Monetary Policy Complementarity: Bank Regulation and the Yield Curve

Stefan Walz*

August 21, 2024

ABSTRACT

Bank capital regulation flattens the yield curve by increasing banks' holdings of long maturity government bonds. I study the implementation of bank capital requirements, and their subsequent relaxation in 2018, to show that stricter requirements lead banks to shift their portfolios toward long bonds, effectively acting as a large scale asset purchase program. I develop a bank portfolio choice model featuring costly bank deposit franchises, counter-cyclical loan losses, and inelastic markets to rationalize the reduced form findings. I quantify the model to evaluate counterfactual bank portfolios and asset prices under alternative regulatory and unconventional monetary policy rules.

Keywords: Banks, Monetary Policy, Term Premium

JEL Codes: G21, E52, G12

*Finance Division, Columbia Business School. Email: swalz24@gsb.columbia.edu. I thank Charles Calomiris, Mario Catalan, Olivier Darmouni, Wenxin Du, Vadim Elenev, Michael Johannes, Ralph Koijen, Elena Loutskina, Yiming Ma, Harry Mamaysky, Stijn van Nieuwerburgh, Pascal Paul, Tomasz Piskorski, Tano Santos, Philipp Schnabl, Suresh Sundaresan, Johan Walden, Kairong Xiao and seminar participants at Columbia, the Federal Reserve Bank of San Francisco, the Federal Reserve Board of Governors, FIRS Berlin, Johns Hopkins, and the Office of Financial Research at the US Treasury for helpful comments. Supported by the Chazen Institute for Global Business at Columbia Business School.

I. Introduction

Central banks set short term interest rates, conduct large scale asset purchases, and regulate banks. Enhanced bank regulation pressure after the Global Financial Crisis lead to concerns over possible distortionary consequences for bank lending and asset prices. On the lending side, capital regulation can make holding loans more costly (Favara et al. (2021), Buchak et al. (2018), Begenau (2020), Diamond et al. (2020)). On the asset pricing side, there are concerns that risk-invariant capital requirements can prohibit banks from engaging in certain high leverage, low-margin near arbitrage activities (Du et al. (2018)).[1] As a major test of the regulatory framework, banks have been negatively affected by the sudden rise in interest rates between 2022 and 2023, leaving banks with large amounts of unrealized losses on their bond holdings (Jiang et al. (2024)). In his 2023 annual shareholder letter, Jamie Dimon stated that regulation had encouraged banks to increase their holdings of US government bonds that dropped in value, stating: 'banks were incented to own very safe government securities because they were considered highly liquid by regulators and carried very low capital requirements.'[2] In this paper I identify an understudied link between bank regulation and long term interest rates. I find that tighter bank capital regulation lead large banks to *ex-ante* increase their holdings of long maturity bonds relative to smaller, less regulated banks who decreased their holdings.[3] The equilibrium quantity of long bonds demanded by the banking sector under tighter capital requirements is so large that long term interest rates fall as the remaining non-bank sector does not have to bear as much interest rate risk.

I rationalize the findings in a model where leverage requirements rotate banks' profits as a function of short interest rates. In particular, when interest rates fall toward zero, banks' profit margins are compressed due to lower income on floating rate assets and counter-cyclical loan losses, despite continued rate insensitive fixed costs. The introduction of capital requirements

[1] Covered Interest Rate Parity (CIP) deviations, Treasury-repo market making, IOER-FF arbitrage.

[2] The CEO of failed Silicon Valley Bank also blamed the regulation for their failure: "Liquidity and capital rules encouraged SVB to invest its flood of new deposits in long-dated government-backed securities that regulators deemed 'safe'". May 2023 WSJ article.

[3] Recent literature has found that only a small fraction of bank asset values is explicitly hedged from interest rate risk (Jiang et al. (2023)). McPhail et al. (2023) finds that the net exposure of banks to interest rates through their interest rate derivatives is approximately zero.

further penalizes depressed equity levels in the low rate state, amplifying the incentives of the bank to hedge against low rate realizations by holding more long bonds. Capital requirements penalize net income volatility, incentivizing banks' holdings of bonds to hedge fluctuations in the rest of their portfolio. Bank value can be decomposed into three different franchises: loans, deposits, and securities (e.g. long maturity government bonds). Banks jointly maximize total value across the three business lines, subject to financial constraints. As interest rates change, the value of each franchise is affected differently. When interest rates fall, bond franchise value increases as fixed coupons are unchanged, while loans and deposits obtain lower spreads. Beyond valuing the coupons paid by long maturity bonds, the largest banks have begun accounting for the mark-to-market value of the bonds held in their available-for-sale portfolio (Granja (2023), Fuster and Vickery (2018), Greenwald et al. (2024)) as part of their equity capital. As interest rates fall, the value of long bonds increases, providing a 'stealth' recapitalization (Brunnermeier and Koby (2018)) in low rate states of the world. Tightened capital requirements introduce a state-contingent constraint on bank profits and a subsequent hedging motive that effectively transfers profits from good (e.g. high rate) states to bad (e.g. low rate) states. In an attempt to hedge against low rate realizations, capital-constrained banks deviate from a first-best portfolio and hold more long bonds ex-ante.

Overall, while the traditional view of bank regulation finds a reduction in the quantity of credit provided to borrowers, the interest rate risk taking channel is a quantitatively significant force that must be weighed against the implications of regulation for lending. In terms of financial stability implications, although the increase in interest rate exposure on the asset side is estimated to be larger than the increase in the liability side, banks are not necessarily made less resilient to interest rate shocks (Drechsler et al. (2021)), as they have larger equity buffers. The common understanding of the 2023 banking crisis suggests that mid-sized banks (e.g. Silicon Valley Bank) took excessive interest rate risk as a result of deregulation. I provide a counterargument to suggest that the deregulation actually led treated banks to take less interest rate risk.[4] This is not to say that SVB was made safer by the deregulation; the key argument of the paper is that

[4] Greg Becker, the former CEO of Silicon Valley Bank, stated: "Liquidity and capital rules encouraged SVB to invest its flood of new deposits in long-dated government-backed securities that regulators deemed 'safe'".

capital regulation (potentially joint with other regulation) incentivizes holding interest rate risk. Since interest rates are a source of aggregate risk, the finding suggests that regulation may make banks more similar in terms of systemic risk (Greenwood et al. (2017)). The paper traces out the effect on banks ex-ante if policymakers decide to install counter-cyclical capital requirements, leading to a more robust financial sector that continues to provide credit even if the level of capital requirements changes. I evaluate the impact of larger state contingent central bank asset purchases, finding that they further enhance the hedging properties of long bonds for banks.

