ABSTRACT

Title of dissertation: SHORT-TERM FUNDING MARKETS AND SYSTEMIC RISK

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This dissertation presents two essays to study both theoretically and empirically the interaction of short-term funding and the banking system and its effects on systemic risk.

Before its collapse in September 2008, Lehman Brothers had been using the repurchase agreement (repo) market to hide up to $50 billion from their balance sheet at the end of each quarter. When this "Repo 105" scheme was uncovered (a type of strategy called window dressing), the Securities and Exchange Commission conducted an inquiry into public US financial institutions and concluded that Lehman was an isolated case. Using confidential regulatory data on daily repo transactions from July 2008 to July 2014, in my first essay, I show that non-US banks continue to remove an average of $170 billion from the US tri-party repo market every quarter-end. This amount is more than double the $76 billion market-wide drop in tri-party repo during the turmoil of the 2008 financial crisis and represents about 10% of the entire tri-party repo market. Window dressing induced deleveraging spills over into agency bond markets and money market funds and affects market quality each quarter.

Demand deposit contracts provide liquidity to investors; however by their nature they can expose the issuer to self-fulfilling runs. Existing models treat depositors as agents facing

uncertain liquidity shocks, who seek to insure against that liquidity risk through use of a bank financed solely by deposits. Welfare-reducing bank runs then arise from the inherent difficulties depositors face in coordinating their withdrawals. My second essay extends the classic model of Diamond & Dybvig (1983) to allow for a more realistic mixed capital structure where the bank's investments are partly financed by equity, and where differing incentives between shareholders and depositors are allowed to operate. I also further extend the model to allow shareholders to choose the level of risk in bank-financed projects. I compute the ex-ante probability of a bank run in consideration of the bank capital ratio, and I additionally compute the level of bank risk chosen by utility-maximizing shareholders who are disciplined by uncoordinated depositors. I find that even in the absence of bank negotiating power of the form in Diamond & Rajan (2000), banks can be welfare-improving institutions, and there exists a socially optimal level of bank capital. I consider the policies of a minimum capital requirement, deposit insurance, and suspension of convertibility, and provide guidance on creating optimal bank regulation. I show that the level of bank capital involves a tradeoff between sharing portfolio risk and sharing liquidity risk. Increased bank capital results in less risk-sharing between shareholders and depositors. The demand deposit contract disciplines the bank and its shareholders, and equity capital in effect disciplines the depositors (by making runs less likely). There is a socially optimal level of natural bank capital, even when I make no further social planner restrictions on bank portfolio choice in the model.

SHORT-TERM FUNDING MARKETS AND SYSTEMIC RISK

by

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Chapter 1: Regulatory Arbitrage in Repo Markets

Introduction

I investigate the stability and composition of the repurchase agreement (repo) market and how window dressing creates spillovers and affects systemic risk. Window dressing is the practice in which financial institutions adjust their activity around an anticipated period of oversight or public disclosure to appear safer or more profitable to outside monitors. The repo market is a form of securitized banking that provides critical overnight funding for the financial system but is vulnerable to runs. Several studies have suggested that instability in the repo market—whether through a margin spiral effect in bilateral repo or a run on individual institutions by their repo lenders in tri-party—helped cause the 2008 financial crisis.[1] Its short-term nature means the repo market can also accommodate window dressing, which was used by Lehman Brothers to hide leverage in the months leading up to its bankruptcy. I show that repo market window dressing has continued to occur each quarter since the 2008 financial crisis among non-U.S. bank dealers, and that window dressing creates spillover effects in other markets.

I use confidential regulatory data on daily tri-party repo transaction summaries since July 2008 obtained from the Federal Reserve Board of Governors (Federal Reserve) and the

[1]See for example Gorton and Metrick (2012), Krishnamurthy, Nagel, and Orlov (2014), Copeland, Martin, and Walker (2011), Martin, Skeie, and von Thadden (2014), and Ivashina and Scharfstein (2010).

U.S. Treasury Office of Financial Research. Tri-party repo is the ultimate source of cash financing for many other repo transactions, and by extension much of the shadow banking system. This dataset covers the entire $1.7 trillion tri-party repo market, includes details on how much a dealer (a "cash borrower") borrows using each type of collateral, and shows how costly it is for the dealer to borrow each day. It also includes data starting from January 2011 on the network of daily repo borrowing between dealers and the various institutions that are their repo counterparties ("cash lenders"). In a time series regression controlling for dealers' home regions, I show that broker-dealer subsidiaries of non-U.S. banks use repo to window-dress roughly $170 billion of assets each quarter, in what appears to be a form of regulatory arbitrage.

In Figure 1, I plot the daily tri-party repo borrowing to highlight this window dressing. Each quarter-end is marked with a vertical gridline, and there is a pronounced decline and subsequent rebound each quarter around that line. The steepness and width of that pattern varies somewhat each quarter, but on average it represents about 10% of the entire tri-party repo market. This quarterly decline is separate from longer-duration market trends: there was a steep decline in repo borrowing following the 2008 financial crisis, but the market gradually increased until the end of 2012. Since then the market has steadily declined—likely due to the Federal Reserve's asset purchases via quantitative easing (QE), which has increased the scarcity of safe liquid assets typically financed in repo.[2]

I further examine where this decline in repo occurs by looking across dealers and

[2]For more on QE's effects on the repo market, see the online note by Elamin and Bednar (2014): http://www.clevelandfed.org/research/trends/2014/0414/01banfin.cfm

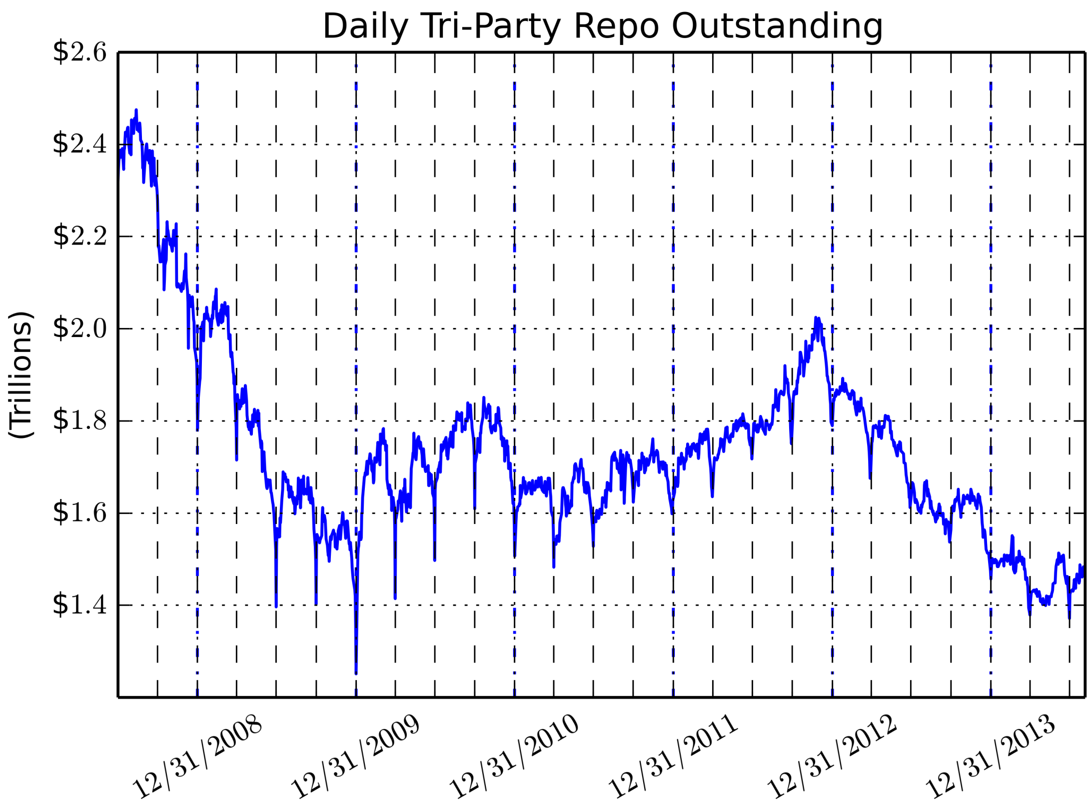

Figure 1.1. Daily Tri-Party Repo Outstanding

Notes: The vertical axis represents the value in trillions of dollars of collateral outstanding pledged in repo each day from July 1, 2008 to July 31, 2014. Quarter-ends are marked with vertical dashed lines, and year-ends are marked with heavier dash-dotted lines. I exclude repo borrowing by the Federal Reserve Bank of New York, and I exclude the dates of 7/17/2008 and 4/11/2013 because of missing data from one of the clearing banks.

Source: Federal Reserve Board of Governors

across types of repo collateral. I find that repo declines are concentrated in the broker-dealer subsidiaries of non-U.S. bank holding companies, using primarily U.S. Treasuries and agency securities. These results suggest a window dressing-based explanation for the phenomenon. U.S. banks report the quarter average as well as quarter-end balance sheet data and ratios, whereas non-U.S. banks only report quarter-end data. This regulatory difference seems to explain why U.S. bank dealers don't window-dress: U.S. banks have little incentive to window-dress at the end of the quarter compared to any other time during the quarter. Previous studies such as Owens and Wu (2012) and Downing (2012), which use quarterly data or U.S. bank holding company data, find at best a mild quarter-end effect, precisely because dealer bank window dressing occurs in just a few days and is mostly done by non-U.S. banks (see Figure 2).

I establish that the decline in repo is caused by the non-U.S. bank dealers—not their repo lenders—by combining this data with reports on money market mutual fund portfolio holdings and assets under management from iMoneyNet and the U.S. Securities and Exchange Commission (SEC) form N-MFP, and quarterly bank parent balance sheet data from Bankscope. I then perform a joint estimation of supply and demand in the repo market and find that a non-U.S. dealer's quarter-end window dressing is strongly predicted by its leverage the prior quarter. To further identify causality, I use network data of repo funding between dealers and cash lenders to perform a within-lender regression that controls for potential omitted cash supply factors.

I show significant spillover effects from repo window dressing to other markets. If non-U.S. bank dealers window-dress to report lower leverage, then when they withdraw collateral from repo, they must also sell those assets. I use the Financial Industry Reg-

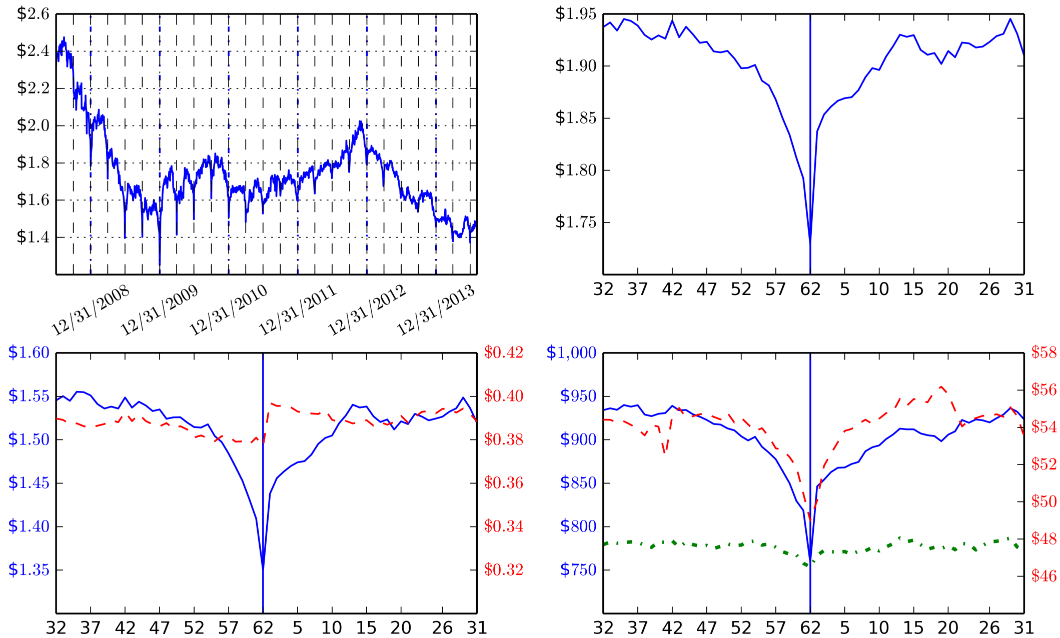

Figure 1.2. Repo Borrowing at the End of an Average Quarter

(Top left): I include a copy of Figure 1, with trillions of dollars in daily repo borrowing, as a reference.
(Top right): This figure represents the average daily repo outstanding over the course of a single quarter. The average quarter has 62 trading days, and I position the end of the quarter (marked by a vertical line) in the middle of the figure to highlight the quarter-end decline and subsequent rebound of repo borrowing. The vertical axis again represents the market value of collateral in trillions of dollars.
(Bottom left): I separate the average repo outstanding over a single quarter by type of asset. The solid blue line uses the left axis and represents average repo borrowing backed by the safest collateral: U.S. Treasuries, agency debentures, and agency mortgage-backed securities, and agency collateralized mortgage obligations. The dotted red line uses the right axis and represents average repo borrowing backed by all other types of collateral. Both axes are in trillions of dollars.
(Bottom right): Here I present the average repo outstanding over a single quarter separated by the region of the repo cash borrower (i.e., the dealer that is pledging collateral in the repo). The left and right axes are both in billions of dollars. I exclude non-bank dealers from this subplot. The dotted green line represents repo borrowing by U.S. bank dealers and can also be distinguished by its distinct behavior: this line touches the left axis at roughly $780 billion and does not dip as markedly as the other two lines at the end of the quarter. The solid blue line represents repo borrowing by European bank dealers. Both U.S. and European bank dealer repo borrowing are in reference to the left axis. The dashed red line shows Japanese bank dealer repo borrowing, and because Japanese bank dealers are a much smaller segment of the repo market, I plot their line using the right axis.
Enlarged individual copies of these figures are included in the appendix.
Source: Federal Reserve Board of Governors

ulatory Authority's (FINRA) Trade Reporting and Compliance Engine (TRACE) Agency bond transaction-level data from 2010 to 2013 in a time series regression with time-fixed effects for each quarter to test whether dealers are trading abnormally around the end of the quarter. I find that dealers sell heavily to customers in the last days of the quarter and immediately buy agency bonds back once the new quarter starts. In an empirical test of the theoretical findings of Froot and Stein (1998), I find that this self-imposed deleveraging causes a significant change in the market quality for agency bonds at quarter-end.

At the same time, declines in repo borrowing due to window dressing leave cash lenders such as money market mutual funds with excess cash that they struggle to invest. My analysis of monthly money market fund (MMF) portfolios shows that despite being able to anticipate window dressing, MMFs are still unable to find any investment at all for about $20 billion of cash each quarter-end before September 2013. The Federal Reserve's reverse repurchase agreement (RRP) program began at that time with the stated intention of being a tool for raising interest rates, but it has become a substitute investment for repo lenders during times of window dressing.

Section 1.1 of this paper reviews the current state of the literature, and how my findings contribute to an understanding of repo markets and their potential for systemic risk and to the literature on seasonality. Section 1.2 provides an overview of the repo markets and the tri-party repo market's important position relative to the bilateral and general collateral repo markets. In section 1.3, I describe the datasets used in this paper, with a particular focus on the regulatory tri-party repo data collection. Section 1.4 lays out my empirical strategy to identify window dressing and establish dealers as the cause of it. I report the results of robustness tests in Section 1.5. Section 1.6 shows how window dressing in repo markets has necessary repercussions in at least two other markets: the market for agency bonds and the money market mutual fund industry. Section 1.7 concludes with some policy recommendations to prevent future window dressing, or at least mitigate its impact.

1.1 Literature Review

My paper contributes to existing literature focused on three main areas: the stability of repo markets, seasonality (and its underlying causes), and the risk management of financial intermediaries.

Since 2008, a surge has occurred in the literature that analyzes the role that repo markets played in the financial crisis. Gorton and Metrick (2009, 2012) suggest that haircuts on collateral in bilateral repo created a destabilizing feedback effect, forcing cash borrowers to delever by selling assets in a fire sale, which caused haircuts to rise even higher, precipitating the banking system's insolvency. However Copeland, Martin, and Walker (2011) and Krishnamurthy, Nagel, and Orlov (2014) find that in tri-party repo there is no spiral effect, and the crisis in tri-party repo is more consistent with a run on certain dealers by their cash lenders.

Difficult to determine in this discussion is the direction of causation for the effects these papers describe. Indeed, Gorton and Metrick (2012) admit that "without a structural model of repo markets, we are only able to talk about co-movement... thus we use the language of 'correlation' rather than 'causation' in our empirical analysis." Martin, Skeie, and von Thadden (2014) present a theoretical model of repo lending that extends earlier bank run models from Diamond and Dybvig (1983) and Qi (1994) to analyze runs on collateralized repo borrowing instead of commercial bank deposits. The paper finds that liquidity constraints (the size, short-term leverage, and profitability of a repo borrower), as well as collateral constraints (the value to lenders from taking ownership of repo collateral directly, the productivity of a borrower from continuing to manage collateral, as well as borrower size and short-term leverage) determine a repo borrower's ability to survive a crisis. However, their model also predicts that outside of a crisis, each borrower invests (and borrows) as much as possible.

In this paper I provide evidence that the quarterly decline in repo is not due to a run-type panic, but rather due to repo becoming relatively less profitable at quarter-end for non-U.S. bank dealers. This is consistent with Martin, Skeie, and von Thadden (2014), who suggest that dealers will adjust their repo borrowing to trade off between profitability and liquidity risk constraints. When repo is more profitable, their paper suggests dealers will take more liquidity risk in the quantity and type of collateral they pledge, increasing their exposure to the risk of a run by their cash lenders. Therefore, if there is a shock to collateral again in the future (like the 2007 asset-backed commercial paper crisis), non-U.S. bank tri-party borrowers may be the ones more vulnerable to a run.

This paper adds to extensive literature on seasonality. Since January effects were documented by Rozeff and Kinney (1976) and Keim (1983), researchers have tried to find underlying explanations for the effect. Ritter (1988) looks at the behavior of investors around the turn of the year and finds individual investors may drive the January effect. Constantinides (1984), Sias and Starks (1997), and Poterba and Weisbenner (2001) look more deeply and find that underlying tax reasons might drive investors' year-end abnormal trading.

Other papers suggest window dressing may explain seasonal effects. Haugen and Lakonishok (1987) suggest the January effect might be explained by fund managers adjusting their portfolios to appear safer for their end-of-year filings. Lakonishok et al. (1991) investigate pension fund managers and find they sell losers in the fourth quarter to make it appear that they are good at picking stocks. In a sample of banks from 1978 to 1986, Allen and Saunders (1992) claim to find upward window dressing, in which banks increase their balance sheet each quarter to appear larger. Musto (1997) finds further support for this by examining the difference in trading behavior of commercial paper and Treasury bills around the year-end, and suggests that intermediaries don't want to show a risky portfolio to regulators or investors. However, Wermers (1999) finds no evidence of window dressing by mutual fund managers at the end of the year versus other quarters. In contrast, I do not see much evidence of January effects in repo, but I do find support for window dressing at the quarterly frequency, which spills over into fixed income markets.

In the repo market specifically, the literature has looked for evidence of window dressing or a liquidity habitat preference. So far the results for window dressing have been mixed. Owens and Wu (2012) and Downing (2012) look at U.S. bank repo behavior at the end of the quarter versus quarter average repo borrowing, and find that banks window-dress modestly at the end of the quarter. However, they are unable to definitively claim that they find window dressing and not just a shift in banks' funding sources. In section 1.5, I show that controlling for the country of a bank dealer is critical to interpreting their results.

Non-U.S. banks were outside the scope of those previous studies, but it is precisely among non-U.S. bank dealers that I find significant window dressing. U.S. banks report the quarter-average as well as quarter-end balance sheet data and ratios, whereas non-U.S.

banks only report quarter-end data. This regulatory difference may help explain why U.S. bank dealers don't window-dress: U.S. banks have little incentive to window-dress at the end of the quarter compared to any other time during the quarter. Other institutional features, or differences in the regulatory environment inside and outside the U.S. may also contribute to a dealer's decision to window-dress, however, differential monitoring seems likely to be a primary factor.

A series of papers by Griffiths and Winters (1997, 2005) and Kotomin, Smith, and Winters (2008) propose that window dressing does not occur in repo, but, instead, repo declines are driven by a preferred liquidity habitat model as in Modigliani and Sutch (1966). In this scenario banks do not actively reduce their repo borrowing to hide leverage. Instead, cash suppliers, such as money market funds, must cut their repo lending in order to redeem their own investors' outflows. In this paper I provide evidence from two data sources on money market funds that show that money funds do not see outflows nearly as large as the drop in repo outstanding, and, in fact, repo lenders have an excess of cash at the end of the quarter. I further identify the quarterly decline as dealer-driven using a within-investor estimation approach similar to that of Khwaja & Mian (2008), which uses time and investor-fixed effects to control for unobserved demand factors.

Theoretical models by Froot, Scharfstein, and Stein (1993) and Froot and Stein (1998) suggests that capital structure policy plays a critical role in risk management. A key implication of their framework for financial intermediaries (including dealers) is that capital adequacy constraints will generate asymmetric price effects in intermediated markets. When dealers are capital-constrained, they will offer worse prices to trades that tighten capital constraints, and better prices to trades that relax those constraints. Empirical research by

Naik and Yadav (2003) uses daily detailed position data on each UK government bond dealer and supports these conjectures.

Recent work by Koijen and Yogo (2013) finds that regulatory arbitrage by financial intermediaries has real economic effects as well. Their study of U.S. life insurers shows that risk transfers to off-balance-sheet and affiliated entities has the effect of reducing the insurers' risk-based capital, and increases their probability of default by a factor of 3.5. Moreover, they estimate that eliminating this regulatory arbitrage would increase the life insurance prices offered by those companies by 12%, and reduce the overall amount of U.S. life insurance provided to households. Although these effects are much harder to detect during the quarter among bank dealers, who can take risk through a diverse portfolio rather than a single product like life insurance, I present evidence that dealer window dressing does reduce market quality at the quarter-end when non-U.S. dealers are deleveraging.

1.2 Mechanics of the Repo Markets

This section provides a basic explanation of how a repurchase agreement works, the differences in the institutional operations of each of the three repo markets, and why tri-party repo matters to the financial system. Readers who are already familiar with repo may wish to skip ahead to Section 3.

A repurchase agreement (commonly shortened to "repo") is a contract in which one party sells securities with the agreement to repurchase those same securities at a specified maturity date. The other party pays cash for those securities and promises to return them when the repo matures and receive their cash plus interest, similar to a collateralized loan.

The second party (the cash lender) typically assigns a haircut to the cash amount they pay, relative to the market value of securities received, as protection in case the first party (the cash borrower) defaults and fails to return the cash. A repo is treated legally as a "true sale," which means the repo collateral is exempt from an automatic stay in bankruptcy if the cash borrower defaults, and the cash lender can sell or hold the securities without any encumbrance. However, many cash lenders will accept collateral that their charter or prospectus would not permit them to hold directly—for example, money market mutual funds (MMMFs) lending cash in repo against long-dated mortgage-backed securities (another form of regulatory arbitrage). A default of the cash borrower could then force the cash lender to immediately sell those securities, regardless of the market liquidity environment. A larger haircut protects cash lenders from potential losses when liquidating collateral in adverse market conditions, as well as from sudden fluctuations in the collateral's value.

Example:

Figure 3 shows a sample repurchase agreement. Dealer A is borrowing \$10,000,000 cash overnight from money market fund B at a 2% nominal annual percentage rate, and pledging U.S. Treasury notes as collateral. Dealer A has simultaneously agreed to repurchase the securities the next day from money market fund B for \$10,000,556 (\$10,000,000 + 2%/360 days * \$10,000,000). Money market fund B assesses a 1% haircut against U.S. Treasury collateral pledged by Dealer A, so in order to obtain the \$10M cash, Dealer A has pledged U.S. Treasury notes worth \$10,101,010 (\$10,000,000/99%).

