Securities Lending as Wholesale Funding: Evidence from the U.S. Life Insurance Industry

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Abstract

This paper studies the supply side of the securities lending market. We match every U.S. life insurers' corporate bond holdings, lending, and cash collateral reinvestment to the universe of corporate bond lending transactions from 2011 to 2015. Focusing on the cross-section of U.S. life insurers holding the same bonds, we find that insurers with the most aggressive cash collateral reinvestment strategy are more likely to lend their bonds. This finding is in sharp contrast with the literature that views securities lenders as primarily responding to borrowers’ demand. We account for this findings in a simple model of life insurer managing interest risk and discuss the financial system vulnerabilities associated with using securities lending as wholesale funding.

JEL Codes: G11, G22, G23
Keywords: securities lending, wholesale funding, repo, risk management, life insurers
Introduction

Securities lending is a critical financial transaction. On a typical day in 2017Q1, $14.4 trillion worth of assets were available to potential borrowers, with $1.3 trillion actually on loan.¹ In a securities lending transaction, securities lenders temporarily transfer economic ownership of their asset in exchange for collateral as part of a sale-and-repurchase contract that is similar to a repo transaction. Financial institutions borrow securities for a variety of well-studied reasons, from meeting short-term regulatory requirements to implementing arbitrage strategies. The suppliers of securities to the market are primarily long-term institutional investors that hold big asset portfolios for asset-liability management or regulatory reasons. In 2015, US institutional investors held about $26 trillion of potentially loanable assets. Without securities lending, these assets would be locked up on the balance sheets of those investors.

Despite its large size and critical role, little is known about the supply side of the securities lending market, as the existing literature focuses almost exclusively on the demand side.² Understanding the supply side of the market is important because, by lending their securities against cash collateral, institutions create short-term liabilities that are prone to run risk and could render the financial system more fragile, as exemplified by AIG during the financial crisis of 2007-2009.³ At the same time, pricing and liquidity in secondary trading markets are crucially dependent on the ability to borrow securities.⁴ As a consequence, the securities lending market implicitly connects financial system fragility with asset price determination.

In this paper, we fill the gap in the literature by studying life insurers’ decisions to lend individual corporate bonds.⁵ We use a new annual dataset from 2011 to 2015 that combines about one million bond holdings reported by US life insurers together with detailed data on US life insurers’ securities lending programs, and with the market for securities lending. We collect new annual regulatory data made available from 2011, which specify the bonds in each life insurer’s portfolio that are on loan at the time of filing as well as the security

¹ Markit Securities Finance Quarterly Review.
² Krishnamurthy, Nagel & Orlov (2014) focus on the cash provided to broker-dealers from money market funds (MMFs) and securities lenders through short-term funding markets, taking as given the lending and reinvestment decisions of securities lenders. Our paper is the first to our knowledge to consider how securities lenders may reinvest the cash collateral they receive from lending their securities.
⁴ Duffie, Gärleanu & Pedersen (2002) study the effect of search and bargaining in the securities lending market on pricing in the securities market. Foley-Fisher et al. (2019) provide empirical evidence of the connection between corporate bond securities lending and corporate bond secondary market liquidity.
level composition of the insurer’s cash collateral reinvestment portfolio. We use these data to construct measures of the degree to which individual life insurers are engaged in liquidity and/or maturity transformation through their securities lending programs. Importantly, the relevant transformation for securities lending is not the difference between the lent security and the reinvestment securities. Instead, the relevant transformation is from safe short-term cash collateral to riskier long-term reinvestment securities. We combine this information with microdata on individual loan transactions from Markit Securities Finance, the most comprehensive source on the securities lending market.

We first document that life insurers’ corporate bond securities lending decisions are correlated with market conditions, such as the equilibrium price for lending a bond. We also show that life insurers tend to lend those corporate bonds in which they hold a large fraction of the amount outstanding. Lastly, we estimate the correlation between the decision to lend an individual corporate bond and the degree of maturity and liquidity transformation in the cash collateral reinvestment portfolio.

We then introduce our empirical strategy for identifying the supply side of the securities lending market. The main empirical challenge is to obtain variation in the decision to lend a bond that is independent of demand factors. First, the demand for securities may vary with observable and unobservable time- and security-specific characteristics. Second, including equilibrium market variables as a control for demand may not be appropriate. This latter concern arises because, when specifying the factors that determine the lending decision, omitting any variable that jointly determines the equilibrium market variables will likely invalidate all the coefficient estimates.6

We address the empirical challenge by exploiting the cross-section of US life insurers that hold the same bonds at the same time in different portfolios. Our specification includes bond–time fixed effects to control for potentially confounding factors in a reduced form that encompasses the cost of cash borrowing as well as the availability and distribution of holdings associated with each bond. We find that, controlling for bond demand, the cross-sectional variation in liquidity transformation by US life insurers accounts for about 45 percent of the variation in their bond lending decision.

We then show that securities lending and repo are substitutes using each individual bond’s specialness, based on the price in the securities lending market. A bond on special is one where the bond borrower that offers cash collateral agrees to receive less return on the borrowing

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6 We demonstrate the severity of the empirical challenge by showing that the cost of borrowing a bond is a function of the distribution of holdings in that bond. Intuitively, this new finding suggests that lenders of hard-to-find bonds can get a better deal on their transaction—as in Duffie (1996)—and the terms of the transaction may affect their decision to lend particular bonds.
transaction than if they had invested the same cash in a risk-free short-term market. In effect, the bond borrower is paying an opportunity cost to obtain the bond on special (Duffie 1996). We can separately identify in the regulatory data when individual bonds are used in repo transactions from when those same bonds are used in securities lending transactions by the same insurer.

We find that, conditional on their cash reinvestment strategy, those insurers that have a smaller fraction of their bonds on special are more likely to repo an individual bond. Moreover, those insurers that have a more aggressive reinvestment strategy and who have a smaller fraction of their bonds on special are more likely to use repo. This relationship is robust to controlling for the size of insurers’ securities lending and repo programs, insurer-bond fixed effects, and the share of each individual bond in the insurer’s portfolio.

Our results prompt the questions: Why do some life insurers have larger securities lending programs than others? And why do some reinvest their cash collateral into relatively longer term assets than other? We provide one possible answer based on interest rate risk management. Life insurers are typically exposed to interest rate risk, because the duration of life insurers’ assets is typically less than the duration of their liabilities (Domanski, Shin & Sushko 2017). A negative duration gap implies that the present value of the the insurer asset an liabilities change at different rates when the interest rate changes, which can lead to an insolvency. Life insurers can manage small shocks to the interest rate by maintaining a positive net worth or policy holder surplus and by adding positive duration to their balance sheet. In general, adding positive duration consist of financing a long-term fixed rate debt instrument with short-term floating rate debt. Using information on life insurers’ open interest rate swap contracts, we show that there is indeed a positive correlation between short-term wholesale funding liabilities issued from life insurers’ general account and the duration added by this insurer’s interest swap portfolio.

Finally, we show that a parsimonious model of a competitive life insurer managing interest rate risk can account for our empirical results. In the model, a life insurer uses long-term assets to back its liabilities with even longer duration. Consequently, the life insurer has a motive to manage the interest rate risk associated with its long-term liabilities (Froot, Scharfstein & Stein (1993) and Froot & Stein (1998)). When interest rates fall sharply, the life insurer can simultaneously narrow the duration gap and restore their net worth by issuing short-term liabilities and reinvesting the proceeds in longer-term assets. In our model, maturity and liquidity transformation using securities lending cash collateral and other types of short-term wholesale funding such as funding agreement-backed securities (Foley-Fisher, Narajabad & Verani 2015), repo and interest rate swaps arises as an outcome of interest rate risk management. The key insight from the model is that heterogeneity in long-term institutional investors’ liability duration
drives variation in their use of wholesale funding for maturity and liquidity transformation.

Taken together, these results point to a significant connection between bond dealers’ market making activity, price discovery, and the creation of short-term safe assets. An important implication of our findings is that the use of securities lending cash collateral as a source of wholesale funding is a new channel through which securities market functioning could be impaired during a time of overall financial stress. As is widely known, liquidity and maturity transformation are associated with vulnerabilities to runs (Diamond & Dybvig 1983, Goldstein & Pauzner 2005) and roll-over risk (He & Xiong 2012, Foley-Fisher et al. 2015). The vulnerability of securities lending to runs has the potential to affect securities markets in two ways. First, as securities borrowers return the securities and demand the return of their cash collateral, securities lenders would likely withdraw their reinvestment of cash collateral from short-term markets, which would reduce funding liquidity and adversely affect securities market liquidity (Brunnermeier & Pedersen 2009). Second, as shown in Foley-Fisher et al. (2019), the return of borrowed securities reduces market making activity, which could also impair the functioning of securities markets. We discuss how this vulnerability was manifest during the 2008-09 financial crisis in our concluding remarks.

The remainder of the paper proceeds as follows. In Section 1 provides an overview of the market for lending securities. Section 2 describes our data and provides summary statistics. Sections 3, 4, 5, and 6 detail our empirical results. In Section 7, we present our model. We discuss some implications of our findings and conclude in Sections 8 and 9.

1 Securities lending and life insurance companies

In this section, we provide some institutional details. We first outline the typical structure of a securities lending transaction, together with the motivations of each party to the deal. Then we provide an overview of the securities lending market and the specific role of US life insurers. And, finally, we discuss the distinction between the demand and supply channels of securities lending.

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7 At an institutional level, these vulnerabilities were manifest at AIG’s $80 billion securities lending program in 2008, which had retained only about 20 percent of its cash collateral in short-term assets, while 65 percent was reinvested in longer-term RMBS and other ABS (Peirce 2014, McDonald & Paulson 2015). Increasing concerns among investors about the value of this reinvestment portfolio drove demands for greater collateral reductions. The cumulative and consequential losses ultimately required AIG to request a series of government interventions.
1.1 Securities lending transactions

In a prototypical loan, the security lender transfers full legal and economic ownership of the security to the borrower. In exchange, the borrower gives the lender collateral in the form of cash or another security. The term of the loan is usually open-ended, with either party able to terminate the deal at any time by returning the security/collateral. The securities lender is free to reinvest the cash and, in some cases, rehypothecate the securities used as collateral. In the case of non-cash collateral, the securities lender earns a fee from the borrower. In the case of cash collateral, the securities lender pays a percentage of the reinvestment income to the securities borrower, called the “rebate.” Both the rebate and fee are equilibrium prices negotiated at the outset of the deal that may reflect the scarcity of the security on loan: A hard-to-find “special” security may command a high fee and a low or negative rebate. Typically, the loan is marked to market daily and is “overcollateralized,” with borrowers providing, for example, $102 in cash for every $100 in notional value of a security. The percentage of overcollateralization is called the “margin,” which serves to insure the securities lender against the cost of replacing the lent security if the borrower defaults. In addition to the loss of collateral, the security borrower is dissuaded from defaulting on the loan by reputational effects: lender–borrower relationships are formed through repeated transactions, and are often governed by a single master agreement. Overall, the structure of cash-collateralized securities lending is closely related to a sale and repo transaction, in which the securities borrower is entering a reverse-repo arrangement (Duffie 1996, Garbade 2006).

A securities lending transaction usually involves three or four parties. The ultimate owner of the security is typically an institutional investor such as a pension fund, insurance company, mutual fund, or sovereign wealth fund. Owners of large portfolios will often conduct their own lending programs, while smaller owners execute their programs through agent lenders, such as custodian banks or asset managers, that act as large warehouses for securities made available for lending. The end users of the borrowed securities are typically dealers and hedge funds. These security market participants generally use large financial institutions—for example, broker-dealers and investment banks—as intermediaries that regularly search for securities and have established relationships with lenders.

The ultimate owners decide which securities in their portfolios will be made available to lend and how the cash collateral proceeds of their lending programs will be reinvested. When they

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8 Although they are transferred by default, the parties may agree that the securities borrower will return any dividend/interest payments and/or voting rights.
9 Flexibility is often preserved, even in term loans, by allowing either party to break the terms early in exchange for a fee.
choose to employ agent lenders, the owners typically provide guidelines or specific instructions for the type of lending transactions (for example, minimum fee criteria or hard-to-find securities only) and for the reinvestment of cash collateral. In some cases, these reinvestment strategies are subject to regulatory limits.

If agent lenders are involved, they execute owners’ instructions to lend particular securities and reinvest cash collateral. Because agent lenders often have access to the same securities from many ultimate owners, they typically allocate borrowing requests to securities using an algorithm that ensures no owner receives preferential treatment. The agents earn a share of the profits associated with lending securities, including fees and/or reinvestment income after rebate. In exchange, agents will customarily provide indemnification against the risk that the non-cash collateral is insufficient to replace the lent securities if the borrower defaults. To be clear, this indemnification does not protect the owner against the risk of losses associated with reinvesting cash collateral.