Relevant Literature: The paper contributes first to the literature that rationalizes the maturity transformation function of banks and how that exposes them to interest rate risks. Departing from the canonical models of bank liquidity transformation (Diamond and Dybvig (1983)), Drechsler et al. (2021) empirically shows that banks optimally expose themselves to interest rate risk by holding long maturity assets, in order to hedge the interest rate exposure of their liabilities and their considerable non-interest expenses.[5] Begenau et al. (2015) provides a novel measurement of the amount of credit and interest rate risk on their balance sheets, finding a large amount of interest rate risk. In this paper I study the interaction between banks' interest rate risk management in their securities portfolio and their capital requirements. The degree to which capital requirements affect banks' portfolio choice depends on banks' ability to derive income from their deposit franchise, the cyclical properties of loan income, and the elasticity of asset markets.[6]

The paper relates to the voluminous literature that studies the impact of bank capital requirements on various macroeconomic outcomes. Much of the literature studies how bank capital

[5]In a competing narrative, Di Tella and Kurlat (2017) argues that risk-averse banks are optimally exposed to duration risk (e.g. their value goes down when rates go up) due to the fact that they can charge larger deposit spreads when rates rise. Paul (2023) provides cross-sectional evidence that bank equity values respond to movement in term premia. Begenau et al. (2015) argues that banks are not hedged and are exposed to substantial interest rate risks, and that existing empirical evidence of bank market power is imperfect. Banks' duration exposures are argued to be key to monetary policy transmission. Brunnermeier and Koby (2018) argues that mark-to-market valuation changes in banks' fixed income portfolios as a result of interest rate changes affect bank lending volumes. Rodnyansky and Darmouni (2017) shows that QE can stimulate bank lending by increasing the mark-to-market value of banks' assets.

[6]While this paper focuses primarily on banks' holdings of long bonds, the paper compliments Li et al. (2019), which finds that banks with more deposit market power fund longer-term, more illiquid projects in their loan portfolio. I find that banks obtain their longer duration exposure through their bond portfolio versus their loan portfolio, which may result from the contemporaneous increases in capital charges for loans.

requirements can reduce loan supply and lead to credit crunches (Peek and Rosengren (1995), Van den Heuvel (2008), Aiyar et al. (2015), Fraisse et al. (2020), Begenau et al. (2015), Elenev et al. (2021)). The literature generally finds that bank capital restrictions can, by making bank leverage more costly, reduce the amount of deposits available and affect banks' loan supply curves.[7] Some (e.g. Admati et al. (2012)) have argued that increasing bank capital requirements can lead to less risk taking by constraining existing shareholders, and literature has found that greater capitalization indeed led to lower ex-post systemic risk influence due to strong information acquisition incentives (Altunbas et al. (2022)). Similar to this paper, Choi et al. (2020) shows that banks exposed to the introduction of the SLR shifted into riskier securities based on a reach-for-yield argument. In a recent paper, Du et al. (2022a) finds that dealers switched from net-short to net-long positions as a result of balance sheet costs in the post-GFC period. In this paper I provide quantity evidence that banks shifted into longer maturity securities, partially substituting out of credit risk, and I link those quantities to prices along yield and loan demand curves.

Beyond the banking literature, the paper also relates to the intermediary-based asset pricing literature (He and Krishnamurthy (2013), He and Krishnamurthy (2018), Adrian et al. (2014), Du et al. (2018), Du et al. (2022b)), which emphasizes the role of net worth constraints of financial intermediaries in explaining movements in risky asset prices. In departing from the focus on broker dealers, I show that banks are relatively large holders of long maturity bonds and banking sector flows affect asset prices due to inelastic government bond markets. The paper relates to literature that studies the price effects of bond demand shocks from the central bank (Krishnamurthy and Vissing-Jorgensen (2011), Christensen and Krogstrup (2018)) and institutional investors (Domanski et al. (2017), Jansen (2021)). In particular, the observed decline in long interest rates may incorrectly be attributed to quantitative easing rather than contemporaneous shocks to institutional demand. I argue banks were an important driver of long rates during the post-GFC era. The level shift in bond demand induced by changes in bank regulation provides a benchmark to study perceived permanence of central bank asset purchases.

[7] Begenau et al. (2015) finds that capital requirements can actually increase lending by lowering deposit funding costs.

Hanson (2014) argues that changes in the supply of duration embedded in MBS affects the Treasury term structure. Similarly, in this paper I find that banks' demand for MBS (in addition to Treasuries) affects the Treasury term structure.

The demand effect emphasized in this paper can be linked to recent literature (Chodorow-Reich et al. (2021)) that studies the role of insurance companies as asset insulators that hold assets that may have a different valuation relative to other market participants. Leverage constrained banks shift the composition of their assets toward longer maturity assets, and hold those assets to maturity. The paper relates to Haddad and Sraer (2020) which studies the role of banks as interest rate arbitrageurs by showing that bank interest rate exposures forecast term premia. I also study banks as relevant agents in the pricing of interest rate risk, but I focus on the long term steady state implications of bank leverage constraints. The mechanism in this paper relates to Hanson and Stein (2015), which argues that monetary policy shocks affect term premia due to a change in the composition of agents in the market for interest rate risk. I use a change in bank capital requirements as a shock to the composition of agents in the market for interest rate risk. Kekre et al. (2024) studies the effect of interest rate changes on term premia, emphasizing the role of arbitrageur wealth. In contrast, in this paper I study the effects of banks' long bond purchases in removing the supply of duration from arbitrageur balance sheets, similar to the classic QE channel (Greenwood and Vayanos (2014), Vayanos and Vila (2021)).