The market for repurchase agreements is divided into three main segments: bilateral, general collateral finance, and tri-party. Figure 4 visually depicts a stylized version of the flow

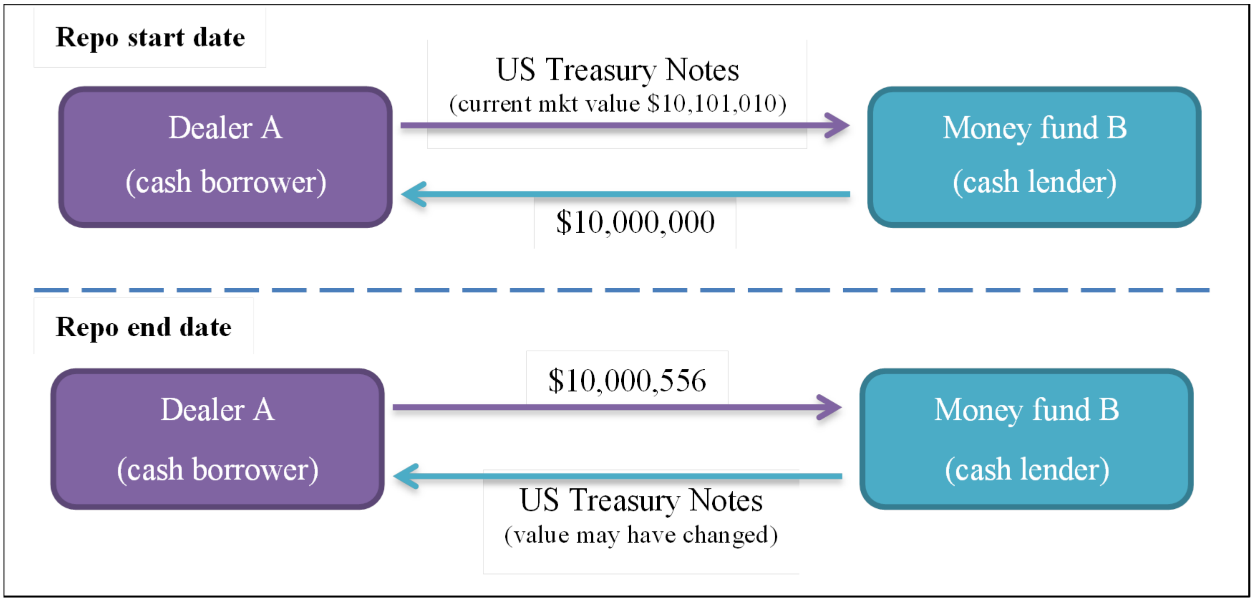

Figure 1.3. A Sample Repurchase Agreement Transaction

Source: OFR analysis

of cash and collateral between participants in these different types of repo. In subsections 1.2.1 through 1.2.3, I offer more details about the key institutional differences and connections between these markets.

1.2.1 Bilateral Repo Market

The bilateral repo market is unique in that its trades do not settle on the books of the two large clearing banks—Bank of New York Mellon Corp. and JPMorgan Chase & Co. Instead, bilateral repos (also called Delivery versus Payment repos) are negotiated and settled directly between dealers and their clients. Dealers can act as either cash borrowers or cash lenders, and their counterparties are primarily hedge funds and real estate investment trusts (REITs), though banks and other institutions may participate to a smaller extent. The purpose of

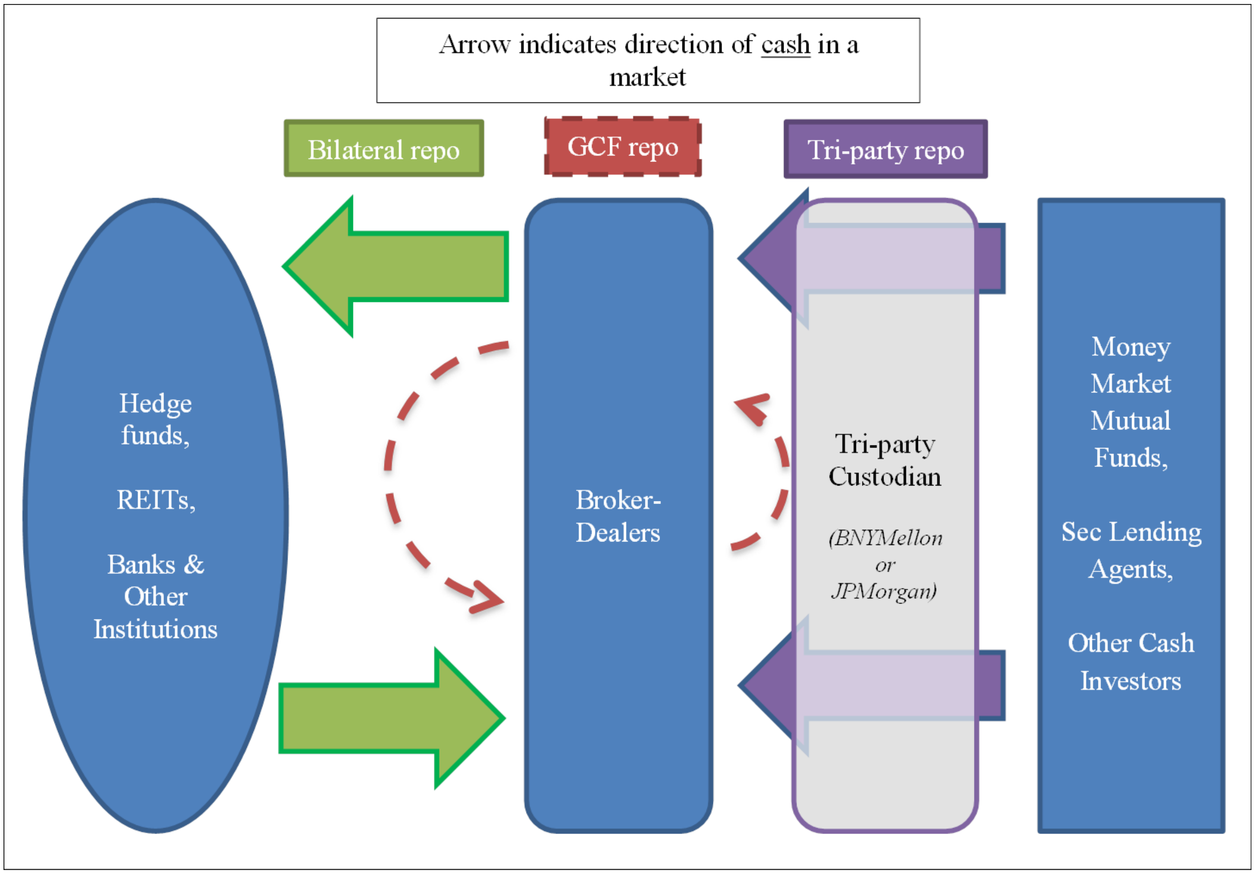

Figure 1.4. A Stylized Diagram of Repo Market Participants and Cash/Collateral Flows

Each arrow represents the direction of cash in a repo agreement; this means collateral moves in the opposite direction. Tri-party repo is denoted by two purple arrows both pointing to the left, passing through the rectangle representing the two tri-party custodians. Cash funding is provided from the investors in the right-most box to the broker-dealers in the center of the figure, in exchange for collateral. Tri-party repo is the largest of three repo markets and a primary cash source for the other two.

General Collateral Finance (GCF) repo is denoted by the two red dotted lines in the middle of the figure that curve and point counterclockwise. This market is inter-dealer and backed only by high-quality collateral: Treasuries, agency mortgage-backed securities, and agency debentures. GCF repo provides funding from one dealer to another, similar to the fed funds market for banks.

Bilateral repo is shown by the solid green arrows on the left half of the figure. The bilateral repo arrows point in both directions because broker-dealers both borrow from and lend to the various institutions shown in the oval on the far left.

Source: OFR analysis

bilateral is also distinct from tri-party and general collateral finance (GCF) repo: bilateral repo is reportedly driven by market participants' needs to acquire specific securities for hedging or settlement purposes, not just to finance a portfolio. A recent study from the Federal Reserve Bank of New York using primary dealer data estimates U.S. Treasuries currently make up 90% of bilateral repo collateral.[3] The estimated size of the bilateral repo market varies: the Federal Reserve Bank of New York estimates the size of the bilateral repo market at $1.4 trillion, on par with tri-party repo daily volume.

1.2.2 General Collateral Finance Repo Market

A general collateral finance (GCF) repo is an inter-dealer repo centrally cleared by the Fixed Income Clearing Corporation (FICC) over Fedwire, in which the cash borrower and cash lender directly negotiate a rate and duration for the repo, and specify a *class* of assets (e.g., all mortgage-backed securities, or Treasuries with fewer than five years to maturity) rather than specific securities, which can be pledged as collateral. GCF repos are unique in that they have no haircut margin. The cash borrower can continue to use his or her securities freely to make markets and clear trades that day until 11 a.m., when the cash borrower must identify the specific securities it will actually deliver to the cash lender. GCF repo was designed to improve inter-dealer liquidity by netting obligations through the FICC and giving dealers flexibility to substitute collateral throughout the day as their portfolio changes. In 2012 the GCF repo market's total (pre-netting) average daily volume was $400 billion. However, since then the market has shrunk considerably, to only $210 billion per

[3]See note by Copeland, Davis, LeSueur, and Martin (2014): http://libertystreeteconomics.newyorkfed.org/2014/07/lifting-the-veil-on-the-us-bilateral-repo-market.html .

day in June 2014.[4]

1.2.3 Tri-party Repo Market

The tri-party repo market gets its name from the manner in which transactions are cleared. Tri-party repo counterparties transact through one of two custodian banks: Bank of New York Mellon and JPMorgan Chase. These two custodians provide tools to value collateral and apply haircuts for cash lenders, and help cash borrowers allocate their portfolio across lenders to achieve the lowest cost of financing. Collateral is moved from a cash borrower's account with the custodian to the cash lender's account with the custodian in exchange for cash at the start of a repo, and the transaction is reversed the next morning when the repo is unwound.[5]

The tri-party repo market finances approximately $1.7 trillion of collateral each day. There are 14 broad classes of collateral accepted, but over 80% of repos are backed by the most liquid assets: U.S. Treasuries or agency-backed securities. There are 63 different dealers, who get their cash funding from 170 different cash lenders (aggregating all subsidiaries to the parent level). Most cash lenders are either money market mutual funds (MMMFs), or securities lending agents, but insurance companies, corporations, municipalities, commercial banks, and central banks also participate.[6] Money market funds can invest cash across a variety of high quality short-term investments such as commercial paper, bankers'

[4]Source: DTCC: http://www.dtcc.com/charts/dtcc-gcf-repo-index.aspx .

[5]In a term repo, this daily unwind still occurs, meaning the custodian extends an intraday loan to the cash borrower until the term repo is rewound in the afternoon. The Tri-Party Repo Infrastructure Reform Task Force has identified this intraday lending as a significant risk, and the two custodians have committed to developing a new settlement regime by the end of 2014 that is much less dependent on intraday credit provision (http://www.newyorkfed.org/newsevents/statements/2014/0213_2014.html .)

[6]I determine this using supplementary tri-party repo data on cash lenders from January 2011, to July 2014.

acceptances, Treasury bills, variable rate demand notes, and repos. Because repos are fully collateralized with a haircut margin, they are a useful way for cash investors to limit their overall counterparty exposure to a dealer.[7]

As part of the custodian-investor relationship, cash lenders submit a custodial agreement that includes a schedule of haircuts to apply to the value of collateral pledged by each dealer in each asset class. The custodian will follow that agreement and can mark collateral to market and apply the haircut on the investor's behalf. The haircut may vary across asset classes (e.g., haircuts on riskier collateral such as corporate bonds or equities are typically above 5%, while haircuts on safer assets like U.S. Treasuries or agency securities may be as low as 1% or 2%), and may also vary by a cash lender's dealer counterparties.

Once set, haircut schedules are very inflexible. Anecdotally, when I asked cash lender repo participants and regulators to describe how haircuts are determined, they *all* responded that it is very burdensome to change the haircut: it takes around a dozen signatures up and down the firm to amend the haircut schedule, and money funds may also have to announce the change to their investors. If a cash lender decides a certain borrower or type of collateral is too risky, they will increase the repo rate they charge or reduce the quantity they lend, instead of adjusting haircuts. This is consistent with the findings of Krishnamurthy, Nagel, and Orlov (2014), who noted during the 2008 financial crisis that the tri-party repo market did not see a haircut spiral like Gorton and Metrick (2009, 2012) described in bilateral repo.

Part of the custodian's services to dealers is that they assist in the collateral allocation process. This means that each day the custodian bank will allocate a cash borrower's portfolio to whichever lenders are cheapest for that collateral. If a cash supplier tightens

[7] For example, other counterparty exposure could arise through holding that dealer's commercial paper.

lending, then its cash borrowers can move to the next cheapest source of financing (taking into account both the changing interest rate and the stable haircut).

1.3 Data

Table 1.1.
Summary of Data Sources

Market	**Data Source**	**Frequency, Granularity of Data**	**Description**
Tri-Party Repo	Federal Reserve Board of Governors	Daily, by Dealer & Collateral Type	Daily Summaries of Tri-Party Repo Transactions
Bank Holding Companies	Bankscope	Quarterly, for each Bank Holding Company	Balance Sheet Information
Money Market Mutual Funds	iMoneyNet	Daily, by Each Fund	Money Market Funds' Assets Under Management
Money Market Mutual Funds	SEC Form N-MFP (since Nov 2010)	Monthly, by Each Fund	Complete Money Market Fund Portfolio
Agency Bonds	FINRA TRACE (via WRDS) (since March 2010)	Intra-Day Transactions, CUSIP-level, with Counterparty Type	Agency Bond Market Dealer-Reported Transactions

Source: OFR analysis

Triparty Repo Data:

Tri-party repo market daily transaction summaries are obtained through the Office of Financial Research and the Federal Reserve Bank of New York, who in turn receive the data as reports from the two tri-party custodians, Bank of New York Mellon and JPMorgan Chase. The data in this sample begins July 1, 2008, and the sample ends July 31, 2014. The data includes the daily amount of cash borrowings for each dealer by each collateral asset class, as well as the market value including interest due at the end of the repo. The ratio of those two quantities gives a measure of the dealer's overall cost of borrowing in that asset class (haircut plus interest, aggregated across all the dealer's counterparties).

I omit July 17, 2008, and April 11, 2013 from the sample, because on those two days I am missing data from one of the custodian banks. I also omit repos in which the Federal Reserve Bank of New York is a cash borrower from the sample, because of its role as a regulator, which causes it to behave very differently from other repo participants.[8]

The total average daily size of the tri-party repo market is $1.7 trillion during the sample period, and the majority of tri-party repo is backed by high-quality assets. The two largest asset classes are agency mortgage-backed securities and U.S. Treasuries and strips, which together comprise 69% of collateral pledged, followed by agency debentures and agency collateralized mortgage obligations (CMOs) (another 15% of the market). Table 2 provides summary statistics for the sizes of each asset class.

iMoneyNet, N-MFP

Money market mutual funds are a primary cash lender in the tri-party repo markets, so I use two separate datasets to observe how their portfolio changes at the end of each quarter.

iMoneyNet tracks the performance and portfolio composition of more than 1,600 U.S. money market funds and reports each money market fund's daily assets under management (AUM) as well as the type of fund (prime, government, or municipal).

In 2010 the SEC implemented reforms to the money market fund industry to reduce

[8]See subsection 1.6.2 for an example of this.

Table 1.2.
Summary Statistics for the Tri-Party Repo Market

This table shows summary statistics for the size and composition of assets pledged as collateral in the tri-party repo market from July 1, 2008, to July 31, 2014.

Asset Class		Average Daily Repo $ Volume		Standard Deviation of Daily Repo $ Volume
Agency CMOs	$	**103,194,451,024**	$	**22,553,502,217**
Agency Debenture	$	**149,569,102,420**	$	**64,636,803,823**
Agency MBS	$	**616,533,453,994**	$	**114,945,935,282**
U.S. Treasuries and Strips	$	**569,974,504,613**	$	**71,111,887,693**
Total Fed-Eligible Collateral	$	**1,439,271,512,051**	$	**163,851,945,388**
Asset Backed Securities	$	40,386,045,329	$	7,718,426,654
Cash	$	671,831,740	$	1,476,710,744
Corporate Bonds	$	90,942,450,339	$	27,226,322,099
DTC-Other	$	1,612,224,985	$	1,847,938,550
Equity	$	90,418,652,876	$	26,316,780,190
Money Market	$	25,232,797,297	$	9,090,884,810
Municipal Bonds	$	14,670,908,771	$	4,249,596,754
Other	$	2,721,950,275	$	1,704,534,903
Private Label CMO	$	40,721,757,360	$	14,305,285,726
Whole Loans	$	5,103,289,663	$	6,327,712,831
Total Non-Fed-Eligible Collateral	$	312,481,908,635	$	63,887,940,704
Total	*$*	*1,751,753,420,686*	*$*	*194,858,199,512*

Source: Federal Reserve Board of Governors

risk and improve disclosure. As part of that reform, money market funds have reported their detailed portfolio holdings every month since November 2010 in form N-MFP. These filings become public 60 days after filing, and the last filing I use is June 2014.

Bankscope

Bankscope reports data on the quarterly balance sheets of U.S. and international banks. I specifically use the balance sheets of banks whose dealers borrow in the tri-party repo market from June 2008 to June 2014, to match the time series of the repo data I have. Some Japanese banks' balance sheets are incomplete or unavailable in Bankscope, and this makes it difficult to empirically analyze the effect of a bank's balance sheet on repo behavior for bank dealers from Japan. For that reason I consider Japanese banks separately from European banks when I look at non-U.S. bank dealer activity in repo. For the U.S. and Europe, I do not run into issues with sample size or statistical power.

TRACE

The SEC mandates that broker-dealers report their transactions in eligible fixed-income securities. The Financial Industry Regulatory Authority collects these transactions through the Trade Reporting and Compliance Engine (TRACE), and makes a nonconfidential version of this content available to researchers through Wharton Research Data Services (WRDS), which I use. Each transaction report identifies the dealer's counterparty as either another dealer or a customer, and the report details the security identifier (CUSIP), price, quantity, and direction of the trade. TRACE reports this data by the type of security, which in WRDS can be corporate bonds or agency bonds. I use the TRACE agency dataset, which begins in March 2010 and continues through June 2014.

1.4 Empirical Results

1.4.1 Repo Declines Significantly at Quarter-End

The decline in repo is visually apparent and statistically very pronounced. Panel A of Table 3 reports a regression of aggregate repo borrowing in the entire market and by the region of bank dealers, using indicator variables for each of the five days preceding and following the end of a quarter. Because the size of the repo market varies over time, I include fixed effects for each quarter. Column (4) of Table 3 shows that in aggregate, quarter-end repo is \$169.4 billion below typical levels. However, on the first day of the quarter, repo strongly rebounds and continues to pick up over the next five days. Panel (B) repeats this analysis, but adds one-day lagged repo borrowing to account for auto-regression in the data and highlight the rebound in repo borrowing around the change of a quarter. Columns (2) and (3) of both Panels (A) and (B) show that this decline and rebound are strongly present in European and Japanese bank dealers as well. Even though their normal repo borrowing is comparable to European bank dealers, the U.S. decline in column (1) is an order of magnitude smaller and largely insignificant. This partially explains why previous studies using U.S. bank holding company Y-9C statements (such as Owens and Wu (2012) and Downing (2012)) fail to find seasonality or window dressing in the repo market: of all bank dealers, those of the U.S. do it the least.

European and Japanese bank dealers reduce their cash borrowing at quarter-end, and they do this consistently across the entire sample. Table 5 reports just quarter-end indicators for each quarter in our sample (2008 Q3 to 2014 Q2). For Europe and Japan, bank dealers reduce their repo borrowing every single quarter. U.S. bank dealers don't follow a consistent pattern. Sometimes they reduce their repo, but just as often their repo borrowing will increase at the quarter-end.

Just as the decline in repo is concentrated in non-U.S. borrowers, the decline is happening only in safer collateral. Table 6 reports quarter-end declines separately for safe collateral—defined as U.S. Treasuries, agency MBS and agency debentures, and money market collateral—and for all other types of collateral. Safer collateral is $148 billion below normal at the quarter-end, when accounting for quarterly fixed effects. Riskier collateral declines by only $13 billion, so per dollar invested the repo market actually becomes riskier at quarter-end.

Table 1.3.
Quarter-End Changes in Repo by Region

In columns (1) to (3) the dependent variable is the total daily market value of collateral pledged in U.S. tri-party repo by all bank dealers whose parent company is headquartered in a given region, which can be the U.S., Europe, or Japan. Column (4) instead uses the daily aggregate market value of collateral pledged by all dealers (bank as well as non-bank) in the entire U.S. tri-party repo market, regardless of dealers' home countries. In Panel A, the regressors are indicator variables for each of the five business days preceding and following a change in calendar quarter, as well as the last and first business day of a month that isn't the end or start of a quarter. In Panel B, the specification is the same except I add the auto-regressive term $Repo\,Borrowing_{region,\,t-1}$, as suggested by an AIC test. Estimation is based on OLS regression with time-fixed effects for each quarter in the sample period. Heteroskedasticity-robust standard errors are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Indicator Variables for Time-of-Quarter

Total Repo Borrowing by Region ($ Billions)	(1) U.S. Bank Dealers	(2) European Bank Dealers	(3) Japanese Bank Dealers	(4) Aggregate Repo Borrowing
Fifth-to-Last Day of a Quarter	-8.729	-47.74***	-4.178***	-62.60***
	(8.790)	(10.40)	(1.111)	(11.49)
Fourth-to-Last Day of a Quarter	-9.343	-57.50***	-5.162***	-72.82***
	(9.113)	(10.03)	(1.243)	(10.70)
Third-to-Last Day of a Quarter	-10.83	-72.29***	-6.838***	-90.40***
	(9.459)	(9.642)	(1.353)	(11.10)
Second-to-Last Day of a Quarter	-16.82*	-96.53***	-7.609***	-119.1***
	(9.620)	(10.09)	(1.398)	(13.57)
Last Day of a Quarter	**-11.15**	**-150.9*** **	**-8.802*** **	**-169.4*** **
	(13.10)	(12.25)	(1.298)	(19.71)
First Day of a Quarter	7.011	-62.12***	-4.700***	-55.35***
	(7.848)	(9.520)	(0.832)	(14.53)
Second Day of a Quarter	5.397	-48.04***	-3.245***	-43.20***
	(7.420)	(8.421)	(0.535)	(12.66)
Third Day of a Quarter	4.172	-42.98***	-2.711***	-38.94***
	(6.963)	(8.804)	(0.523)	(12.30)
Fourth Day of a Quarter	1.747	-36.18***	-2.294***	-35.30***
	(7.107)	(7.519)	(0.466)	(11.06)
Fifth Day of a Quarter	3.868	-33.99***	-2.031***	-30.87***
	(6.827)	(6.157)	(0.477)	(9.892)
Last Day of a Month That Isn't a	7.183*	0.0272	0.0349	7.049*
Quarter-End	(3.819)	(2.233)	(0.318)	(4.098)
First Day of a Month That	2.340	13.02***	0.388	16.09***
Isn't the First Day of a Quarter	(2.629)	(1.377)	(0.323)	(3.296)
Constant	724.9***	855.7***	43.04***	1,749***
	(0.661)	(0.795)	(0.111)	(1.080)
Observations	1,522	1,522	1,522	1,522
R-squared	0.018	0.414	0.323	0.342

Source: Federal Reserve Board of Governors

(continued)

Panel B: AR(1) Term Added to Estimation

Total Repo Borrowing by Region ($ Billions)	(1) U.S. Bank Dealers	(2) European Dealers	(3) Japanese Bank Dealers	(4) Aggregate Repo Borrowing
Yesterday's Repo Borrowing	0.873***	0.902***	0.893***	0.878***
	(0.0352)	(0.0308)	(0.0275)	(0.0288)
Fifth-to-Last Day of a Quarter	-3.832*	-15.16***	-1.049**	-20.20***
	(2.128)	(2.535)	(0.485)	(3.890)
Fourth-to-Last Day of a Quarter	-1.519	-14.04***	-1.401***	-17.10***
	(2.259)	(2.627)	(0.413)	(3.479)
Third-to-Last Day of a Quarter	-2.470	-20.02***	-2.198***	-25.70***
	(2.530)	(2.314)	(0.345)	(3.154)
Second-to-Last Day of a Quarter	-7.160***	-30.91***	-1.472***	-38.95***
	(2.529)	(4.849)	(0.364)	(5.183)
Last Day of a Quarter	**3.735**	**-63.38*** **	**-1.977*** **	**-64.12*** **
	(6.196)	(5.897)	(0.454)	(11.75)
First Day of a Quarter	**0.949**	**55.18*** **	**4.070*** **	**59.86*** **
	(6.305)	(6.243)	(0.738)	(10.76)
Second Day of a Quarter	-0.399	8.432***	0.988**	6.170
	(2.436)	(2.584)	(0.401)	(4.012)
Third Day of a Quarter	-0.215	0.795	0.222	-0.238
	(1.789)	(3.138)	(0.301)	(2.694)
Fourth Day of a Quarter	-1.571	3.024	0.163	-0.325
	(1.808)	(1.989)	(0.308)	(3.483)
Fifth Day of a Quarter	2.666	-0.920	0.0531	0.899
	(2.474)	(1.913)	(0.248)	(3.374)
Last Day of a Month That Isn't a Quarter-End	6.587***	-1.018	-0.139	5.681
	(1.970)	(2.411)	(0.222)	(3.577)
First Day of a Month That Isn't the First Day of a Quarter	-3.725	13.38***	0.386**	10.69***
	(2.901)	(1.931)	(0.168)	(3.805)
Constant	91.93***	83.18***	4.569***	213.3***
	(25.53)	(26.30)	(1.193)	(50.43)
Observations	1,522	1,522	1,522	1,522
R-squared	0.762	0.899	0.855	0.861

Source: Federal Reserve Board of Governors

Table 1.5.
Quarter-End Drops In Repo Borrowing Over Time

In columns (1) to (3) the dependent variable is the total daily market value of collateral pledged in U.S. tri-party repo by all bank dealers whose parent company is headquartered in a given region, which can be the U.S., Europe, or Japan. Column (4) instead uses the daily aggregate market value of collateral pledged by all dealers (bank as well as non-bank) in the entire U.S. tri-party repo market, regardless of dealers' home countries. The regressors are indicator variables for the last business day of each quarter in the sample, to indicate how the size of the quarter-end decline in repo borrowing changes over time. Estimation is based on OLS regression with time-fixed effects for each quarter in the sample period. Heteroskedasticity-robust standard errors are used to determine significance, but not reported separately due to space constraints. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