The borrowing intermediary generally performs three functions as it matches end-user requests for securities with lenders’ availability. First, the intermediary helps to assuage securities lenders’ potential concerns about the credit quality of end users, which may be small and weakly regulated. Second, by establishing relationships with lenders and borrowers, they can lower search costs. In the case of broker-dealers, their securities lending intermediation is often combined with prime brokerage to lower costs further. Third, the intermediary may assume some liquidity risk by establishing open-ended loans with lenders, giving them the freedom to recall the securities as needed, and extending term loans to end users so they can be sure their short positions are covered. In exchange for these services, the borrowing intermediary receives a payment from the end user.10

The end users have a variety of reasons for borrowing a particular security. The most common motivations are to manage inventory (Faulkner 2008); to take a short position or to cover a naked short position (Duffie 1996, Keane 2013); to avoid a settlement/delivery failure (Musto, Nini & Schwarz 2011), possibly as part of market making activity; to combine one security with other securities as part of an arbitrage trading strategy; to obtain collateral for use in other transactions (Dive, Hodge, Jones & Purchase 2011); and to take advantage of tax or regulatory arbitrage (Faulkner 2006). The details of these trading strategies are often complex and we refer the reader to the reference list for further explanation.

Figure 1 summarizes how the securities lending market fits into the broader map of the shadow banking system. The cloud represents the general functioning of securities markets, 10 Huh & Infante (2018) show how securities lending allows broker-dealers to separate their own portfolio positions from their ability to fulfill client orders.
illustrated with the example of hedge funds taking long and short positions. Securities market participants typically borrow both cash funding and securities using broker-dealers as intermediaries. Broker-dealers obtain cash from several sources, for example, MMFs through short-term funding markets. Securities lenders decide whether to lend assets from their portfolio and whether to invest the cash collateral they receive back into short-term markets or into long-term markets. In the latter case, they may invest, for example, in relatively longer-term corporate bonds or asset-backed securities. Duffie et al. (2002) study the effect of search and bargaining in the securities lending market on pricing in the securities market, abstracting from the reinvestment decisions of securities lenders (Figure 2a). Brunnermeier & Pedersen (2009) and Gorton & Metrick (2012) consider securities market transactions funded through margin accounts and bilateral repurchase agreements (repo), abstracting from the source of securities (Figure 2b). Krishnamurthy et al. (2014) focus on the cash provided to broker-dealers from MMFs and securities lenders through short-term funding markets, taking as given the lending and reinvestment decisions of securities lenders (Figure 2c).

1.2 Overview of US life insurers in the securities lending market

The US is a major entity in the global securities lending market, accounting for about half of the worldwide lending. Figure 3 shows US institutions’ securities lending broken down by the type of lender. Retirement and pension funds account for more than 60 percent of securities lending by US institutions, followed by mutual and investment funds, which together cover about 30 percent of the market. Insurance companies are the third largest group of US securities lenders. Because life insurers typically invest in fixed income securities rather than equities, their lending is heavily biased towards bonds, in particular the corporate bond market. Indeed, as shown in Figure 4, US life insurers were the principal lenders of corporate bonds in the pre-crisis period and remain key participants in the market even though their programs shrank during the 2008-09 financial crisis Foley-Fisher et al. (2019).

Most securities lent by US life insurers are against cash collateral, which means the reinvestment of cash collateral is an essential component of their lending strategies. In the US, about half of securities lending transactions are collateralized by cash, which the lender is allowed to reinvest at their discretion. In the lending market for corporate bonds, which is the focus of our paper, the prevalence of cash collateral is much higher at around 80 percent.

To better understand the supply channel of securities lending requires detailed data on

11 Although agent lenders are often involved in the securities lending process, as we describe in Section 1, their role is incidental to our analysis.
12 The consequences of the crisis reached beyond US securities lending markets. Anecdotal evidence suggests that Dutch pension funds also scaled back their securities lending programs following the crisis.
individual loans and cash reinvestment decisions. For this reason, the 2010 adoption by state insurance regulators of the NAIC guidelines for enhanced reporting on securities lending programs presents a golden opportunity to observe new and detailed information about all aspects of securities lending and cash reinvestment activities by US life insurers. We can observe for the first time the individual bonds that are lent by life insurers, the maturity of the collateral they received, and their cash reinvestment portfolios. When combined with security-level data on the broader securities lending market, we can deepen our understanding of the strategic use of securities lending by US life insurers.

2 Data

We combine several data sources to obtain the dataset we use in our analysis. The data on insurance company holdings and securities lending activity come from the NAIC Annual Statutory Filings for yearend 2011 through to yearend 2015. Within these filings, Schedule D contains reports of all life insurers’ individual fixed income holdings at year-end, together with cross-sectional information about each security, including the CUSIP identifier and whether the bond was on loan as part of the insurer’s securities lending program or subject to a repurchase agreement (repo). We drew information about the total size and performance of the life insurer’s investment portfolio from the summary balance sheet. We focus on all insurance companies that had a securities lending program at any point during our sample period. Our baseline dataset includes information on 111 life insurers, with holdings data on almost one million bonds. The first four columns of Table 1 report descriptive statistics for the baseline sample. The average bond holding is about $9 million with a standard deviation of $27 million. The dummy variable for securities lending indicates that about 3 percent of US life insurers’ bond holdings were on loan during the period.

We merge life insurers’ holdings data with Mergent FISD using the CUSIP identifier. FISD provides a wide range of security-level information for fixed income securities, including corporate, agency, and government bonds, with a geographical focus on the US. While approximately one-half of all Schedule D holdings by insurers in our sample appear in FISD, 95 percent of the lent securities in our data are matched. Our interpretation is that almost all securities lent in our sample are non-privately placed fixed income bonds issued by US entities. Excluding the bond holdings that do not appear in FISD reduces the size our data sample to about half a million individual bond holdings across the same set of 111 life insurers.

13 Historical NAIC Quarterly and Annual Statutory Filings are contained in the NAIC Financial Data Repository, a centralized warehouse of financial data used primarily by state and federal regulators.
Columns 5 through 8 of Table 1 report the additional descriptive statistics, including amount issued, offering yield, credit rating, and residual maturity. In this merged subsample, the average offering amount of the bonds held is about $1 billion (with a standard deviation of $1.2 billion) and a yield at origination of about 6 percent. The average residual maturity across all year-end bond holdings is 11.3 years (with a standard deviation of 10 years). Our numerical rating measure indicates that the average is about 20, equivalent to a Standard & Poor’s bond rating of BBB.\textsuperscript{14} Lastly, the average total amount outstanding across all bonds held by life insurers is about $900 million.

The NAIC Quarterly and Annual Statutory Filings also contain the Schedule DL, a relatively new report of individual investments made by life insurers using cash collateral received from securities lending, both on- and off-balance sheets. The Schedule DL was introduced in 2010 as one of many changes to the reporting and statutory accounting of securities lending transactions adopted as a response to the 2008-09 financial crisis.\textsuperscript{15} Figure 5 shows an extract from one life insurer’s filing in 2012 showing a sample of the individual investments made using cash collateral received in exchange for lending securities. In general, the new data allow us to better track the securities lending transactions entered into by an insurer and to observe detailed information about the life insurers’ use of the collateral received. For example, from 2010, if the collateral received from securities lending could “be sold or pledged by custom or contract by the reporting entity or its agent,” then the reinvested collateral should be recorded on the balance sheet.\textsuperscript{16} We hand-coded data about the maturity of the collateral received in the securities lending transactions from the regulatory Note 5(e) to the Financial Statements. Figure 6 shows the relevant notes for the same 2012 sample regulatory filing. Because we rely on the detailed information collected as part of the new reporting requirements, our sample by necessity begins in 2011.

Figure 7 shows that the total amount of cash collateral raised by US life insurers from

\textsuperscript{14} We collect data on ratings from Moody’s, Fitch, and Standard & Poor’s and combine them into a single rating using the lowest rating when only two are available and the median rating when all three are available. To average the ratings, we set AAA, or equivalent = 28, AA+ = 26, AA = 25, AA- = 24 ... CCC- = 9, CC = 7, and C = 4.

\textsuperscript{15} The new guidelines stem from a review of the securities lending practices at AIG that contributed to its collapse during the 2008-09 financial crisis. In particular, the guidelines specify that borrowers should post cash in the amount of at least 102 percent of domestic securities borrowed (and at least 105 percent if the securities are foreign), that individual loans should not be more than 5 percent of admitted assets, that cash reinvestment should be “prudent,” and that all cash reinvestment securities (on- and off-balance sheet) are reported in the NAIC Quarterly and Annual Statutory Filing Schedule DL. In addition, each asset financed with cash collateral recorded in the NAIC Quarterly and Annual Statutory Filing Schedule D attracts a risk-based capital charge consistent with its NAIC designation code.

http://www.naic.org/capital_markets_archive/110708.htm

\textsuperscript{16} Amendments to SSAP No. 91-R, Accounting for Transfers and Servicing of Financial Assets and Extinguishments of Liabilities.
lending securities hovered around $50 billion between 2011 and 2015. The same figure reports at an aggregated level how that cash collateral was reinvested. Each category is based on classifications determined by state regulators (NAIC) and reported by individual insurers. The reinvestment in relatively illiquid assets is suggested by the significant portion that is reinvested in private label ABS and corporate bonds.

We can demonstrate further that insurers reinvest their cash collateral in relatively illiquid assets by comparing the bonds they lent (Schedule D) to the securities in which they reinvested the cash collateral they received (Schedule DL). The sample reinvestment portfolio reported in Figure 5 indicates that a large proportion of CUSIP identifiers contain “#” and “@” symbols representing privately placed securities.\(^\text{17}\) Indeed, if we attempt to merge FISD by CUSIP on the reinvestment portfolios, we can match only 30 percent of individual securities even when excluding cash and cash-like reinvestments.\(^\text{18}\) Recall, by comparison, that we can match over 95 percent of bonds being lent with FISD. This contrast in match rates hints at the liquidity transformation created by securities lending programs. That said, the lack of information about privately placed securities makes it difficult to measure the degree of maturity and liquidity transformation accurately.

Our proxy for maturity and liquidity transformation is based on the residual maturity that is reported for all types of securities in the regulatory filings. Specifically, we calculate the fraction of assets in an insurer’s cash reinvestment portfolio that have a residual maturity of more than one year minus the fraction of cash collateral that is received by the life insurer for a duration of more than one year. The one-year threshold is not crucial for the results in the paper. Rather, we choose it so that our variable represents the investment by life insurers in assets that MMFs cannot purchase for regulatory reasons.\(^\text{19}\) It follows that these assets are likely to offer a higher return than cash instruments. Figure 8 shows that there is considerable variation in the calculated fraction across life insurers and over time.

Lastly, we add information on the market for securities lending using Markit Securities Finance. This dataset covers about 85 percent of the global market and more than 90 percent of the US market. The daily transaction level data include identifiers for individual lent securities, such as CUSIP and ISIN, as well as the value, quantity, duration, lending fee, rebate rate, and collateral of the loan. For each lent security, the total value and quantity of the inventory

\(^{17}\) https://www.cusip.com/pdf/CUSIP_Intro_03.14.11.pdf

\(^{18}\) We identify cash and cash-like reinvestments by selecting descriptions that contain variations of the words “cash”, “money market”, “MMMM”, “prime money”, and “MMKT.”

\(^{19}\) Amendments to regulation Rule 2a-7, adopted by the SEC in July 2014, imposes a set of constraints on MMMF investment portfolio, including that every security in the portfolio must have a maturity not exceeding 397 days, and that the dollar-weighted maturity of the entire portfolio cannot exceed 60 days. Thus, our one year threshold is six times the regulatory limit on the overall maturity of a mutual fund’s cash reinvestment portfolio. https://www.sec.gov/rules/final/2014/33-9616.pdf
available to lend is also reported. We cannot observe counterparties to individual loans, nor information on lenders’ reinvestment of cash collateral. We construct weighted averages of the available variables, for each security, across all transactions conducted during the 14 days around year-end and merge with our other data using the CUSIP identifier. Roughly three-quarters of all bond holdings that appear in both regulatory filings and FISD can be matched to Markit. Moreover, consistent with the high coverage of the securities lending market, more than 95 percent of the securities that insurers report as being on loan are observed in Markit. The high proportion of bond holdings covered by Markit Securities Finance hints at the enormous potential for securities lending by US life insurers.

Our final three-way merged dataset of 107 life insurers contains information on over 350,000 bond holdings, of which more than 23,000 are recorded as being on loan. Columns 9 through 12 of Table 1 report the descriptive statistics for this final dataset. The information from the securities lending market suggests that the weighted average rebate on the bonds is about zero. On average, life insurers hold about 2 percent of each security’s total lendable amount (with a standard deviation of 13 percent), and a Herfindahl–Hirschman Index (HHI) of the concentration of holdings equal to 0.28. Lastly, our measure of each security’s market tightness, defined as the ratio of the total amount lent to the total amount that is lendable, indicates that, on average, about 1 percent of the available amount of each security is actually lent. The remaining entries in these columns show that the other observable characteristics of the bond holdings do not vary significantly between the baseline and merged datasets.