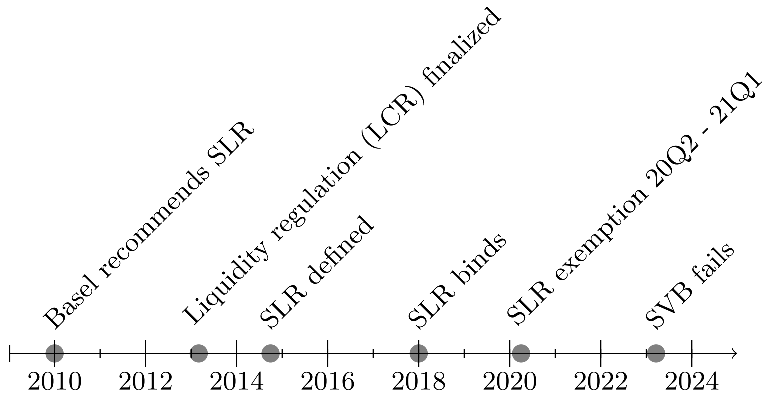
Last, the paper relates to the growing literature that employs structural models to study the banking sector (e.g. Xiao (2019), Diamond et al. (2020), Buchak et al. (2018)). I pair a traditional deposit demand system with a broader inelastic asset market to study how institutional features of the banking sector spill over along the yield curve. In particular, I draw on recent innovation in the estimation of macro-elasticities (Koijen and Yogo (2019), Gabaix and Koijen (2021)) and apply a Granular Instrumental Variable identification methodology to estimate the elasticity of government bond markets.

II. Empirical Evidence

First I describe the regulatory environment for banks. In response to the Global Financial Crisis, the Basel Committee recommended several regulatory changes to bank regulation starting around 2010. The Supplementary Leverage Ratio (SLR) is a key pillar in the US implementation of the Basel regulation, and imposes a 3% risk-unadjusted minimum leverage ratio for US banks with assets greater than $250 billion or with foreign exposures larger than $10 billion. The SLR effectively requires that banks set aside a certain amount to cover losses on all assets, including some off-balance sheet exposures. I display a timeline of relevant bank regulatory developments in Figure 1. The Federal Reserve introduced the enhanced Supplementary Coverage Ratio (eSLR) in 2014 to impose stricter requirements on the largest and most systemically important banks and bring their minimum leverage ratio up to 5%, and they must maintain a 6% ratio to be considered "well-capitalized". Furthermore, the depository institution subsidiary must maintain a 6% SLR. The final definition for the SLR was completed in 2014Q3, and banks needed to comply with the SLR's thresholds by 2018Q1. SLR ratios began to appear in the FRBY9C call reports in 2016 and became binding in 2018. I follow Choi et al. (2020) and use 2014Q3 as the relevant treatment date for SLR banks in the subsequent analysis. During the COVID crisis in 2020, the Fed relaxed the SLR by excluding Treasuries and Reserves from the denominator. Previous work finds that the relaxation increased credit provision for treated banks (Koont and Walz (2021)).

Next I describe the data used in the subsequent analysis and present a few key stylized facts. I obtain bank-level financial statement data from the Federal Reserve Call Reports. I include data at both the bank-holding company (BHC) and bank-level at the quarterly frequency. The complete dataset uses data from 1998Q1-2022Q4, while I focus on data starting in 2011Q1 and ending in 2019Q4 to study the effect of post-crisis regulation. I complement the bank level data with macroeconomic data from FRED, including data on the yield curve. I subset the data to the largest 500 banks in each time period with non-missing assets and securities data. I show the summary statistics in Table 4 in the Appendix.

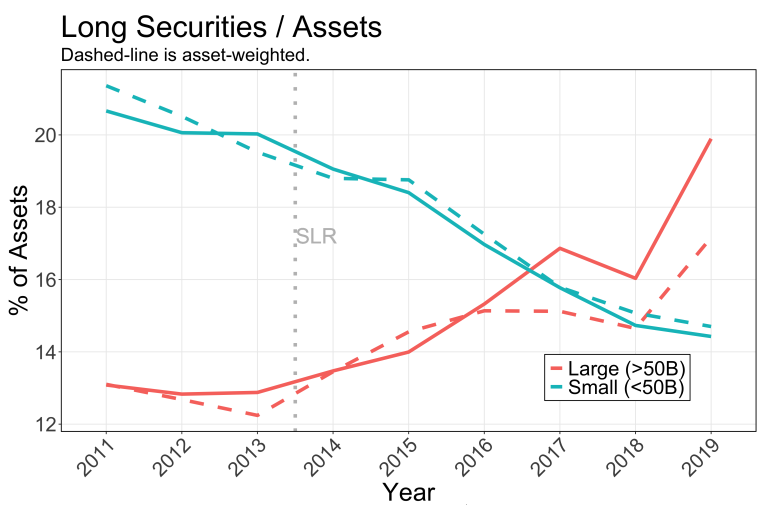
Figure 1. Timeline of Bank Regulatory Developments



A. Fact 1: Large Banks Significantly Expanded Long Bond Holdings

In this section I document trends in bank balance sheets in the post-GFC period across size buckets. I split banks into small (<$50B) and large (>$50B) size buckets based on their average assets from 2011-2019.[8]

Figure 2. Large Banks Significantly Expanded Long Bond Holdings



In the panel I show the balance sheet share of long maturity (maturing in more than 1-year) bond holdings. The dotted line shows the same series weighted by total assets.

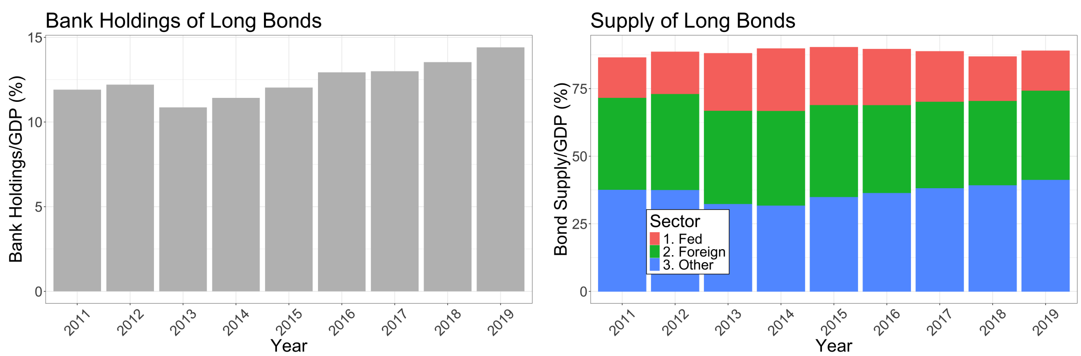
[8]I focus on the pre-COVID years to estimate effects of the regulation on bank portfolios. In later analysis I incorporate the subsequent COVID period and increasing interest rates.