Total Repo Borrowing by Region ($ Billions) Quarter & Year Fixed Effects	(1) U.S. Bank Dealers	(2) European Bank Dealers	(3) Japanese Bank Dealers	(4) Aggregate Repo Borrowing
2008Q3	128.4***	-84.31***	-5.384***	-111.5***
2008Q4	13.14***	-331.8***	-1.597***	-333.0***
2009Q1	-105.5***	-171.0***	-7.679***	-281.9***
2009Q2	-164.6***	-197.3***	-0.527***	-363.0***
2009Q3	-75.09***	-144.9***	-1.900***	-227.4***
2009Q4	-86.09***	-202.6***	2.045***	-290.2***
2010Q1	-81.13***	-168.0***	-2.404***	-261.0***
2010Q2	-48.41***	-110.2***	-0.0172***	-176.3***
2010Q3	-40.29***	-147.9***	-0.938***	-157.0***
2010Q4	-6.341***	-228.8***	-5.102***	-254.7***
2011Q1	-0.345***	-165.8***	-12.82***	-163.4***
2011Q2	8.424***	-118.6***	-13.91***	-104.7***
2011Q3	49.85***	-105.7***	-13.90***	-45.76***
2011Q4	15.22***	-74.31***	-6.012***	-68.86***
2012Q1	6.913***	-94.08***	-13.10***	-92.32***
2012Q2	53.53***	-122.0***	-8.168***	-48.36***
2012Q3	58.51***	-135.9***	-10.16***	-67.75***
2012Q4	27.16***	-169.8***	-13.99***	-143.9***
2013Q1	-47.02***	-114.6***	-16.13***	-157.6***
2013Q2	6.149***	-144.5***	-15.06***	-142.3***
2013Q3	17.08***	-72.09***	-12.04***	-48.12***
2013Q4	13.55***	-145.7***	-16.76***	-148.1***
2014Q1	-31.54***	-78.52***	-14.10***	-112.8***
2014Q2	24.41***	-105.0***	-6.993***	-71.09***
Constant	725.0***	848.1***	42.38***	1,742***
Observations	1,530	1,530	1,530	1,530
R-squared	0.076	0.199	0.132	0.185

Source: Federal Reserve Board of Governors

Table 1.6.
Declines in Quarter-End Repo Borrowing by Type of Collateral

In Column (1) the dependent variable is the total daily market value of **fed-eligible collateral** pledged in U.S. tri-party repo by all dealers. In Column (2) the dependent variable is the total daily market value of **non-fed-eligible collateral** pledged in U.S. tri-party repo by all dealers. Regressors are indicator variables for the last and first business days of a quarter and the last and first business days of a month that isn't the end or start of a quarter. Estimation is based on OLS regression with time-fixed effects for each quarter in the sample period. Heteroskedasticity-robust standard errors are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

Total Repo Borrowing by Collateral Type ($ Billions)	(1) Fed-Eligible Collateral	(2) non-Fed-Eligible Collateral
Last Day of a Quarter	-147.8***	-12.92***
	(17.90)	(4.384)
First Day of a Quarter	-47.81***	1.082
	(11.72)	(6.262)
Last Day of a Month That Isn't a Quarter-End	14.94***	0.710
	(4.185)	(0.986)
First Day of Month That Isn't the Start Of a Quarter	23.87***	0.979
	(3.501)	(1.003)
Constant	1,429***	312.1***
	(0.306)	(0.0533)
Observations	1,529	1,529
R-squared	0.155	0.012

Source: Federal Reserve Board of Governors

1.4.2 The Role of Cash Suppliers in Seasonal Repo Volume

A simple explanation for the decline in tri-party repo could be that cash lenders hoard liquidity at the end of the quarter for their own purposes. Money market mutual funds are one of the primary lenders in the tri-party repo market, and they could cut their lending to meet outflows by their own investors at the end of the quarter. Those investors in turn could need cash to settle obligations like dividend payouts, taxes, settlement on derivatives, or debt payments. In other words, knowing only the quantity of repo, I would not be able to determine whether repo demand effects or repo supply effects are driving the quarter-end decline. Data from both iMoneyNet and the new form N-MFP filings (starting in November 2010) show that cash supply is not causing the drop in repo.

Using daily data on from iMoneyNet, I apply the same specification I used in Panel B of Table 3 except I use money funds' assets under management (AUM) as the dependent variable. Table 7 shows that money funds do see outflows at the end of the quarter followed by inflows at the start of the new quarter, but they are less than a tenth the size of repo declines. Additionally, there is no significant decline in MMFs' AUM before the last day of the quarter, unlike the accelerating drawdown over several days that happens in repo. Therefore, money fund outflows cannot explain the size and scope of the repo market effect.

Although money funds are one of the two primary types of cash lenders in tri-party repo, they are not the only tri-party cash provider. Securities lending agents also reinvest cash collateral in tri-party repo, so a regular and sudden quarter-end unwinding of securities lending could also pull cash out of the tri-party repo system. Although I do not have data on securities lending covering this period, I do have data on money market funds' detailed

Table 1.7.
Money Market Fund Changes in AUM around Quarter-End

The dependent variable is the total daily assets under management (AUM) of all U.S. money market mutual funds (MMFs) in millions of dollars, and excluding tax-free MMFs. Feeder funds are excluded from this amount. Data on the type of a fund and its AUM is obtained from iMoneyNet, and spans the time period from July 1, 2008, to February 13, 2014. Lagged total MMF AUM is included to account for auto-regression. In columns (1) and (2), indicator variables for the last day of a quarter, and the days surrounding a quarter-end and a month-end (that isn't a quarter-end) are included, respectively. In columns (3) and (4), I modify all of the indicator variables to only indicate those quarter- (month-) ends in which the last business day of that quarter (month) is also a Friday, to control for potential cash outflows to meet MMF investors' cash needs, such as for payroll. Estimation is based on OLS regression with time-fixed effects for each quarter in the sample period. Heteroskedasticity-robust standard errors are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

(7/1/2008–2/13/2014) Total MMF AUM ($ millions, and excluding tax-free funds)	(1)	(2)	(3) Only Friday Quarter-ends	(4) Only Friday Quarter-ends
Yesterday's AUM	0.999***	1.000***	0.999***	1.000***
	(0.000840)	(0.000761)	(0.000856)	(0.000828)
Fifth-to-Last Day of a Quarter		5,125**		4,492
		(2,041)		(4,501)
Fourth-to-Last Day of a Quarter		1,981		4,689***
		(1,718)		(1,543)
Third-to-Last Day of a Quarter		1,790		-1,067
		(1,380)		(1,441)
Second-to-Last Day of a Quarter		-2,411		1,927
		(1,902)		(1,982)
Last day of a Quarter	**-12,447*** **	**-13,748*** **	**-14,078*** **	**-14,008*** **
	(2,425)	(2,625)	(2,392)	(2,404)
First day of a Quarter		1,003		-5,855**
		(2,603)		(2,689)
Second day of a Quarter		9,053***		6,495***
		(2,043)		(1,437)
Third day of a Quarter		3,926***		4,567**
		(1,251)		(2,280)
Fourth day of a Quarter		2,930**		537.4
		(1,299)		(2,630)
Fifth day of a Quarter		2,495*		-1,078
		(1,372)		(1,962)
Second-to-Last Day of a Month		298.7		3,018*
That Isn't a Quarter-End		(1,390)		(1,593)
Last Day of a Month That Isn't a		-12,553***		-13,322***
Quarter-End		(1,635)		(2,673)
First Day of a Month that Isn't		-2,197		-5,128*
the Start of a Quarter		(1,781)		(2,749)
Second Day of a Month that Isn't		9,600***		11,223***
the Start of a Quarter		(846.1)		(1,206)
Constant	1,409	172.1	1,652	819.0
	(2,098)	(1,896)	(2,138)	(2,061)
Observations	1,405	1,526	1,405	1,526
R-squared	0.999	0.999	0.999	0.999

Source: iMoneyNet

portfolio holdings from the new form N-MFP, which contradicts this account.

Since form N-MFP is a monthly, not quarterly, filing, I do not have to worry about money funds themselves window-dressing their quarter-end holdings any more than they would for a different month. Therefore, I can compare quarter-end holdings to holdings at the end of other months to see what changes. Table 8 shows that at the quarter-end, money funds' repo holdings decline, even though their AUM does not decline significantly. I omit non-repo asset classes from the table because no other reported investment classes have significant quarter-end changes. However, the remainder from subtracting the sum of all its investments from a fund's reported AUM reveals the amount of *uninvested* cash.[9]

Table 9 reports that money funds are holding excess cash at the end of the quarter, both individually and in aggregate. Money market funds specialize in making short-term investments, but prime and government/agency MMFs together cannot find temporary investments for nearly $20 billion dollars,[10] meaning there is an excess—not a shortage—of cash supply at quarter-end. If securities lenders or other tri-party repo cash suppliers were choosing to cut their repo lending and dealers' demand for repo was unchanged, dealers would have been able substitute and borrow cash from money market funds instead, and money market funds would not have this excess cash.

[9]Normally, a money fund will actually have a cash balance of zero or just slightly less than zero, with any shortfall due to the fact that a sponsor may have invested its own money in the fund to support it, which is not reflected in the fund's AUM.

[10]$12.62 billion for prime MMFs, $7.188 billion for govt/agency MMFs, see column (4) of Table 9.

Table 1.8.
MMF Repo Cash Lending at the End of the Quarter

In Panels A and B, column (1), the dependent variable is the assets under management (AUM) of an individual prime or government/agency money market mutual fund (MMF), respectively, in millions of dollars. In column (2), the dependent variable is the total market value of repo cash lending by an individual MMF that is backed by agency securities as collateral. In column (3), the dependent variable is the same as in column (2), except receiving Treasury securities as collateral, and in column (4), it is repo backed by all other types of collateral. In Panel C, I change the dependent variables to the total aggregate AUM or repo lending across the entire MMF industry, and change the units to billions of dollars. The data is obtained from monthly form N-MFP filings, the sample in this regression is November 2011 to July 2013. The regressor is an indicator variable for the date being the last month of the quarter. Estimation is done by OLS regression. Heteroskedasticity-robust standard errors are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Prime MMFs	(1)	(2)	(3)	(4)
($ Million)	Total Assets	Agency Repo	Treasury Repo	Other Repo
Last Month	-21.72	-192.7***	-142.4***	4.769
of Quarter	(426.5)	(63.09)	(37.29)	(131.9)
Constant	6,999***	1,052***	504.0***	1,211***
	(251.1)	(40.30)	(27.95)	(75.71)
Observations	6,313	3,979	2,779	1,791
R-squared	0.000	0.002	0.004	0.000

Panel B: Govt/Agency MMFs				
($ Million)	Total Assets	Agency Repo	Treasury Repo	Other Repo
Last Month	115.1	-22.77	-185.0**	112.8
of Quarter	(380.6)	(232.0)	(73.44)	(316.3)
Constant	4,817***	2,233***	805.7***	560.3***
	(220.0)	(135.5)	(51.63)	(193.1)
Observations	2,653	1,704	1,389	119
R-squared	0.000	0.000	0.004	0.001

Panel C: Total MMF Industry				
($ Billion)	Total Industry AUM	Agency Repo	Treasury Repo	Other Repo
Last Month	-22.80	-35.83***	-25.64***	-1.384
of Quarter	(19.92)	(10.96)	(6.173)	(5.685)
Constant	2,214***	307.5***	96.06***	84.28***
	(12.90)	(7.650)	(4.087)	(3.258)
Observations	32	32	32	32
R-squared	0.038	0.229	0.337	0.002

Source: SEC Form N-MFP

Table 1.9.
MMF Cash Surplus at the End of the Quarter

In columns (1) and (2), the dependent variables are the percent of an individual money market mutual fund's (MMF's) assets under management (AUM) that is held in uninvested cash at the end of the month, and the value of an individual MMF's uninvested cash in millions of dollars, respectively. Uninvested cash is calculated as the remainder of an MMF's AUM after subtracting the value of all securities in an MMF's portfolio. In columns (3) and (4), the dependent variables are aggregate AUM at the end of the month and aggregate uninvested cash holdings at the end of the month, respectively, for all MMFs in an industry classification (prime or govt/agency). Both (3) and (4) report in billions of dollars. Panel A reports results among all prime MMFs, and Panel B repeats the exercise for all government/agency MMFs. The data is obtained from monthly form N-MFP filings; the sample in this regression is November 2011 to July 2013. The regressor is an indicator variable for the date being the last month of the quarter. Estimation is done by OLS regression. Heteroskedasticity-robust standard errors are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Prime MMFs

	(1) % of AUM Held as Cash	(2) Cash Holdings ($ Millions)	(3) Aggregate AUM ($ Billions)	(4) Aggregate Cash Holdings ($ Billions)
Last Month of	0.00534***	51.96***	-10.34	12.62***
Quarter	(0.00191)	(8.805)	(24.92)	(3.941)
Constant	0.00217*	-38.69***	1,701***	-9.403***
	(0.00111)	(4.498)	(15.73)	(2.676)
Observations	6,339	6,313	26	26
R-squared	0.001	0.006	0.007	0.270

Panel B: Govt/Agency MMFs

	% of AUM Held as Cash	Cash Holdings ($ Millions)	Aggregate AUM ($ Billions)	Aggregate Cash Holdings ($ Billions)
Last Month of	0.0101***	70.48***	10.63	7.188***
Quarter	(0.00283)	(12.53)	(9.045)	(1.831)
Constant	-0.00116	-33.89***	491.9***	-3.461***
	(0.00154)	(5.744)	(5.070)	(.8366)
Observations	2,659	2,653	26	26
R-squared	0.005	0.014	0.057	0.441

Source: SEC Form N-MFP

1.4.3 Dealer Leverage Explains Non-U.S. Bank Dealer Repo Quarter-End Declines

Earlier tests in this paper showed no evidence to support a cash supply-driven effect, but here I do find evidence consistent with a cash demand-driven effect. Among the differences across capital regulation regimes in the U.S., Europe, and Japan, the most relevant aspect for this study is the reporting requirement. U.S. banks are required to report capital ratios for the last day of the quarter as well as an average across all days of the quarter. In contrast, non-U.S. banks can simply report for the last day of the quarter. Therefore, U.S. banks have very little incentive to window-dress their balance sheet at the end of the quarter—it will not affect their capital requirements any more than a deviation any other time in the quarter would. If this is indeed what's driving the difference I observe between U.S. and non-U.S. bank dealers, I would expect more levered non-U.S. bank dealers to be more likely to window-dress.

I link the tri-party repo holdings for each bank dealer to that bank's quarterly balance sheet, using data obtained from BankScope. One limitation of BankScope is that it does not contain data on all banks, especially Japanese banks. However, for the U.S. and Europe, I am able to link almost all dealers to their banks. In Table 10, I test a fixed-effects regression model for each region, where I supplement my end-of-quarter indicator variables with the linked bank balance sheet for the previous quarter. To specifically test whether highly levered banks are reducing their dealers' repo borrowing at the end of the quarter to report lower leverage, I interact the bank's Tier 1 capital ratio from the previous quarter with an indicator for the last day of the current quarter. A higher Tier 1 capital ratio means less leverage, so if window dressing is driving repo declines, this regression coefficient must be positive. The first row of column (3) shows that for European bank dealers, this coefficient is positive and significant, suggesting window dressing incentives do explain their repo borrowing. Moreover, the same coefficient for U.S. bank dealers in column (2) is insignificant and actually negative, just as we would expect given their quarter-average reporting requirement. Therefore, this cross-region test seems to confirm that the difference between U.S. and European bank dealer behavior is explained by window dressing.

1.4.4 Joint Model Test

Thus far, in looking at cash suppliers and cash demanders separately, evidence rejects a supply shift and favors a demand shift. However, to confirm this result, I use a proxy for the price of repo borrowing (the sum of the haircut and the repo rate) in each asset class. With this dealer-specific measure of the price of repo, I can test both quantity and price at the end of the quarter, to determine whether the dominant effect is from cash demand or supply. I will then present a simple model of repo supply and demand and jointly estimate the two in a three-stage least squares specification with endogenous price.

Because the cost of borrowing in repo is dealer-specific as well as asset class-specific, I test quarter-end effects in quantity and price of repo by each dealer, in each of their collateral types. I control for variation between dealers and between asset types by adding fixed effects for each quarter, dealer, and asset class in Table 11. Column (4) shows that while non-U.S. bank dealers do less repo at the end of the quarter, the cost to borrow does not rise at all—in fact, the coefficient is slightly negative.[11]

[11]In contrast, U.S. bank dealers do not window-dress, and their borrowing cost even rises slightly (and

Table 1.10.
Repo Borrowing by a Dealer

The dependent variable is the daily market value of collateral pledged in repo by an individual dealer. In column (1), the sample includes all dealers in U.S. tri-party repo, in columns (2) to (4), I reduce the sample to dealer subsidiaries of U.S. banks, European banks, and Japanese banks, respectively. Regressors include end-of-quarter reported Tier 1 capital ratio (as percent, not decimal, i.e., 12 not .12), and the total value in billions of dollars of derivatives and of total assets for the dealer's parent bank the prior quarter. These regressors are also interacted with an indicator variable for the last day of the current quarter ("Quarter-end"). I also include time dummies for the days preceding a quarter- or month-end, as well as the days following a new quarter; however, they are not reported due to page constraints but available upon request. Quarterly balance sheet data is obtained from Bankscope and covers most U.S. and European banks. However, it does not cover enough Japanese banks to report the full empirical specification in column (4). Estimation is based on OLS regression with time-fixed effects for each quarter in the sample period. Heteroskedasticity-robust standard errors are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

Repo Borrowing by a Dealer ($ Millions)	(1) All Dealers	(2) U.S. Bank Dealers	(3) European Bank Dealers	(4) Japanese Bank Dealers
Quarter-end x Tier 1 Ratio	682.0***	-852.2	**755.1****	-504.9
	(264.7)	(667.9)	(323.7)	(353.5)
Quarter-end x Derivatives	-13.44***	191.6***	-8.061***	-19.58
Outstanding($ Billions)	(2.803)	(70.40)	(2.892)	(27.89)
Quarter-end x Total Assets	0.602	-3.068**	-0.659	3.990*
($ Billions)	(0.560)	(1.491)	(1.114)	(2.217)
Tier 1 Ratio	15.96	70.27**	8.748	–
	(15.01)	(32.02)	(21.57)	
Total Quarter-End Dealer	0.219*	1.790	0.233	–
Derivatives Outstanding($ Billions)	(0.132)	(3.643)	(0.142)	
Total Quarter-End Assets	0.0821**	0.104	0.125***	–
($ Billions)	(0.0367)	(0.102)	(0.0442)	
1-Day Lagged Repo	0.997***	0.996***	0.996***	0.927***
Borrowing ($ Millions)	(0.000709)	(0.00101)	(0.00120)	(0.0156)
Last Day of a Quarter	-8,462***	10,844	-10,315**	-2,021
	(3,072)	(8,571)	(4,110)	(3,679)
First Day of a Quarter	2,745***	-1,978***	5,971***	4,102***
	(477.9)	(699.2)	(867.3)	(694.9)
Last Day of a Month That Isn't	339.6	1,189***	-112.2	-235.0
a Quarter-End	(237.1)	(227.7)	(326.6)	(200.1)
Constant	-168.9	-879.7**	-114.9	2,486***
	(178.1)	(440.0)	(227.8)	(552.7)
Observations	22,256	7,308	11,781	1,251
R-squared	0.996	0.997	0.995	0.885

Source: BankScope and Federal Reserve Board of Governors

Table 1.11.
Estimating Repo Quantity and Price Separately

In columns (1) and (3), the dependent variable is the daily market value of collateral pledged in repo by a single dealer, using a single class of collateral, in millions of dollars. In columns (2) and (4), the dependent variable is the daily cost of borrowing, which I calculate as the ratio minus 1 of the market value of collateral pledged in repo by a single dealer, using a single class of collateral, over the value of cash received in repo by that dealer using that collateral, times 100. The regressors include the cost of borrowing and the prior day's total market value of collateral pledged in repo by that dealer using that collateral for columns (1) and (3), and in columns (2) and (4), they instead include the prior day's cost of borrowing and the current day's total market vlaue of collateral pledged in repo by that dealer using that collateral type. Regressors also include indicator variables for the 5 business days before and after the turn of a quarter, as well as the day before and after the start of a month that isn't the end or start of a quarter. I do not report results for the indicators 2–5 days around the turn of a quarter; however, they are available upon request. Columns (1) and (2) use the sample of dealer subsidiaries of U.S. banks, and columns (3) and (4) use the sample of dealer subsidiaries of non-U.S. banks. Estimation is based on OLS regression with time-fixed effects for each quarter, dealer, and collateral asset class. Bootstrapped heteroskedasticity-robust standard errors are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

(Fixed Effects by Each Quarter, Dealer & Asset Class)	(1) U.S. Bank Repo Borrowing ($ Millions)	(2) U.S. Bank Haircut (%)	(3) Non-U.S. Bank Repo Borrowing ($ Millions)	(4) Non-U.S. (%) Bank Haircut (%)
Haircut (%)	-24.80***		-13.46***	
	(3.186)		(2.444)	
Yesterday's Repo Borrowing ($ Millions)	0.963***		0.983***	
	(0.00410)		(0.00166)	
Repo Borrowing ($ Millions)		-6.66e-06***		-3.35e-06***
		(1.39e-06)		(4.59e-07)
		(2.93e-06)		(7.71e-07)
Yesterday's Haircut		0.794***		0.931***
		(0.0445)		(0.00885)
Last Day of a Quarter	**70.66**	**0.0423***	**-527.0*****	**-0.00871**
	(93.00)	(0.0247)	(67.75)	(0.0159)
First day of a Quarter	3.236	0.0502*	644.7***	-0.0121
	(72.58)	(0.0281)	(69.52)	(0.0128)
Last Day of a Month That Isn't a Quarter-End	87.53***	0.00297	-13.46	-0.00846
	(28.20)	(0.0207)	(27.05)	(0.00769)
First Day of a Month that Isn't the Start of a Quarter	-56.06*	0.00853	136.2***	-0.0155
	(29.54)	(0.0154)	(27.64)	(0.0102)
Constant	470.0***	1.05***	188.8***	0.305***
	(48.09)	(0.225)	(19.34)	(0.0385)
Observations	115,044	115,043	157,517	157,512
R-squared	0.927	0.636	0.968	0.875

Source: Federal Reserve Board of Governors

As a further test of window dressing versus other explanations, I consider a joint model of cash supply and demand where price is endogenous. Cash suppliers are driven by the needs of their investors; they will invest in repo when they have inflows, but they might view dealers from different regions as more or less risky (especially given reports by Chernenko and Sunderam (2014) that money fund investors responded to the European sovereign debt crisis in 2011 by reducing their exposure to European banks).

Cash demanders finance their portfolio in repo, based on the size of their total assets, their risk propensity (measured by their use of derivatives), and their leverage. At the end of the quarter, high leverage may incentivize window dressing to mask risk. The price of repo borrowing is endogenously determined, to equate supply and demand so that markets clear. To capture quarter-end effects, I again interact each term with a quarter-end indicator. Table 11 reports the results of simultaneously estimating supply and demand in each dealer and asset class, and again the results are consistent with window dressing.

For both U.S. and non-U.S. bank dealers, price and demand are negatively correlated: a decrease in the price of borrowing leads to more demand for repo, as we would expect. However, for non-U.S. dealers this effect is reversed on the last day of the quarter: a lower cost of borrowing correlates with a larger quarter-end decline in repo. This agrees with our earlier finding: window dressing is concentrated in safe assets, which are already cheaper to finance in repo, but likewise cheaper to liquidate for deleveraging purposes. Therefore, declines in repo borrowing appear to be explained by non-U.S. bank dealers' window-dressing their balance sheets in a form of regulatory arbitrage.

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there is no reversal at the start of the new quarter).