Simple tabulations show that, conditional on the portfolios they hold, life insurers did not disproportionately lend bonds issued by particular industries. Of the bonds lent by life insurers, roughly 62 percent were issued by industrial companies, 23 percent by financial companies, 10 percent by utilities, 5 percent by government and agencies, and less than half a percent by other institutions. The distribution of insurers’ bond lending across types of issuers is almost the same as the distribution of their bond holdings.\textsuperscript{20} Table 2 offers more detail on the types of bonds used in lending transactions compared with those bonds that are not lent. In general, life insurers tend to lend the bonds that they hold in larger amounts and that have a longer residual maturity in comparison with the rest of their portfolio. Life insurers also tend to lend bonds with a lower rebate (higher fee) and in which there is a greater concentration of holding and market tightness. Of course, these pairwise comparisons of characteristics are only indicative.

\textsuperscript{20} About 60 percent of their bond holdings were issued by industrial companies, 23 percent by financial companies, 12 percent by utilities, 4 percent by government and agencies, and half a percent by other institutions. As before, each bond holding is counted as a separate observation, because we do not know how much of each security is actually lent.
3 Characteristics of bond loans and bond “specialness”

Table 3 investigates the association between insurers’ decision to lend individual bonds, bond rebate rate—which is proportional to bond “specialness”—and insurers’ market share in these bonds. Column 1 shows the results from a regression of Loan$_{ijt}$, the binary lending decision that takes a value of 1 if insurer $j$ is loaning bond $i$ at year $t$, and 0 otherwise, on insurer $j$’s market share ($\text{Market share}_{ijt}$) in bond $i$ controlling for the bond rebate rate as well as insurer, year, and bond issuer fixed effects. Market share$_{ijt}$ is the year-$t$ holding by insurer $j$ in bond $i$ as a share of the total amount of the bond that is made available to securities borrowers by all lenders. The association between Loan$_{ijt}$ and Market share$_{ijt}$ is positive and statistically significant at less than the 1 percent level. The coefficient on Market share$_{ijt}$ suggests that, on average, a one standard deviation (10.3 percent) increase in an insurer’s market share in a particular bond is associated with a 0.8 percent increase in the probability that the bond is loaned.

Column 2 shows that this association is robust to controlling for bond characteristics, loan market tightness, and concentration for individual securities in the life insurance industry. Loan market tightness is defined as the fraction of a bond that is on loan relative to the total amount of that bond that is made available for loan by all lenders. Bond characteristics include the issuer, residual maturity, offering yield, offering amount, amount outstanding, and credit rating. Bond concentration is measured by the Herfindahl–Hirschman Index (HHI) computed at the bond-year level using only life insurers’ market shares in each individual bond.$^{21}$

Column 3 reports the results from a regression of the bond’s rebate ($\text{Rebate}_{it}$) on Market share$_{ijt}$ controlling for insurer, year, and bond issuer fixed effects. The coefficient on Market share$_{ijt}$ is positive and statistically significant at less than the 1 percent level. Column 4 shows that this association is robust to controlling for loan market tightness, holdings concentration, and other bond-level characteristics.

Taken together, the results in Table 3 suggest that lenders of hard-to-find securities get a better deal on their transaction—as in Duffie (1996)—and this may affect their decision to lend particular securities. Moreover, it is likely that other potentially unobservable determinants of the lending decision are also correlated with the bond’s rebate. In the next section, we show how we can use our detailed data to overcome this endogeneity problem to indentify the supply channel of securities lending.

The main empirical challenge is to obtain variation in the decision to lend securities that is independent of demand factors. First, the demand for securities may vary with observable and

$^{21}$The calculation of the HHI is limited by our ability to observe only life insurers’ holdings in our data—i.e., by necessity, it assumes atomistic holdings by other institutions.
unobservable time- and security-specific characteristics. Second, including equilibrium market variables as a control for demand may not be appropriate. This latter concern arises because, when specifying the factors that determine the lending decision, omitting any variable that jointly determines the equilibrium market variables will likely invalidate all the coefficient estimates. We demonstrate the severity of the empirical challenge by showing that the cost of borrowing a bond is a function of the distribution of holdings in that bond. Intuitively, this new finding suggests that lenders of hard-to-find bonds can get a better deal on their transaction—as in Duffie (1996)—and the terms of the transaction may affect their decision to lend particular bonds.

We address the empirical challenge by exploiting the cross-section of US life insurers’ holdings the same bonds at the same time across different life insurers’ portfolios. Our specification includes bond–time fixed effects to control for potentially confounding factors in a reduced form that encompasses the cost of cash borrowing as well as the availability and distribution of holdings associated with each bond. We find that, controlling for bond demand, the cross-sectional variation in liquidity transformation by US life insurers accounts for about 45 percent of the variation in their bond lending decision.

4 Correlation between securities lending program size and maturity transformation

We first estimate the correlation between the lending decision measured by Loan\(_{ijt}\) and Transformation\(_{jt}\), which is a proxy for the degree of maturity and liquidity transformation. We calculate Transformation\(_{jt}\) as the fraction of assets in insurer \(j\)’s cash reinvestment portfolio that has a residual maturity of more than one year minus the fraction of cash collateral that is received by the life insurer for a duration of more than one year. Figure 8 shows the variation of Transformation\(_{jt}\) across insurers and over time. While the mean—indicated by the horizontal blue line in the shaded rectangular region—is close to zero, there is a wide range and some insurers have almost all their cash reinvested in longer-term assets. The distribution of this proxy for liquidity transformation is similar to the distribution of an alternative proxy, shown in Figure 9, which is calculated as the fraction of the cash reinvestment portfolio that insurers report as being invested in corporate bonds and asset-backed securities.

The main empirical challenge is to obtain variation in the decision to lend securities that is independent of demand factors. Estimates of the correlation between Loan\(_{ijt}\) and Transformation\(_{jt}\) will be biased if there is unobservable variation in bond-specific demand and
insurer-specific heterogeneity. In a linear regression setting, one way to control for unobservable variation in individual bond-specific demand and insurer-specific heterogeneity is to include a set of fixed effects (α) to absorb heterogeneity across securities, life insurers, and report dates:

\[ Loan_{ijt} = \alpha_1^i + \alpha_2^j + \alpha_3^t + \beta Transformation_{jt} + Z_{it} \gamma + \epsilon_{ijt}. \] (1)

That said, the coefficient on Transformation_{jt} when estimating Equation 1 may still be biased if the unobservable bond-specific demand and insurer-specific heterogeneity are time varying.

Including bond-specific equilibrium lending market variables as time-varying proxies for demand will likely produce inconsistent estimates of the partial correlation between the lending decision and liquidity transformation. Intuitively, either quantities traded or prices could proxy for demand if the lender is sufficiently small relative to the overall market. However, life insurers that have the potential to affect these equilibrium market variables and factors that affect the lending decision may also affect these demand proxies. To see this endogeneity problem more formally, consider the previous regression specification representing the loan decision in conjunction with a specification that represents the equilibrium rebate:

\[ Loan_{ijt} = \alpha_1^i + \alpha_2^j + \alpha_3^t + \beta Transformation_{jt} + \mathbf{Z}_{it} \gamma + \epsilon_{ijt}. \] (2)

\[ Rebate_{it} = \tilde{\alpha}_1^i + \tilde{\alpha}_3^t + \tilde{\beta} Transformation_{jt} + \tilde{\mathbf{Z}}_{it} \tilde{\gamma} + \tilde{\epsilon}_{ijt}. \]

If any common variable in \( \tilde{\mathbf{Z}}_{it} \) and \( \mathbf{Z}_{it} \) is omitted from the loan decision specification, the estimate of the \( \beta \) coefficient will be inconsistent (Greene 2012). Although it is difficult to accurately gauge the severity of this endogeneity problem, the regression results in Table 3 suggest it is significant.

To overcome this endogeneity problem, we exploit the ability to observe in our data the same bonds at the same time across different life insurers’ portfolios. We introduce security-time fixed effects to control for potentially confounding time-varying bond-specific demand factors in a reduced form that encompasses the cost of cash borrowing, as well as the availability and distribution of holdings:

\[ Loan_{ijt} = \alpha_1^i + \alpha_2^j + \alpha_3^t + \alpha_1^i \times \alpha_3^t + \beta Transformation_{jt} + \epsilon_{ijt}. \] (3)

Recall that, since we seek only a partial correlation between Loan_{ijt} and Transformation_{jt} that is plausibly orthogonal to demand, our strategy relies only on the assumption that the interaction term, \( \alpha_1^i \times \alpha_3^t \), fully absorbs demand factors. In particular, we are assuming that demand does not directly affect Transformation_{jt}. This assumption holds, for example, when
lenders are simply endowed with a portfolio of securities over which they can make lending
decisions. In the US life insurance industry, the investment portfolios are determined first and
foremost by asset-liability (actuarial) management considerations. Only after their investment
portfolios have been determined do portfolio managers consider lending securities. A standard
practice is for insurers to use agent lenders, who are instructed only in the management of the
securities lending portfolio and are not responsible for the insurer’s asset liability management
or broad investment strategy.

Columns 1 and 2 of Table 4 summarize our main result. Columns 1 reports the baseline results
of estimating equation 3 including insurer, bond, year, and bond–year fixed effects and Huber-
White heteroskedasticity consistent standard errors. Column 2 reports errors two-way clustered
by insurer and bond for the baseline specification as a replacement for the heteroscedasticity-
robust Huber-White standard errors, which has no effect on the statistical significance of the
results. The coefficient on \( Transformation_{jt} \) suggests that, controlling for corporate bond
demand, life insurers with a more aggressive reinvestment strategy tend to lend the same bond
at the same time more often. Averaging the lending decision over bond holdings (collapsing by
insurer-year), the variation in \( Transformation_{jt} \) accounts for about 45 percent of the variation
in bond lending across insurers.

Column 3 interacts \( Transformation_{jt} \) with \( Liquidity_{jt} \), which is the fraction of cash collateral
that is reinvested in corporate bonds and private label ABS. Figure 9 plots the variation of
\( Liquidity_{jt} \) across insurers. The negative and statistically significant coefficient on the interaction
terms suggest that the correlation between the decision to lend and the degree of maturity
transformation is more pronounced when insurers reinvest more of their cash collateral in illiquid
asset such as private label ABS and corporate bonds. As robustness tests, column 4 includes
insurer–bond fixed effects and column 5 includes the size of an insurer securities lending program
(\( SL\ Program\ size_{jt} \)) and the share of each individual bond holding in an insurer’s portfolio (\( Bond\ share_{ijt} \)).

22 For example, the traditional business of life insurers typically consists of meeting a known liability with
unknown timing with a lump sum payment. Life insurers also offer annuities-type contracts that may include life
and non-life contingencies. Since the liabilities of life insurers tend to be of longer duration, part of the company’s
asset-liability management process is to select longer duration and inflation protected assets to match those of
the liability.
23 http://www.naic.org/capital_markets_archive/110708.htm
24 See, for example, this Nov. 2, 2009 press release by J.P. Morgan announcing that it would provide securities
25 We obtain this estimate by multiplying the standard deviation of \( Transformation_{jt} \) by the estimated
coefficient and scaling by the standard deviation of the average lending decision. We also verified that most
of the variation in both variables comes from the cross section and not the time series.
5 Substitution between securities lending and repo funding

Repo transactions are economically similar to securities lending transactions and both are treated in almost the same manner under SSAP accounting. The bonds lent under either a securities lending transaction or a repo transaction remain on the insurers’ balance sheet for accounting purposes. The cash received in exchange for bonds under both types of transactions creates a matching liability on the insurer’s balance sheet. The assets purchased with either securities lending cash collateral or repo cash are included in the insurer’s general account and are subject to a regulatory capital charge. Both transactions are marked-to-market daily. Figure 10 depicts how the balance sheet reports of US life insurers are affected by securities lending and repo transactions.

One key difference between securities lending and repo transactions from the insurers’ perspective is the amount of cash that can be raised using the same bond. With securities lending, insurers typically receive 102 percent of the value of the bond (plus the rebate, if negative), while they usually receive 95 percent or less with repo. For less liquid securities such as corporate bonds, the repo haircut is typically much higher than 5 percent. The difference in these haircuts reflects the different counterparty risk faced by the insurer in the two transactions. The ultimate borrower in a securities lending transaction is often a small hedge fund, for example, while the counterparty to a repo transaction is typically an institutional investor, such as a large money market mutual fund.

The different margins on securities lending and repo transactions present the insurer with a trade off. On the one hand, an insurer financing a portfolio of relatively illiquid assets can do so relatively cheaply by entering securities lending transactions. On the other hand, there is a risk associated with relying on securities lending transactions that an insurer’s bonds might not be in high demand. For those insurers that aggressively reinvest in relatively illiquid assets, the risk associated with securities lending transactions is important because, in times when their bonds are not in high demand, they may be forced to sell their relatively illiquid assets. In an effort to avoid such sales, insurers whose bonds are not in high demand may be more likely to use repo to maintain their investment portfolio.