In Figure 2, I show the evolution of large and small banks' holdings of long maturity bonds (as a percentage of their total assets). I define long maturity bonds to be securities that mature in more than 1-year. In the red line, we observe that large banks significantly increased their holdings of long maturity bonds starting in 2013 from around 13% of their assets to around 20% in 2019. In the dotted line we see a similar trend for the asset-weighted series which captures aggregate bond holdings. Meanwhile, we see that small banks decreased their holdings throughout the period. The divergence in holdings of long bonds between large and small banks is the key trend to be explored in the remainder of the paper.

In Figure 10 in the Appendix I show the balance sheet shares of short securities and loans. We observe that large banks increased (decreased) their holdings of short securities (loans) relative to small banks several quarters before the introduction of the SLR. The combined evidence suggests that larger banks tilted their portfolio toward long bonds and away from loans throughout the 2010s. The portfolio shifts out of loans and into short rate assets occurred as regulators introduced and enacted the liquidity coverage ratio (LCR) regulation (Sundaresan and Xiao (2022)). I discuss the interaction between difference types of regulation in greater detail later in the paper. In Figure 10, I also show the total assets of each set of banks. We observe that large banks grew from around 10T in assets to nearly 15T by 2019, while smaller banks increased from around 2T to around 2.5T. Overall, the significantly larger asset base of large banks suggests that the total demand for long bonds coming from the banking sector significantly increased throughout the sample period.

Next I present evidence regarding the supply of long bonds over the sample in Figure 3. In the left panel, we observe that banks increased their total holdings from around 11% of GDP of holdings in 2013 to nearly 15% in 2019. In the right panel I show the total supply of long bonds, indicating the amounts held by the Federal Reserve, Foreign and Other sectors in red, green, and blue, respectively. The total supply of long bonds remain somewhat constant around 90% throughout the sample. We observe that foreign investors and the Federal Reserve hold about half of the total supply outstanding. The total supply of bonds net of foreign and Fed purchases does not change significantly from the start of the sample to the end. In Figure 11 in the Appendix, I include the years 2020-2022. During the COVID years, banks significantly increased their holdings of long bonds, while the supply of long bonds increased to nearly 100% of GDP. The interest rate risk management mechanism helps to rationalize why banks chose to buy long bonds during the later years. As interest rates appeared to be in a low-for-long trajectory, banks needed to hold long bonds to generate sufficient yield to cover their running costs and remain above their equity capital constraints.

Figure 3. Changing Composition of Government Bond Holdings



In the left panel I show estimates for the amount of long Treasuries and Agencies (greater than 1-year maturity) that are held by the banks. In the right panel I show the total supply of long bonds. I obtain the holdings data from the Flow of Funds. I obtain the maturity structure of the Federal Reserve's holdings from FRED. I obtain the maturity structure of banks' holdings from the Call Reports.

The baseline analysis compares the evolution of SLR banks' balance sheets with non-SLR banks' balance sheets around the finalization of the SLR. There are other banking regulatory initiatives post-crisis (e.g. the Liquidity Coverage Ratio (LCR), risk-weighted capital requirements and stress tests) that affect bank balance sheets. For instance, Sundaresan and Xiao (2022) finds that the installation of the LCR lead banks to horde high quality liquid assets (HQLA) and reduce lending. Second, there could be some influence from risk-weighted capital requirements. For instance, Favara et al. (2021) shows that GSIB capital surcharges lead treated banks to provide less credit. To further sharpen the analysis, I study a triple difference specification that narrowly tests whether simple capital requirements, enhanced liquidity ratios, or weighted capital requirements are more associated with the shift into long maturity bonds. Stress tests capture an amalgamation of the regulations and the results that proceed help to evaluate the consequences of any bank capital tests conducted. In general, the model presented later in the paper flexibly captures a variety of regulations that can encourage banks to hold more long government bonds.

B. Fact 2: Bank Regulatory Intensity Drives Long Bond Holdings

Next I formalize the analysis of the interaction between the SLR and banks' willingness to hold long maturity securities, in addition to other balance sheet items. I estimate the following regression (1) using two-way fixed effects and time-varying bank controls.

$$\mathrm{Y}_{it} = \beta \cdot \text{SLR Bank x Post}_{it} + \gamma X_{it} + \alpha_i + \alpha_t + \epsilon_{it} \tag{1}$$

The time-varying bank controls include size and deposit funding ratios. I show the estimation results in Table 1. I cluster standard errors at the bank level. I use 2014Q3 as the start of the post period and I define the relevant treatment group to be banks that ever reported the SLR in FRBY9C forms.

Table 1 Bank Regulation and Long Bond Holdings

	Long Sec./Assets	Long Sec./Assets	Long Sec./Assets	Long Sec./Assets
SLR Bank x Post	5.63^{***}	2.15	3.09^{***}	0.64
	(0.72)	(1.41)	(1.19)	(1.34)
SLR Bank x Low Equity x Post		4.40^{***}		5.25^{***}
		(1.42)		(1.49)
SLR Bank x LCR Gap x Post		-0.56^{*}		-0.06
		(0.29)		(0.28)
SLR Bank x Low RWA Ratio x Post		0.70		-2.34^{*}
		(1.11)		(1.34)
Weights	Simple	Simple	Assets	Assets
Bank Controls	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes
Num. obs.	18058	13906	18058	13906
R^2	0.84	0.82	0.88	0.84

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

The table reports estimation results from regression (1). All specifications include bank and time fixed effects, and time-varying bank controls including log assets and deposits' share of assets. All standard errors are clustered at the bank level.