Table 1.12.
3SLS Demand and Supply Simultaneously Estimated

In each column, the dependent variable is the total daily repo borrowing by a single dealer in a single class of collateral. In columns (1), (3), and (5), this is modeled as demand, while in columns (2), (4), and (6) this is modeled as supply. The regressors include the cost of borrowing and the prior day's total market value of collateral pledged in repo by that dealer using that collateral, as well as dummies for the last day of a quarter and a month. In the demand estimations, I include the bank balance sheet measures from Table 10. In the supply estimations, I include money market fund assets under management (AUM) measures from Table 7. Estimation is based on 3SLS regression with time fixed effects for each quarter, dealer, and collateral asset class. Bootstrapped heteroskedasticity-robust standard errors are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1) Aggregate Demand	(2) Aggregate Supply	(3) U.S. Bank Demand	(4) Supply	(5) European Bank Demand	(6) Supply
Yesterday's Repo	0.997***	0.996***	0.991***	0.997***	0.998***	0.995***
Borrowing	(0.000429)	(0.000345)	(0.000981)	(0.000474)	(0.000578)	(0.000592)
Haircut (not %)	2.410e+09***	1.115e+09**	**-7.228e+09*** **	**1.723e+09** **	**5.558e+09*** **	**-2.765e+08**
	(6.925e+08)	(5.677e+08)	(1.479e+09)	(6.728e+08)	(9.007e+08)	(9.764e+08)
Haircut x Last Day	301.1e+09***	301.2e+09***	**-634.5e+09*** **	**-634.3e+09*** **	**650.2e+09*** **	**650.2e+09*** **
Of the Quarter	(709.0e+08)	(709.5e+08)	(135.4e+09)	(135.4e+09)	(946.9e+08)	(947.5e+08)
Last Day of the	-2.700e+08***	-2.898e+08***	6.413e+08***	7.632e+08**	-8.259e+08***	-9.691e+08***
Quarter	(4.436e+07)	(6.094e+07)	(1.671e+08)	(3.872e+08)	(8.561e+07)	(1.153e+08)
Last Day of a Month	3.188e+07*	3.139e+07*	1.341e+08***	1.364e+08***	-2.873e+07	-3.131e+07
That Isn't Quarter-end	(1.822e+07)	(1.821e+07)	(2.961e+07)	(2.917e+07)	(2.854e+07)	(2.823e+07)
Bank's Tier 1 Ratio	-3.183e+06		3.056e+07***		-8.626e+06***	
(%)	(2.279e+06)		(5.669e+06)		(2.108e+06)	
Tier 1 Ratio x Last Day	2.760e+06		-2.163e+07**		7.896e+06**	
of the Quarter	(2.007e+06)		(1.085e+07)		(3.512e+06)	
Dealer's Assets	-0.00918		0.0140***		-0.0543***	
($Thousand)	(0.00657)		(0.00478)		(0.0132)	
Dealer's Assets x Last	0.00752		-0.00431		0.0519***	
Day of the Quarter	(0.00571)		(0.0342)		(0.0173)	
Derivatives Holdings	0.000939		2.000***		-0.000315	
($Thousand)	(0.000885)		(0.379)		(0.00250)	
Derivatives x Last	-0.00237		-1.013		-0.0117	
Day of the Quarter	(0.00491)		(0.927)		(0.0202)	
Total MMF		26.70		-169.3		108.1
AUM ($Million)		(25.77)		(163.1)		(86.44)
Yesterday's		-36.73		114.4		-161.9*
MMF AUM		(31.31)		(161.2)		(90.33)
MMF AUM, Last		6.738		-39.12		44.16
Day of the Quarter		(9.160)		(162.8)		(28.98)
Constant	-1.630e+07	1.031e+07	-1.243e+08***	6.855e+07	1.561e+07	1.982e+08***
	(2.557e+07)	(4.043e+07)	(4.336e+07)	(6.141e+07)	(3.928e+07)	(7.594e+07)
Observations	179,851	179,851	63,399	63,399	93,410	93,410
R-squared	0.992	0.992	0.993	0.993	0.991	0.991

Source: Bankscope, Federal Reserve Board of Governors, and SEC Form N-MFP

1.4.5 Identification Using the Dealer-Lender Network

One limitation of my analysis so far is that it still suffers from the potential for omitted variable bias. Non-U.S. bank dealers may be borrowing from a different set of lenders than U.S. bank dealers, and those lenders may face different shocks at the end of the quarter. To control for any other potential cash lender effects, I use an additional data set on the network of tri-party repo lending since 2011. Similar to Khwaja and Mian (2008), I can use the network to examine the quarter-end effect within a cash lender using both lender and time-fixed effects. Table 13 reports that within a single lender, quarter-end repo borrowing by European bank dealers drops 13.6%, while U.S. and Japanese bank dealer borrowing is not significantly affected.

In a further test, I use a subset of the dealer-investor network that allows me to identify price effects in the haircut and the repo rate separately. Since November 2010, money market funds have published complete end-of-month portfolio holdings, including all repurchase transactions and the haircut and rate applied on the underlying collateral[12]. To fully identify price and quantity effects, I collect and use this data on the sub-network of tri-party repo transactions where money market funds are the cash investor. Table 14 shows that while money funds lend less to European dealers at quarter-end, repo rates drop at quarter-end for both U.S. and European bank borrowers and haircuts are not significantly affected for any participants. This drop in both quantity (for European banks) and in market price (via the repo rate) is consistent with a shock to cash demand rather than cash supply,

[12]A recent paper by Hu, Pan, and Wang (2014) uses this N-MFP filing data to conduct an extensive survey of tri-party repo pricing practices, and is the only other paper I am aware of which takes advantage of this pricing data.

Table 1.13. Within-Lender Variation in Repo Lending

The dependent variable is the natural log of the daily total market value of collateral pledged in repo by an individual dealer to an individual repo cash lender. The regressors are the natural log of the prior day's total market value of collateral pledged, as well as indicator variables for the last business day of a quarter and month, the country of origin of a dealer's parent bank, and the interaction of those terms. Estimation is based on OLS regression with lender-time-fixed effects for each quarter in the sample period, for each cash lender in the sample. Heteroskedasticity-robust standard errors clustered by lender are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1) log(Total Repo)	(2) log(Total Repo)
Yesterday's log(Total Repo)	0.991***	0.991***
	(0.000386)	(0.000379)
Last Day of a Quarter	0.000184	0.000324
	(0.0324)	(0.0324)
Europe Quarter-End	**-0.136*** **	**-0.137*** **
	(0.0182)	(0.0182)
Japan Quarter-End	-0.0281	-0.0287
	(0.0185)	(0.0185)
U.S. Quarter-End	-0.00876	-0.00782
	(0.0157)	(0.0157)
Last Day of a Month That		-0.0668
Isn't a Quarter-End		(0.0463)
Europe Month-Not-Quarter-End		-0.0296***
		(0.0105)
Japan Month-Not-Quarter-End		-0.0219*
		(0.0130)
U.S. Month-Not-Quarter-End		0.0203*
		(0.0109)
Europe	0.00983***	0.0107***
	(0.00133)	(0.00134)
Japan	0.00365*	0.00427**
	(0.00204)	(0.00205)
U.S.	0.00749***	0.00665***
	(0.00133)	(0.00132)
Constant	0.183***	0.186***
	(0.00771)	(0.00744)
Observations	301,620	301,620
R-squared	0.984	0.984

Source: Federal Reserve Board of Governors

which supports window dressing as the likely explanation for the quarter-end repo anomaly.

1.5 Robustness Tests

1.5.1 Unit Root

If repo borrowing follows a unit root process, this might lead to a problem of spurious regression. I test for unit roots in the quantity of repo borrowing using an Augmented Dickey-Fuller test allowing for drift in the series and find rejection of that hypothesis. Because I am also testing repo borrowing at the dealer level, I further test for unit roots across the panel using a Fisher-type Augmented Dickey-Fuller test, and again reject the null hypothesis that repo borrowing is a unit root process.

If repo borrowing is not a unit root process but is actually near unit root, my tests for a unit root would suffer from reduced power. Therefore, I also test for window dressing using changes in logs rather than an AR(1) specification. Again, I find a significant quarter-end drop and subsequent rebound in repo borrowing for non-U.S. banks, which is concentrated in highly levered banks and in repo backed by safe, liquid collateral.

1.5.2 Panel VAR

I chose to use simultaneous equations for my main empirical strategy because quarter-ends obviously arrive exogenously. However, to test the identification of my model of supply and demand, I used a vector auto-regression (VAR) approach. Because tri-party repo haircuts are dealer– and collateral-specific, I run a panel VAR at the dealer and asset-class level. Standard model selection technique (AIC) suggests I use 1-period lags. My panel VAR

Table 1.14. Within-Investor Identification Using Pricing Data

In column (1), the dependent variable is the natural log of the total market value of collateral pledged in repo by an individual dealer to an individual money market fund on the last day of a month. In columns (2) and (3), the dependent variables are the average repo rate and haircut, respectively, charged to a dealer by a money market fund on the last day of a month. The regressors are indicators for the last day of a quarter, as well as the last day of a quarter interacted with indicators for whether the repo borrower belongs to a bank from the U.S., Europe, or Japan, respectively. Additionally, the natural log of a money market fund's assets under management (AUM) is added as a regressor, and in columns (1) to (3), a 1-period lag term of the dependent variable is also added. Estimation is based on OLS regression with lender-time-fixed effects for each quarter in the sample period, for each cash lender in the sample. Heteroskedasticity-robust standard errors clustered by lender are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

VARIABLES	(1) ln(Repo Lending)	(2) Repo Rate	(3) Haircut
Quarter-End	-0.0594***	-0.0223***	0.0345
	(0.0228)	(0.00231)	(0.0239)
U.S.×Quarter-End	0.0305	-0.00627***	-0.0158
	(0.0280)	(0.00198)	(0.0197)
Europe×Quarter-End	-0.168***	-0.00574***	0.0299
	(0.0253)	(0.00175)	(0.0567)
Japan×Quarter-End	0.0267	0.0143***	-0.0180
	(0.0585)	(0.00390)	(0.0183)
Δ ln(AUM)	0.901***	-0.0212***	-0.0454
	(0.0590)	(0.00678)	(0.0439)
ln(Repo Lending$_{t-1}$)	0.651***		
	(0.0103)		
Repo Rate$_{t-1}$		0.847***	
		(0.0111)	
Haircut$_{t-1}$			0.672***
			(0.0217)
Constant	6.499***	0.0341***	0.0624***
	(0.191)	(0.00234)	(0.0130)
Observations	48,036	48,036	48,036
R-squared	0.427	0.743	0.411

Source: SEC Form N-MFP

results are still consistent with window dressing: dealer leverage predicts significantly lower quarter-end repo borrowing, although I do not retain significance on other balance sheet measures.

1.5.3 U.S. Bank Holding Company Data

Other researchers have used data on U.S. bank holding companies (BHCs) to find evidence of window dressing by U.S. banks. This is inconsistent with my results using the tri-party repo data, in which I find that window dressing was concentrated in highly leveraged non-U.S. BHCs. The most compelling results are from Owens and Wu (2012), who use public reports filed by BHCs in form Y-9C. These reports include the quarter-average and quarter-end balance sheet data of these banks, and those authors take the discrepancy between those two measures as evidence of window dressing. To test their result, I repeat their analysis using Y-9C data from 2001 through 2013, which I obtain through WRDS. Column (1) of Table 15 reports similar findings to their Table (4) Column (1): window dressing is indeed concentrated among BHCs with high leverage.

In Columns (2) and (3), I divide the sample into BHCs that are U.S.-based, and those bank holding companies that are subsidiaries of a non-U.S. parent.[13] The effect of leverage is entirely concentrated in the few non-U.S. BHCs, and the size effect is quite nearly captured by non-U.S. BHCs as well. Additions to loan loss reserves during the prior quarter are intended to account for non-window dressing pressures to de-leverage, and this effect remains for the U.S. BHCs but not the non-U.S. BHCs. These results are consistent with

[13] I also impose the same requirement as Owens and Wu (2012) that these bank holding companies have total consolidated assets greater than $500 million.

my findings in tri-party repo: non-U.S. bank holding companies window-dress and thereby improve the appearance of their parents' own financial statements.

Table 1.15.
Quarterly Changes in Repo and Fed Funds Liabilities By Country

The dependent variable is the measure of window dressing of repo and fed funds liabilities proposed by Owens and Wu (2012) for an individual bank holding company (BHC). The regressors are also those proposed by the same paper. These are the prior quarter's average leverage for the BHC; the natural logarithm of quarterly average total assets; an indicator variable that = 1 if quarter t ended between 2007 Q4 and 2009 Q2, inclusive, and 0 otherwise; and the loan loss provision as a percentage of gross loans for the prior quarter. Column (1) estimates using the entire sample of BHCs that report in form Y-9C and have total assets greater than $500 million, columns (2) and (3) reduce that sample to those BHCs whose ultimate parent is either in the U.S. or not in the U.S., respectively. Estimation is based on OLS regression. Heteroskedasticity-robust standard errors are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

Owens & Wu (2012) Window Dressing Measure	(1) All BHCs	(2) U.S. BHCs	(3) non-U.S. BHCs
Quarter-Average Leverage$_{t-1}$	-3.92e-05***	-4.26e-06	-3.68e-05***
	(4.56e-06)	(7.97e-06)	(8.28e-06)
ln(Size)$_{t-1}$	-0.000829***	-0.000301*	-0.0110***
	(0.000160)	(0.000163)	(0.00137)
Crisis Period	0.000385	0.000492	-0.00533
	(0.000579)	(0.000576)	(0.00792)
LLR$_{t-1}$	-0.139***	-0.141***	0.0963
	(0.00865)	(0.00860)	(0.130)
Constant	0.0128***	0.00494**	0.169***
	(0.00230)	(0.00235)	(0.0229)
Observations	18,306	18,118	188
R-squared	0.019	0.015	0.369

Source: Federal Reserve Form Y-9C

1.6 Spillover Effects from Window Dressing

1.6.1 Agency Bond Markets

Repurchase agreements give cash in exchange for collateral, and when a dealer decides not to repo an asset, they must either find alternative financing or sell the asset. Repo window dressing is concentrated in safe assets: Treasuries, agency MBS and agency bonds, and money market assets (e.g., CDs). Since March 2010, the Financial Industry Regulatory Authority (FINRA) has collected data on all agency bond transactions involving dealers, and made them available to researchers through WRDS.[14] In this subsection, I use this data, including the price, quantity, time of execution and settlement, and direction (dealer-to-dealer or dealer buying/selling to a non-dealer) of each trade, to examine the impact of dealer window dressing on market quality for agency bonds.

When looking across markets, it's important to control for differences in the settlement process of each security. Repurchase agreements are "T+0" transactions, meaning that cash and securities are exchanged on the same day as the trade is executed. Agency bonds typically settle on "T+1," meaning the next business day after execution. If a dealer chooses not to finance his or her securities in repo anymore on a given day, he or she will still need to return cash to repurchase their securities that same day. Therefore, from the dealer's perspective, cash timing across markets is strategically important for window dressing. TRACE includes data on settlement as well, so to compare bonds and repo, I adjust each trade in Agency TRACE to the date of cash settlement. For the remainder of this paper, I will call the time of a trade the date of its settlement instead of its execution.

Table 16 shows that in the days preceding a quarter-end, dealers are on net, selling heavily to non-dealers (giving up assets for cash). However, once the new quarter starts, dealers are immediately relevering by buying back agency bonds. In the inter-dealer network, Column (2) reports that inter-dealer trading rises to three times normal levels at the end

[14] I am unable to locate high-frequency data on Treasury transactions, and in a follow-up extension to this paper, I am currently processing data from FINRA's new TRACE dataset of agency MBS transactions, which are not included in this paper.

of the quarter, and then collapses once the new quarter begins.[15] As a whole, the dealer system is therefore delevering at the end of the quarter through sales to customers and then relevering once the new quarter starts, consistent with window dressing. Moreover, even if market participants understand and anticipate this behavior, it is in practice very similar to Lehman's repo 105 transactions, just executed through bond markets rather than mistreatment of repo accounting.

Furthermore, if dealers are deleveraging through the bond markets, we should expect an impact on market quality as measured by price impact. Froot and Stein (1998) predict that when capital constraints bind, intermediaries will offer worse prices to customers in transactions that increase their capital burden, and better prices for transactions that reduce their capital burden. Indeed, Naik and Yadav (2003) find that when market demand for securities brings dealers' positions closer to intraday capital limits, customers face significantly asymmetric effects on market quality. Window dressing is a self-imposed constraint on dealer leverage, which is only necessary at the end of the quarter, so the prediction of Froot and Stein (1998) should therefore extend to a seasonal effect on market quality.

I compute the daily percent price change of each bond, as a function of the net dealer buying minus selling on that bond each day. However, individual bonds can trade very infrequently, so I look only at price changes when the bond has traded at least once that day and the day before. Dealers act as market makers in agency bonds, so typically a trade between a dealer and a customer is customer-initiated. Therefore, I expect a dealer buying from a customer to have a negative price impact. Indeed, Table 17 shows this is the case

[15] This may be due to window-dressing dealers seeking out less-levered dealers, and in a follow-up project, I examine newly available TRACE transactions data that includes dealer identities to definitively test this hypothesis.

Table 1.16.
Quarter-End Dealer Selling Pressure

The dependent variable is the settlement-adjusted daily total market volume in millions of dollars of dealer purchases from customers minus dealer sales to customers (column (1)), or of trades between two dealers (column (2)), in which the security was an agency bond. Regressors are indicator variables for the five days before and after a change in quarter. Data is obtained from WRDS TRACE. Each transaction is considered at the date of settlement rather than execution. Estimation is based on OLS regression. Bootstrapped heteroskedasticity-robust standard errors are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

Agency Bonds	(1)	(2)
Daily Market Volume ($ Millions)	Net Dealer Buying	Inter-Dealer Trading
Fifth-to-Last Day of	-253.1*	3,708
Quarter	(146.4)	(13,840)
Fourth-to-Last Day of	-598.8**	22,810***
Quarter	(236.1)	(8,487)
Third-to-Last Day of	-1,294***	80,000***
Quarter	(259.7)	(25,610)
Second-to-Last Day	-1,520***	108,100**
of Quarter	(425.5)	(43,220)
Last Day of Quarter	-1,534***	129,000**
	(556.6)	(63,860)
First Day of Quarter	408.2**	-19,070
	(191.5)	(14,940)
Second Day of	366.7**	-30,890***
Quarter	(172.4)	(8,940)
Third Day of Quarter	427.2***	-17,550
	(98.96)	(16,750)
Fourth Day of Quarter	97.41	-16,260**
	(144.5)	(6,358)
Fifth Day of Quarter	124.5	-12,040
	(177.7)	(8,265)
Constant	-1,125***	64,290***
	(30.89)	(2,227)
Observations	476	476
R-squared	0.341	0.221

Source: FINRA

during normal times. However, in the five days before the end of the quarter, when dealers are selling heavily to customers, the price impact of selling to a dealer rises by 12%. Once the new quarter starts, the price impact in selling to a dealer decreases but is not significant. This appears to be consistent with a quarterly drop in market quality due to dealer window dressing.

Table 1.17.
Price Effects of Window Dressing Deleveraging Pressure

The dependent variable is the one-day percentage change in price of an Agency bond. Net directional volume is the daily total value of bonds bought by dealers from customers minus the total value of bonds sold by dealers to customers. This regressor is also interacted with pre- and post-quarter-end indicator variables which =1 for all of the 5 days before or after the change in quarter, respectively. Estimation is based on OLS regression. Heteroskedasticity-robust standard errors are presented in parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% level, respectively.

	(1) Percent Change in Price
Net Directional Volume	-0.00731***
	(0.000136)
Net Directional Volume x Pre-Quarter-End	-0.000895*
	(0.000513)
Net Directional Volume x Post-Quarter-End	0.000690
	(0.000503)
Constant	0.000537***
	(1.19e-05)
Observations	394,660
R-squared	0.008

Source: FINRA

1.6.2 Money Market Mutual Funds

Agency bond markets see dealers selling assets for cash, but as shown earlier, money market funds have a surplus of quarter-end cash. Due to regulatory restrictions, money market funds cannot invest in long-dated securities such as agency bonds, so there is effectively a dislocation of cash in the markets each quarter. Repo is a conduit for short-term money to finance longer-term investments, and quarterly window dressing is a regular stress on this conduit. Money market funds have had to play a quarterly game of musical chairs to find short-term assets that they can roll out of when repo resumes at the start of the quarter. The Federal Reserve's reverse repurchase agreement program (RRP) was instituted in September 2013, and it appears to be facilitating this process.

In the current zero-interest-rate policy environment, the Fed funds market has become relatively inactive,[16] and the RRP was originally proposed as a new tool to impose a floor in interest rates by raising the repo rate. To do this, the Federal Reserve will lend collateral to cash suppliers (mostly money market funds), in essentially a tri-party repo transaction in which the Fed is the dealer.

Each quarter, the Federal Reserve has increased the amount of collateral it is willing to repo. Figure 5 shows that at the end of each quarter, cash from money funds surges into the RRP and immediately flows back out. On September 19, 2014, the Federal Reserve announced[17] (perhaps in an effort to make money funds less reliant on the Federal Reserve to help cope with window dressing) it would lower the cap on its reverse repo transactions to $300 billion, which sent rates on ultra-low Treasury bills maturing October 2 below zero. The RRP was intended to be a tool for raising interest rates by pulling cash out of the money markets, but at the end of the quarter, it seems the RRP is being overwhelmed by window dressing.

[16] Afonso, Entz, and LeSueur (2013) online: http://libertystreeteconomics.newyorkfed.org/2013/12/whos-lending-in-the-fed-funds-market.html

[17] http://online.wsj.com/articles/fed-rate-hike-tool-stirs-some-concern-1411164329

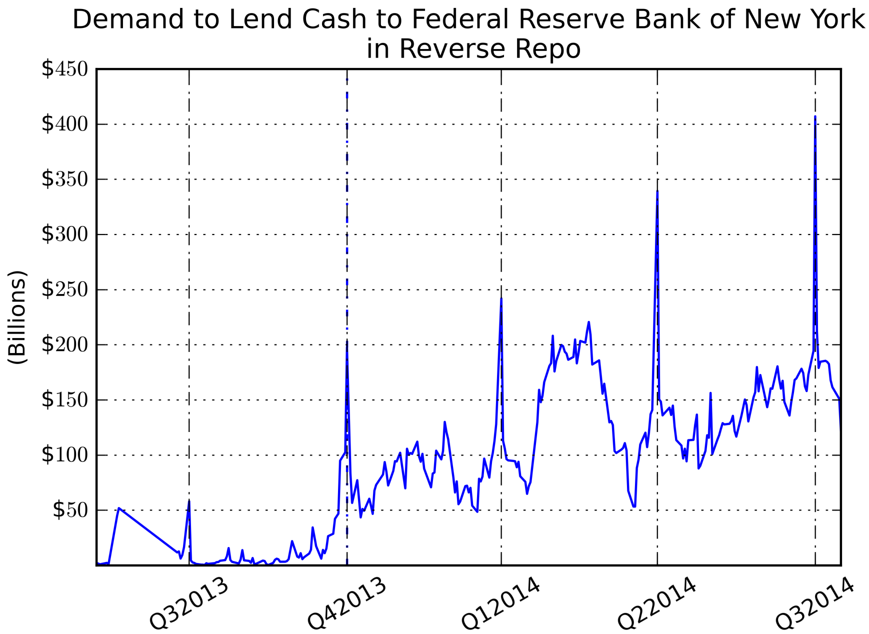

Figure 1.5. Daily Demand to Lend to the Federal Reserve Bank of New York

Notes: The vertical axis represents the value in billions of dollars of cash submitted in auction to the Federal Reserve Bank of New York (FRBNY) to finance collateral pledged by the FRBNY in an overnight repo each day through its Reverse Repurchase (RRP) program. The program was first discussed in a July 2013 policy meeting, early testing began August 7, 2013, and this chart shows submissions each day from then until October 15, 2014. Quarter-ends are marked with vertical dashed lines, and year-ends are marked with heavier dash-dotted lines. Almost every day, the amount submitted in auction was then used that same day to finance FRBNY collateral. The only exceptions to this are in mid-August 2013 when the program was still being tested and was limited to $5 billion, and on September 30, 2014, when the FRBNY limited the value of collateral it would pledge in repo to $300 billion.

Source: Federal Reserve Bank of New York

1.7 Conclusion

Non-U.S. bank dealers window-dress. The effect is not driven by cash lenders, and dealer leverage explains the quarter-end decline in repo. A joint model of supply and demand shows that non-U.S. dealers are voluntarily reducing their demand and do not face higher costs at the end of the quarter as they would from reduced supply.

Window dressing understates a dealer bank's leverage and maturity mismatch, which means systemic risk is higher than we would believe using only quarter-end measures. Window dressing also creates spillovers into other markets, and dislocates cash from productive financial intermediation. Other agents can take advantage of this phenomenon: the end of the quarter is a very good time for bond funds to buy from dealers, although the round trip costs of trading with a dealer do not appear to allow an arbitrage-like opportunity. Morey and O'Neal (2006) find that bond mutual funds window-dress as well, by buying government bonds before disclosure; bank window dressing and bond fund window dressing may be complementary to each other.

This raises interesting implications for previous studies of the repo market during the financial crisis. Quantities (or prices) of repo borrowing cannot separately by themselves demonstrate a run on dealers. To really determine what's happening in repo, we need an integrated approach to looking at supply, demand, and especially at deleveraging pressures. In quarter-end window dressing, the effect is dealer-initiated. It is not clear whether the haircut spirals documented in Gorton and Metrick (2009) were driven by dealers unwilling to lend to hedge funds, or whether the dealers themselves were being forced to delever and wind down their repo operations. By collecting more data on bilateral repo transactions as well as investment flows from securities lending and segregated accounts, we may be able to better answer whether the 2008 crisis was a run on repo or whether repo behavior was simply a symptom of a deleveraging banking system.

My findings offer some clear policy recommendations as well. As part of the Basel III bank capital reforms, a new supplementary leverage ratio (SLR) is currently being implemented. U.S. regulators have announced they intend to calculate the SLR from the daily quarter average. However, outside the U.S., the SLR's current implementation will calculate the ratio from the average of the last day of each month in a quarter. Because non-U.S. banks are currently window dressing at the end of each quarter, it is very likely that a change to using month-ends for capital regulation will simply increase the frequency of window dressing, with commensurate challenges for money market funds and other repo lenders. In other words, the frequency of reporting a regulatory ratio may matter as much as the required level of the ratio itself. Of course, Tier 1 and other regulatory ratios would also be more informative outside the U.S. if foreign banks switched to a quarter-average calculation as well.

