*}(\kappa',\kappa') - \pi_{p,y}^{t*}(\kappa,\kappa) = \int_{\theta=-\infty}^{+\infty} \left[\pi_p^t\left(\theta+\varepsilon, \ell_{\theta+\varepsilon,y}^{\kappa+\varepsilon}\right) - \pi_p^t\left(\theta, \ell_{\theta,y}^{\kappa}\right)\right] d\Phi\left(\frac{\theta-\kappa}{S}\right),$$

whence

$$\frac{d}{d\kappa}\pi_{p,y}^{t*}(\kappa,\kappa) = \int_{\theta=-\infty}^{+\infty} \left[\frac{d}{d\varepsilon}\pi_p^t\left(\theta+\varepsilon, \ell_{\theta+\varepsilon,y}^{\kappa+\varepsilon}\right)\right]_{\varepsilon=0} d\Phi\left(\frac{\theta-\kappa}{S}\right). \tag{4.21}$$

By (4.7), $\frac{1}{\ell_{\theta,y}^{\kappa}}\left[\frac{\partial}{\partial\theta}\ell_{\theta,y}^{\kappa} + \frac{\partial}{\partial\kappa}\ell_{\theta,y}^{\kappa}\right] = -\frac{\sigma}{\tau^2}h\left(z_{\theta,y}^{\kappa}\right)$ where $z_{\theta,y}^{\kappa}$ is defined in (4.19). Hence, by (4.2),

$$\left[\frac{d}{d\varepsilon}\pi_p^t\left(\theta+\varepsilon, \ell_{\theta+\varepsilon,y}^{\kappa+\varepsilon}\right)\right]_{\varepsilon=0} = \begin{cases} \underline{\Lambda}_{p,y}^t(\theta,\kappa) & \text{if} \quad \ell_{\theta,y}^{\kappa} \le t \\ \overline{\Lambda}_{p,y}^t(\theta,\kappa) & \text{if} \quad \ell_{\theta,y}^{\kappa} \ge t \end{cases}$$

where $\underline{\Lambda}_{p,y}^t(\theta,\kappa)$ denotes

$$\frac{e^{\theta} f\left(\ell_{\theta,y}^{\kappa}\right)}{p}\left[1 - \frac{\sigma}{\tau^2}\frac{f'\left(\ell_{\theta,y}^{\kappa}\right)}{f\left(\ell_{\theta,y}^{\kappa}\right)} h\left(z_{\theta,y}^{\kappa}\right)\ell_{\theta,y}^{\kappa}\right]$$

and $\overline{\Lambda}_{p,y}^t(\theta,\kappa)$ denotes

$$\frac{t}{p\ell_{\theta,y}^{\kappa}}\left(e^{\theta} f(t) + \frac{\sigma}{\tau^2}h\left(z_{\theta,y}^{\kappa}\right)\left[e^{\theta} f(t) - p\right]\right)$$

. Let $\theta_{t,y}^{\kappa}$ be the state θ at which $\ell_{\theta,y}^{\kappa} = t$. By (4.7), $\ell_{\theta,y}^{\kappa}$ is increasing in θ, so $\theta \gtrless \theta_{t,y}^{\kappa}$ as $\ell_{\theta,y}^{\kappa} \gtrless t$. By (4.2) and (4.8), we can write $\pi_{p,y}^{t*}(\kappa,\kappa)$ as a sum $A+B$ where A denotes $\int_{\theta=-\infty}^{\theta_{t,y}^{\kappa}} \pi_p^t\left(\theta,\ell_\theta^\kappa\right) d\Phi\left(\frac{\theta-\kappa}{S}\right)$ and B denotes $\int_{\theta=\theta_{t,y}^{\kappa}}^{+\infty} \pi_p^t\left(\theta,\ell_\theta^\kappa\right) d\Phi\left(\frac{\theta-\kappa}{S}\right)$. Using (4.21) we can write $\frac{d}{d\kappa}\pi_{p,y}^{t*}(\kappa,\kappa)$ as the sum $A'+B'$ where A' denotes $\int_{\theta:\ell_{\theta,y}^{\kappa}\le t} \underline{\Lambda}_{p,y}^t(\theta,\kappa)\, d\Phi\left(\frac{\theta-\kappa}{S}\right)$ and B' denotes $\int_{\theta:\ell_{\theta,y}^{\kappa}\ge t} \overline{\Lambda}_{p,y}^t(\theta,\kappa)\, d\Phi\left(\frac{\theta-\kappa}{S}\right)$. Since $\ell_{\theta,y}^{\kappa}$ is increasing in θ by (4.7), it follows from (4.2) that $\pi_{p,y}^t\left(\theta,\ell_{\theta,y}^{\kappa}\right)$ is negative (positive) for all states θ below (above) some threshold θ^* that depends on t, p, and κ. Hence, if $\pi_{p,y}^{t*}(\kappa,\kappa)$ is zero, then $A < 0 < B$. To show that $\frac{d}{d\kappa}\pi_{p,y}^{t*}(\kappa,\kappa)$ is positive, it thus suffices to show that $A' > 0$ and