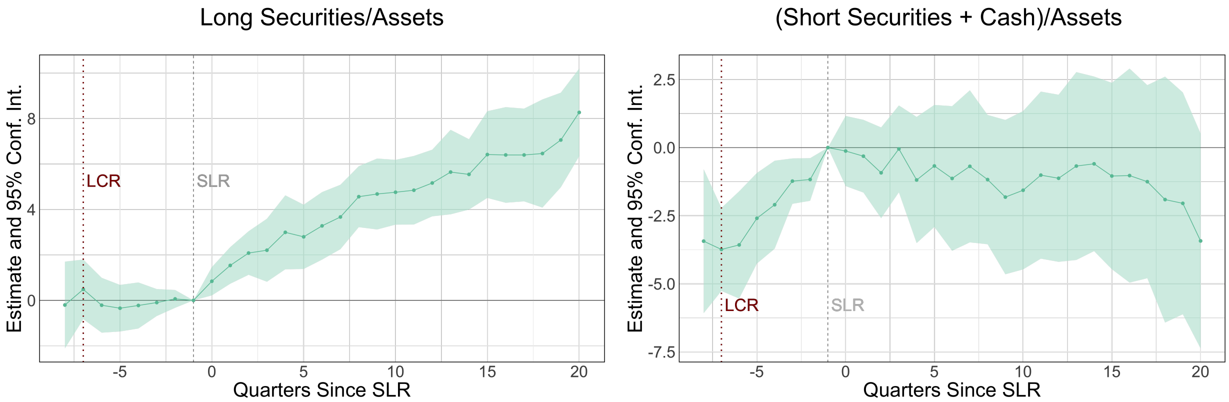
In the first column of Table 1, I show the baseline result indicating that SLR banks significantly expanded their holdings of long maturity bonds relative to control banks. On average in the post period, SLR banks allocated nearly 6% more of their balance sheet to long bonds. Next I study the triple difference specification to more precisely uncover the type of financial constraint driving SLR banks to modify their portfolio. There are three dimensions I add to the baseline regression. First, I construct an additional split that captures the unweighted equity ratio of banks as of end-2013. I define banks as low capital if they were below the median capital ratio as of 2013Q4. Second, I use the LCR gap as of 2012 constructed by Sundaresan and Xiao (2022) that captures banks' exposures to the LCR regulation. I normalize the gap such that a value of 1 corresponds to a one-standard deviation change in the cross-section of banks. The post period for the LCR corresponds to years from 2013 onward. Third, I define a bank as low risk-weighted (RWA) ratio if their risk-weighted capital ratio is below the median as of 2013Q4. In the second column I show the estimation results for the triple difference specification. We observe that the effect is concentrated within low equity SLR banks, while the coefficients for liquidity regulation and weighted capital ratio variables are marginally significant and insignificant, respectively. In the third and fourth columns I show the same two estimations but I instead weight the observations by total assets. The results are similar.

The main assumption required to enable a causal interpretation of the relationship between leverage constraints and bank portfolio choice portfolios rests on the idea that both the treatment and control banks would have evolved similarly absent the treatment. I study a dynamic specification of the treatment effect from 6 quarters before to 20 quarters after the finalization of the SLR in regression (2). I study the effect on both long securities and short securities (including cash and central bank reserves).

$$\mathrm{Y}_{it} = \sum_{j=-6(\neq -1)}^{20} \beta_j \cdot \text{SLR Bank x Post}_{it+j} + \alpha_i + \alpha_t + \epsilon_{it} \tag{2}$$

I cluster standard errors at the bank level. I present the results in Figure 4. There are three observations that arise from the plot of the dynamics. First, in the left panel, we observe that there is no significant pre-trend that indicates different paths for the treated and control banks before the treatment date. In particular, the introduction of the Liquidity Coverage Ratio in

Figure 4. Dynamics: Bank Capital Requirements and Asset Portfolio Choice



The left panel reports the coefficient estimates from dynamic regression (2) where the outcome variable is the long maturity securities share of total assets. The right panel shows the analogous results for the short term asset share of total assets. Standard errors are clustered at the bank level.

2013 does not (immediately) lead to an increase in the share of long bonds. Second, we observe a diffusion of the effect over the quarters following the treatment date. This likely results from treated banks holding their existing portfolios to maturity and subsequently purchasing longer maturity assets, leading to an accumulation of the effect over the post period.[9] In terms of magnitudes, SLR banks have around 8% more of their balance sheet in long term securities by 5-years after the finalization of the SLR. Third, in the right panel, we observe a pre-trend for the effect of the SLR on banks' holdings of short term securities.[10] The pre-trend suggests that the LCR drove banks to hold more short term assets, while the delayed response in long term securities points toward the SLR.

In the Appendix I show several extensions of the baseline analysis. First I show the dynamics for loans in Figure 12. We observe that the decline in loans shares begins around the introduction of the LCR, consistent with previous literature (Sundaresan and Xiao (2022)). We do not observe an effect on loan risk taking as measured by loan loss reserves. I show the complete triple-diff results in Table 5. I show the results of estimating the specification at the bank (rather than BHC level) for long securities, short securities, and loans in Table 6 and Figure 13. The results are quantitatively and qualitative similar. I show results for banks' total asset growth and long

[9] This can also reflect the slow phasing in of the requirement after the finalization in 2014Q3.
[10] Short term securities includes securities that mature in less than 1Y and cash (including Reserves).

securities growth Figure 14. In the top two panels, we observe null effects on asset growth, motivating the focus on portfolio shares. We observe that long security portfolios grew faster in the years after the regulation change. In the middle two panels, we observe stronger effects for banks that hold a non-trivial amount of securities (greater than 10% balance sheet shares). In the bottom two panels, we observe that treated banks increased their usage of the HTM designation (Granja (2023), Fuster and Vickery (2018)), consistent with a reaching for yield mechanism, and a positive but small effect on the average maturity of liabilities. In particular, SLR banks extended the average maturity of their liabilities by about a month, partially offsetting the increase in holdings of long bonds.

B.1. Evidence from the Trump Deregulation in 2018

In this section I provide a setting to more sharply study the influence of regulatory initiatives on banks' portfolio choice problem. As part of the Trump administration's deregulatory agenda, the Economic Growth, Regulatory Relief, and Consumer Protection Act was passed in May 2018. While Dodd-Frank effectively subjected all banks with assets greater than 50B to stress tests and capital and liquidity rules, the 2018 law effectively removed stress tests and loosened capital and liquidity regulation for banks with less than 100B in assets. Furthermore, the act gave the Federal Reserve the option, but not the requirement, to impose capital and liquidity rules on banks with assets between 100B and 250B, also allowing for less periodic stress tests.

In what proceeds, I filter the data to medium and large banks with at least 25B in assets. I define treated as those banks with less than 100B in assets as of 2017Q4. This leaves banks with more than 100B as the control group. The hypothesis is that the medium sized banks would shift their portfolio out of long bonds as they received regulatory relief. I repeat the decomposition of the effect into the three channels as in the previous section. I replace the LCR gap variable with their actual LCR. I define the variables as of 2017Q4. The effect of the deregulation should be more pronounced for banks with lower capitalization ratios as they experience greater relief. I show the estimation results in Table 2.