SLR should be quarter-average, all capital requirements should be quarter-average. Fitch Ratings has claimed that making SLR a daily average instead of month-end average represents a concession to U.S. custodian banks.[18] However, this paper suggests that the opposite is true. Daily averaging of capital requirements disincentivizes window dressing, which improves the effectiveness of bank regulation.

Lehman Brothers was excoriated for their window dressing through Repo 105 and Repo 108, but many dealers are doing a very similar thing. In fact, because most dealers were

[18] Custodian banks are typically cash-rich banks, as opposed to most cash-poor dealer banks. https://www.fitchratings.com/gws/en/fitchwire/fitchwirearticle/US-Leverage-Rule .

window dressing by cutting repo, Lehman might have had an easier time putting $50 billion into repo, because cash lenders had a surplus and no one else to lend to.

The RRP appears to be absorbing significant cash each quarter-end that arrives due to window dressing. The RRP was intended to be a tool for increasing interest rates as an alternative to fed funds.[19] However, the September 17, 2014, announcement capping the RRP at $300 billion sent money market investors scrambling for alternative short-term investments for their anticipated excess cash from repo, and dropped yields on short-term Treasury bills into negative territory. By providing cash lenders with a safe repo counterparty when others window-dress, the Federal Reserve may be making those lenders dependent on the RRP at quarter-ends. If window dressing is not fixed, the Fed can at least modify the RRP to make it flexible during the quarter, increasing the amount of collateral financed at quarter-end to absorb the surge in cash, but then lowering it during the quarter to match the decrease in uninvested cash. The recent addition of term repurchase agreements to the RRP is likely effective in ameliorating this problem.

[19] http://www.newyorkfed.org/markets/rrp_faq.html .

Chapter 2: Capital and Bank Runs

Introduction

The financial crisis of 2007-2008 demonstrated the fragility of financial intermediation. Specifically, when long-term investments are financed by short-term funding there is rollover risk. Banks face a trade-off between providing a liquid investment to a pool of depositors who have a temporary cash surplus, and facing a run when depositors simultaneously demand that liquidity. Similar funding arrangements exist in repo lending and money market mutual funds. The sudden contraction in available liquidity after a run is generally considered to impose significant externalities on the economy. This is sometimes referred to as the "real effect" of a financial crisis–the bankruptcies and layoffs and disinvestments that companies may have to undergo due to a lack of appropriate financing.

History shows that when runs spread to the entire banking system they have jolted populations into enacting sweeping reforms in an attempt to prevent the danger from recurring. The 1907 financial panic brought us the Federal Reserve, the bank runs across the US in the 1930s brought the Federal Deposit Insurance Corporation (among many other reforms), and the 2007-2008 crisis brought the passage of the Dodd-Frank Act, the formation of the Financial Stability Oversight Council, and an upgrade of the Basel Capital Accords. The full impact of these measures is very difficult to judge–as evidenced by the plethora of proposed metrics for measuring "systemic risk" that have been put forward since the recent financial crisis. This paper hopes to bring some further understanding to the debate about bank regulation by extending traditional bank run models to allow endogenous portfolio selection by the bank. I create a class of investors who provide bank equity and explore bank capital's role in mitigating or preventing bank runs. The model presented here will show two effects of bank capital. First, capital provides a limited form of deposit insurance to depositors, thus increasing the severity of a credit event needed to make informed depositors run. Second, it disciplines the bank's choice of portfolio portfolio risk, since shareholders must internalize depositor run risk. Bank capital structure therefore affects the degree of liquidity risk- and portfolio risk-sharing in the economy. I then use this model to analyze the social welfare trade-offs between depositors and shareholders due to a change in the bank capital ratio.

Literature Review

The literature on bank runs is extensive and multifaceted. Bryant (1980) investigated bank runs in the context of heterogeneous agents as well as asymmetric information. Certain agents knew they were "early diers" and engaged in utility-increasing wealth transfers with other agents. However, this early take on liquidity insurance would result in "runs" if some depositors received early information about the likelihood of some uninsurable event occurring. Diamond & Dybvig (1983) present a model where agents are instead ex ante homogeneous, but they each face an i.i.d. liquidity shock λ, which forces them to consume before the investment technology can bear fruit. In this model, they show that "sunspot" equilibria can arise, where both running and not running are equilibrium outcomes, since depositors are neither able to commit to an action nor to coordinate their actions with each other to ensure a unique equilibrium. This lack of a unique equilibrum has been used as a rationale for the existence of bank deposit insurance, whereby the sovereign is able to credibly commit to a policy of redeeming all deposits even if the bank collapses, and thereby prevent the run outcome.

Jacklin & Bhattacharya (1988) consider the use of peer inference in a run. Agents may get a signal about the bank's prospects, and they may also observe their fellow agents queueing up to withdraw from the bank. This observation may inform the agent's own signal, telling her that the bank must be insolvent because so many of her peers are already lining up, so therefore she too will line up to withdraw. The cascading effect of this peer inference results in the entire depositor base choosing to run on the bank, even though the agents' own information might have indicated the bank was solvent. Therefore the authors are able to distinguish between information-based and panic-based runs, and claim that an institution should choose between funding by deposits or by equity depending on the risk and information attributes of the underlying investment projects.

He & Xiong (2012) take a similar approach, but add the interesting feature that agents hold short-term debt contracts rather than demand deposits, and agents anticipate their peers' decision to run by observing a public signal of bank fundamentals, rather than observing their peers' decisions directly. This coordinates depositors into a pre-emptive run, where the bank is unable to roll over part of its portfolio and therefore fails. They seek to explain the behavior observed during the financial crisis where seemingly healthy banks suddenly experienced runs by their creditors and required extensive government liquidity support, and their model indicates that even small changes in the volatility or liquidation value of assets can trigger a run.

In contrast, Goldstein & Pauzner (2005) look at the simultaneous coordination of depositors over independent private signals, and seek to determine the optimal level of risk-sharing among agents. They find that a bank provides a worse level of risk-sharing (parametrized by the deposit rate r_1) than what a benevolent social planner could provide, but ex ante utility is still higher than under autarky, so banks as institutions are social welfare-improving. Their paper is of most direct impact to the current paper, which seeks to extend the model framework developed by Goldstein & Pauzner (2005) to include bank capital, and ask to what degree banks and bank regulatory policies (minimum bank capital requirements, deposit insurance, and suspension of convertibility) are welfare improving.

Diamond (1984) considers a bank as the delegated monitor for a project, and finds economic rents from the reduced duplication of monitoring activity, as well as the ability of the bank to diversify its portfolio across more projects. From their analysis, they conclude that the optimal capital structure of a bank is to have a very diversified porfolio backed by deposits and very little capital. Diamond & Rajan (2000 & 2001) provide a further rationale for bank deposit finance by the negotiating advantage it gives to the bank when contracting with entrepreneurs: the bank cannot renegotiate and accept less payment from the entrepreneur because if they were to do so, their depositors would run and force the bank to call in the loan. Therefore, bank deposits serve as a commitment device that helps enforce contracts. More broadly, they make the point that devices such as a bank that tie human capital to assets create liquidity. Diamond & Rajan (2000) also seeks to explain the decline in bank capital over 200 years due to the trade-off between creating liquidity (through issuing deposits as a commitment device on the bank manager) and robustness (through softer claims like equity and long-term debt that can be renegotiated under negative shocks, but allow the bank manager to capture some rents). They claim that due to generally increased asset liquidity (in addition to implicit government capital in the form of deposit insurance and regulatory oversight), banks naturally become more levered. However, the paper leaves room for examining the social welfare implications of a more levered banking system in the absence of the rent-extraction problem. Given the trend towards securitization and the maturation of the parallel financial system (sometimes called "shadow banking"), investors are able to replicate much of the bank's contracting power through an asset-backed security which is held in a conduit facility financed by commercial paper. The ease of setting up such an institution, and the fluidity with which new forms of these contracts can be created makes it more appealing to study the abstract security, setting aside assumptions about relationship-specific negotiations.

Admati et al. (2010 and 2012) analyze the leverage decision of a bank, and address several common flaws in arguments used to support the notion that equity is expensive for banks. They find that equity requirements for banks could be set significantly higher than they currently are and claim that such a shift would have large positive social benefits and minimal, if any, costs. The authors suggest tha bank managers accrue benefits from high bank leverage, at the expense of the general public as well as diversified shareholders, and would rationally resist deleveraging. They use a model of debt overhang to show a dynamic incentive to "ratchet" leverage up and not down, creating an "addiction" to leverage once an exogenous portfolio and capital structure has been set. Our paper uses a very different model to look instead at the *ex ante* incentives of risk-shifting in the presence of bank runs to analyze the social tradeoffs of changing capital requirements. As we will show later in this paper, the risk of runs by depositors can discipline the bank's risk-taking at different levels of leverage, which critically affects optimal bank capital policy.

2.1 Model Setup

i) Agents

There are 3 periods in the model: t$\in$ $(0, 1, 2)$, and two types of agents, having aggregate $t = 0$ endowment $1 + e$. All agents are born at time 0 and are endowed with one unit of the consumption good. Consumption occurs only in period 1 and 2. Mass 1 of agents are uncertain at t=0 about their true type–patient or impatient. Patient agents can consume at either period, their utility is $u\left(c_1 + c_2\right)$. Impatient agents can only consume at $t = 1$, their utility is $u\left(c_1\right)$. Uncertain agents know that at $t = 1$ they will learn their type (as private information), and with probablity λ, will be impatient. Uncertain agents' types are i.i.d., so at $t = 1$ mass λ will be impatient, $(1 - \lambda)$ will be patient. Meanwhile, the remaining mass e of agents are certain–they know at t=0 that they are patient. I assume utility is twice continuously differentiable, increasing, and for $c \geq 1$ has relative risk-aversion greater than 1, as in Goldstein & Pauzner (2005). To simplify analysis of the model, we assume $u\left(0\right) = 0$ without loss of generality.

ii) Projects

At t=0, investments can be made in the productive technology, which gives a positive expected long-run return. There are I mutually exclusive possible projects which vary in risk and are only available to banks. A bank invests in project $i \in I$, which offers gross return $R_i \geq 1$ if successful. At $t = 1$, any risky project can be liquidated to yield the same exogenous recovery value γ. At $t = 2$, risky projects that weren't liquidated can pay out to investors. Let $\hat{F}_i(\cdot)$ denote the mean-shifted standard normal $N(\mu_i, 1)$ cumulative distribution function. With probability $\hat{F}_i(\theta)$ project i delivers R_i units of output, and with probability $1 - \hat{F}_i(\theta)$, the investment fails and delivers 0. Projects are fairly priced, meaning for a certainly patient investor, $\mathbb{E}[u(\textit{investing in project } i)] = u(R)$, $\forall i \in I$, and where R is the risk-free rate[1]. The state of all investments' prospects is captured by θ and is imperfectly observed at $t = 1$, though investors know at $t = 0$ that θ is drawn from a standard normal distribution $N(0, 1)$[2]. The riskless asset is available only to the bank, and without loss of generality I assume it offers zero interest, i.e. $R = 1$.

ii) First Best Solution

In autarky, impatient agents will consume γ in period 1. Patient agents will liquidate early and consume γ as well if signal θ_i is sufficiently bad ($\hat{F}_i(\theta_i)u(R_i) < u(\gamma)$), otherwise they will stay with their investment, wait until period 2, and consume R_i units in period 2 with probability $\hat{F}_i(\theta)$. A benevolent social planner who could observe agents' types (patient or impatient) could improve uncertain agents' ex ante overall welfare, by setting impatient agents' consumption c_1. Namely, choosing c_1 to maximize the ex ante expected utility of an

[1] I also assume that μ_{R_i} satisfies $E_0\left[\hat{F}_i(\theta)\right] u(R_i) > u(\gamma)$, so for patient agents it is *ex ante* preferable to let the investment mature at $t = 2$ rather than liquidate at $t = 1$.

[2] This particular distributional assumption is chosen to ensure that the state variable θ has unbounded support, while the probability of any project's success is still within $[0, 1]$

agent:

$$\lambda u\left(c_1\right)+(1-\lambda)\left[u(\frac{1-\frac{\lambda c_1}{\gamma}}{1-\lambda}R_i)\mathbb{E}_\theta\left[\hat{F}_i(\theta)|stay\right]+u(\frac{1-\frac{\lambda c_1}{\gamma}}{1-\lambda}\gamma)\mathbb{E}_\theta\left[liquidate\ early\right]\right] \tag{2.1}$$

Then in good times when $\hat{F}_i(\theta_i)u(R_i) > u(\gamma)$, λc_1 units of investment would be liquidated early to satisfy impatient agents, and patient agents receive with probability $\hat{F}_i(\theta)$ an equal share of successful payoff R_i from the remaining $\left(1-\frac{\lambda c_1}{\gamma}\right)$ invested in the productive technology. In bad times, the entire project is liquidated early (efficient liquidation), but impatient agents will still receive c_1 while the rest of the liquidation value is prorated among the other investors. Because uncertain agents are ex ante identical and indifferent over choice of R_i, I assume they choose an arbitrary common risk level R_i. Thus we obtain a first-order condition similar to (1) in Goldstein & Pauzner (2005) for the first-best promised c_1,equating the marginal benefit to impatient agents and the marginal cost to (ex post but originally uncertain) patient agents:

$$\begin{aligned} u'\left(c_1^{FB}\right) =&R_i u'\left(\frac{1-\frac{\lambda c_1^{FB}}{\gamma}}{1-\lambda}R_i\right)\cdot prob(stay\ and\ success) \\ &+\gamma u'\left(\frac{1-\lambda c_1^{FB}}{1-\lambda}\gamma\right)\cdot prob(liquidate\ early) \end{aligned} \tag{2.2}$$

where $prob(stay\ and\ success) = \mathbb{E}\left[\hat{F}_i\left(\theta\right)|stay\right]$ and $prob(liquidate\ early) = 1 - prob(stay) = F\left(\hat{F}_i^{-1}\left(\frac{u(\gamma)}{u(R_i)}\right)\right)$

At $c_1 = \gamma$, the marginal benefit is greater than marginal cost due to our assumption that $E_\theta\left[\hat{F}_i\left(\theta\right)\right]u\left(R_i\right) > u\left(\gamma\right)$ and the coefficient of relative risk aversion is greater than 1. Therefore at the social planner's Pareto optimum that $c_1 > \gamma$, i.e. there is risk-sharing among the uncertain agents. The social planner is not able to Pareto-improve all agents' expected welfare by including *certainly patient* agents in this pooling scheme, because certainly patient agents would face decreased utility from the partial liquidation of their portfolio with the uncertain agents when liquidation is inefficient, and would never receive c_1. Pareto optimality is an important restriction on the first-best, because certainly patient agents would not voluntarily participate in the risk-pooling that the social planner could offer. Therefore aggregate expected welfare at the Pareto-optimum would be

$$\begin{aligned} \lambda u\left(c_1^{FB}\right) &+ \left[e \cdot u(R_i) + (1-\lambda)\, u\left(\frac{1 - \frac{\lambda c_1^{FB}}{\gamma}}{1-\lambda} R_i\right)\right] \cdot prob(stay\ and\ success) \\ &+ \left[e \cdot u(\gamma) + (1-\lambda)\, u\left(\frac{1 - \frac{\lambda c_1^{FB}}{\gamma}}{1-\lambda} \gamma\right)\right] \cdot prob(liquidate\ early) \end{aligned} \tag{2.3}$$

iii) Banks

When types are unobservable, the above contract offered by the social planner becomes unenforceable. Diamond & Dybvig showed that the demand-deposit contract can still effectively allow for a co-insurance scheme among depositors, while Goldstein & Pauzner demonstrated that the degree of risk-sharing would be less than the social planner's first-best optimum. This paper seeks to show how incorporating certainly patient agents as *equity holders* in the bank contract affects the degree of risk-sharing and the *optimal level* of bank portfolio risk (something the aforementioned papers did not have the structure to immediately consider). The demand deposit contract is as follows: in exchange for a deposit of 1 unit at $t = 0$, the bank promises a depositor a fixed payment $r_1 > \gamma$ if she chooses withdrawal at $t = 1$. If the depositor chooses to wait until $t = 2$ to withdraw, she will receive $\tilde{r}_2$ which is a portion of the remaining (nonliquidated) investment's payoff at $t = 2$. If at $t = 1$ too many agents withdraw and the bank is unable to recover enough from liquidating its assets to pay the promised r_1 to depositors, then there will be a sequential service of withdrawal requests, i.e. the first $\frac{(1+e)\gamma}{nr_1}$ depositors receive r_1 and the rest receive 0. Agents who are certain about their type as patient agents not needing liquidity at $t = 1$ are offered the equity contract rather than the demand deposit contract, which distributes all residual payoff at $t = 2$. Equity holders also can specify both the level of risk in the portfolio and the deposit rate (subject to competitive constraints described below). Further, I price the equity contract such that it satisfies individual rationality for certainly patient types.

Because we allow equity holders to specify both the deposit rate and portfolio risk, the issue of rent extraction deserves delicate treatment.[3] Otherwise, shareholders could take excessive advantage of depositors. I find it reasonable to imagine that the banking industry witnesses free entry, and therefore bank equity holders face a competitive floor on the deposit rate r_1 they can use to attract depositors. Certainly patient agents are thereby indifferent between holding the equity claim and depositing their own money in the bank. In other words, $E_{certainly\,patient}\left[u\left(shares\right)\right] = E_{certainly\,patient}\left[u\left(deposit\right)\right]$ (the individual rationality constraint). Therefore we will simplify our analysis and think of the banking industry as a single bank.

To compare this bank to our social planner from earlier, consider if the bank sets $r_1 = c_1^{FB}$. If only impatient agents will withdraw at $t = 1$, the expected utility of patient depositors from waiting until $t = 2$ will be $\hat{F}_i\left(\theta\right) \cdot u\left(r_1 \cdot \tilde{r}_2\left(\theta\right)\right)$, and as long as this is greater

[3] This issue does not arise in the previous Diamond-Dybvig run literature, because agents financing the bank have typically been assumed to be homogeneous in their liquidity needs. The addition of heterogeneous investors to the model is a main contribution of this paper.

than $u(r_1)$, only impatient agents will demand early withdrawal, and the first-best allocation will be a possible equilibrium. However, because the bank cannot contract upon types, runs are still possible where all depositors choose to withdraw at $t = 1$, and receive r_1 with probability $\frac{(1+e)\gamma}{r_1}$. Any agent who deviates and chooses to wait until $t = 2$ will get 0, unless $e > \frac{r_1}{\gamma} - 1 + u^{-1}\left(\frac{u(r_1)}{u(R_i)\hat{F}_i(\theta)}\right)$, i.e. the bank has so much equity it can credibly absorb the liquidation of its entire deposit base and still offer any remaining depositor a sufficiently enticing deposit r_2 to not withdraw.

2.2 Payoff Information: Private Signals for Unique Equilibrium

At $t = 1$, depositors that are not liquidity-shocked (fraction $(1 - \lambda)$ of the initial depositors) receive a signal θ_j that denotes the probability of the risky project succeeding. Agents' prior is that $\theta \sim N(0, 1)$. The probability of success of a project is $prob(success) = \hat{F}_i(\theta)$, where $\hat{F}_i(\cdot)$ denotes the mean-shifted cumulative standard normal $N(\mu_i, 1)$ distribution function. When θ is realized from the distribution, each agent j receives an individual signal $\theta_j = \theta + \varepsilon_j$, where $\varepsilon_j \sim N(0, \sigma_\varepsilon^2)$ represents noise in the observation. This feature will allow us to have signals with unbounded support, which will be useful later in our analysis. It also lets agents rationally coordinate their actions (withdraw or stay) via a thresholding decision, and I can thereby determine the *ex ante* probability of a run on the bank. This *ex ante* probability of a run allows bank shareholders to choose the optimal level of risk in their portfolio, and allows a social planner to understand the optimal capital structure of the bank.

2.2.1 Renegotiation at $t = 1$

The bank management receives a signal θ_{bank} with the same type of noise as depositors' signal, and reveals that signal to depositors through the setting of the deposit rate r_2 for staying until project's completion. I assume $r_2 \geq 1$ to maintain incentive compatibility for patient depositors who stay, and interest is compounded–depositors who stay are promised $r_1 \cdot r_2$ in total. Because bank shareholders are seeking to maximize their own profits, they will offer the minimum $r_2 \geq 1$ such that the remaining mass $(1 - \lambda)$ of depositors are indifferent between staying (possibly getting $r_1 \cdot r_2$ at $t = 2$), and leaving (getting r_1 if they are lucky and end up early enough in line to withdraw, or else getting 0). However r_2 is also bounded from above by the level of bank equity that can be pledged to depositors. If depositors observe the risk of failure generally to be very high, the bank can't credibly offer a high enough r_2 to satisfy depositors, so depositors will choose to run. If the depositors withdraw (run), the bank is forced to redeem deposits and if it faces sufficiently high liquidation costs from redeeming deposits (γ is sufficiently low), the equity holders will be left with nothing–all project value will have been liquidated and $t = 2$ payoff is 0. Otherwise, the bank gets to wait until $t = 2$ to find out whether the project succeeds or not.

I assume that at the extremes of signals, agents no longer care about what other patient depositors choose to do, their action becomes completely independent. This assumption allows us to obtain a threshold equilibrium, where depositors run below a threshold signal and choose to stay if their signal is above the threshold.

For a very low signal the probability of success is very low, and therefore the expected utility of waiting until period 2 is near zero. We can define a lower extreme below an arbitrarily low signal where the probablity of success is be arbitrarily close to zero. Because the expectd utility of withdrawing at $t = 1$ is always positive (receiving r_1 with probability $\geq \frac{(1+e)\gamma}{r_1}$ and 0 otherwise), the patient agent finds it optimal to run, regardless of her expectation of n, the number of other depositors who choose to withdraw early. I denote the point of a depositor's indifference between running and staying at $t = 1$ as $\underline{\theta}_i\,(r_1,\, r_2^*) = \theta_i\; s.t.$

$$u\,(r_1) = \hat{F}_i\,(\underline{\theta}_i) \cdot u\,(r_1 r_2^*)$$

where

$$r_2^* = \frac{(1+e) - \frac{\lambda r_1}{\gamma}}{1-\lambda} \cdot \frac{R_i}{r_1}$$

represents the maximum credible r_2 the bank can promise depositors. Any depositor who receives a signal in the region of signals $(-\infty,\, \underline{\theta}_i\,(r_1,\, r_2^*))$ will choose to run regardless of others' actions, and regardless of the deposit rate offered.

I also define a range of signals $\left(\bar{\theta}_i,\, \infty\right)$ wherein any depositor will choose to stay, regardless of others' actions. I do this by truncating the distribution of θ_i at some value $\bar{\theta}_i$ arbitrarily large, in effect causing $\hat{F}_i\left(\theta_i \geq \bar{\theta}_i\right) = 1$.[4] Given this assumption, our proposed region of dominant staying behavior is consistent: regardless of her belief about other agents' actions, a patient depositor offered $r_2 \geq 1$ has no reason to run, since agents can withdraw at most r_1 from the bank in aggregate, and the market value of bank assets is $(1+e) \cdot R_i > r_1$.

Even though I can assume $\underline{\theta}_i$ arbitrarily small, and $\bar{\theta}_i$ arbitrarily large, the existence of

[4] Assume that there exists an outside investor who is always willing to buy riskless assets at the risk-free rate (zero in our model) from anyone, including the bank. When the fundamental signal θ_i is extremely high, the long-term return $R_i$is now risklessly guaranteed due to the truncated distribution, and so I assume that there are agents willing to purchase the asset from the bank without a penalty, should the bank be forced to liquidate assets.

these two regions of dominant behavior will cause knock-on effects on the inference of agents with signals near to but outside of either of these two regions, which will cause the region of agent indifference between the two strategies (withdrawing or staying) to collapse to a single point θ_i^*, where $\forall\, \theta_i < \theta_i^*$ the dominant strategy is to withdraw, and $\forall\, \theta_i > \theta_i^*$, the dominant strategy is to stay. This is because an agent receiving a signal $\theta_{ij} = \underline{\theta}_i + \varepsilon_{small}$ will infer that some of her fellow depositors received a signal $\theta_{ik} < \underline{\theta}_i$ meaning those depositors will surely run. For ε_{small} small enough, sufficiently many of her fellow depositors will likely run that agent j finds it optimal to also run, since she knows she cannot any longer hope to receive the full amount $r_1 r_2^*$ from waiting. Similarly an agent receiving a signal $\theta_{ij} = \bar{\theta}_i - \varepsilon_{small}$ will infer that some of her fellow depositors received a signal in the upper dominance region, and therefore will certainly not run. For ε_{small} small enough, agent j will find it optimal to also stay, since the probability of success is so close to 1 and the risk of a run big enough to break the bank (because of depositors receiving lower signals) is so small. Therefore these dominance regions influence behavior potentially far from the regions themselves, since agents are taking into account the actions of their neighbors (fellow depositors receiving lower or higher signals), who are in turn taking into account the actions of their neighbors, and so on until the actions are consistent with the dominance regions. From this argument we arrive at the conclusion given by Theorem 1:

> *Theorem 1: the model has a unique equilibrium in which agents run if they observe a signal θ_{ij} below a threshold signal $\theta_i^*\,(r_1,\, r_2^*)$ and they do not run if they observe a signal above that.*

2.2.2 Proof

At $t = 1$, after depositors have received their own individual signal θ_{ij} as well as the bank management's signal θ_{bank}, they form a posterior distribution $\tilde{\theta}_{ij} \sim N\left(\frac{\theta_{ij}+\theta_{bank}}{2+\left(\sigma_{\varepsilon}^{2}/\sigma_{\theta}^{2}\right)}, \frac{\sigma_{\theta}^{2}\cdot\sigma_{\varepsilon}^{2}}{\sigma_{\varepsilon}^{2}+2\sigma_{\theta}^{2}}\right)$. I will call this $\tilde{\theta}_{ij} \sim N\left(\tilde{\mu}_{ij}, \tilde{\sigma}_{ij}^{2}\right)$ and denote the probability density function of the posterior as $\tilde{f}_{ij}(\theta)$. Therefore all depositors will have equal uncertainty $\hat{\sigma} = \hat{\sigma}_i \; \forall j$. The posterior of all agents will incoroproate the bank's weighted signal $\frac{\theta_{bank}}{2+\left(\sigma_{\varepsilon}^{2}/\sigma_{\theta}^{2}\right)}$ (in expectation this is zero). Note that this is why we made the technical assumption about the distribution of $\tilde{\theta}$ earlier.