To test this hypothesis, we collected additional data from insurers’ statutory filings. The data tell us whether a bond in the general account of an insurer is on repo at yearend, how much total cash the insurer raises through repo transactions, and how it re-invests the cash received.
from repo. We implement the test by estimating the following equation:

\[
\text{Repo}_{ijt} = \alpha_1 i + \alpha_2 j + \alpha_3 t + \alpha_4 i \times \alpha_3 t + \beta_1 \text{Transformation}_{jt} \\
+ \beta_2 \text{Fraction Specials}_{jt} + \beta_3 \text{Transformation}_{jt} \times \text{Fraction Specials}_{jt} + \epsilon_{ijt},
\]

where \(\text{Repo}_{ijt}\) is a binary variable that takes a value of 1 if the bond \(i\) held by insurer \(j\) is in a repo transaction at the end of year \(t\), and 0 otherwise. \(\text{Transformation}_{jt}\) is the fraction of assets funded by both securities lending cash collateral and repo cash that have a residual maturity of more than one year. And \(\text{Fraction Specials}_{jt}\) is the fraction of an insurer’s balance sheet that is on special at time \(t\). We calculate \(\text{Fraction Specials}_{jt}\) by first identifying all the bonds that are lent by insurers that reinvest all of their cash collateral in assets with residual maturities of 90 days or less and then calculating the fraction of these bonds in each insurer’s portfolio. Figure 11 plots the distribution of \(\text{Transformation}_{jt}\) across year and insurers. As before, the \(\alpha\)’s are fixed effects to absorb heterogeneity across securities, life insurers, and report dates. Note that while there are about 100 life insurers with active securities lending programs, only about 20 of them are also involved in repo transactions. These 20 insurers form the sample we use in this exercise.

Table 5 summarizes the main results. The coefficient on \(\text{Fraction Specials}_{jt}\) in Column 1 indicates that conditional on their reinvestment strategy, those insurers that have a greater fraction of their bonds on special are less likely to repo an individual bond. Moreover, the coefficient on the interaction term suggests that those insurers that have a more aggressive reinvestment strategy and who have a greater fraction of their bonds on special are less likely to use repo. This relationship is robust to controlling for the size of insurers’ securities lending and repo programs (Column 2), insurer-bond fixed effects (Column 3), and the share of each individual bond in the insurer’s portfolio (Column 4).

6 Securities lending and interest rate risk management

Securities borrower demand, for example from hedge funds implementing short positions, cannot alone explain the results presented in the previous section. That said, our results thus far prompt the questions: Why do some life insurers have larger securities lending programs than others? And why do some reinvest their cash collateral into relatively longer term assets than others? In this section and the next, we provide one possible answer based on interest rate risk

\[26\] Information on the cash reinvestment is available only by maturity bucket and not by individual security, unlike the cash reinvestment portfolio of securities lending.
Life insurers back their long-term liabilities with long-term assets. Because the basic life insurance business model consists of matching the cash flows of assets and liabilities, life insurers' assets are heavily biased towards fixed income investment, such as corporate and government bonds, mortgages, and asset-back securities. However, the duration of life insurers' assets is typically less than the duration of their liabilities, because frictions in the securities market restrict the availability of long-term assets. For example, U.S. firms, excluding financial and utility companies, issued bonds with a median maturity of about 5 years and standard deviation of about 6 years from 2002 to 2012 (Choi, Hackbarth & Zechner 2018). By contrast, long-duration insurance liabilities, such as whole life insurance products, long-term care, and annuities contracts, have a horizon that can extend well beyond 30 years.

A negative duration gap implies that life insurers are exposed to interest rate risk, the present value of the insurer asset and liabilities change at different rates when the interest rate changes. Life insurers can manage small shocks to the interest rate by maintaining a positive net worth, which is the difference between the present value of the statutory asset and liabilities, and is also referred to as policy holder surplus. A sizable decrease in the long-term interest rate will erode an insurer net worth because the present value of liabilities increases more than the present value of its asset, which could lead to an insolvency.

Life insurers can manage their exposure to interest rate risk by adding positive duration to their balance sheet. In general, adding positive duration consist of financing a long term fixed rate debt instrument with short term floating rate debt. Life insurer can add duration without actually financing a fixed rate bond with short term funding by entering into a long term fixed-for-float interest rate swap. The use of interest rate swap by managers aiming to match the duration of assets with that of long-term liabilities is well known. It should also be evident from the previous discussion that using security lending overnight cash collateral to finance relatively long-term assets is an economically similar transaction, which adds duration to the life insurer balance sheet.

In the remaining of this section, we investigate if there is a positive correlation between short-term wholesale funding liabilities issued from life insurers’ general account and the duration implied by the same insurer interest swap portfolio. Although it is not possible to measure life insurers’ duration gap for a number of reasons, we can construct a proxy for the average duration of life insurers’ interest rate swap portfolio. The duration of a fixed-for-float swap

---

27 We recognize that there could be alternative explanations, such as the need for portfolio managers to generate additional income or alpha. We leave the considerable challenge of empirically identifying the relevant mechanism for future work.

28 EXPLAIN WHY CAN’T WE MEASURE DURATION HERE
contract is the difference between the (hypothetical) underlying fixed rate instrument minus the duration of the floating rate liabilities that finances the fixed rate instrument, and vice versa for float-for-fixed swaps.

We collected additional data from NAIC Statutory filings of life insurer Schedule DB. Schedule DB report all open derivative position include a description of the contract term and its notional amount. Because we are interested in a life insurer overall risk management strategy, we aggregates life insurance companies that are part of an insurance holding companies to obtain a single life insurer. We parsed the text of 63,227 individual contract-year observation from 43 life insurers from 2011 to 2015 and extracted the receiving leg, notional amount and residual maturity of the contracts. The average swap notional amount is $48 million with a standard deviation of $84 million. The median swap notional amount is $24 million.

We construct a proxy for life insurer interest rate swap duration in two steps. First, we proxy for the individual fixed-for-float and float-for-fixed duration by $1$ and $-1$ times the individual swap contract residual maturity, respectively. We then take the average over individual life insurer’s swap portfolio weighting each swap contract by their outstanding notional amount. We obtain 245 life insurer-year observations. Life insurers median swap duration is 0. The mean swap duration is 1.5 years with a standard deviation of 5 years.

We implement the test by estimating the following equation:

$$\text{Swap duration}_{jt} = \alpha_t + \beta \text{Wholesale funding ratio}_{jt} + \gamma \text{Transformation}_{jt} + \epsilon_{jt},$$

where $\text{Swap duration}_{jt}$ is a proxy for the balance sheet duration added by life insurers interest rate swap exposure and $\text{Transformation}_{jt}$ is the fraction of assets funded by securities lending cash collateral that have a residual maturity of more than one year. The variable $\text{Wholesale funding ratio}_{jt}$ is defined as the the sum of all short-term wholesale funding liabilities issued from the life insurer’s general account divided by the general account’s policy holder surplus. These short-term wholesale funding liabilities includes securities lending cash collateral, as well as repo cash and funding agreement-backed securities (FABS) with residual maturity of less than one year.

Table 6 summarizes the main results. The coefficient on $\text{Wholesale funding ratio}_{jt}$ in Column 1 indicates that across life insurers, there is a statistically significant and positive association between the proportion of short-term wholesale funding liabilities and the insurer average swap duration. Column 2 show that this association is greater when focusing on the sample of life insurers that engage in maturity and liquidity transformation with their securities lending program. Column 3 shows that the much of the the variation $\text{Wholesale funding ratio}_{jt}$
is absorbed by the variation in Transformation, which is our proxy for life insurers’ securities lending program maturity and liquidity transformation. Column 4 through 6 repeat the specification of Column 1 through 3, respectively by removing MetLife form the sample, as its Wholesale funding ratio ratio is close to 200 percent and more than twice the ratio of the other life insurers in the sample.

7 A parsimonious theory of life insurer interest risk management

In this section, we show that a simple model of life insurers managing their interest rate risk can account for our empirical results. We focus on the decisions of a single life insurer managing its duration gap in a continuous time environment with infinite horizon. To simplify our exposition, our life insurer sells fixed annuities to policy holders. That said, our model is general and applies equally well to a pension fund manager issuing similar type of products and aiming to match the duration of assets with that of long-term liabilities.29

A insurer operating under limited liabilities competitively sells fixed annuities to atomistic policy holders with mortality rate δ. The annuity contract is a promise to make a constant stream of payments, c, after receiving an initial investment from policy holders. The insurer’s aggregate cash flow is deterministic, as policy holders are small and face the same fixed mortality rate. The annuities are the insurer’s main liabilities and have a present value of \( \frac{c}{r_L + \delta} \), where \( r_L \) denotes the long-run interest rate.

The insurer backs its liabilities by investing the policy holders’ initial investment in a zero-coupon bond with maturity \( t_B \in (0, T] \), where \( T \) is an upper bound on bond maturity. Normalizing the principal amount of assets to 1, the present value of the bond is \( e^{-r_L t_B} \).

The difference between the assets and liabilities is the insurer’s net worth, \( NW \).30 It follows that the largest feasible annuity payment stream an insurer can commit to policy holders is

\[
e = (r_L + \delta) \left( e^{-r_L t_B} - NW \right)
\]

However, so long as bond maturity is capped by \( T < \frac{1}{r_L + \delta} \), the insurer cannot back its annuities with bonds without being exposed to a negative duration gap. To see this, note that, under our assumption, the elasticity of the present value of a zero-coupon bond of maturity \( t_B \) with respect to the long term rate \( r_L \) is \( t_B \), while the elasticity of the present value of the annuities with decay rate \( \delta \) with respect to \( r_L \) is \( (r_L + \delta)^{-1} \). Therefore, an insurer backing annuities with a bond of maturity \( t_B \leq T \) is exposed to interest rate risk because \( t_B \leq T < (r_L + \delta)^{-1} \). That

29 Two commonly-used measures of bond duration are Macaulay duration and Modified duration. There is no distinction between these two measures in our continuous-time model, because they are numerically equal when the bond yield is continuously compounded.

30 The net worth of an insurer appears on the balance sheet under a variety of terms, including partnership equity, shareholder value, or surplus.
is, even a small decline in $r_L$ increases the present value of the liabilities more than that of the assets.

[[The insurer manages interest rate risk by choosing a level of net worth that it finances with the annuity markup. The annuity markup is competitive and given by $\frac{1-r}{r_L+\delta}$, which is positive when $NW > 0$. A positive markup means that the fixed annuity price is set above the actuarial fair price. Limited liabilities and perfect competition implies that this annuity price is the lowest feasible competitive price that the life insurer can credibly offer to customers. No customers would purchase annuities from a life insurer offering a lower annuity, as the life insurer could become insolvent with small shocks to the interest rate. In other words, customers can infer the quality of the life insurer’s risk management by looking at its annuity price.]]

The insurer risk management problem consists of maximizing the value of its annuities without creating a duration gap between its assets and liabilities. That is, the insurer solves the following problem:

$$\max_{NW,t_B} c$$

s.t.

$$e^{-r_L t_B} \times 1 = \frac{c}{r_L + \delta} + NW,$$  \hspace{1cm} (5)

$$\frac{d}{dr} \left( e^{-r t_B} \times 1 - \frac{c}{r + \delta} \right) |_{r=r_L} = 0,$$  \hspace{1cm} (6)

$$t_B \leq T.$$  \hspace{1cm} (7)

**Lemma 7.1** If $T < (r_L + \delta)^{-1}$, the insurer manages the interest rate risk associated with small fluctuations in $r_L$ by investing in bonds with the longest possible maturity, such that $t_B = T$. The insurer’s net worth in this case is equal to a fraction $1 - (r_L + \delta) T$ of its assets.

**Proof** The condition for no duration gap, (6), implies $\frac{c}{r_L + \delta} = t_B (r + \delta) \cdot e^{-r_L t_B}$. Thus, increasing $t_B$ to its maximum possible limit, $T$, allows the institutional investor to maximize its annuities while satisfying (7). If $t_B = T$, then the balance sheet condition, (5), implies that $NW = (1 - (r_L + \delta) T) \cdot e^{-r t_B}$, where $e^{-r t_B}$ is the value of the institutional manager’s assets.