Table 2 Bank Deregulation and Bank Asset Choice

	Long Sec./Assets	Long Sec./Assets
Medium Bank x Post	-1.82	2.53
	(1.15)	(2.01)
Medium Bank x Low Capital x Post		-5.62^{***}
		(1.97)
Medium Bank x Low LCR x Post		-1.27
		(1.86)
Medium Bank x Low RWA Ratio x Post		-1.11
		(1.79)
Bank Controls	Yes	Yes
Bank FE	Yes	Yes
Date FE	Yes	Yes
Num. obs.	452	292
R^2	0.94	0.92

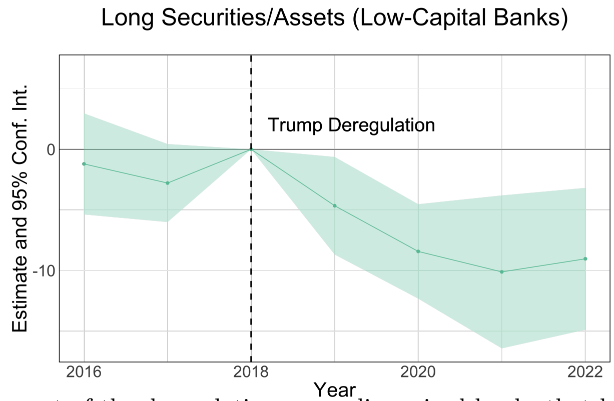
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

All specifications include bank and time fixed effects, time-varying bank controls including log assets and deposits' share of assets. Standard errors are clustered at the bank level.

In the first column I show the baseline result that medium banks weakly decreased their holdings of long bonds relative to large banks. In the second column I show the coefficients resulting from the triple difference specification. In the second row, we observe the estimated effect is largely concentrated within medium banks with low capital leading up to the deregulation. We observe insignificant effects for the LCR variable and the risk-weighted capital ratio. As before, the identification assumption need to allow for a causal interpretation is the lack of a pre-trend difference between the two groups. I show the dynamics in Figure 5. I focus on the treatment effect for low capital banks only. Note that I include controls for the treatment effect for the other triple-difference terms.

We observe that treated banks significantly decreased their holdings of long term bonds after deregulation. Overall, the finding suggests that the regulatory relief led treated banks to hold less interest rate risk, providing caution to the narrative that the deregulation caused banks to reach for yield by investing in the long maturity bonds that declined in value once the Fed started raising rates in 2022.

Figure 5. Trump Deregulation in 2018: Focus on Low-Capital Banks



In the panel I show the impact of the deregulation on medium sized banks that had below median capital ratios going into the deregulation.

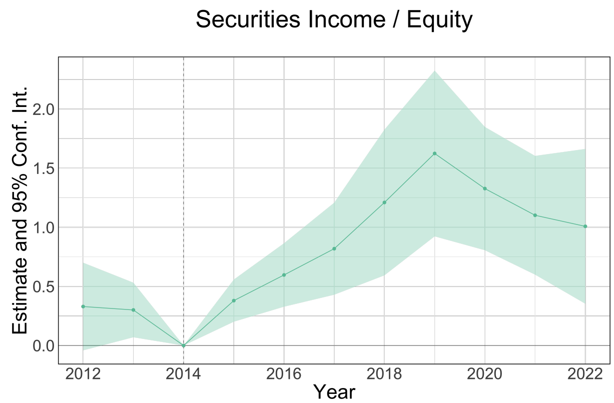
C. Mechanism: Bond Income as a Hedge for Low Rate Losses

Next I study the evolution of SLR banks' reliance on bond income. In particular, we would expect that SLR banks would obtain a larger share of their profitability from securities income, especially in low rate states. I compare the evolution of SLR banks' return on equity derived from securities to that of non-SLR banks in the years around the definition of the SLR. I focus on annual data due to the noisy income data at the quarterly frequency.

$$\frac{\text{Securities Income}_{it}}{\text{Equity}_{i,t-1}} = \sum_{y=2012(\neq 2014)}^{2022} \beta_y \cdot \text{SLR Bank x Year}_{it} + \alpha_i + \alpha_t + \epsilon_{it} \tag{3}$$

I show the resulting coefficient estimates for each year in Figure 6. We observe that SLR banks increased their reliance on bond income in the years after 2014, rising to around 1.5% higher in 2019. The median SLR bank obtained a profitability of around zero net of shareholder payouts in 2019, highlighting the important influence of higher securities income. In general, banks often pay out 70-100% of their net income to shareholders in the form of dividends and share repurchases (Hirtle and Zebar (2023)), so any residual income can be important for shareholders in order to maintain equity capital bases. The Federal Reserve raised rates from 2015 to 2019 leading the sample period to underestimate the effect, as the income generated by short assets increased relative to income generated by long bonds purchased previously.

Figure 6. Dynamics: Bank Regulation and Securities Income Reliance



The left panel reports the coefficient estimates from a dynamic regression where the outcome variable is securities income over bank equity. The right panel shows the estimates of the effect on bond income over net income. Standard errors are clustered at the bank level. I include time varying bank controls, including log assets and deposits' share of assets.

Overall, the reduced form evidence suggests that SLR banks significantly increased their demand for long bonds relative to non-SLR banks. Given SLR banks' larger size, the total increase in long bonds demanded from the banking sector point toward a potential price impact. Next I provide an estimation methodology to connect the portfolio flows to long term rates.

D. Estimating the Yield Curve Impact of Banks' Bond Purchases

In this section I provide an identification strategy to estimate the impact of banks' bond purchases on the yield curve. In a frictionless benchmark, there would be little to no price impact as counterparties would sell bonds at their fundamental value. Why would there be price effects? While Treasury (and Agency) bonds comprise one of the most liquid markets in the world (e.g. micro-elastic), these bonds are special given their safe asset properties, making them less substitutible (Brunnermeier et al. (2022)). There exists ample evidence that bond markets are inelastic (e.g. Vayanos and Vila (2021), Gabaix and Koijen (2021)). Indeed, one of the motivations for unconventional monetary policy is to affect long term rates, beyond the signalling channel (Krishnamurthy and Vissing-Jorgensen (2011), Bauer and Rudebusch (2014)). I employ a Granular Instrumental Variables (GIV) methodology (Gabaix and Koijen (2021)) to extract exogenous demand shocks which I use to estimate yield curve effects. The goal of the exercise is to answer the following question: what is the price impact on long maturity bonds if banks increase their demand for those bonds by X%? Importantly, we need a valid instrument for the demand for long term bonds.