Given r_2, r_1, D, E, γ, and λ, depositors calculate the *threshold quality* of the project, i.e. a value θ^* such that for posterior $\tilde{\theta}_{ij} \geq \theta^*$, depositor j will not run. A depositor's utility differential from staying with the bank versus running is given by

$$
\begin{aligned}
v(\theta, n) \;=\; & \hat{F}_i(\theta)\cdot u\left(min\left(r_1 r_2, \frac{(1+e)-\frac{n\cdot r_1}{\gamma}}{1-n}\cdot R_i\right)\right) + \\
& \left(1-\hat{F}_i(\theta)\right)\cdot u(0) \\
& -u(r_1) \;\; if\, \frac{(1+e)\gamma}{r_1} \geq n \geq \lambda \\
& \\
& 0 - \frac{(1+e)}{n\cdot r_1}\cdot u(r_1) \;\; if\, 1 \geq n \geq \frac{(1+e)\gamma}{r_1}
\end{aligned}
\tag{2.4}
$$

Because v is monotonically decreasing whenever it is positive, it satisfies one-sided strategic complementarities.

I seek to demonstrate the existence and uniqueness of an equilibrium by first showing that only a single unique threshold equilibrium exists. Then I will show that all equilibria of this game are threshold equilibria. Threshold equilibria mean equilibrium strategies in which all patient depositors run if their signal is below some common threshold $\theta^*$and do not run if they observe a signal above θ^*.

If I restrict solutions to threshold equilibria, I can consider a depositor j's *expected* utility differential at $t = 1$ given a posterior signal $\tilde{\theta}_{ij}$. I call this expectation function $\Delta^{ij}\left(r_1,\ r_2,\ \tilde{\theta}_{ij},\ \dot{\theta}\right)$, where $\dot{\theta}$ is assumed to be the common posterior threshold signal below which depositors run, and above which they stay. Given a posterior $\tilde{\theta}_{ij} > \dot{\theta}$, this means the expected value differential of staying rather than running is positive, (and for $\tilde{\theta}_{ij} < \dot{\theta}$, expected differential is negative). Note that agent j's posterior is distributed over $\tilde{\theta}_{ij} \sim N\left(\hat{\mu}_{ij},\ \hat{\sigma}_i^2\right)$, and therefore I can express the expected differential as:

$$\Delta^{ij}\left(r_1,\ r_2,\ \tilde{\theta}_{ij},\ \dot{\theta}\right) = \int_{\theta=-\infty}^{\infty} v\left(\theta,\ n\left(\theta,\ \dot{\theta}\right)\right) \cdot \tilde{f}_{ij}\left(\theta\right) d\theta \tag{2.5}$$

Where n is the proportion of agents who are liquidity constrained, as well as those who receive a signal $\tilde{\theta}_{ij} < \dot{\theta}$:

$$n\left(\theta,\ \dot{\theta}\left(r_1,\ r_2,\ \theta\right)\right) = \lambda + (1-\lambda) \cdot \int_{-\infty}^{\infty} 1_{\left\{\theta<\dot{\theta}\right\}} \cdot \dot{f}\left(\theta\right) d\theta \tag{2.6}$$

Because v is monotonically decreasing whenever positive, $\tilde{f}_i$ and $\dot{f}$ are weakly positive, and n is weakly increasing in $\dot{\theta}$, this means Δ^{ij} is monotonically decreasing in $\dot{\theta}$ and positive for $\dot{\theta} = -\infty$, negative for $\dot{\theta} = \infty$, and so by the single crossing property we have a unique equilibrium, given by threshold signal $\dot{\theta}$.

As a simplifying technique from the global games literature, I will focus on the cases where σ_ε is very close to 0. This means the function $n\left(\theta,\ \dot{\theta}\right)$ becomes a step function with value λ when $\theta \geq \dot{\theta}$ and 1 otherwise. This allows us to proceed by method of backward induction to investigate the optimal $t = 0$ choice of R_i by the bank.

2.3 Solving the Model: Backward Induction

Given a particular realization of the fundamental θ_i at $t = 1$, I can determine whether a bank run occurs, using the thresholding argument of Theorem 1. Working backwards, I can then say what the $t = 0$ *ex ante* likelihood is of observing a realization $\theta_i < \theta_i^* \left(r_1,\, r_2^*\right)$ which would cause a run. This then informs the bank's choice of r_1, the short-term deposit rate, and allows us to calculate the shareholders' (certainly patient agents') expected utility for a given level of risk choice R_i. From that shareholders are able to maximize their expected utility by choosing the optimal level of project risk R_i, and I as an observer can then comment on the social optimality of bank risk-taking as well as certain social planner policies that affect the bank's decisions such as bank capital requiremens, deposit insurance, and suspension of convertibility.

I can assume that all agents are rational and anticipate future actions, therefore I can seek to identify the bank's optimal choice of risk at $T = 0$ by backward induction:

Note that at $T = 1$, bank management offers $r_2\left(\theta,\ r_1\right)$ to maximize equity value:

$$\begin{aligned} r_2 &= min\, r_2 \\ s.t. &\quad depositors\, don't\, run \\ \Rightarrow r_2 \quad s.t. &\quad \theta^* = \theta_{observed} \end{aligned}$$

I get r_2 by solving indifference equation for $r_2^* \geq 1$–this sensibility constraint assumes intuitively that the bank won't offer negative interest, to carry intuition from an infinitely repeated game.

At $r_2 = r_2^*$, given a realization of θ, I have depositors (indifferently) choosing to stay with the bank and not run unless they are liquidity constrained–>$n = \lambda$ (assuming that $\epsilon \to 0$ so in the limit there is no uncertainty).

Given that knowledge about n when $r_2 = r_2^*$, this greatly simplifies our solution for r_2^*:

$$\begin{aligned} u(r_1) &= u(r_1 r_2^*) \; for\, riskless\, debt \left(\hat{F}_i(\theta) = 1\right) \to r_2^{*,riskless} = 1 \qquad (2.7) \\ &= \hat{F}_i(\theta) \cdot u(r_1 r_2^*) + \left(1 - \hat{F}_i(\theta)\right) \cdot u(0) \; for\, risky\, debt \\ \Rightarrow u(r_1 r_2^*) &= \frac{u(r_1)}{\hat{F}_i(\theta)} \\ \Rightarrow r_2^* &= u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta)}\right) \cdot \frac{1}{r_1} \end{aligned}$$

Now I can continue backwards induction to note that at $T = 0$:

$$\begin{aligned} E[r_2 \,|\, r_1] &= E\left[u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta)}\right) \cdot \frac{1}{r_1} \,|\, r_1\right] \\ &= \int_{\theta=-\infty}^{\infty} u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta)}\right) \cdot \frac{1}{r_1} \cdot f(\theta)\, d\theta \end{aligned}$$

I want to solve for $r_1(R_i)$, then I can solve for $R_{optimal}$ as a function of our parameters (most especially e, the capital ratio parameter). To do this, call $\underline{\theta}$ the lowest value of θ given r_1 s.t. the management can offer r_2^* to prevent a run–any realization of $\theta < \underline{\theta}$ will result in a run by the depositors. On the other hand, any realization $\theta > \underline{\theta}$ will not result in a run, because shareholders get 0 in the event of a run, and non-negative payoff if depositors do not run, so they will offer r_2 sufficiently high whenever possible. This allows us to express our solution of $r_1(R_i)$ more intuitively:

$$
\begin{aligned}
& E_{certainly\,patient}\left[u\left(deposit\right)\right] = E_{certainly\,patient}\left[u\left(equity\,shares\right)\right] \\
\Rightarrow\quad & prob\left(run\right)\cdot u\left(r_1\right)\cdot\frac{\left(1+e\right)\gamma}{r_i} + prob\left(success\bigcap no\,run\right)\cdot u\left(r_1 r_2\right) \\
=\quad & prob\left(success\bigcap run\right)\cdot u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^{+}R_i}{e}\right) + prob\left(success\bigcap no\,run\right)\cdot u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-\left(1-\lambda\right)}{e}\right. \\
\Rightarrow\quad & F\left(\theta^*\right)\cdot u\left(r_1\right)\cdot\frac{\left(1+e\right)\gamma}{r_1} + u\left(r_1 r_2\right)\cdot\left(1-F\left(\theta^*\right)\right)\cdot\int_{\theta=\theta^*}^{\infty}\hat{F}\left(\theta\right)f\left(\theta\right)d\theta \\
=\quad & \left(1-F\left(\theta^*\right)\right)\cdot\int_{\theta=\theta^*}^{\infty}u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-\left(1-\lambda\right)r_1 r_2}{e}\right)\hat{F}\left(\theta\right)f\left(\theta\right)d\theta \\
& +F\left(\theta^*\right)\cdot u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^{+}R_i}{e}\right)\cdot\int_{\theta=-\infty}^{\theta^*}\hat{F}\left(\theta\right)f\left(\theta\right)d\theta
\end{aligned}
$$

Therefore r_1 is simply the solution to the above equation–although the analytical solution is not readily tractable, the numerical solution is straightforward.

I've been using $\bar{\theta}$ without fully defining it; now is an appropriate point to do that. I definedθ^* as the minimum realization of θ at which the bank shareholders can credibly promist r_2 high enough to stop a run. In other words, this means the value of θ at which

$$
\begin{aligned}
r_1 r_2^*\left(\theta^*,\, r_1\right) &= \frac{\left(1+e\right)-\frac{\lambda r_1}{\gamma}}{1-\lambda}R_i \\
\Rightarrow r_2^*\left(\theta^*,\, r_1\right) &= \frac{\left(1+e\right)-\frac{\lambda r_1}{\gamma}}{1-\lambda}\frac{R_i}{r_1}
\end{aligned}
$$

And using our previous solution for $r_2^*(\theta, r_1)$, I can express this as

$$u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta^*)}\right)\cdot\frac{1}{r_1}=\frac{(1+e)-\frac{\lambda r_1}{\gamma}}{1-\lambda}\frac{R_i}{r_1}$$

and solve for θ^*:

$$\begin{aligned}\hat{F}_i(\theta^*)\cdot u\left(\frac{(1+e)-\frac{\lambda r_1}{\gamma}}{1-\lambda}R_i\right) &= u(r_1)-\left(1-\hat{F}(\theta^*)\right)\cdot u(0)\\ \Rightarrow \hat{F}_i(\theta^*) &= \frac{u(r_1)}{u\left(\frac{(1+e)-\frac{\lambda r_1}{\gamma}}{1-\lambda}R_i\right)}\\ \Rightarrow \theta^* &= \hat{F}_i^{-1}\left(\frac{u(r_1)}{u\left(\frac{(1+e)-\frac{\lambda r_1}{\gamma}}{1-\lambda}R_i\right)}\right)\end{aligned}$$

Now I can use θ^* to calculate r_1 given R_i (from above):

$$\begin{aligned}0 &= \left[F(\theta^*)\cdot u(r_1)\cdot\frac{(1+e)\gamma}{r_1}+u(r_1r_2)\cdot(1-F(\theta^*))\cdot\int_{\theta=\theta^*}^{\infty}\hat{F}(\theta)f(\theta)\,d\theta\right]\\ &\quad-(1-F(\theta^*))\cdot\int_{\theta=\theta^*}^{\infty}u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-(1-\lambda)r_1r_2}{e}\right)\hat{F}(\theta)f(\theta)\,d\theta\\ &\quad-F(\theta^*)\cdot u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^+R_i}{e}\right)\cdot\int_{\theta=-\infty}^{\theta^*}\hat{F}(\theta)f(\theta)\,d\theta\\ &= F(\theta^*)\cdot u(r_1)\cdot\frac{(1+e)\gamma}{r_1}+u(r_1)(1-F(\theta^*))^2\\ &\quad-\int_{\theta=\theta^*}^{\infty}\left[F(\theta^*)\cdot u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^+R_i}{e}\right)+(1-F(\theta^*))\cdot u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-(1-\lambda)\cdot u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta^*)}\right)}{e}\right)\right]\hat{F}(\theta)f(\theta)\end{aligned}$$

Note that $u(r_1)$ is an increasing function of r_1, $F(\theta^*)$ is an increasing function of r_1, $u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^+R_i}{e}\right)$ and

$u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-(1-\lambda)\cdot u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta^*)}\right)}{e}\right)$ are both decreasing functions of r_1, and $\frac{u(r_1)}{r_1}$ is a decreasing function of r_1. Therefore a uniques solution for r_1 can be shown to exist. The root of the backward induction problem is thus the optimal selection of R_i, the risk parameter, by bank shareholders.

Atomistic bank shareholders seek to maximize their expected utility:

$$\begin{aligned} R^* &= \underset{R_i}{argmax} E_{certainly\, patient}\left[u\left(shares\right)\right] \\ s.t. &\quad R \leq R_i\left(assumed\, risk\, boundaries\right) \end{aligned}$$

Where

$$T = 2\, shareholder\, consumption = max\left(\frac{\left(1+e-\left(\frac{nr_1}{\gamma}\right)\right)\cdot OUTCOME-(1-n)\cdot r_1r_2}{e}, 0\right)$$

Thus the problem for shareholders becomes:

$$\begin{aligned} R^* &= \underset{R_i}{argmax} E\left[u\left(\left(\frac{\left(1+e-\left(\frac{nr_1}{\gamma}\right)\right)\cdot OUTCOME-(1-n)\cdot r_1r_2}{e}\right)^+\right)\right] \\ &= \underset{R_i}{argmax}\int_{\theta=-\infty}^{\infty}[u\left(\left(\frac{\left(1+e-\left(\frac{nr_1}{\gamma}\right)\right)\cdot R_i-(1-n)\cdot r_1r_2}{e}\right)^+\right)\cdot\hat{F}_i\left(\theta\right) \\ &\quad +u\left(0\right)\cdot\left(1-\hat{F}_i\left(\theta\right)\right)]\cdot f\left(\theta\right)d\theta \\ &= \underset{R_i}{argmax}\int_{\theta=-\infty}^{\infty}\left[u\left(\left(\frac{\left(1+e-\left(\frac{nr_1}{\gamma}\right)\right)\cdot R_i-(1-n)\cdot r_1r_2}{e}\right)^+\right)\cdot\hat{F}_i\left(\theta\right)\right]\cdot f\left(\theta\right)d\theta \\ &(s.t.\quad 0\leq R\left(assumed\, risk\, boundaries\right)) \end{aligned}$$

Where of course n is a function of θ, r_1, $and\, r_2$, r_2 is a function of $\theta\, and\, r_1$, and r_1 is a (formidable) function of R_i. While this problem is still analytically difficult, numerically it is now tractable.

2.4 Social Welfare Implications–the Viability of Banks

A social welfare planner seeking to maximize the total welfare of all agents in the economy can consider at least three forms of risk-sharing besides autarky. The "coinsurance" form arises from a Diamond-Dybvig type model where there are no certainly patient depositors. The "coinsurance for uncertain agents, mutual fund for certain agents" line of proposals put forward by Admati (2013) and others, where banks would be completely equity-financed and therefore could share some of the characteristics of a private equity firm or mutual fund. My model exhibits welfare tradeoffs between the liquidity risk sharing of these otehr models, and endogenous portfolio risk sharing between bank shareholders and depositors.

I earlier established that in autarky, aggregate expected utility can be expressed as

$$\lambda \cdot u\left(\gamma\right) + \left(1 + e - \lambda\right) \cdot u\left(R_i\right) \cdot \hat{F}_i\left(\mu_{signal} = 0\right)$$

$$= \lambda \cdot u\left(\gamma\right) + \left(1 + e - \lambda\right) \cdot R$$

where $\forall i,\ R = u\left(R_i\right) \cdot \hat{F}_i\left(0\right) > u\left(\gamma\right)$ is the expected return on any risky investment (I had adjusted $\mu_i | R_i$ to make that the case $\forall i$).

Theorem 2: Banks provide greater social welfare than autarky for $\frac{R}{\gamma}$ *sufficiently large.*

Given an initial ratio of e certainly patient agents for each uncertain agent, and asset expected returns R, I can infer first that the bank will choose project i with promised successful payout R_i, and I can express the aggregate expected utility of agents as

$$F\left(\theta_i^*\right)\cdot\left(u\left(r_1\right)\cdot min\left(1,\,\frac{\left(1+e\right)\gamma}{r_1}\right)+u\left(\frac{max\left(0,\,1+e-\frac{r_1}{\gamma}\right)}{e}R_i\right)\right) \tag{2.8}$$

$$+F\left(\theta_i^*\right)\cdot\left(e\cdot\int_{\theta=-\infty}^{\theta_i}u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^{+}R_i}{e}\right)\hat{F}_i\left(\theta\right)f\left(\theta\right)d\theta\right) \tag{2.9}$$

$$+\left(1-F\left(\theta_i^*\right)\right)\cdot\left(\lambda\cdot u\left(r_1\right)+\left(1-\lambda\right)\cdot\int_{\theta=\theta_I^*}^{\infty}u\left(r_1r_2\right)\cdot\hat{F}_i\left(\theta\right)f\left(\theta\right)d\theta\right)$$

$$+\left(1-F\left(\theta_i^*\right)\right)\cdot\left(e\cdot\int_{\theta=\theta_i^*}^{\infty}u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-\left(1-\lambda\right)r_1r_2}{e}\right)\hat{F}_i\left(\theta\right)f\left(\theta\right)d\theta\right)$$

The second-period deposit rate r_2 is chosen by the bank to me the minimum $r_2>1$ given the bank's signal about project quality $\theta_{i,\,bank}$ that will prevent a run. First-period deposit rate r_1 is chosen competitively by the bank such that $E_{certainly\,patient}\left[u\left(deposit\right)\right]=E_{certainly\,patient}\left[u\left(equity\,shares\right)\right]$, by our constraing on bank rent extraction. This implies $r_1>\gamma$, i.e. there is risk-sharing offered by the certainly patient shareholders to the uncertain depositors. I also note that $F\left(\theta_i^*\right)$–the *ex ante* probality of a run–is a decreasing function of the risk premium R, because $\hat{F}_i\left(\cdot\right)$ is an increasing function of R and therefore θ_i^* is a decreasing function of R. Similarly, I also note that run probability $F\left(\theta_i^*\right)$ decreases when the liquidation value γ of assets decreases–depositors become "trapped" by the prospect of withdrawing early and the expected payoff from running on the bank decreases. Therefore, as R increases, the weight on the first main term in Eq. (7) decreases. As $R\to\infty$, the equation for aggregate social welfare becomes

$$\left(\lambda \cdot u\left(r_{1}\right)+(1-\lambda) \cdot \int_{\theta=-\infty}^{\infty} u\left(r_{1} r_{2}\right) \cdot 1 \cdot f(\theta)\, d\theta+e \cdot \int_{\theta=-\infty}^{\infty} u\left(\frac{\left(1+e-\frac{\lambda r_{1}}{\gamma}\right) R_{I}-(1-\lambda) r_{1} r_{2}}{e}\right) \cdot 1 \cdot f(\theta)\, d\theta\right)$$

Additionally, I note that as $F\left(\theta_{I}^{*}\right) \rightarrow 0$, $E\left[r_{2}\right]$ must go to 1, because the expected payoff to a depositor from waiting will come to dominate the payoff from running. At the same time, r_1 must increase to make $u\left(r_{1} r_{2}\right)=u\left(\frac{\left(1+e-\frac{\lambda r_{1}}{\gamma}\right) R_{I}-(1-\lambda) r_{1} r_{2}}{e}\right)$, again because of the competition constraint on r_1 mentioned earlier. As $E\left[r_{2}\right] \rightarrow 1$, this means $E\left[u\left(r_{1} r_{2}\right)\right] \rightarrow u\left(r_{1}\right)$, and therefore aggregate welfare under a bank becomes

$$\left(\lambda \cdot u\left(r_{1}\right)+(1-\lambda) \cdot u\left(r_{1}\right)+e \cdot u\left(r_{1}\right)\right)=(1+e) \cdot u\left(r_{1}\right)$$

Because the aggregate *payoff* under a bank is the same as under autarky–a portion of exactly λ depositors withdraw early–the total aggregate consumption in either case is $\lambda \cdot \gamma+(1+e-\lambda) \cdot R_{i}$. However, aggregate utility must be higher with a bank than with autarky: consumption utility preferences are concave, and the bank offers each agent r_1 in the limit, whereas autarky doesn't allow for equalizing payoffs. Thus there is clearly a set of parameters where banking is viable, and I can explore the dimensions of this set using numerical simulations, as well as compare mixed-capital structure banks with all-equity banks. Because the Diamond-Dybvig model does not admit a unique equilibrium, we will refrain from comparison directly, but we will examine the effectiveness of stabilizing measures mentioned in that paper.

[H]

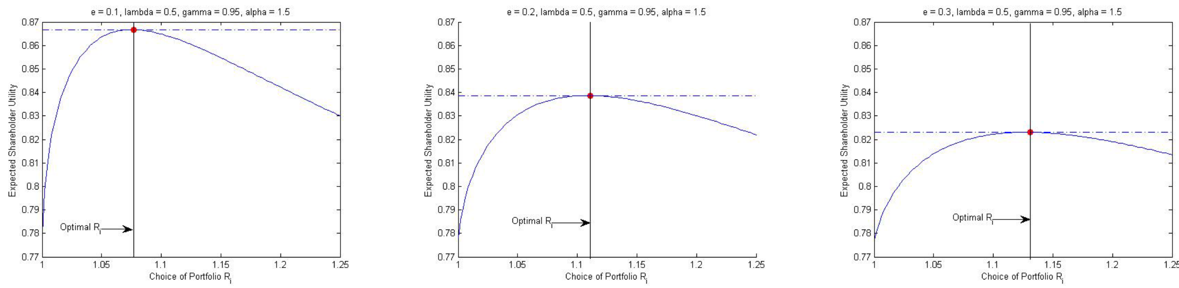

Figure 2.1. Optimal Portfolio Choice When Capital Ratio Increases

The horizontal axis shows a given level of portfolio risk (R_i). The vertical axis shows an individual shareholder's expected utility at $t = 0$ from taking that level of risk. From left to right, each subfigure increases the ratio of equity in the bank's capital structure, from 10%, to 20%, to 30%. The choice of risk which maximizes shareholder expected utility is highlighted in each figure. This optimal risk choice R_i increases as the capital ratio increases (left to right), indicating shareholders prefer riskier portfolios as capital increases

2.5 Simulation Results

For equity holders, simulation results verify that there is an optimal choice of risk, which depends on the bank's level of capital. As the bank becomes better capitalized, it takes on more risk in absolute terms (R_i increases):

However the per-shareholder risk $\frac{R_i}{e}$ is declining in e. This means that although absolute portfolio risk increases, the probability of a run decreases, and the bank is safer:

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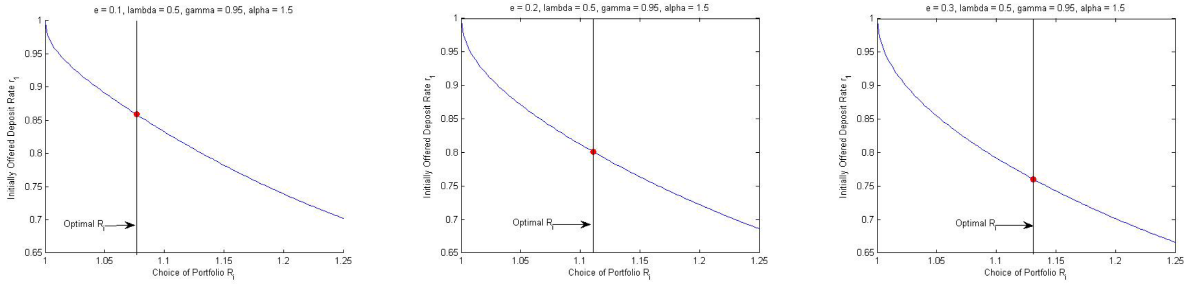

Figure 2.5. Initial Deposit Rate When Capital Ratio Increases

The horizontal axis shows a given level of portfolio risk (R_i). The vertical axis shows the 1-period deposit rate offered by the bank to depositors at $t = 0$ (r_1). From left to right, each subfigure increases the ratio of equity in the bank's capital structure, from 10%, to 20%, to 30%. The choice of risk which maximizes shareholder expected utility is highlighted in each figure. This optimal risk choice R_i increases as the capital ratio increases (left to right), however the deposit rate r_1 decreases, indicating less risk-sharing between shareholders and depositors.