$B' > B$. For the former inequality, $h(z)\,\ell^{\kappa}_{\theta,y} = m\Phi'\left(z^{\kappa}_{\theta,y}\right) \in \left(0, m/\sqrt{2\pi}\right)$ by (4.19) whence, by (4.1), $1 - \frac{\sigma}{\tau^2}\frac{f'\left(\ell^{\kappa}_{\theta,y}\right)}{f\left(\ell^{\kappa}_{\theta,y}\right)} h\left(z^{\kappa}_{\theta,y}\right)\ell^{\kappa}_{\theta,y}$ is at least $1 - \frac{\sigma\Omega m}{\tau^2\sqrt{2\pi}}$. Thus, by (4.10), $\underline{\Lambda}^{t}_{p,y}(\theta,\kappa)$ is positive when $\ell^{\kappa}_{\theta,y} \leq t$, whence $A' > 0$. As for B', assume $\theta \geq \theta^{\kappa}_{t,y}$ so that $\ell^{\kappa}_{\theta,y} \geq t$. Then $z^{\kappa}_{\theta,y} \leq \Phi^{-1}\left(1 - \frac{c}{m}\right)$ by (4.3) and (4.19) whence $h\left(z^{\kappa}_{\theta,y}\right)$ does not exceed $h\left(\Phi^{-1}\left(1-\frac{c}{m}\right)\right)$ which, by (4.10), is less than $\frac{\tau^2}{\sigma}$. Thus, $\overline{\Lambda}^{t}_{p,y}(\theta,\kappa)$ exceeds $\frac{t}{p\ell^{\kappa}_{\theta,y}}\left[e^{\theta}f(t) - p\right] = \pi^{t}_{p}\left(\theta, \ell^{\kappa}_{\theta,y}\right)$ and so $B' > B$ as claimed. □

Proof of Claim 4.3.2. We first require the following preliminary result:

Lemma 4.6.4. *For any $\varepsilon > 0$ and real number θ_0 satisfying*

$$\theta_0 > \varphi_y(\varepsilon) \overset{d}{=} \tau\left[\tau^2 + (\tau+1)\left(\frac{1}{2} + \frac{y}{\tau}\right) - \ln\left(\frac{\sqrt{2\pi}}{\tau}\right) - \ln\varepsilon\right], \tag{4.22}$$

we have

$$E_{\theta}\left[e^{\theta}1_{\theta\geq\theta_0}\right] < \varepsilon \tag{4.23}$$

where the expectation is taken under the firm's belief that $\theta \sim N\left(y, \tau^2\right)$.