I start with the panel dataset of quarterly bank balance sheets. I consider banks' holdings of long maturity securities as the representative quantity for the purpose of the exercise. The instrument includes securities that mature in more than 1-year. I estimate the panel regression:

$$\log(\text{LT Securities})_{bt} = \alpha_b + \alpha_t + \hat{q}_{bt} \tag{4}$$

I next compute the standard deviation of $\hat{q}_{bt}$ for each bank. In each quarter, I split banks into 20 groups based on the standard deviation of their residual flows into and out of long maturity assets. By group and quarter, I average the residuals $\hat{q}_{bt}$ to create the variable $\hat{q}_{gt}$, where g denotes the volatility group. I next extract principal components from the panel of $\hat{q}_{gt}$. Similar to Gabaix and Koijen (2021), the intuition is that banks with similar volatility in their demand for long bonds are likely exposed to similar risk. I use principal components as one way to control for common factors driving demand across bank. The key identifying assumption is that the inclusion of principal component controls and other macro risk factors captures systemic risk, allowing for the aggregated residuals to be treated as exogenous demand shocks. I aggregate the GIV instrument in the following way:

$$\text{GIV}_t = \sum_{b=1}^{N} \omega_b \hat{q}_{bt} \tag{5}$$

ω_b captures the average assets for bank b over the sample. Note that this means that the variation in the instrument is not coming from time-varying weights in the aggregation. We can then estimate the following macro-elasticity regression:

$$\text{Y}_t = \alpha + \beta \text{GIV}_t + \lambda' \eta_t^e + e_t \tag{6}$$

η_t^e includes the Fed Funds rate, the first six principal components estimated from the 20 volatility groups $\hat{q}_{gt}$, the lagged 10-year rate and the 9 macro factors from Ludvigson and Ng (2009).

I show the results of estimating regression (6) in Table 3. I use Newey-West adjusted standard errors with four lags. An increase of .1 for the GIV instruments corresponds to an increase in demand for long maturity assets by 10%.

Table 3 Long Bond GIV Results

	Y_{10Y}	Y_{10Y}
GIV	-2.06^{***}	-1.94^{***}
	(0.36)	(0.38)
Fed Funds Rate	0.54^{***}	0.52^{***}
	(0.04)	(0.04)
$Y_{10Y,t-1}$		0.07
		(0.06)
PC1	0.13^{***}	0.11^{***}
	(0.03)	(0.03)
PC2	0.01	0.01
	(0.03)	(0.03)
PC3	0.18^{***}	0.18^{***}
	(0.05)	(0.04)
LN1	-0.37^{*}	-0.32
	(0.21)	(0.21)
LN2	1.11^{***}	1.07^{***}
	(0.25)	(0.24)
LN3	2.64^{***}	2.53^{***}
	(0.44)	(0.42)
SE	NW4	NW4
PC Controls	6	6
Ludvigson and Ng Controls	9	9
Num. obs.	94	93
R^2	0.95	0.95

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

The table reports estimation results from regression (6). I use Newey-West standard errors with 4 lags for all specifications.

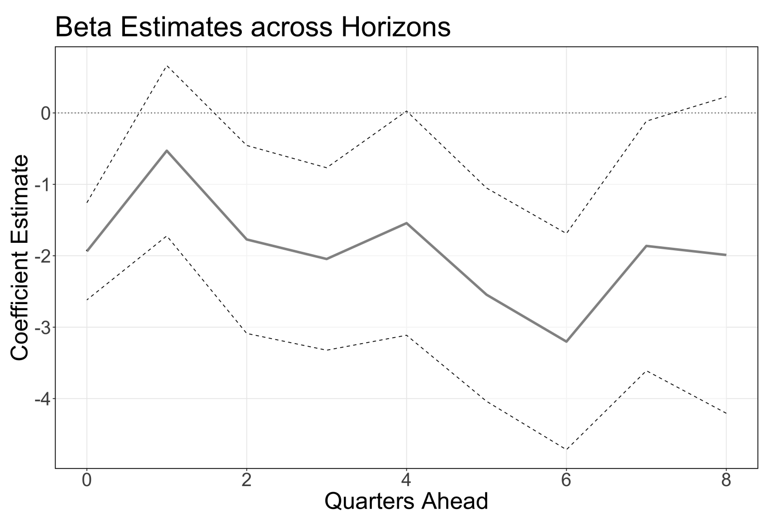
In the baseline regression in the first column, I show the specification the GIV instrument, the fed funds rate, six PC controls from the volatility groups, and the 9 macro factors from Ludvigson and Ng (2009). In the second column I add the lagged 10-year rate from the previous quarter. Across specifications, we observe a strong impact of the GIV instrument across the yield curve. A 10-percent increase in demand for long bonds lowers rates by around 20 basis points across the specifications. While the coarseness of the instrument in terms of grouping all bonds above maturities of 1-year does not indicate which price is most relevant, the impact across the curve can be interpreted through the lens of the preferred habitat model Vayanos and Vila (2021) where arbitrageurs transmit shocks across maturities.

Next I investigate the persistence of the price effect. The core prediction is that banks' purchases of long bonds cause a level shift in the yields of long bonds that does not quickly mean revert. Similar to Gabaix and Koijen (2021), I estimate the persistence in the following specification:

$$Y_{10Y,t+h} = \alpha_h + \beta_h \mathrm{GIV}_t + \gamma_h Y_{10Y,t-1} + \lambda_h' \eta_t^e + e_{t+h} \tag{7}$$

I estimate local projections of the future 10-year yield at horizons of h quarters ahead. In addition to the six principal component and 9 Ludvigson and Ng (2009) controls, I include the control for the lagged value of the 10-year rate. I show the result β_h estimates in Figure 7.

Figure 7. Impacts of Flows at Longer Horizons



We observe that the effect on yields is generally stable at horizons of up to 8 quarters, indicating that yields do not simply mean-revert. When would this estimation methodology go wrong? The primary concern is that the non-systemic factors that cause large banks to increase their within-bank demand for longer maturity assets are correlated with other excluded risk factors, beyond those captured by the principal components and the other systematic risk factors. The GIV instrument overweights large banks, and the forces that drive large banks to differentially demand long bonds relative to smaller banks are assumed to be conditionally exogenous to other risk factors. The key drawback of the model is that the residuals are not directly tied to a policy change or to an explicitly exogenous mechanism.