This initial net worth immunizes the insurer against small fluctuations in the long-term interest rate. However, a large shock to the long-run interest rate or to policy holders’ mortality rate could hamper the insurer’s ability to manage interest rate risk. For example, once the insurer has committed to its annuity payment stream, $c$, a relatively large decline in the long-run interest rate to $r \ll r_L$ erodes the insurer’s net worth to a level $NW'$ that is insufficient to
manage the resulting duration gap.\footnote{The ex-post value of net worth, given by $NW' = e^{r T} - \frac{c r}{r + \delta}$, is not sufficiently large to let the insurer cushion small changes around the ex-post long-run interest rate, $r$. The decline in net worth associated with the decline in long term interest rate is given by $NW - NW' = e^{-r L T} \left( T (r_L - r) \frac{r L + \delta}{r + \delta} + 1 - e^{(r_L - r) T} \right)$, which can be used to derive a condition for solvency, as in Domanski et al. (2017).}

In response to a large shock, the insurer can restore its capacity to manage its duration gap by re-configuring its balance sheet. Intuitively, the insurer needs to compensate for the decline in asset duration relative to the duration of its liabilities, to which the insurer committed at the inception of the annuity contract. It follows that the insurer’s objectives in the aftermath of a large shock are to recover its net worth and narrow its duration gap subject to the constraint that the duration of assets is capped by $T$. One way to achieve both of these objectives is to issue short-term liabilities and use the proceeds to purchase additional long-term assets to add positive duration to the balance sheet.\footnote{The insurer could also use derivatives, such as interest rate swaps, or restructure its liabilities to close the duration gap. These alternatives are not mutually exclusive and are not the focus of this paper.}

Denote by $SL$ the short-term liabilities issued by the insurer to finance additional long-term bonds of maturity $t_R \leq T$. [[This could be implement synthetically with a fixed-for-float interest rat swap or by physically financing the long term bond with short term cash-like liabilities, and the model applies to both.]] The insurer can recover the decline in its net worth because the interest rate paid on $SL$ is less than the interest rate earned from reinvestment in long-term bonds. Assuming that the short-term interest rate, $r_S$, is paid continuously during the period before the principal matures, the optimal $SL$ and $t_R$ are such that the net present value of profit from engaging in this form of maturity transformation is equal to the lost net worth.\footnote{The present discounted value of the interest payments is $\int_0^{t_R} (r_S \cdot SL) \cdot e^{-r t} \, dt$. The timing of repayment is not crucial for our results. We could instead assume the insurer rolls over its short-term liabilities without paying any interest for $t_R$ periods and then pays both the principal and interest.}

\begin{equation}
SL \cdot \left[ e^{-r t_R} \left( e^{r t_R} - 1 \right) - \frac{r S}{r} \left( 1 - e^{-r t_R} \right) \right] = SL \cdot \left( 1 - \frac{r S}{r} \right) \left( 1 - e^{-r t_R} \right)
\end{equation}

\begin{equation}
= NW - NW'.
\end{equation}

Financing long-term assets with short-term liabilities also lets the insurer eliminate its duration gap. To be sure, the duration of the asset side of the balance sheet is still capped by $T$ and the additional reinvestment causes the asset duration to decrease if $t_R < T$. However, the duration of the insurer’s liabilities decreases relatively more, as the insurer issues short-term liabilities with zero duration. Equating the assets and liabilities duration yields a second...
condition for $SL$ and $t_R$:

$$
\frac{T \cdot e^{-rT} + t_R \cdot SL}{e^{-rT} + SL} = \left( \frac{1}{r_L + \delta} \right) \cdot \left( \frac{c}{r_L + \delta} \right) + 0 \cdot SL + 0 \cdot NW' + 0 \cdot NW',
$$

(9)

where the left-hand and right-hand sides of Equation 9 are the durations of the assets and liabilities, respectively.

**Proposition 7.2** If $T < \frac{1}{r_L + \delta}$, $r$ is not too small, and $r_S$ is not too large, there exists a pair $\{SL, t_R\}$ such that the insurer can simultaneously recover its net worth (Equation 8) and eliminate the duration gap (Equation 9). Moreover, the $\{SL, t_R\}$ locus is decreasing in $\delta$.

The proof of Proposition 7.2 is relatively long and relegated to Appendix A.

Proposition 7.2 illustrates how heterogeneity in the duration of insurers’ liabilities drives variation in their maturity transformation. A smaller $\delta$ is associated with a larger liability duration. Thus, the effect of a change in long-term interest rate on an insurer’s net worth and its duration gap is larger when $\delta$ is lower. An insurer facing a relatively lower $\delta$ can recover its net worth and close its duration gap by issuing a relatively larger amount of short-term liabilities to finance bonds with relatively longer maturity. Consequently, the model implies a positive correlation between the size of an insurer’s short-term liabilities and the maturity transformation associated with those liabilities.\(^{34}\)

**Proposition 7.3** Given the locus $\{SL, t_R\}$ that recovers the insurer’s net worth (Equation 8) and eliminates the duration gap (Equation 9), $SL$ and $t_R$ are increasing and decreasing, respectively, in the short-term interest rate, $r_S$.

**Proof** An increase in $r_S$ decreases the right-hand side of (12). To keep the equality, $t_R$ must decrease, because the left-hand side of (12) is increasing in $t_R$. Therefore, $t_R$ is decreasing in $r_S$. From equation (15), a smaller $t_R$ results in a larger $SL$. Thus, $SL$ is increasing in $r_S$. Note that if $r_S$ becomes too small, then $t_R$ could potentially become larger than $T$, which the life insurer cannot implement.

Proposition 7.3 shows that an insurer in an environment with a lower short-term interest rate tends to engage in relatively more maturity transformation to take advantage of the difference between the short-term and long-term rates. However, the insurer will need a smaller expansion of its balance sheet to restore its net worth and reduce its duration gap. Thus, while the insurer

\(^{34}\) The empirical correlation supporting this result is strong in the cross-section of insurers. Results are available from the authors on request.
reduces its issuance of short-term liabilities, it will increase the maturity of its reinvestment. We discuss some broader implications of this finding in the next section.

8 Discussion

One natural implication of our model is that factors determining the duration gap, such as the shape of the yield curve, can affect long-term institutional investors’ decisions to lend their securities. The model predicts that a steeper yield curve encourages maturity transformation in securities lending programs. Consistent with this prediction, MetLife’s 2017 SEC Form 10-K regulatory filing makes explicit reference to the benefits of lending securities when interest rates are low and the yield curve is steep.35

“...there are positive offsets under the Low Interest Rate Scenario as short-term rates are much lower ... and the yield curve is steeper than that of the business plan. For example, our securities lending business performs better ... because it is driven by the slope of the yield curve rather than by the level of interest rates.”

Moreover, when the short-term interest rate is relatively high and the yield curve is relatively flat, as it was in 2006 and 2007, our model implies that long-term institutional investors lend relatively more securities to compensate for the reduced returns to maturity transformation (Proposition 7.3). This prediction is consistent with the sharp rise and subsequent fall in the amount of securities lent against cash collateral, as depicted in Figure 3.

As a consequence, distortions to the yield curve can have a broader impact on financial markets through their effect on securities lending decisions. Distortions to the yield curve could arise, for example, if investors in riskless short-term assets derive monetary benefits that cause the yield of these assets to be significantly lower than the predictions of standard asset pricing model (Krishnamurthy & Vissing-Jorgensen (2012); Greenwood & Vayanos (2014); Greenwood, Hanson & Stein (2015)). Our model implies that the existence of a convenience yield—for example, due to a scarcity of short-term safe assets can steepen the yield curve—encourages maturity transformation while also reducing the size of securities lending programs.36

Securities lending markets provide two separate channels through which the existence of a convenience yield may negatively affect financial markets. First, smaller securities lending

36 Establishing empirical support for this prediction is challenging because we need to measure how the convenience yield affected individual insurance companies and there are no regulatory data on the duration of life insurers’ liabilities. The same data limitation prevents us from establishing even a correlation between the size of life insurers’ securities lending programs and their duration gaps.
programs reduce the availability of securities and impair liquidity in secondary trading markets. For example, (Foley-Fisher et al. 2019) show that the shutdown of AIG’s securities lending program in 2008 caused a significant reduction in the market liquidity of corporate bonds predominantly held by AIG, as dealers relied on interdealer market trading to fulfill client orders. In addition, smaller securities lending programs can potentially decrease the amount of funding that is available through tri-party repo, further worsening the functioning of the trading markets (Brunnermeier & Pedersen 2009). Both of these factors frustrate efficient pricing of assets. Second, the fragility of overnight cash collateral is a vulnerability for securities lenders, especially those using the cash collateral to finance long-term assets. Concerns about the maturity or liquidity of reinvestment portfolios may drive securities borrowers to rapidly withdraw their cash collateral, as happened to AIG and others in late 2008.\footnote{Similarly, concerns about credit quality of securities in the reinvestment portfolio may also play a role.}

The financial stability risks of runnable products are well known (Bao, David & Han 2015). Setting to one side the role of securities lending as a channel for the effects of a convenience yield, the net benefit in broad terms of more securities lending for financial market participants is ambiguous. On the one hand, as noted above, more securities lending can improve secondary trading market liquidity and increase the supply of funding. On the other hand, the creation of maturity transformation is a key financial stability concern.

The collapse of tri-party repo funding during the 2008-09 financial crisis provides a further example of the financial stability risks associated with securities lending. Figure 12a shows the total cash collateral held by securities lenders (red dashed line) compared to the total assets held by MMFs (blue solid line). Amid widespread concerns about reinvestment portfolios, securities borrowers ran on securities lenders.\footnote{Runs occurred contemporaneously elsewhere in the financial system, including repo markets (Gorton & Metrick 2010a,b, 2012), asset-backed commercial paper (Covitz, Liang & Suarez 2013, Schroth, Suarez & Taylor 2014), MMFs (Schmidt, Timmermann & Wermers 2016), and life insurance companies (Foley-Fisher et al. 2015).} By the first quarter of 2009, cash collateral from securities lending had fallen almost $1 trillion while MMF assets had only begun to decline from pre-crisis levels. Contagion to the broader financial system occurred when, to meet the demand to return cash, securities lenders drew first on the portion of cash collateral that was reinvested in short-term funding markets. The run severely reduced market funding, as shown by the lines in Figure 12b depicting tri-party repo funding provided by securities lenders (red dashed line) and MMFs (blue solid line).\footnote{Figures 12a and 12b reflect only part of the stylized map in Figure 1. Figure 12a shows the total cash collateral that flowed from broker-dealer to securities lenders. However, the red dashed line in Figure 12b shows only the part of cash collateral that was reinvested directly into repo; it does not include cash collateral that was reinvested by securities lenders in MMFs.} By the first quarter of 2009, repo funding from securities lenders had collapsed by almost $300 billion while MMF funding remained relatively more available. Data limitations prevent us from exploring this run further, the new regulatory data on insurer’s

\footnote{Figures 12a and 12b reflect only part of the stylized map in Figure 1. Figure 12a shows the total cash collateral that flowed from broker-dealer to securities lenders. However, the red dashed line in Figure 12b shows only the part of cash collateral that was reinvested directly into repo; it does not include cash collateral that was reinvested by securities lenders in MMFs.}
securities lending programs begin only after the crisis period.

In light of this discussion, it should be clear that measures such as the degree of maturity and liquidity transformation in securities lending programs and the extent to which securities lenders provide tri-party repo funding are important financial stability metrics. Careful monitoring of securities lenders’ programs is especially important for the functioning of corporate bond markets, where financial stability concerns are greatest. Although these measures are available to some extent in the regulatory filings of U.S. life insurers, they are not widely available for all securities lenders.\(^{40}\)

9 Conclusion

This paper studies the supply side of the corporate bond lending market using a new annual dataset from 2011 to 2015 that combines about one million bond holdings reported by US life insurers together with detailed data on US life insurers’ securities lending programs, and with the market for securities lending. We find that, controlling for bond demand, the cross-sectional variation in liquidity transformation by US life insurers accounts for about 45 percent of the variation in their bond lending decision. This finding is in sharp contrast with the literature that assumes securities lenders primarily respond to borrowers’ demand.

References


\(^{40}\) Measures of maturity mismatch and repo funding associated with securities lending programs would augment the data collection proposed by Adrian, Begalle, Copeland & Martin (2012). Koijen & Yogo (2015) note that life insurers’ statutory filings lack details on the international dimensions of life insurers’ securities lending programs.


Figure 1: A stylized map of securities lenders’ role in the shadow banking system. Broker-dealers obtain cash from money market mutual funds and securities lenders through short-term funding markets. The dealers provide the cash to securities market participants. The cloud represents the general functioning of securities markets, illustrated with the example of hedge funds taking long and short positions. Securities market participants borrow both cash funding and securities. Securities lenders decide whether to lend assets from their portfolios in exchange for collateral, in the form of either cash or other securities, from broker-dealers. When they receive cash collateral, securities lenders decide whether to invest back into short-term markets or into long-term markets. In the latter case, they may invest, for example, in long-term corporate bonds or asset-backed securities.
Figure 2: Coverage of the stylized map of securities lending by the existing literature. Duffie et al. (2002) (Panel (a)) study the effect of interactions between securities lenders and broker-dealers on pricing in the securities market. Brunnermeier & Pedersen (2009) and Gorton & Metrick (2012) (Panel (b)) consider the effect of haircuts on cash funding and the functioning of securities markets. Krishnamurthy et al. (2014) (Panel (c)) describe how securities lenders and MMFs participate in short-term funding markets. The overall map is described in the notes to Figure 1.