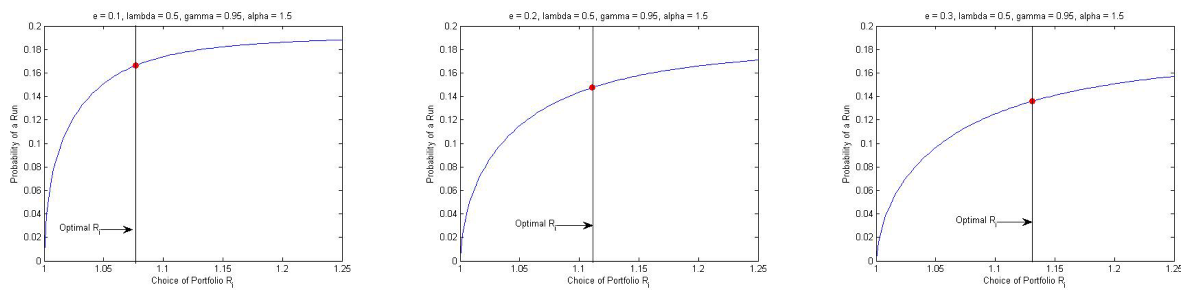

Figure 2.3. Probability of a Run When Bank Capital Ratio Increases

The horizontal axis shows a given level of portfolio risk (R_i). The vertical axis shows the ex ante ($t = 0$) probability of a run at $t = 1$ from taking that level of risk. From left to right, each subfigure increases the ratio of equity in the bank's capital structure, from 10%, to 20%, to 30%. The choice of risk which maximizes shareholder expected utility is highlighted in each figure. This optimal risk choice R_i increases as the capital ratio increases (left to right), however the ex ante level of run risk is actually decreasing.

One key interaction that remains to be discussed is the actual liquidity insurance provision that I expressed by the deposit rate r_1. As bank equity increases, depositors will receive less promised payment r_1, because they are more likely to be repaid by shareholders.

Therefore the amount of ex-ante risk-sharing among financial agents has decreased.

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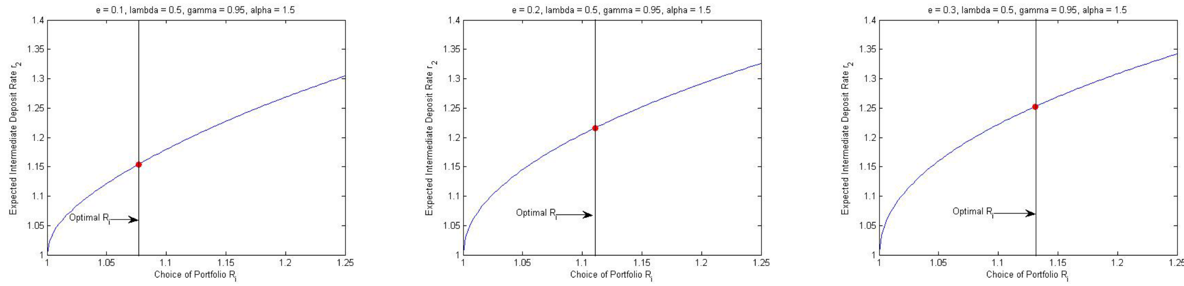

Figure 2.7. Expected Second-Round Deposit Rate When Capital Ratio Increases

The horizontal axis shows a given level of portfolio risk (R_i). The vertical axis shows the 1-period deposit rate offered by the bank to depositors at $t = 1$ (r_2). From left to right, each subfigure increases the ratio of equity in the bank's capital structure, from 10%, to 20%, to 30%. The choice of risk which maximizes shareholder expected utility is highlighted in each figure. This optimal risk choice R_i increases as the capital ratio increases (left to right), and the deposit rate r_2 increases as well. This allows equity owners to share portfolio risk with long-lived depositors, who no longer face liquidity risk.

Because the portfolio has become more risky in absolute terms, the intermediate deposit rate r_2 will rise as equity rises. This means risk-sharing now occurs at the intermediate stage rather than the initial stage: at $t = 0$ the shareholders bear more run risk, but they get funded with a lower deposit rate r_1. At $t = 1$, the shareholders are then able to share greater risk with the remaining depositors, who now are homogeneous agents with the equity holders (both are "long-lived" agents) and are only distinguished by the contracts they hold. Thus having greater equity capital allows the bank to better separate liquidity risk from portfolio risk, which is an interesting finding.

In terms of expected social welfare, however, I see that the socially optimal choice of risk is less than the level of risk chosen by shareholders:

Therefore, the bank is able to extract private benefits that reduce overall utility by taking excessive risk.

I can instead briefly turn our attention to the earlier-stage problem of this game: the optimal level of *bank capital*. Given that the social planner cannot restrict the level

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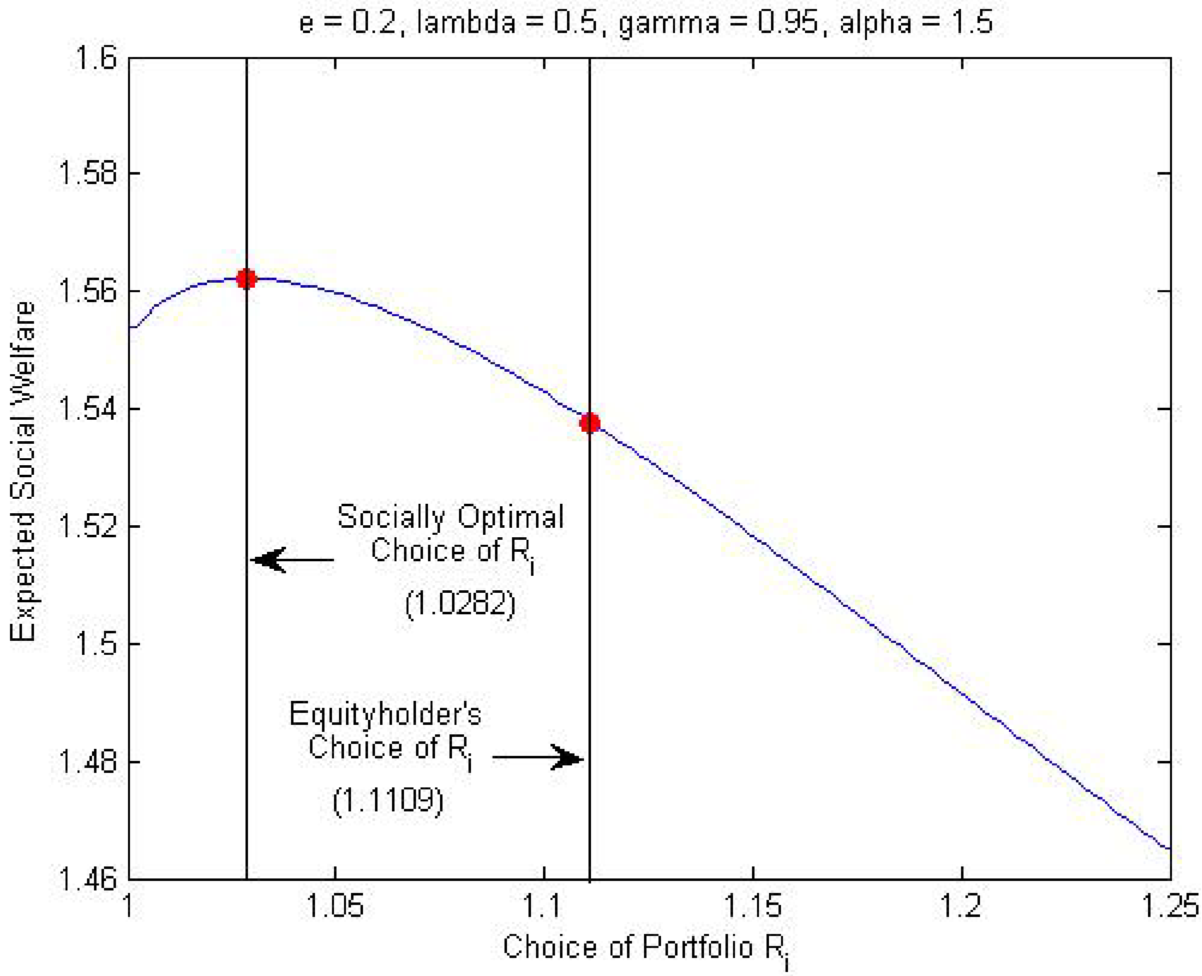

Figure 2.9. Expected Social Welfare For A Given Level of Capital

The horizontal axis shows a given level of portfolio risk (R_i). The vertical axis shows the expected social welfare (from both equity owners and depositors) from a bank's choice of portfolio risk R_i. The level of bank equity capital is fixed at 20%. The choice of risk which maximizes shareholder expected utility is highlighted, as well as the choice of risk which would maximize social welfare. This optimal risk choice R_i is greater for shareholders than for society as a whole.

of portfolio risk taken by the bank, the social planner can still seek for a "second-best" outcome by requiring a certain level of bank capital, which will then naturally produce a certain level of portfolio risk by the bank. Therefore the social planner faces a trade-off: as we saw, greater equity leads to greater portfolio risk choice R_i and greater period 1 risk-sharing through deposit rate r_2. However, r_1 falls, meaning what I observe is less liquidity risk-sharing (which is captured in the r_1 term only, since at $t = 1$ there is no longer any unrealized liquidity risk). Thus a greater level of equity brings less liquidity risk-sharing and more portfolio risk-sharing. It is the tradeoff between these two factors that gives us an optimal level of bank capital. Below we plot the normalized expected social welfare (normalized to account for the changing asset base $(1 + e)$ as e increases):

Interestingly, a low capital ratio can be better than a higher capital ratio. This is because for low levels of bank capital, the bank is well-disciplined by depositors, and chooses a level of portfolio risk closer to the social optimum. Additionally, it offers a higher r_1, meaning greater liquidity risk insurance provided by the bank to depositors. While there is less portfolio risk-sharing at low levels of equity, the overall effect is higher social welfare. At very high levels of equity capital, very little liquidity risk sharing occurs, but the bank shareholders are able to extract more value from the limited liability put option by taking greater portfolio risk.

2.6 Optimal Bank Regulation Policies'

I consider the social welfare implications of a capital subsidy, which can be thought of either in the form of underpriced deposit insurance or a too-big-to-fail implicit government backing

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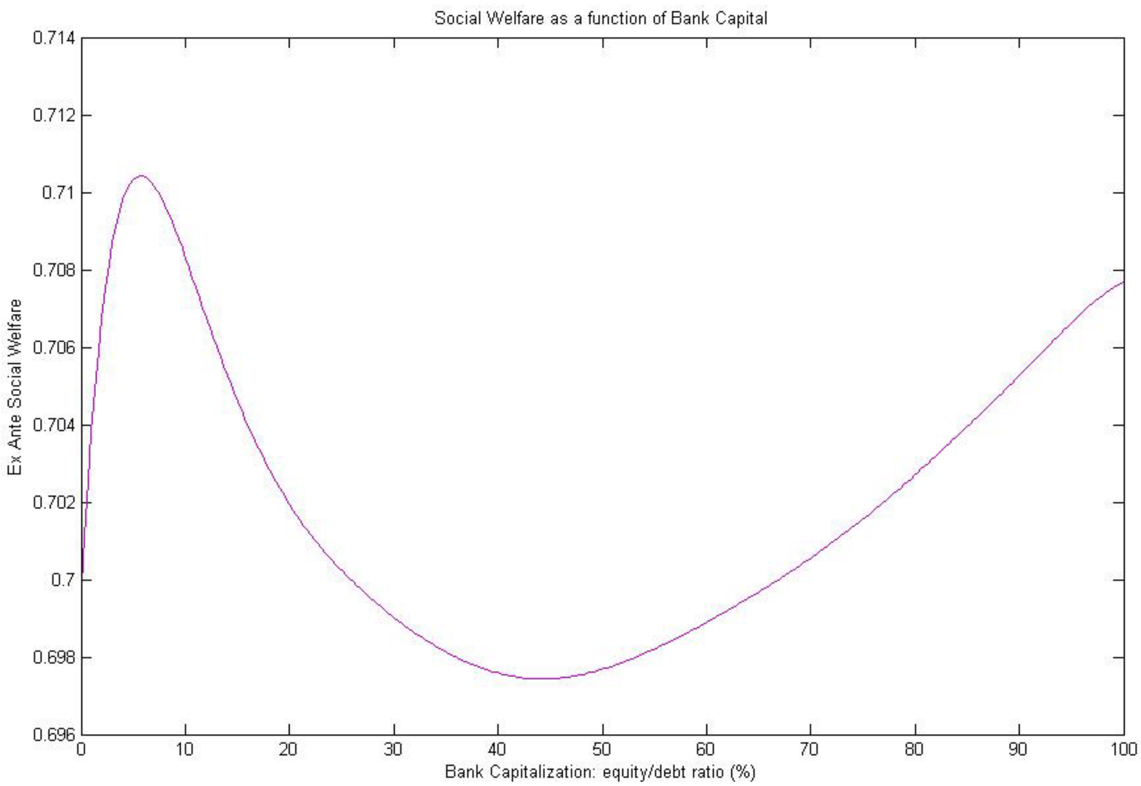

Figure 2.10. Expected Social Welfare When Capital Ratio Increases

The horizontal axis shows a given capital ratio, which varies from ε% to (100-ε)%. The vertical axis shows the expected social welfare (from both equity owners and depositors) from a bank's choice of portfolio risk R_i, that shareholders will rationally choose given a level of equity.

of the banking sector. I will also in a later iteration consider the effects of suspension of convertibility on social welfare.

DEPOSIT INSURANCE/CAPITAL SUBSIDY:

Under a capital subsidy, depositors see the bank as having more capital than they actually have raised through shareholders. However, the bank clearly can't use it's "phantom capital" to increase its portfolio size, it can only exploit this capital through the value it has in the eyes of depositors. We can call the total level of capital observed by depositors $e_{total} = e_{shares} + e_{subsidy}$. Clearly, the role in our model of a capital subsidy is to reduce the likelihood of a run on the bank. For a given level of risk R_i, the threshold signal decreases from $\theta_i^* = \hat{F}_i^{-1}\left(\frac{u(r_1)}{u\left(\frac{(1+e_{shares})-\frac{\lambda r_1}{\gamma}}{1-\lambda}R_i\right)}\right)$ to

$$\theta^*_{i,\,capital\,subsidy} = \hat{F}_i^{-1}\left(\frac{u(r_1)-min\left(1,\frac{equity\,subsidy}{r_1}\right)\cdot u(r_1)}{u\left(\frac{(1+e_{shares})-\frac{\lambda r_1}{\gamma}}{1-\lambda}R_i\right)-min\left(1,\frac{equity\,subsidy}{r_1}\right)\cdot u(r_1)}\right).$$

Because the denominator increases, the fraction inside decreases, which makes $\hat{F}_i^{-1}(\cdot)$ decrease, because $\hat{F}_i(\cdot)$ is an increasing function of θ. Therefore, the threshold required signal decreases, which means $F(\theta_i^*)$, the likelihood of a run, decreases when a capital subsidy is introduced. Below we can see simulation results for a capital subsidy of 10% of deposits, as the level of actual equity/deposits increases from 10% to 30%:

When I allow the social planner to (costlessly) offer deposit insurance, we see that the bank clearly engages in moral hazard and takes more portfolio risk, beyond the socially optimal amount.

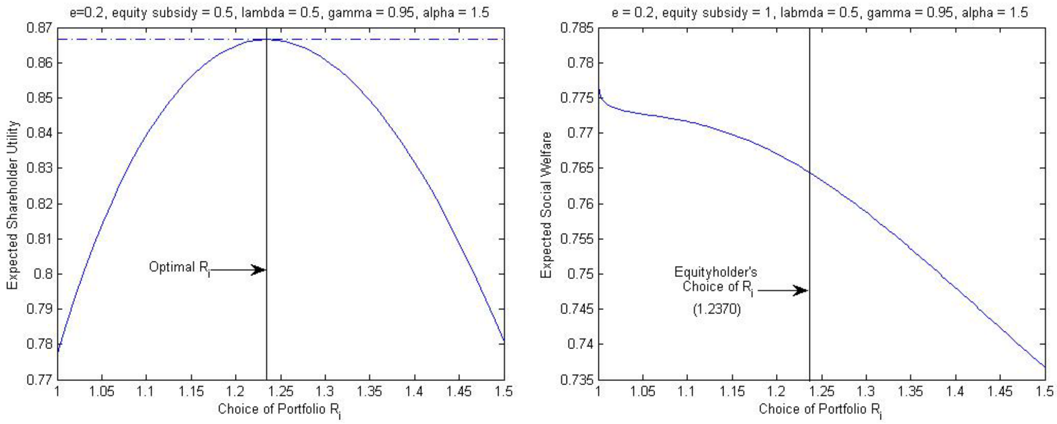

Figure 2.11. Choice of Risk and Social Welfare with Significant Deposit Insurance

The horizontal axis in both subfigures shows a given level of portfolio risk (R_i). In the left subfigure, the vertical axis shows an individual shareholder's expected utility at $t = 0$ from taking that level of risk. The right subfigure shows the expected social welfare (from both equity owners and depositors) from a bank's choice of portfolio risk R_i, when the capital ratio is fixed at 20% and deposit insurance is fixed at 50%. The choice of risk which maximizes shareholder expected utility is highlighted in each figure.

2.7 Conclusion

I find that banks can be a *viable* institution, meaning they improve social welfare over autarky. As the level of bank capital increases, banks take on more portfolio risk and provide less liquidity insurance to depositors. At the intermediate stage of the game $t = 1$ when remaining depositors now know they do not face a liquidity shock, shareholders engage in welfare-improving risk-sharing with the remaining depositors. The main source of welfare loss as the ratio of shareholders to depositors increases is the reduction in liquidity provision that short-term depositors suffer, as well as risk-shifting by shareholders taking additional portfolio risk.

Further research from this model could include accounting for the transmission of financial panics to the real sector, to quantify additional costs of a bank run. Additionally, one could explore the pricing of deposit insurance in this particular model, as well as the social cost of limited liability, to better measure the tradeoffs between different bank regulation policies. I leave it to future papers to seek to tie this strain of bank run literature to the contributions of Diamond & Rajan (2000) concerning bank information rents and negotiating strength and their influence on the optimal level of bank capital. Given the prevalent and growing need for credit, liquidity, and maturity transformation that is being witnessed in world markets today, this type of analysis could also be of use in understanding the dynamics of other short-term funding markets such as repurchase agreements, money-market mutual funds, and the non-traditional financial intermediation that has been termed "shadow banking." The interaction of liquidity demanders and suppliers is not confined solely to the banking sector, and effective modern policy would do well by seeking to regulate the features of contracts such as demand deposits, rather than only addressing sets of institutions. Effective regulation should understand that capital requirements are not without potential downsides when economic agents are allowed to be strategic.

Additional Repo Market Information

A.1. Window Dressing and Lehman's Repo 105 Scheme

When financial institutions such as banks must report results on a predictable quarterly schedule, they may be tempted to alter their portfolio just before the period ends to appear safer or more profitable than they really are. This practice is called window dressing, after the way retail shops stage their store windows to attract customers. For example, if a bank's capital requirement is assessed against its end-of-quarter portfolio of assets, that bank can sell assets at the end of the quarter so it can operate with less equity. This also boosts the bank's return on equity and earnings per share, which can increase the share price or bring management bigger bonuses.

If most banks window dress their quarter-end financial statements, rational investors and regulators might simply assume all banks are gaming their disclosures, and filter out the window dressing so share prices are unaffected. This would penalize banks that do not window dress (but are assumed to), so window dressing becomes a dominant strategy. However, the practice is harmful because regulators need accurate information in order to protect shareholders and monitor effectively, and window dressing makes it more difficult to detect an emerging systemic risk. During the 2007–08 subprime mortgage crisis, Lehman Brothers used window dressing to hide risk in a bid to stay alive that ultimately jeopardized the entire financial system.

On September 10, 2008, rating agency Moody's Investor Services, Inc. threatened to downgrade Lehman Brothers' credit rating after several potential buyers walked away from a deal with Lehman, and after Lehman announced a projected $3.9 billion loss for the quarter. Lehman's stock price immediately collapsed by 42%, and by the end of the week, it was unable to find lenders willing to roll over its $150 billion of overnight tri-party repo financing. On September 15, Lehman filed for bankruptcy, with $639 billion in assets, making it the largest bankruptcy in history. Lehman's bankruptcy caused the Reserve Primary money market fund to "break the buck," which in turn triggered a run on money markets that threatened the entire U.S. financial system and required unprecedented government intervention. In a subsequent bankruptcy report led by special examiner Anton Valukas, Lehman's chief executive Richard Fuld revealed that "rating agencies were particularly focused on net leverage; Lehman knew it had to report favorable net leverage numbers to maintain its ratings and confidence."

In order to present a low leverage ratio despite mounting losses over the prior year, Lehman had resorted to a now-notorious scheme called "Repo 105." In Repo 105, Lehman would accept a 5% haircut on fixed-income assets it pledged as collateral in a repurchase agreement that extended across the end of a quarter, and then buy back those same assets once the new quarter began. Because of the high (and therefore expensive) haircut, Lehman was able to account for the transaction as a "true sale" instead of financing. This reduced Lehman's reported balance sheet by as much as $50 billion—reducing reported net leverage from 13.9 to 12.1 for the second quarter of 2008.

Lehman had not disclosed its use of Repo 105 to regulators, rating agencies, investors, or even its own board of directors. When the Valukas report revealed the practice, the SEC conducted an inquiry of 24 U.S. public financial institutions and concluded that Lehman's window dressing was an isolated case. However, using confidential regulatory data on U.S.

tri-party repurchase agreements since July 1, 2008, I show that a very similar form of window dressing continues to occur every quarter among non-U.S. banks: every quarter end, roughly $170 billion of banks' most liquid assets are pulled out of repo, and then immediately brought back once a new quarter begins (see Figure 20). To give some perspective, that is over half the value of primary dealers' net positions, and over three times the window dressing done by Lehman.