Proof. Using the change of variables $z = \frac{\theta - y}{\tau}$, $dz = (d\theta)/\tau$,

$$E_{\theta}\left[e^{\theta}1_{\theta\geq\theta_0}\right] = \int_{\theta=\theta_0}^{+\infty} e^{\theta}d\Phi\left(\frac{\theta-y}{\tau}\right) = \frac{\tau e^{y}}{\sqrt{2\pi}}\int_{z=\frac{\theta_0-y}{\tau}}^{+\infty} e^{g(z)}dz \tag{4.24}$$

where $g(z) = z\tau - z^2/2$. As g is strictly concave and has a slope of -1 at $z = \tau + 1$, it follows that

$$g(z) \leq g(\tau+1) - (z - \tau - 1) = \tau^2 + (\tau+1)/2 - z$$

for all z. Hence, $\int_{z=\frac{\theta_0-y}{\tau}}^{+\infty} e^{g(z)}dz \leq \exp\left(\tau^2 + \frac{\tau+1}{2} + \frac{y-\theta_0}{\tau}\right)$ which when substituted into (4.24) yields

$$E_{\theta}\left[e^{\theta}1_{\theta\geq\theta_0}\right] \leq \frac{\tau e^{y}}{\sqrt{2\pi}}\exp\left(\tau^2 + \frac{\tau+1}{2} + \frac{y-\theta_0}{\tau}\right). \tag{4.25}$$

Finally, the right hand side of (4.25) is less than ε if and only if (4.22) holds. □

For any public signal y, let $\kappa^{t}_{p,y}$ denote the subscription threshold that results from the firm's choices (p,t): the unique solution to

$$\pi^{t*}_{p,y}\left(\kappa^{t}_{p,y}, \kappa^{t}_{p,y}\right) = 0. \tag{4.26}$$

Further, let

$$\ell_{p,y}^{t}(\theta)=\ell_{\theta,y}^{\kappa_{p,y}^{t}} \tag{4.27}$$

denote the subscription rate that results from the public signal y and the firm's choices (p,t) when the state is θ.[16] By Claim 4.6.1, $\kappa_{p,y}^{t}$ is not less than $\ln p-\ln f(m)-S^2/2$. By (4.7), this implies a bound on the subscription rate at θ given y and the choices (p,t):

$$\ell_{p,y}^{t}(\theta)\leq m\left[1-\Phi\left(\frac{\left(\sigma^2+\tau^2\right)\left(\ln p-\ln f(m)-S^2/2\right)-\sigma^2 y-\tau^2\theta}{\tau^2\sigma}\right)\right]. \tag{4.28}$$

As this bound is increasing in the state θ, for any price p the subscription rate $\ell_{p,y}^{t}(\theta)$ is at most $c/2$ as long as θ does not exceed[17]

$$\theta_{p,y}\overset{d}{=}\frac{\left(\sigma^2+\tau^2\right)\left(\ln p-\ln f(m)-S^2/2\right)-\sigma^2 y-\tau^2\sigma\Phi^{-1}\left(1-\frac{c}{2m}\right)}{\tau^2}. \tag{4.29}$$

Hence, the firm's relative payoff from doing the IPO is strictly less than

$$\begin{aligned}
&\int_{\theta=-\infty}^{\theta_{p,y}} e^{\theta}\left[f\left(\ell_{p,y}^{t}(\theta)\right)-f(c)\right]d\Phi\left(\frac{\theta-y}{\tau}\right)\\
&+\int_{\theta=\theta_{p,y}}^{+\infty} e^{\theta}\left[f\left(\ell_{p,y}^{t}(\theta)\right)-f(c)\right]d\Phi\left(\frac{\theta-y}{\tau}\right)\\
<\ & E\left[e^{\theta}\right]\left[f(c/2)-f(c)\right]+E\left[e^{\theta}1_{\theta\geq\theta_{p,y}}\right]\left[f(m)-f(c)\right]
\end{aligned}$$

where the expectations take y as given and assume $\theta\sim N\left(y,\tau^2\right)$. Under this belief, $E\left[e^{\theta}\right]$ equals $e^{y+\tau^2/2}$. Thus, the firm's relative payoff must be negative as long as

$$E\left[e^{\theta}1_{\theta\geq\theta_{p,y}}\right]<\frac{f(c/2)-f(c)}{f(m)-f(c)}e^{y+\tau^2/2}.$$