(a) Duffie, Gârleanu & Pedersen (2002)

(b) Brunnermeier & Pedersen (2009), Gorton & Metrick (2012)

(c) Krishnamurthy, Nagel & Orlov (2014)
Figure 3: Securities lending against cash collateral in the United States. These daily data aggregate the fair value of all securities lent against cash collateral in the United States, including equity, Treasuries, agency securities, and corporate bonds. The category of other lenders includes corporations, endowments, foundations, and government bodies. Source: Authors’ calculations based on data from Markit Securities Finance.

![Figure 3: Securities lending against cash collateral in the United States.](image1)

Figure 4: Corporate bond lending against cash collateral in the United States. These daily data aggregate the fair value of all corporate bonds lent against cash collateral in the United States. The category of other lenders includes corporations, endowments, foundations, and government bodies. Source: Authors’ calculations based on data from Markit Securities Finance.

![Figure 4: Corporate bond lending against cash collateral in the United States.](image2)
Figure 5: Extract from Schedule DL. The exhibit below is an extract from the 2012 regulatory filing by the Metropolitan Life Insurance Company, showing a sample of the individual security-level investments made using cash collateral received from securities lending.

<table>
<thead>
<tr>
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<td>1,115.19</td>
<td>-0.02</td>
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<td>1,115.19</td>
<td>STE</td>
<td>1,115.19</td>
<td>1,115.19</td>
<td>-0.02</td>
<td>1,115.19</td>
<td>1,115.19</td>
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<tr>
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<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>STE</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
</tr>
<tr>
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<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
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<td>1,000.00</td>
<td>STE</td>
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<td>1,000.00</td>
<td>1,000.00</td>
<td>STE</td>
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<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>STE</td>
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<td>1,000.00</td>
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<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>STE</td>
<td>1,000.00</td>
<td>1,000.00</td>
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<td>1,000.00</td>
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</tr>
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<td>369042 B3</td>
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<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>STE</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
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<tr>
<td>369043 A3</td>
<td>3FEDERAL NATIONAL MORTGAGE...</td>
<td>ZTA</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>STE</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
</tr>
<tr>
<td>369044 A4</td>
<td>5STANFORD MORTGAGE CAPITAL...</td>
<td>ZTA</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>STE</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
</tr>
<tr>
<td>369045 A5</td>
<td>7STANFORD MORTGAGE CAPITAL...</td>
<td>ZTA</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>STE</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
</tr>
<tr>
<td>369046 A6</td>
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<td>ZTA</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>STE</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
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<td>ZTA</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>STE</td>
<td>1,000.00</td>
<td>1,000.00</td>
<td>-0.00</td>
<td>1,000.00</td>
<td>1,000.00</td>
</tr>
</tbody>
</table>

Note: The table above shows a sample of the investments made using cash collateral received from securities lending.
Figure 6: Extract from Note 5(e) to the Financial Statements. The exhibit below is an extract from the 2012 regulatory filing by the Metropolitan Life Insurance Company, showing a breakdown by maturity of the cash collateral received from securities lending.

NOTES TO THE FINANCIAL STATEMENTS

(5) The Company performs a regular evaluation, on a security-by-security basis, of its securities holdings in accordance with its OTTI policy in order to evaluate whether each investment is other-than-temporarily impaired. Management considers a wide range of factors about the security issuer and uses its best judgment in evaluating the cause of the decline in the estimated fair value of the security and in assessing the prospects for near-term recovery. Factors considered include fundamentals of the industry and geographic area in which the security issuer operates, as well as overall macroeconomic conditions. Projected future cash flows are estimated using assumptions derived from management’s best estimates of likely scenario-based outcomes after giving consideration to a variety of variables including, but are not limited to: (i) general payment terms of the security; (ii) the likelihood that the issuer can service the scheduled interest and principal payments; (iii) the quality and amount of any credit enhancements; (iv) the security’s position within the capital structure of the issuer; (v) possible corporate restructurings or asset sales by the issuer; and (vi) changes to the rating of the security or the issuer by rating agencies. Additional considerations are made when assessing the unique features that apply to certain loan-backed and structured securities including, but are not limited to: (i) the quality of underlying collateral; (ii) expected prepayment speeds; (iii) current and forecasted loss severity; (iv) consideration of payment terms of the underlying assets backing the security; and (v) the payment priority within the tranching structure of the security. For loan-backed or structured securities in an unrealized loss position as summarized in the immediately preceding table, the Company does not have the intent to sell the securities, believes it has the intent and ability to retain the securities for a period of time sufficient to recover the carrying value of the security and, based on the cash flow modeling and other considerations as described above, believes these securities are not other-than-temporarily impaired.

E. Repurchase Agreements and/or Securities Lending Transactions

(1) For repurchase agreements, the Company requires a minimum of 100 percent of the fair value of securities purchased under repurchase agreements to be maintained as collateral. Cash collateral received is invested in short-term investments with an offsetting liability for collateral to be returned to the counterparty.

The Company participates in a securities lending program whereby blocks of securities, which are included in invested assets, are loaned to third parties, primarily major brokerage firms and commercial banks. Generally, the Company accepts collateral of 102 percent of the fair value of the loaned securities to be separately maintained as collateral for the loans. The Company is liable for the return of the cash collateral under its control to its counterparties.

(2) The Company pledged its assets at book/adjusted carrying value of $13,475 million as collateral as of December 31, 2012.

(3) Collateral received

The Company participates in a securities lending program as discussed in Note 17.

a. The aggregate amount of collateral received as of December 31, 2012, was as follows (in millions):

<table>
<thead>
<tr>
<th>Securities Lending</th>
<th>Fair Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open(1)</td>
<td>$3,638</td>
</tr>
<tr>
<td>30 days or less</td>
<td>10,591</td>
</tr>
<tr>
<td>31 to 60 days</td>
<td>3,116</td>
</tr>
<tr>
<td>61 to 90 days</td>
<td>1,396</td>
</tr>
<tr>
<td>Greater than 90 days</td>
<td></td>
</tr>
<tr>
<td>Sub-Total</td>
<td>$18,441</td>
</tr>
<tr>
<td>Securities received</td>
<td>-45</td>
</tr>
<tr>
<td>Total collateral received</td>
<td>$18,486</td>
</tr>
</tbody>
</table>

(1) The related loaned security could be returned to the Company on the next business day requiring the Company to immediately return the cash collateral.

3. The Company did not have any cash collateral received from dollar repurchase agreements.

Securities with a cost or amortized cost of $15,652 million and an estimated fair value of $17,982 million were on loan under the Company’s securities lending program as of December 31, 2012.

b. As of December 31, 2012, the aggregate fair value of all securities acquired from the sale, trade or use of the accepted collateral (reinvested collateral) was (in millions):

<table>
<thead>
<tr>
<th>Securities Lending</th>
<th>Fair Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>reinvested collateral</td>
<td>$18,496</td>
</tr>
</tbody>
</table>

c. The estimated fair value of the securities related to the cash collateral as open terms was $3,544 million at December 31, 2012, of which $3,417 million were U.S. Treasury and agency securities which, if put to the Company, can be sold to satisfy the cash requirements. The remainder of the securities on loan, related to the cash collateral aged less than thirty days to ninety days or greater, were primarily U.S. Treasury and agency securities and liquid RMBS. The reinvestment portfolio acquired with the cash collateral consisted principally of fixed maturity securities (including RMBS, ABS, U.S. corporate and foreign corporate securities).
Figure 7: Securities lending by US life insurers. This chart shows the quarterly amount of cash collateral received by US life insurers through their securities lending programs and the composition of the cash collateral reinvestment. The categories presented in the figure are based on state regulators (NAIC) classification and reported by individual insurers. Source: Authors’ calculations based on data from quarterly Statutory Filings.
Figure 8: Variation in life insurers’ liquidity, maturity and credit transformation. We proxy for liquidity, maturity and credit transformation using the fraction of each life insurer’s cash reinvestment portfolio that has a residual maturity of more than one year minus the fraction of the cash collateral the insurer received that has a duration of more than one year. The figure below shows box-and-whisker plots for each year 2011-2015 that represent the distributions of transformation over the 100 available US life insurance companies. Each plot has a solid area that covers the 25th to 75th percentiles and a line within the solid area showing the median of the distribution. The whiskers reflect the remaining observations, up to 1.5 times the interquartile range, and the dots are outliers. There is a considerable variation in the degree of transformation across life insurers, in some instances reinvesting almost all their cash collateral into securities with a residual maturity of more than one year. Source: Authors’ calculations based on NAIC Annual Statutory Filings.
Figure 9: Variation in life insurers’ liquidity transformation. We measure liquidity transformation by calculating the fraction of each life insurer’s cash reinvestment portfolio that is invested in relatively illiquid corporate bonds and private label ABS. The figure below shows box-and-whisker plots for each year 2011-2015 that represent the distributions of liquidity transformation over the 100 available US life insurance companies. Each plot has a solid area that covers the 25th to 75th percentiles and a line within the solid area showing the median of the distribution. The whiskers reflect the remaining observations, up to 1.5 times the interquartile range, and the dots are outliers. There is considerable variation in the degree of liquidity transformation across life insurers, in some instances reinvesting almost all their cash collateral into relatively illiquid securities. Source: Authors’ calculations based on NAIC Annual Statutory Filings.
Figure 10: Securities lending and repo on the balance sheets of US life insurers. The left-hand balance sheet depicts the balance sheet of a traditional life insurer, whose main liabilities are insurance policies. This insurer matches the expected cash flows on its insurance policies with cash flow income from its assets, including corporate bonds and Treasuries. The right-hand balance sheet shows how a life insurer can increase the size of its balance sheet by lending securities. When the insurer lends a security in either a repo or a securities lending transaction, it records the cash it receives as a liability. The reinvestment of that cash by the insurer is recorded as an asset. The insurer can earn a spread by reinvesting the cash collateral in securities that offer a higher return than the cost of funding. The figure shows how insurers can scale up their balance sheets by lending their securities to raise and maintain a pool of funding for relatively longer-term and illiquid investments.

<table>
<thead>
<tr>
<th>Life Insurer</th>
<th>Life Insurer Lending Securities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assets</td>
<td>Liabilities</td>
</tr>
<tr>
<td>Corporate bonds</td>
<td>Insurance</td>
</tr>
<tr>
<td>Treasuries</td>
<td>Policies</td>
</tr>
<tr>
<td>Other assets</td>
<td>Equity</td>
</tr>
<tr>
<td></td>
<td>Cash collateral</td>
</tr>
<tr>
<td></td>
<td>reinvestment</td>
</tr>
</tbody>
</table>
Figure 11: Variation in life insurers’ portfolio “specialness.” We identify special bonds as those bonds that are lent by insurers that do not engage in any liquidity, maturity or credit transformation with the cash collateral they received. We then use this list of bonds to calculate the fraction of each insurers’ bond portfolio that is special on this given date. The figure below shows box-and-whisker plots for each year 2011-2015 that represent the distributions of portfolio specialness over the 100 available US life insurance companies. Each plot has a solid area that covers the 25th to 75th percentiles and a line within the solid area showing the median of the distribution. The whiskers reflect the remaining observations, up to 1.5 times the interquartile range, and the dots are outliers. There is considerable variation in the degree of portfolio specialness across life insurers and over time. Source: Authors’ calculations based on NAIC Annual Statutory Filings.
Figure 12: Securities lenders’ and MMFs’ tri-party repo market funding. Panel (a) shows the total resources potentially available to securities lenders and MMFs for lending. Panel (b) shows the amount of funding that securities lenders and MMFs provided through the tri-party repo market. Source: Krishnamurthy, Nagel & Orlov (2014), based on data from Risk Management Associates.
Table 1: Summary statistics. Columns 1 through 4 report the number of observations, mean, median, and standard deviation of variables used in our analysis from the annual Statutory filings of insurance companies. Securities lending programs are scaled by the size of the general account. Liquidity transformation is the fraction of the cash reinvestment portfolio that has a residual maturity of at least one year minus the fraction of cash collateral that has a residual maturity of more than one year. Columns 5 through 8 show statistics after merging the Statutory filings with Mergent FISD, adding information on bond characteristics. We numerically translate and average credit ratings across the three main agencies, setting AAA, or equivalent = 28, AA+ = 26, AA = 25, AA- = 24 ... CCC- = 9, CC = 7, and C = 4. Columns 9 through 12 provide statistics after subsequently merging with Markit Securities Finance data on the securities lending market. Weighted averages are calculated using the value of the loan.