A.0.1 Enlarged Charts

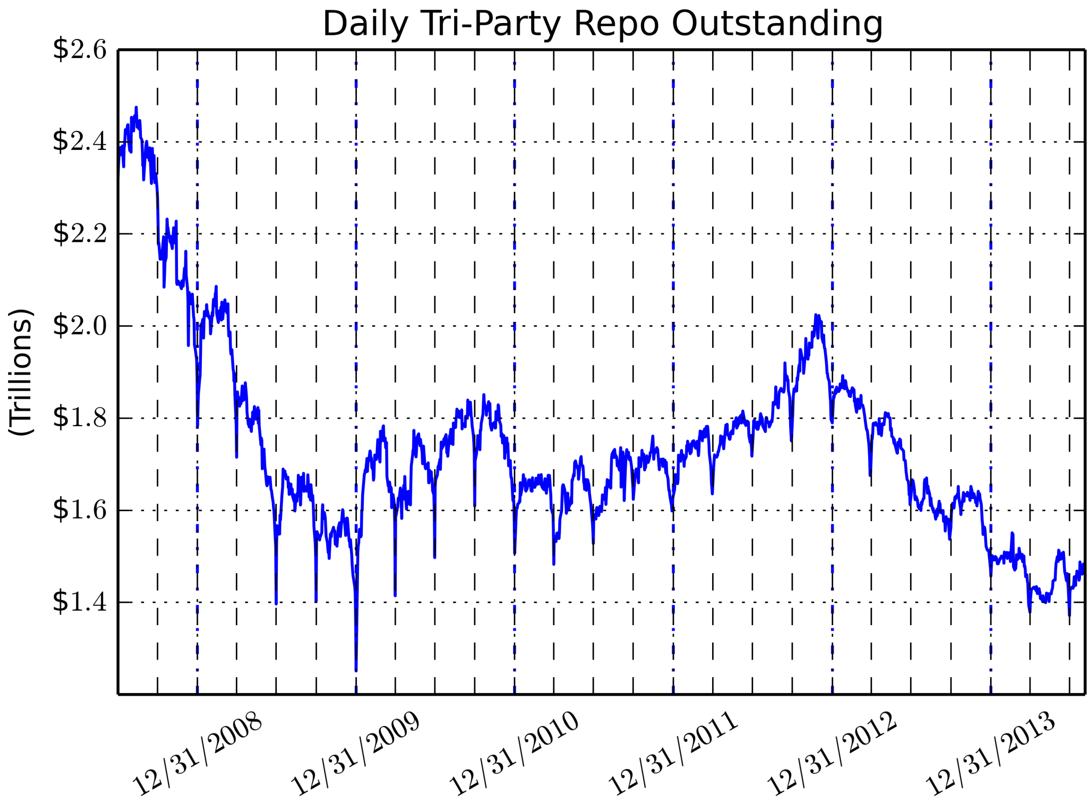

Figure 12. Daily Tri-Party Repo Outstanding

The vertical axis represents the value in trillions of dollars of collateral outstanding pledged in repo each day from July 1, 2008, to July 31, 2014. Quarter-ends are marked with vertical dashed lines, and year-ends are marked with heavier dash-dotted lines. I exclude repo borrowing by the Federal Reserve Bank of New York. Furthermore, I exclude the dates of 7/17/2008 and 4/11/2013, because of missing data from one of the clearing banks.
Source: Federal Reserve Board of Governors

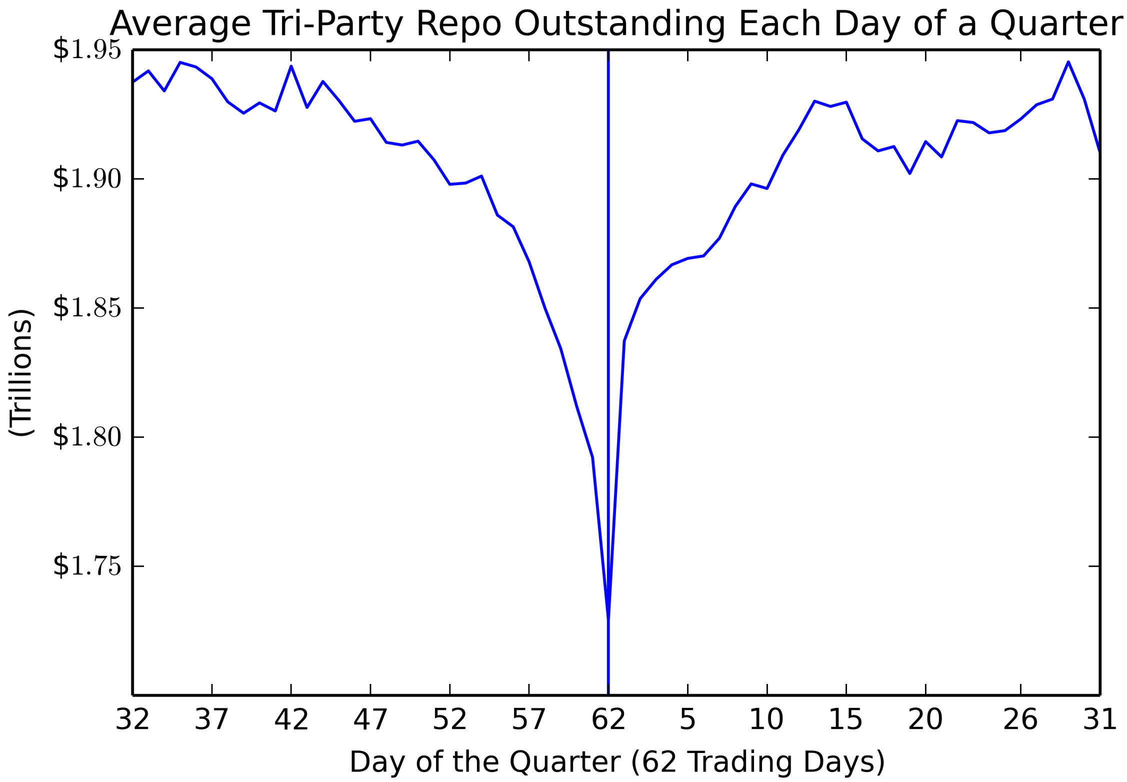

Figure 13. Average Tri-Party Repo Outstanding Each Day of a Quarter

This figure represents the average daily repo outstanding over the course of a single quarter. The average quarter has 62 trading days, and I position the end of the quarter (marked by a vertical line) in the middle of the figure to highlight the quarter-end decline and subsequent rebound of repo borrowing. The vertical axis represents the market value of collateral in trillions of dollars.
Source: Federal Reserve Board of Governors

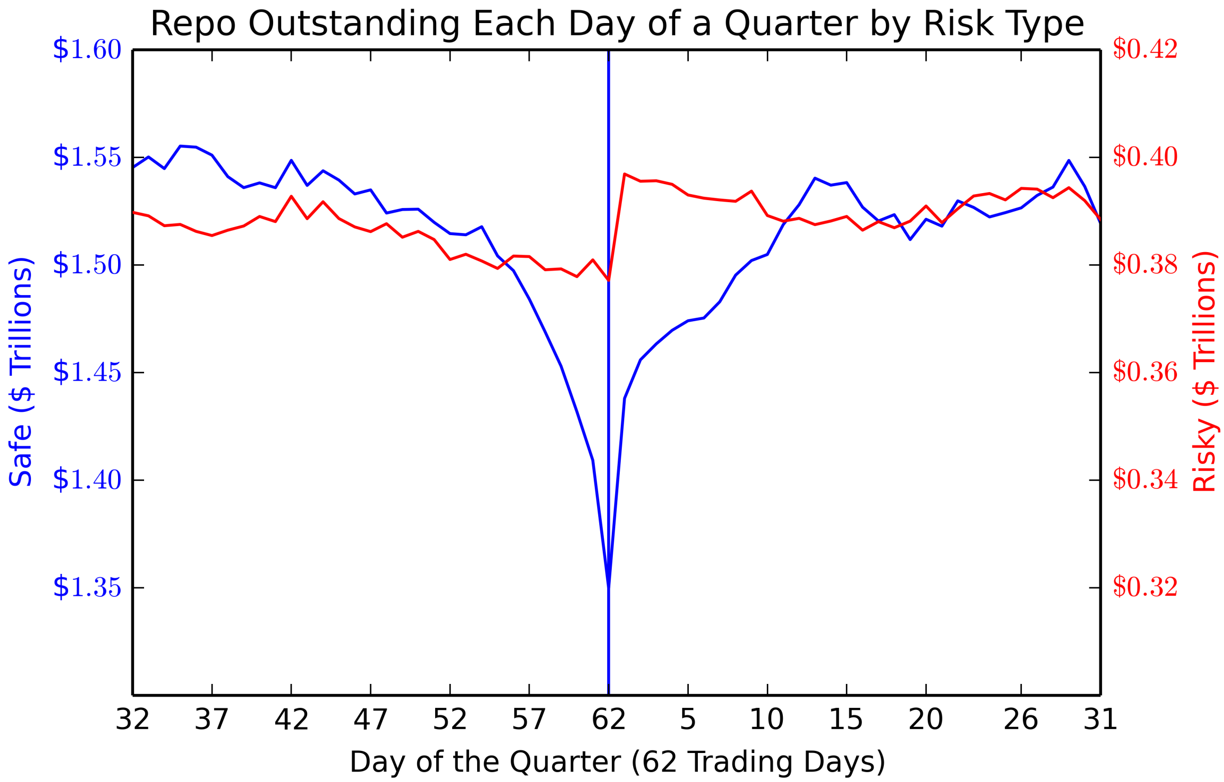

Figure 14. Repo Outstanding Each Day of a Quarter, by Type of Collateral

I separate the average repo outstanding over a single quarter by type of collateral. The solid blue line uses the left axis, and represents average repo borrowing backed by fed-eligible collateral: U.S. Treasuries, agency debentures, and agency mortgage-backed securities, and agency collateralized mortgage obligations. The dotted red line uses the right axis and represents average repo borrowing backed by all other types of collateral. Both axes are in trillions of dollars.
Source: Federal Reserve Board of Governors

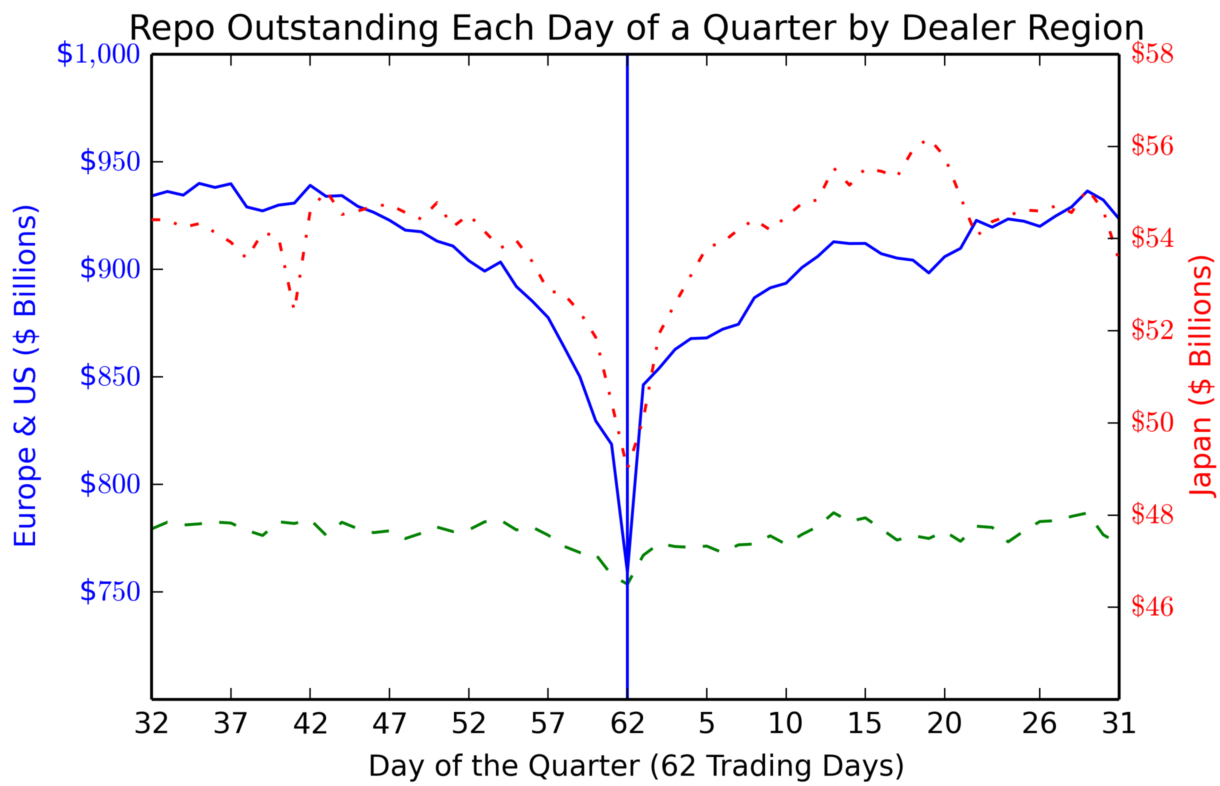

Figure 15. Repo Outstanding Each Day of a Quarter by Dealer Region

This figure presents the average repo outstanding over a single quarter separated by the region of the repo cash borrower (i.e., the dealer that is pledging collateral in the repo). The left and right axes are both in billions of dollars. I exclude non-bank dealers from this subplot. The dotted green line represents repo borrowing by U.S. bank dealers, and can also be distinguished by its distinct behavior: this line touches the left axis at roughly $780 billion and does not dip as markedly as the other two lines at the end of the quarter. The solid blue line represents repo borrowing by European bank dealers. Both U.S. and European bank dealer repo borrowing are in reference to the left axis. The dashed red line shows Japanese bank dealer repo borrowing, and because Japanese bank dealers are a much smaller segment of the repo market, I plot their line using the right axis.
Source: Federal Reserve Board of Governors

Solving the bank runs model by backward induction

Given a particular realization of the fundamental θ_i at $t = 1$, I can determine whether a bank run occurs, using the thresholding argument of Theorem 1. Working backwards, I can then say what the $t = 0$ *ex ante* likelihood is of observing a realization $\theta_i < \theta_i^* (r_1,\, r_2^*)$ which would cause a run. This then informs the bank's choice of r_1, the short-term deposit rate, and allows us to calculate the shareholders' (certainly patient agents') expected utility for a given level of risk choice R_i. From that shareholders are able to maximize their expected utility by choosing the optimal level of project risk R_i, and I can then make a comment on the social optimality of bank risk-taking as well as certain social planner policies that affect the bank's decisions such as bank capital requiremens, deposit insurance, and suspension of convertibility.

I assume that all agents are rational and anticipate future actions, therefore I seek to identify the bank's optimal choice of risk at $T = 0$ by backward induction:

Note that at $T = 1$, bank management offers $r_2 (\theta,\ r_1)$ to maximize equity value:

$$\begin{aligned} r_2 &= min\, r_2 \\ s.t. & \quad depositors\, don't\, run \\ \Rightarrow r_2 \quad s.t. & \quad \theta^* = \theta_{observed} \end{aligned}$$

I get r_2 by solving indifference equation for $r_2^* \geq 1$–this sensibility constraint assumes intuitively that bank won't offer negative interest, to carry intuition from an infinitely repeated game.

At $r_2 = r_2^*$, given a realization of θ, we have depositors (indifferently) choosing to stay with the bank and not run unless they are liquidity constrained–>$n = \lambda$ (assuming that $\epsilon \to 0$ so in the limit there is no uncertainty).

Given that knowledge about n when $r_2 = r_2^*$, this greatly simplifies our solution for r_2^*:

$$\begin{aligned} u(r_1) &= u(r_1 r_2^*) \; for\, riskless\, debt \left(\hat{F}_i(\theta) = 1\right) \to r_2^{*,riskless} = 1 \qquad (10) \\ &= \hat{F}_i(\theta) \cdot u(r_1 r_2^*) + \left(1 - \hat{F}_i(\theta)\right) \cdot u(0) \; for\, risky\, debt \\ \Rightarrow u(r_1 r_2^*) &= \frac{u(r_1)}{\hat{F}_i(\theta)} \\ \Rightarrow r_2^* &= u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta)}\right) \cdot \frac{1}{r_1} \end{aligned}$$

Now I can continue our backwards induction to note that at $T = 0$:

$$\begin{aligned} E[r_2 \,|\, r_1] &= E\left[u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta)}\right) \cdot \frac{1}{r_1} \,|\, r_1\right] \\ &= \int_{\theta=-\infty}^{\infty} u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta)}\right) \cdot \frac{1}{r_1} \cdot f(\theta)\, d\theta \end{aligned}$$

I want to solve for $r_1(R_i)$, then we can solve for $R_{optimal}$ as a function of our parameters (most especially e, the capital ratio parameter). To do this, call $\underline{\theta}$ the lowest value of θ given r_1 s.t. the management can offer r_2^* to prevent a run–any realization of $\theta < \underline{\theta}$ will result in a run by the depositors. On the other hand, any realization $\theta > \underline{\theta}$ will not result in a run, because shareholders get 0 in the event of a run, and non-negative payoff if depositors do not run, so they will offer r_2 sufficiently high whenever possible. This allows us to express our solution of $r_1(R_i)$ more intuitively:

$$
\begin{aligned}
&E_{certainly\,patient}\left[u\left(deposit\right)\right] = E_{certainly\,patient}\left[u\left(equity\,shares\right)\right]\\
&\Rightarrow prob\left(run\right)\cdot u\left(r_1\right)\cdot\frac{\left(1+e\right)\gamma}{r_i} + prob\left(success\bigcap no\,run\right)\cdot u\left(r_1 r_2\right) =\\
&prob\left(success\bigcap run\right)\cdot u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^{+}R_i}{e}\right)\\
&+prob\left(success\bigcap no\,run\right)\cdot u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-\left(1-\lambda\right)r_1 r_2}{e}\right)\\
&\Rightarrow F\left(\theta^*\right)\cdot u\left(r_1\right)\cdot\frac{\left(1+e\right)\gamma}{r_1} + u\left(r_1 r_2\right)\cdot\left(1-F\left(\theta^*\right)\right)\cdot\int_{\theta=\theta^*}^{\infty}\hat{F}\left(\theta\right)f\left(\theta\right)d\theta =\\
&\left(1-F\left(\theta^*\right)\right)\cdot\int_{\theta=\theta^*}^{\infty}u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-\left(1-\lambda\right)r_1 r_2}{e}\right)\hat{F}\left(\theta\right)f\left(\theta\right)d\theta\\
&+F\left(\theta^*\right)\cdot u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^{+}R_i}{e}\right)\cdot\int_{\theta=-\infty}^{\theta^*}\hat{F}\left(\theta\right)f\left(\theta\right)d\theta
\end{aligned}
$$

Therefore r_1 is simply the solution to the above equation–although the analytical solution is not readily tractable, the numerical solution is straightforward.

I've been using $\bar{\theta}$ without fully defining it; let's do that now. θ^* is the minimum realization of θ at which the bank shareholders can credibly promist r_2 high enough to stop a run. In other words, this means the value of θat which

$$
\begin{aligned}
r_1 r_2^*\left(\theta^*,\, r_1\right) &= \frac{\left(1+e\right)-\frac{\lambda r_1}{\gamma}}{1-\lambda}R_i\\
\Rightarrow r_2^*\left(\theta^*,\, r_1\right) &= \frac{\left(1+e\right)-\frac{\lambda r_1}{\gamma}}{1-\lambda}\frac{R_i}{r_1}
\end{aligned}
$$

And using our previous solution for $r_2^*(\theta, r_1)$, I can express this as

$$u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta^*)}\right)\cdot\frac{1}{r_1}=\frac{(1+e)-\frac{\lambda r_1}{\gamma}}{1-\lambda}\frac{R_i}{r_1}$$

and solve for θ^*:

$$\begin{aligned}\hat{F}_i(\theta^*)\cdot u\left(\frac{(1+e)-\frac{\lambda r_1}{\gamma}}{1-\lambda}R_i\right) &= u(r_1)-\left(1-\hat{F}(\theta^*)\right)\cdot u(0)\\ \Rightarrow \hat{F}_i(\theta^*) &= \frac{u(r_1)}{u\left(\frac{(1+e)-\frac{\lambda r_1}{\gamma}}{1-\lambda}R_i\right)}\\ \Rightarrow \theta^* &= \hat{F}_i^{-1}\left(\frac{u(r_1)}{u\left(\frac{(1+e)-\frac{\lambda r_1}{\gamma}}{1-\lambda}R_i\right)}\right)\end{aligned}$$

Now we can use θ^* to calculate r_1 given R_i (from above):

$$
\begin{aligned}
0 &= \left[F(\theta^*)\cdot u(r_1)\cdot\frac{(1+e)\gamma}{r_1} + u(r_1r_2)\cdot(1-F(\theta^*))\cdot\int_{\theta=\theta^*}^{\infty}\hat{F}(\theta)f(\theta)\,d\theta\right] \\
&\quad -\left[(1-F(\theta^*))\cdot\int_{\theta=\theta^*}^{\infty} u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-(1-\lambda)r_1r_2}{e}\right)\hat{F}(\theta)f(\theta)\,d\theta\right] \\
&\quad -\left[F(\theta^*)\cdot u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^+ R_i}{e}\right)\cdot\int_{\theta=-\infty}^{\theta^*}\hat{F}(\theta)f(\theta)\,d\theta\right] \\
&= F(\theta^*)\cdot\left[u(r_1)\cdot\frac{(1+e)\gamma}{r_1} - u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^+ R_i}{e}\right)\cdot\int_{\theta=-\infty}^{\theta^*}\hat{F}(\theta)f(\theta)\,d\theta\right] \\
&\quad +(1-F(\theta^*))\cdot\left[\int_{\theta=\theta^*}^{\infty} u(r_1r_2) - u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-(1-\lambda)r_1r_2}{e}\right)\hat{F}(\theta)f(\theta)\,d\theta\right] \\
&= F(\theta^*)\cdot\left[u(r_1)\cdot\frac{(1+e)\gamma}{r_1} - u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^+ R_i}{e}\right)\cdot\int_{\theta=-\infty}^{\theta^*}\hat{F}(\theta)f(\theta)\,d\theta\right] \\
&\quad +(1-F(\theta^*))\cdot\left[\int_{\theta=\theta^*}^{\infty} u\left(r_1\cdot u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta^*)}\right)\cdot\frac{1}{r_1}\right)\right] \\
&\quad -(1-F(\theta^*))\cdot\left[u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-(1-\lambda)r_1\cdot u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta^*)}\right)\cdot\frac{1}{r_1}}{e}\right)\hat{F}(\theta)f(\theta)\,d\theta\right] \\
&= F(\theta^*)\cdot\left[u(r_1)\cdot\frac{(1+e)\gamma}{r_1} - u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^+ R_i}{e}\right)\cdot\int_{\theta=-\infty}^{\theta^*}\hat{F}(\theta)f(\theta)\,d\theta\right] \\
&\quad +(1-F(\theta^*))\cdot\left[\int_{\theta=\theta^*}^{\infty}\frac{u(r_1)}{\hat{F}_i(\theta^*)} - u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-(1-\lambda)\cdot u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta^*)}\right)}{e}\right)\hat{F}(\theta)f(\theta)\,d\theta\right]
\end{aligned}
$$

$$
\begin{aligned}
= \;& F(\theta^*) \cdot \left[u(r_1) \cdot \frac{(1+e)\gamma}{r_1} - u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^+ R_i}{e} \right) \cdot \int_{\theta=-\infty}^{\theta^*} \hat{F}(\theta) f(\theta)\, d\theta \right] \\
& + (1-F(\theta^*)) \cdot \left[u(r_1) \int_{\theta=\theta^*}^{\infty} f(\theta)\, d\theta \right] \\
& - (1-F(\theta^*)) \cdot \left[\int_{\theta=\theta^*}^{\infty} u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right) R_i - (1-\lambda) \cdot u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta^*)}\right)}{e} \right) \hat{F}(\theta) f(\theta)\, d\theta \right] \\
= \;& F(\theta^*) \cdot \left[u(r_1) \cdot \frac{(1+e)\gamma}{r_1} - u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^+ R_i}{e} \right) \cdot \int_{\theta=-\infty}^{\theta^*} \hat{F}(\theta) f(\theta)\, d\theta \right] \\
& + (1-F(\theta^*)) \cdot \left[u(r_1)(1-F(\theta^*)) \right] \\
& - (1-F(\theta^*)) \cdot \left[\int_{\theta=\theta^*}^{\infty} u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right) R_i - (1-\lambda) \cdot u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta^*)}\right)}{e} \right) \hat{F}(\theta) f(\theta)\, d\theta \right] \\
= \;& F(\theta^*) \cdot \left[u(r_1) \cdot \frac{(1+e)\gamma}{r_1} - u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^+ R_i}{e} \right) \cdot \int_{\theta=-\infty}^{\theta^*} \hat{F}(\theta) f(\theta)\, d\theta \right] \\
& + u(r_1)(1-F(\theta^*))^2 \\
& - \left(1 - \frac{u(r_1)}{u\left(\frac{(1+e)-\frac{\lambda r_1}{\gamma}}{1-\lambda} R_i\right)} \right) \int_{\theta=\theta^*}^{\infty} u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right) R_i - (1-\lambda) \cdot u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta^*)}\right)}{e} \right) \hat{F}(\theta) f(\theta)\, d\theta
\end{aligned}
$$

I note that $u(r_1)$ is an increasing function of r_1, $F(\theta^*)$ is an increasing function of r_1, $u\left(\frac{\left(1+e-\frac{r_1}{\gamma}\right)^+ R_i}{e}\right)$ and $u\left(\frac{\left(1+e-\frac{\lambda r_1}{\gamma}\right)R_i-(1-\lambda)\cdot u^{-1}\left(\frac{u(r_1)}{\hat{F}_i(\theta^*)}\right)}{e}\right)$ are both decreasing functions of r_1, and $\frac{u(r_1)}{r_1}$ is a decreasing function of r_1. Therefore a uniques solution for r_1 can be shown to exist. Now I have the apparatus required to get to the root of the backward induction problem: the optimal selection of R_i, the risk parameter, by bank shareholders.

Atomistic bank shareholders seek to maximize their expected utility:

$$\begin{aligned} R^* &= \underset{R_i}{argmax} E_{certainly\, patient}\left[u\left(shares\right)\right] \\ s.t. &\quad R \leq R_i \left(assumed\, risk\, boundaries\right) \end{aligned}$$

Where

$$T = 2\, shareholder\, consumption = max\left(\frac{\left(1+e-\left(\frac{nr_1}{\gamma}\right)\right)\cdot OUTCOME-\left(1-n\right)\cdot r_1 r_2}{e}, 0\right)$$

Thus the problem for shareholders becomes:

$$\begin{aligned} R^* &= \underset{R_i}{argmax} E\left[u\left(\left(\left(\frac{\left(1+e-\left(\frac{nr_1}{\gamma}\right)\right)\cdot OUTCOME-\left(1-n\right)\cdot r_1 r_2}{e}\right)^+\right)\right)\right] \\ &= \underset{R_i}{argmax}\int_{\theta=-\infty}^{\infty}[u\left(\left(\left(\frac{\left(1+e-\left(\frac{nr_1}{\gamma}\right)\right)\cdot R_i-\left(1-n\right)\cdot r_1 r_2}{e}\right)^+\right)\right)\cdot \hat{F}_i\left(\theta\right) \\ &\quad +u\left(0\right)\cdot\left(1-\hat{F}_i\left(\theta\right)\right)]\cdot f\left(\theta\right)d\theta \\ &= \underset{R_i}{argmax}\int_{\theta=-\infty}^{\infty}\left[u\left(\left(\left(\frac{\left(1+e-\left(\frac{nr_1}{\gamma}\right)\right)\cdot R_i-\left(1-n\right)\cdot r_1 r_2}{e}\right)^+\right)\cdot \hat{F}_i\left(\theta\right)\right]\cdot f\left(\theta\right)d\theta \\ (s.t. &\quad 0 \leq R\left(assumed\, risk\, boundaries\right)) \end{aligned}$$

Where of course n is a function of θ, r_1, $and\, r_2$, r_2 is a function of $\theta\, and\, r_1$, and r_1 is a (formidable) function of R_i. While this problem is still analytically difficult, numerically it is now tractable.

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