By Lemma 4.6.4, this must hold if

$$\begin{aligned}
\theta_{p,y} &> \tau\left[\tau^2+(\tau+1)\left(\frac{1}{2}+\frac{y}{\tau}\right)-\ln\left(\frac{\sqrt{2\pi}}{\tau}\right)-\ln\left(\frac{f(c/2)-f(c)}{f(m)-f(c)}e^{y+\tau^2/2}\right)\right]\\
&= \frac{\tau^3+\tau^2+\tau}{2}+y-\tau\ln\left(\frac{\sqrt{2\pi}}{\tau}\frac{f(c/2)-f(c)}{f(m)-f(c)}\right)
\end{aligned}$$

which by (4.29) can be transformed to $p>\overline{p}_y$. Q.E.D.

[16] The function $\ell_{\theta,y}^{\kappa}$ is defined in (4.7).

[17] The bound in (4.29) is obtained by setting the bound in (4.28) equal to $c/2$ and solving for θ.

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CHAPTER 5. FUTURE WORK SUMMARY AND DISCUSSION

5.1 Deposit Insurance and Shadow Banking System

Does deposit insurance bring extra moral hazard issues for commercial banks? The answer is no. Although deposit insurance weakens depositor discipline, regulator discipline is built from the fact that the deposit insurance transfers risks from depositors to the regulator, so the regulator has the incentive to monitor banks. Compared to depositors, the regulator has more information about banks' financial positions, so it is able to monitor banks more effectively than depositors. Empirically, even with no deposit insurance, the effectiveness of depositor discipline is questionable. Moreover, unregulated shadow banks suffered much more impact than regulated commercial banks during the Great Recession. It further demonstrates the existence of regulator discipline. After the enactment of the Dodd-Frank Act, we have more reliable rules and regulations on the banking system. We could believe that regulator discipline trumps depositor discipline in monitoring banks.

In terms of the liability side of the balance sheet, deposit insurance separates the debt of the banking system into two parts: covered deposits and uncovered shadow banking financing instruments. The whole banking system is half-covered. When the market risks increase, investors transfer their funds from shadow banks to commercial banks as an increase in deposits. The success of the half-covered banking system depends on whether commercial banks offer liquidity backup to shadow banks. In most cases, it works. However, when market risks are so large that commercial banks would rather keep the increase in deposits as cash on hand than give liquidity support to shadow banks, the half-covered banking system fails.

During the Great Recession, liquidity did not flow out of the banking sector but was reallocated internally. Deposits increased, but the volume of shadow banking financing instruments decreased. Commercial banks that relied more heavily on core deposit and equity capital financing could still lend and purchase securitized assets compared to other banks. After the bankruptcy of Lehman

Brothers, commercial banks kept the large increase in deposits as cash on hand, which could be crucial liquidity backup for shadow banks (see Table 3.2). This may have been due to the counter-party risks or the newly introduced policy by the Federal Reserve to pay interest on bank reserves. Or sometimes, commercial banks would rather squeeze their credit and acquire securitized assets at fire-sale price liquidated by shadow banks than offer liquidity backup to high risky counter-parties (Acharya et al. (2010)). Although there were unprecedented government bailouts after Lehman's bankruptcy, securitized assets have already been priced at extremely risk-averse preference from fixed-income investors. Using their securitized assets as collateral, shadow banks cannot raise enough funds compared to times when securitized assets are in nearly risk-neutral pricing. No liquidity can arbitrage securitized assets back to nearly risk-neutral pricing, and even if any, it takes a too long time to go back, and survival could be a problem.

After the Great Recession, BHCs were potential winners and owned more and more shadow banking subsidiaries. Although the number of independent shadow banks decreased, we have the internal FTQ circle in BHCs. BHCs can enjoy the synergy by holding commercial banks and shadow banks together. However, deposits may not be enough for some BHCs to survive in the next crisis. Funds will transfer from some BHCs to others, and regulations should be able to stimulate BHCs with rich liquidity to help BHCs in trouble but not stand by and profit from the trouble. Chapter 3 also proposes that regulations should focus on not only sufficient capital, but also sufficient core deposits.