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<th>NAIC Annual Statements</th>
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<th>Merge with Markit</th>
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<td>(5) (6) (7) (8)</td>
<td>(9) (10) (11) (12)</td>
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<tr>
<td>Obs.</td>
<td></td>
<td>Obs.</td>
<td>Obs.</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>Mean</td>
<td>Mean</td>
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<td>Life insurance companies</td>
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<tr>
<td>General account value ($bn)</td>
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<td>111</td>
<td>111</td>
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<tr>
<td>Securities lending (SL program size)</td>
<td>506 24.3 6.51 45.55</td>
<td>506 24.3 6.51 45.55</td>
<td>506 24.3 6.51 45.55</td>
</tr>
<tr>
<td>SL Liquidity transformation (Transformation)</td>
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<td>395 0.16 0 0.28</td>
<td>395 0.16 0 0.28</td>
</tr>
<tr>
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<td>395 0.17 0 0.28</td>
<td>395 0.17 0 0.28</td>
</tr>
<tr>
<td>Fraction of bonds on special (Fraction Special)</td>
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<td>395 0.25 0.25 0.1</td>
<td>395 0.25 0.25 0.1</td>
</tr>
<tr>
<td>Fair value of bond holding ($m)</td>
<td>997,100 9.26 4 27.22</td>
<td>456,372 9.87 5 22.08</td>
<td>354,153 10.05 5 24.44</td>
</tr>
<tr>
<td>Dummy variable for lent security (Loan)</td>
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<td>456,372 0.05 0 0.22</td>
<td>354,153 0.07 0 0.25</td>
</tr>
<tr>
<td>Dummy variable for repo security (Repo)</td>
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<td>456,372 0 0 0.07</td>
<td>354,153 0 0 0.06</td>
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<td>Offering amount ($bn)</td>
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<td>456,371 0.86 1 1.24</td>
<td>343,911 1.04 1 1.33</td>
</tr>
<tr>
<td>Offering yield (percent)</td>
<td></td>
<td>376,873 5.54 6 1.66</td>
<td>282,342 5.33 5 1.62</td>
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<tr>
<td>Residual maturity (yrs)</td>
<td></td>
<td>454,137 11.34 8 9.71</td>
<td>342,281 11.41 8 9.34</td>
</tr>
<tr>
<td>Amount outstanding ($bn)</td>
<td></td>
<td>250,955 0.83 1 1.27</td>
<td>183,411 1.04 1 1.36</td>
</tr>
<tr>
<td>Credit rating</td>
<td></td>
<td>445,193 19.94 20 3.01</td>
<td>337,283 19.85 20 3.05</td>
</tr>
<tr>
<td>Weighted avg rebate (Rebate)</td>
<td></td>
<td>354,153 0 0 0.07</td>
<td>354,153 0 0 0.07</td>
</tr>
<tr>
<td>% total lendable held (Market share)</td>
<td></td>
<td>354,153 0.02 0 0.13</td>
<td>354,153 0.02 0 0.13</td>
</tr>
<tr>
<td>HHI of life insurers' holdings (HHI)</td>
<td></td>
<td>354,153 0.28 0 6.47</td>
<td>354,153 0.28 0 6.47</td>
</tr>
<tr>
<td>Total lent/total lendable (Market tightness)</td>
<td></td>
<td>354,153 0.01 0 0.1</td>
<td>354,153 0.01 0 0.1</td>
</tr>
</tbody>
</table>
Using the final merged dataset, the two panels compare characteristics of bonds lent by insurance companies with those that are not lent.

<table>
<thead>
<tr>
<th></th>
<th>Non-lent securities: $Loan_{ijt} = 0$</th>
<th>Lent securities: $Loan_{ijt} = 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) (2) (3) (4)</td>
<td>(5) (6) (7) (8)</td>
</tr>
<tr>
<td></td>
<td>Obs.</td>
<td>Mean</td>
</tr>
<tr>
<td>Fair value of bond holding ($m$)</td>
<td>330,367</td>
<td>9.86</td>
</tr>
<tr>
<td>Offering amount ($bn$)</td>
<td>320,544</td>
<td>1.03</td>
</tr>
<tr>
<td>Offering yield (percent)</td>
<td>263,726</td>
<td>5.32</td>
</tr>
<tr>
<td>Residual maturity (yrs)</td>
<td>319,118</td>
<td>11.38</td>
</tr>
<tr>
<td>Amount outstanding ($bn$)</td>
<td>171,450</td>
<td>1.05</td>
</tr>
<tr>
<td>Credit rating</td>
<td>314,304</td>
<td>19.87</td>
</tr>
<tr>
<td>Avg weighted rebate ($Rebate_{it}$)</td>
<td>330,367</td>
<td>0.05</td>
</tr>
<tr>
<td>% total lendable held ($Market:share_{ijt}$)</td>
<td>330,367</td>
<td>0.08</td>
</tr>
<tr>
<td>HHI of total lendable held ($HHI_{it}$)</td>
<td>330,367</td>
<td>0.37</td>
</tr>
<tr>
<td>Total lent/total lendable ($Market:tightness_{it}$)</td>
<td>330,367</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Table 3: Determinants of corporate bond lending and specialness. The unit of observation is a bond-insurer-year. In columns 1 and 2, the dependent variable \( Loan_{ijt} \) takes a value of 1 if insurer \( j \) is lending bond \( i \) at time \( t \) and 0 otherwise. Column 1 reports a regression of \( Loan_{ijt} \) on the transaction-weighted average rebate (\( Weighted\ Rebate_{it} \)), the insurer’s holding as a share of the amount available to borrow (\( Market\ share_{ijt} \)), and our measure of liquidity transformation in the insurer’s securities lending program (\( Transformation_{jt} \)). Column 2 adds controls for the concentration of life insurers’ holdings (\( HHI_{it} \)), the amount available to borrow relative to the amount outstanding (\( Market\ tightness_{it} \)), residual maturity, amount outstanding, rating, offering yield, and amount issued. Column 3 reports a regression of \( Weighted\ Rebate_{it} \) on \( Market\ share_{ijt} \) and \( Transformation_{jt} \). Column 4 adds the same set of controls as in Column 2. All the regressions include fixed effects for insurer, year, and bond issuer; and specify Huber-White standard errors. *** p<0.01; ** p<0.05; * p<0.1.

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Market\ share_{ijt} )</td>
<td>0.0778***</td>
<td>0.0714***</td>
<td>-0.0238***</td>
<td>-0.0213***</td>
</tr>
<tr>
<td>( Transformation_{jt} )</td>
<td>0.105***</td>
<td>0.107***</td>
<td>-0.00195</td>
<td>-0.00240</td>
</tr>
<tr>
<td>( Weighted\ Rebate_{it} )</td>
<td>-0.214***</td>
<td>-0.148***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( Residual\ maturity_{it} )</td>
<td>0.000666***</td>
<td></td>
<td>0.000400***</td>
<td></td>
</tr>
<tr>
<td>( Amount\ outstanding_{it} )</td>
<td>0.0113***</td>
<td></td>
<td>0.00151**</td>
<td></td>
</tr>
<tr>
<td>( Rating_{it} )</td>
<td>-0.000493</td>
<td></td>
<td>0.00771***</td>
<td></td>
</tr>
<tr>
<td>( Offering\ yield_{i} )</td>
<td>-0.00229***</td>
<td></td>
<td>-0.000188</td>
<td></td>
</tr>
<tr>
<td>( Offering\ amount_{i} )</td>
<td>-0.00539*</td>
<td></td>
<td>0.00187***</td>
<td></td>
</tr>
<tr>
<td>( Market\ tightness_{it} )</td>
<td>0.467***</td>
<td>0.731***</td>
<td>-0.154***</td>
<td>-0.235***</td>
</tr>
<tr>
<td>( HHI_{it} )</td>
<td>-0.0153***</td>
<td>-0.0125***</td>
<td>-0.0162***</td>
<td>-0.0161***</td>
</tr>
</tbody>
</table>

Fixed effects:

- Insurer, Year, Issuer: Y Y Y Y

Observations: 265,879 109,671 265,879 109,671
R-squared: 0.153 0.164 0.694 0.687
Table 4: The supply channel of securities lending. The unit of observation is a bond-insurer-year. The dependent variable \((Loan_{ijt})\) takes a value of 1 if at time \(t\) insurer \(j\) is lending bond \(i\), and 0 otherwise. The main explanatory variable \((Transformation_{jt})\) is the fraction of cash collateral reinvestment that has a residual maturity of more than one year minus the fraction of cash collateral that has a residual maturity of more than one year. Columns 1 reports the baseline correlation including insurer, bond, year, and bond–year fixed effects, with Huber-White heteroskedasticity consistent standard errors. Column 2 reports errors two-way clustered by insurer and bond for the baseline specification. Column 3 interacts \(Transformation_{jt}\) with \(Liquidity_{jt}\), which is the fraction of cash collateral that is reinvested in corporate bonds and private label ABS. Column 4 includes insurer–bond fixed effects. Figure 2 and 3 in this document plot the variation of \(Transformation_{jt}\) and \(Liquidity_{jt}\) across insurers, respectively. Column 5 includes the size of an insurer securities lending program \((SL\ Program\ size_{jt})\) and the share of each individual bond holding in an insurer’s portfolio \((Bond\ share_{ijt})\). Column 3 through 5 report errors two-way clustered by insurer and bond. *** \(p<0.01\); ** \(p<0.05\); * \(p<0.1\).

<table>
<thead>
<tr>
<th>Dep. variable: (Loan_{ijt})</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Transformation_{jt})</td>
<td>0.0691***</td>
<td>0.0691***</td>
<td>0.0419**</td>
<td>0.0640***</td>
<td>0.0691***</td>
</tr>
<tr>
<td>(0.00541)</td>
<td>(0.0182)</td>
<td>(0.0208)</td>
<td>(0.0219)</td>
<td>(0.0191)</td>
<td></td>
</tr>
<tr>
<td>(Transformation_{jt} \times ) (Liquidity_{jt})</td>
<td>0.0803**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.0358)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Liquidity_{jt})</td>
<td>-0.00435</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.0166)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(SL\ Program\ size_{jt})</td>
<td></td>
<td>1.353**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.527)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Bond\ share_{ijt} \times ) 2011</td>
<td></td>
<td>0.0336***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.0104)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Bond\ share_{ijt} \times ) 2012</td>
<td></td>
<td>-0.0210</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.0173)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Bond\ share_{ijt} \times ) 2013</td>
<td></td>
<td>-0.00955</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.00987)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Bond\ share_{ijt} \times ) 2014</td>
<td></td>
<td>-0.0159</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.0106)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Bond\ share_{ijt} \times ) 2015</td>
<td></td>
<td>-0.0150*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.00830)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fixed effects:
- \(Insurer; Bond; Year\)  
- \(Bond \times Year\)  
- \(Bond \times Insurer\)  

Standard errors: Huber-White

Observations: 605,953 605,953 605,953 536,046 605,582

R-squared: 0.292 0.292 0.292 0.585 0.294
Table 5: Specialness and substitution with repo

The unit of observation is a bond-insurer-year. The dependent variable \( \text{Repo}_{ijt} \) takes a value of 1 if at time \( t \) bond \( i \) on the balance sheet of insurer \( j \) is part of a repo transaction, and 0 otherwise. The main explanatory variable is the interaction of \( \text{Transformation}_{jt} \), defined as the fraction of securities lending cash collateral and repo cash that is reinvested in assets with residual maturity of more than one year, and \( \text{Special}_{jt} \), defined as the fraction of an insurer’s portfolio that is on special. The sample is restricted to about 20 insurers that were counterparties to at least one repo transaction in the period 2011-2015. Column 1 reports the baseline correlation including insurer, bond, year, and bond–year fixed effects. Column 2 includes the size the securities lending and repo program. Column 3 includes insurer–bond fixed effects. Column 4 includes the share of each individual bond holding in an insurer’s portfolio \( \text{Bond share}_{ijt} \). Huber-White standard errors are reported in parentheses. *** \( p<0.01; ** \( p<0.05; * \) \( p<0.1 \).

<table>
<thead>
<tr>
<th>Dep. variable: ( \text{Repo}_{ijt} )</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Transformation}_{jt} )</td>
<td>0.0515***</td>
<td>0.0363***</td>
<td>-0.00907</td>
<td>0.0448***</td>
</tr>
<tr>
<td></td>
<td>(0.0113)</td>
<td>(0.0117)</td>
<td>(0.0101)</td>
<td>(0.0120)</td>
</tr>
<tr>
<td>( \text{Transformation}<em>{jt} \times \text{Fraction Special}</em>{jt} )</td>
<td>-0.456***</td>
<td>-0.335***</td>
<td>-0.275***</td>
<td>-0.371***</td>
</tr>
<tr>
<td></td>
<td>(0.0566)</td>
<td>(0.0579)</td>
<td>(0.0512)</td>
<td>(0.0592)</td>
</tr>
<tr>
<td>( \text{Fraction Special}_{jt} )</td>
<td>-0.341***</td>
<td>-0.397***</td>
<td>-0.277***</td>
<td>-0.397***</td>
</tr>
<tr>
<td></td>
<td>(0.0262)</td>
<td>(0.0304)</td>
<td>(0.0284)</td>
<td>(0.0304)</td>
</tr>
<tr>
<td>( \text{SL &amp; Repo program size}_{jt} )</td>
<td>0.528***</td>
<td>0.322***</td>
<td>0.512***</td>
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</tr>
<tr>
<td></td>
<td>(0.0674)</td>
<td>(0.0539)</td>
<td>(0.0681)</td>
<td></td>
</tr>
<tr>
<td>( \text{Bond share}_{ijt} \times 2011 )</td>
<td></td>
<td></td>
<td></td>
<td>0.00655</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.00424)</td>
</tr>
<tr>
<td>( \text{Bond share}_{ijt} \times 2012 )</td>
<td></td>
<td></td>
<td>0.00990*</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.00519)</td>
<td></td>
</tr>
<tr>
<td>( \text{Bond share}_{ijt} \times 2013 )</td>
<td></td>
<td></td>
<td>0.0511***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.00673)</td>
<td></td>
</tr>
<tr>
<td>( \text{Bond share}_{ijt} \times 2014 )</td>
<td></td>
<td></td>
<td>0.0567***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.00731)</td>
<td></td>
</tr>
<tr>
<td>( \text{Bond share}_{ijt} \times 2015 )</td>
<td></td>
<td></td>
<td>0.0372***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.00609)</td>
<td></td>
</tr>
</tbody>
</table>

Fixed effects:
- \( \text{Insurer}, \text{Year}, \text{Issuer} \): Y Y Y Y Y
- \( \text{Bond } \times \text{Year} \): Y Y Y Y Y
- \( \text{Bond } \times \text{Insurer} \): N N Y N

Observations: 145,656 145,656 121,526 145,579

\( R^2 \): 0.497 0.497 0.774 0.499

46
Table 6: Short-term wholesale funding and interest rate swaps

The unit of observation is a life insurer-year. We aggregate life insurance companies that are part of an insurance holding companies to obtain a single life insurer. The dependent variable (\(\text{Swap duration}_{jt}\)) is a proxy for the balance sheet duration added by life insurers interest rate swap position. The main explanatory variable is \(\text{Wholesale funding ratio}_{jt}\) defined as the fraction of short-term wholesale funding liabilities issued from the life insurer’s general account to the the general account’s policy holder surplus. The variable \(\text{Transformation}_{jt}\) is defined as the fraction of securities lending cash collateral that is reinvested in assets with residual maturity of more than one year. The sample contains 43 life insurers in the period 2011-2015. Column 1 reports the baseline correlation including year effects. Column 2 restricts the sample to those life insurer with \(\text{Transformation}_{jt} > 0\). Column 3 includes \(\text{Transformation}_{jt}\) as an explanatory variable. Column 4-6 are analogs of Column 1-3 excluding Met-Life whose \(\frac{\text{Wholesale funding}}{\text{Policyholders surplus}}\) ratio is more than twice as large as the other life insurers in the sample. Huber-White standard errors are reported in parentheses. *** p<0.01; ** p<0.05; * p<0.1.

<table>
<thead>
<tr>
<th>Dep. variable: Swap duration_{jt}</th>
<th>(1)</th>
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<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wholesale funding ratio_{jt}</td>
<td>1.560***</td>
<td>2.535***</td>
<td>0.326</td>
<td>2.421**</td>
<td>6.153***</td>
<td>1.118</td>
</tr>
<tr>
<td></td>
<td>(0.600)</td>
<td>(0.854)</td>
<td>(0.902)</td>
<td>(1.074)</td>
<td>(1.396)</td>
<td>(1.257)</td>
</tr>
<tr>
<td>Transformation_{jt}</td>
<td>2.311</td>
<td>2.516*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.402)</td>
<td>(1.429)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>245</td>
<td>165</td>
<td>170</td>
<td>240</td>
<td>160</td>
<td>165</td>
</tr>
<tr>
<td>R²</td>
<td>0.023</td>
<td>0.050</td>
<td>0.026</td>
<td>0.026</td>
<td>0.082</td>
<td>0.029</td>
</tr>
<tr>
<td>Year FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>
A Model Appendix

Proof of Proposition 7.2 Following a significant change in the long-term interest rate, the institutional investor will face an increase the duration gap and its net worth will fall by $NW - NW' = e^{-r_LT} \left( T (r_L - r) \frac{r_L + \delta}{r + \delta} + 1 - e^{(r_L - r) T} \right)$. To eliminate the duration gap (9) and recover net worth (8), the institutional investor needs to choose $SL$ and $t_R$ to simultaneously solve two equations:

\[ A = T \cdot e^{-r_LT} + t_R \cdot SL - \left( \frac{1}{r + \delta} \right) \cdot \left( \frac{c}{r + \delta} \right) \]
\[ = T \cdot e^{-r_LT} + t_R \cdot SL - \left( \frac{r_L + \delta}{r + \delta} \right)^2 T \cdot e^{-r_LT} = 0, \tag{10} \]

\[ B = SL \cdot \left( 1 - \frac{r_S}{r} \right) \left( 1 - e^{-rt_R} \right) - e^{-r_LT} \left( T (r_L - r) \frac{r_L + \delta}{r + \delta} + 1 - e^{(r_L - r) T} \right) = 0. \tag{11} \]

By solving for $SL$ from (10) and plugging it into (11), we get the following implicit equation governing $t_R$:

\[ \frac{t_R}{1 - e^{-rt_R}} = \left( 1 - \frac{r_S}{r} \right) \frac{1}{r_L - r} \left( \frac{r_L + \delta}{r + \delta} \right)^2 - e^{(r_L - r) T} \left( \frac{r_L + \delta}{r + \delta} \right) \frac{1 - e^{(r_L - r) T}}{T (r_L - r)}. \tag{12} \]

The left-hand side of (12) is increasing in $t_R$. That is because $\frac{dt_R}{dt_R} \frac{1}{1 - e^{-rt_R}} = \frac{1 - (1 + rt_R) e^{-rt_R}}{(1 - e^{-rt_R})^2} > 0$ follows from $e^{rt_R} > (1 + rt_R)$. Also, $\lim_{t_R \to 0} t_R \frac{1}{1 - e^{-rt_R}} = \frac{1}{r}$ and $\lim_{t_R \to \infty} t_R \frac{1}{1 - e^{-rt_R}} \to \infty$. Therefore, so long as the left-hand side of (12) is larger than $\frac{1}{r}$, there exist a $t_R > 0$ that solves (12).

If $r$ is not too small and $r_S$ is not too large, then the right-hand side of (12) is larger than $\frac{1}{r}$. In particular, for

\[ r > r_L - \frac{2 (r_L + \delta) + r_L - \sqrt{(2 (r_L + \delta))^2 + (r_L)^2}}{2}, \tag{13} \]

we have $r > \left( \frac{r + \delta}{r_L + \delta} \right) (r_L - r)$.\(^{41}\) So $r_S$ could be positive and still satisfy

\[ r_S < r - \left( \frac{r + \delta}{r_L + \delta} \right) (r_L - r), \tag{14} \]

\(^{41}\)Note that $(2 (r_L + \delta) + r_L)^2 > (2 (r_L + \delta))^2 + (r_L)^2$. So $r$ could be smaller than $r_L$ and still satisfy (13).
in which case we have \((1 - \frac{r_S}{r}) \frac{1}{(r_L - r)} \left( \frac{r_L + \delta}{r + \delta} \right) > \frac{1}{r}\). Because \(0 < (r_L - r) T < (r_L + \delta) T < 1\), the right-hand side of (12) is larger than \(\cdot (1 - \frac{r_S}{r}) \frac{1}{(r_L - r)} \left( \frac{r_L + \delta}{r + \delta} \right)\) and, thus, larger than \(\frac{1}{r}\).

Given the solution for \(t_R\), the solution for \(SL\) follows from (10) as

\[
SL = \frac{1}{t_R} T \cdot e^{-r_L T} \left( \left( \frac{r_L + \delta}{r + \delta} \right)^2 - 1 \right). \tag{15}
\]

Next we show that the \(t_R\) and \(SL\) that solve (10) and (11) are both decreasing in \(\delta\). Using the implicit equations (10) and (11) we get

\[
\frac{dt_R}{d\delta} = -\left| \begin{array}{cc} \frac{\partial A}{\partial \delta} & \frac{\partial A}{\partial SL} \\ \frac{\partial B}{\partial \delta} & \frac{\partial B}{\partial SL} \\ \frac{\partial A}{\partial t_R} & \frac{\partial A}{\partial SL} \\ \frac{\partial B}{\partial t_R} & \frac{\partial B}{\partial SL} \end{array} \right| \cdot \frac{(r_L - r) T \cdot e^{-r_L T} \left[ t_R (r_L - r) - 2 \left( \frac{r_L + \delta}{r + \delta} \right) \cdot \left( 1 - \frac{r_S}{r} \right) (1 - e^{-r_L T}) \right]}{SL \cdot (1 - \frac{r_S}{r}) (1 - e^{-r_L T} (1 + r t_R))} \tag{16}
\]

and

\[
\frac{dt_R}{d\delta} = -\left| \begin{array}{cc} \frac{\partial A}{\partial \delta} & \frac{\partial A}{\partial SL} \\ \frac{\partial B}{\partial \delta} & \frac{\partial B}{\partial SL} \\ \frac{\partial A}{\partial t_R} & \frac{\partial A}{\partial SL} \\ \frac{\partial B}{\partial t_R} & \frac{\partial B}{\partial SL} \end{array} \right| \cdot \frac{SL \left( \frac{r_L - r}{(r + \delta)} \right) T \cdot e^{-r_L T} \left[ \left( \frac{r_L + \delta}{r + \delta} \right) \cdot \left( 1 - \frac{r_S}{r} \right) (re^{-r_L T}) - (r_L - r) \right]}{SL \cdot (1 - \frac{r_S}{r}) (1 - e^{-r_L T} (1 + r t_R))}. \tag{17}
\]

The denominators of (16) and (17) are both positive because \(r_S < r\) and \(1 + rt_R < e^{rt_R}\). To show that \(t_R\) and \(SL\) are decreasing in \(\delta\) we should show that the numerators of (16) and (17) are both negative.

The numerator of (16) is negative if and only if
\[
2 \left( \frac{r_L + \delta}{r + \delta} \right) \cdot \left( 1 - \frac{r_S}{r} \right) \frac{1}{(r_L - r)} > \frac{t_R}{(1 - e^{-tr_R})}
\]

\[
= \left( 1 - \frac{r_S}{r} \right) \left( \frac{1}{r_L - r} \right) \left( \frac{r_L + \delta}{r + \delta} \right)^2 - e^{(r_L - r)T} \frac{r_L + \delta}{r + \delta} + \frac{1 - e^{(r_L - r)T}}{T(r_L - r)},
\]

where the equality follows from (12). The inequality (18) holds if and only if we have

\[
e^{(r_L - r)T} < \left( \frac{r_L + \delta}{r + \delta} \right)^2 \frac{1}{(r_L - r)} \left( 1 - \frac{r_S}{r} \right) \frac{1}{r_L - r} < \frac{e^{tr_R}}{r}.
\]

Because \(0 < (r_L - r)T < (r_L + \delta)T < 1\), the left hand side and the right hand side of (19) are respectively smaller and larger than \(\left( \frac{1}{1-(r_L - r)T} \right)^{2+(r_L - r)T} \frac{1}{2 \left( \frac{1}{1-(r_L - r)T} \right)^{(r_L - r)T}}\). Therefore, inequality (19) and, thus, inequality (18) hold.

The numerator of (17) is negative if and only if

\[
\left( \frac{r_L + \delta}{r + \delta} \right) \cdot \left( 1 - \frac{r_S}{r} \right) \frac{1}{(r_L - r)} < \frac{e^{tr_R}}{r}.
\]

Note that \(\frac{t_R}{1 - e^{-tr_R}} < \frac{e^{tr_R}}{r}\). Therefore, inequality (20) holds if its left hand side is smaller than have \(\frac{t_R}{1 - e^{-tr_R}}\). That is (20) holds if

\[
\left( \frac{r_L + \delta}{r + \delta} \right) \cdot \left( 1 - \frac{r_S}{r} \right) \frac{1}{(r_L - r)} < \frac{t_R}{(1 - e^{-tr_R})}
\]

\[
= \left( 1 - \frac{r_S}{r} \right) \left( \frac{1}{r_L - r} \right) \left( \frac{r_L + \delta}{r + \delta} \right)^2 - e^{(r_L - r)T} \frac{r_L + \delta}{r + \delta} + \frac{1 - e^{(r_L - r)T}}{T(r_L - r)},
\]

where the equality follows from (12). The inequality (21) holds if and only if we have

\[
e^{(r_L - r)T} > \left( \frac{(r_L + \delta)T}{(r_L + \delta)T - (r_L - r)T} \right) - (r_L - r)T.
\]

Because \(0 < (r_L - r)T < (r_L + \delta)T < 1\), the left hand side and the right hand side of (22) are respectively larger and smaller than \(1 + (r_L - r)T\). Therefore, inequality (22) and, thus, inequality (20) hold.