In Chapter 3, since I have time series data, and VAR models can identify the concurrent correlation and dynamic correlation for time series data with endogenous variables, I use the VAR models to identify the two hypotheses about deposits and financial CP outstanding. Future research could collect high-frequency micro-level panel data about shadow banks and commercial banks. The VAR model cannot be used for panel data. However, if we only consider the dynamic correlation (liquidity backup from commercial banks to shadow banks) and ignore the probable problem of endogeneity, a simple regression model based on Gatev and Strahan (2006) and Cornett et al.

(2011) can be used as follows:

$$\begin{aligned}\Delta\text{Financial CP}_{i,t}/\text{Assets}_{i,t-1} = T_t + B_i &+ \beta_1\Delta\text{Deposit}_{t-1} + \beta_2\Delta\text{Deposit}_{t-1} * C_{t-1} \\ &+ \beta_3\text{Capital}_{i,t-1}/\text{Assets}_{i,t-1} \\ &+ \beta_4\text{Capital}_{i,t-1}/\text{Assets}_{i,t-1} * \Delta\text{Deposit}_{t-1} \\ &+ \beta_5\text{Capital}_{i,t-1}/\text{Assets}_{i,t-1} * \Delta\text{Deposit}_{t-1} * C_{t-1} \\ &+ \beta_6 \ln(\text{Assets}_{i,t-1}) \\ &+ \beta_7 \ln(\text{Assets}_{i,t-1}) * \Delta\text{Deposit}_{t-1} \\ &+ \beta_8 \ln(\text{Assets}_{i,t-1}) * \Delta\text{Deposit}_{t-1} * C_{t-1} + e_{i,t},\end{aligned}$$

where T_t is the time effect that sweeps out aggregate shocks and B_i is shadow bank-level fixed effect that absorbs unobserved heterogeneity at each shadow bank. In addition, C_{t-1} is the time dummy variable, which equals one if the time $t-1$ happens in the crisis. $\Delta\text{Deposit}_{t-1}$ is the change of total deposits at time $t-1$. All other variables are shadow bank-level data. If the results of Chapter 3 hold, we expect to find significantly positive β_1 and significantly negative β_2. The heterogeneity in shadow banks is also interesting if we have the panel data. Personally speaking, I expect healthy and large shadow banks can receive more liquidity backup from commercial banks. Hence, we may find significantly positive β_4 and β_7.

There is one caveat: Chapter 3 only considers the liquidity risks and therefore, the liability side of financial institutions. Most financial institutions failed in the Great Recession because of their holdings of MBSes, especially subprime MBSes. When the prices of their assets (mostly MBSes) declined, financial institutions could be insolvent even with no liquidity problem. The neglected credit risks and bubbles in prices of collateral (mostly real estate) largely account for the price decline of securitized assets. Liquidity risks also play a role in explaining the price decline. As the story in Chapter 3, when the liquidity backup from commercial banks broke down, shadow banks could not roll over their debt and had to liquidate their securitized assets. The liquidation leads to the further price decline of MBSes. Excluding the neglected credit risks and bubbles, MBSes are priced from nearly risk-neutral to extremely risk-averse valuation because extremely risk-averse investors dominate the markets. It is hard to say that the failed financial institutions hold a large number of MBSes intentionally or they cannot resell the MBSes they issued or underwrote. From a risk-neutral perspective, their holdings of MBSes may be correct, but they cannot survive into the time when markets are full of liquidity and dominated by nearly risk-neutral arbitragers again.

5.2 Underpricing in Initial Public Offerings

Some issuers go public (equity financing) because they need to raise funds for working capital or payment of debt. They are more compatible with our model than the issuers who go public only for marketability. The latter founders just want to turn their private company to the public in order to monetize their assets. Further research could identify the use of proceeds of IPOs. If our model can explain the reality, IPOs which use the proceeds for working capital or payment of debt should have significantly larger underpricing than that for marketability.

5.3 References

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