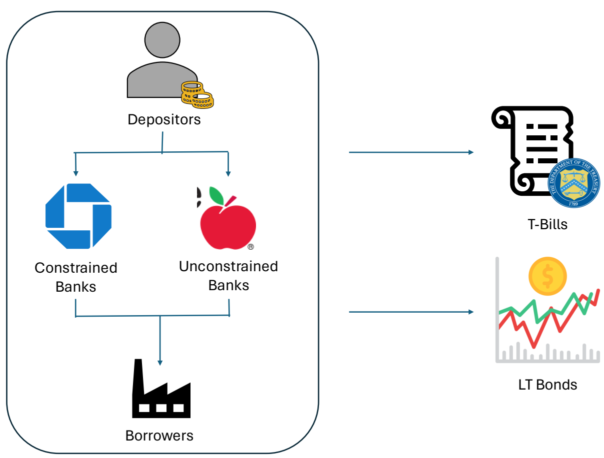
We can benchmark the estimates against previous estimates of the effect of quantitative easing on long term rates. Williams (2014) provides a comprehensive summary of the price impacts of 600B of QE. The paper surveys the literature to find a price impact on long term rates of 0-100 basis points. At the lower bound, Modigliani and Sutch (1966) estimates approximately zero price impact of a twist operation in the 1960s, while D'Amico and King (2013) estimates a price impact of around 100 basis points. There is a high degree of uncertainty on the estimates. Dropping the highest and lowest two studies, the remaining central range is 14 to 45 basis points. The largest price impact estimates a price effect of 125 basis points in D'Amico and King (2013). Taking 15T to be GDP as of 2010, the quantity purchased can be normalized to around 4% of GDP. As another theoretical benchmark, using the actual maturity distribution of the Fed's QE programs, Vayanos and Vila (2021) estimates that purchasing 12% of GDP reduces the 10Y rate by only 8 to 54 bps. The numbers vary based on the half-life of the purchase and the assumed risk-aversion of arbitrageurs.

Returning to the numbers in this paper, I find that treated banks shifted around 8% more of their balance sheet into long bonds relative to smaller banks. Note that this effect can come from a combination of large banks increasing their holdings and smaller banks decreasing their holdings. For instance, as large banks push down long rates, smaller banks may be less eager to earn lower yields going forward. If we assume the quantity effect in this paper to be an increase from 13% to 21% for large banks and zero effect on small banks, the demand shock corresponds to an increase of around 60%. A demand shock of that size implies that the relaxation would reduce 10-year rates by around 80 basis points according to the GIV estimate. Importantly, the assumption of zero spillover to smaller banks is not likely to hold as they would sell bonds to accommodate large bank demand. Importantly, the GIV based estimate captures only the direct effect of the portfolio channel and does not include the negative market liquidity effects (Duffie et al. (2016)) or the signalling effect (Bauer and Rudebusch (2014)), both of which would attenuate the estimate. As a potential amplifier of the estimate relative to QE, the price evidence may capture a 'permanent' demand shock, while the QE estimates may incorporate an expectation that the purchases would be unwound (e.g. shorter half-life compared to Vayanos and Vila (2021)). Ultimately I validate the price inelasticity parameter within the quantitative model in the next section.[11]

III. Bank Portfolio Choice Model

In this section I outline the model framework that studies banks' portfolio choice problem as a function of their bank capital requirements. The goal is to rationalize the reduced form findings and to build a framework that can be subsequently used to study counterfactual economies. I show the basic framework in Figure 8.

Figure 8. Model Overview



There are three time periods t $\in \{1, 2, 3\}$. The short rate has a value r_1 and takes an uncertain value in the second period. In particular, $r_2 = \overline{r}$ with probability p and $\underline{r}$ with probability 1-p.[12] The game finishes at the start of the third period. Banks compete with cash and a money

[11] Gagnon et al. (2011) finds that cumulatively QE (pre-COVID) reduced 10-year yields by 91 basis points, leaving a large decline in the term premium to be explained. Adrian et al. (2013) finds that the term premium fell from 2 to -1% from 2014 to 2019, largely after the first QE wave was finished.

[12] The shareholders of the bank in the model are assumed to be risk-neutral, hence there is no distinction here between risk-neutral and physical probabilities. In reality, shareholders could be risk-averse and the probability

market asset to raise funds from depositors in periods 1 and 2. In period 1, banks can invest in three assets. First, there is a two-period coupon bond (e.g. Treasury bond) that matures in time 3. Second, there is a floating rate loan that contains a positive credit spread that offers state-contingent returns.[13] Third, any remaining funds are invested in a floating rate asset (e.g. T-bill), where rate changes are passed through perfectly. Loan, bond, and deposit markets are segmented from each other.

A. Asset Markets

First I describe the structure of the deposit market. I parameterize the deposit market using a logit demand system (Dick (2008)). The depositor chooses between bank deposits, cash, and a money market fund, where cash and deposits provide non-price utility relative to the money market fund.[14] Depositors are denoted by i and allocate their wealth in each time t. I denote the size group of banks with subscript s. Depositors have indirect utility over rates and liquidity services x_s:

$$u_{is} = \alpha_d r_s^d + \gamma_d x_s + \xi_{is} \tag{8}$$

Under the usual assumption of a logit demand system, namely by assuming a T1-EV distribution for ξ_{ij}, we can define the choice probability of choosing a deposit in time t as the following:

$$D_s(r_t^d | r_t) = W_d \times \frac{\exp^{\alpha_d r_{ts}^d + \gamma_d x_{ts}}}{\exp^{\alpha_d r_t} + \exp^{\gamma_d x_{\text{Cash}}} + \sum_s^{\{Big, Small\}} \exp^{\alpha_d r_{ts}^d + \gamma_d x_{ts}}} \tag{9}$$

There exist long strands of literature that estimate the elasticities that determine the price sensitivity of deposit (Hutchison and Pennacchi (1996), Drechsler et al. (2021), Dick (2008), Xiao (2019)) and loan markets (Wang et al. (2022), Diamond et al. (2020)). I allow the bank to obtain non-deposit financing R_t at the prevailing short rate.

could be interpreted under a risk-neutral measure. The key friction in the model would simplify change the curvature of the transformation from objective to risk-neutral probabilities.

[13]The rate offered on the loan contains a repricing component and a credit risk component. The key idea is that the return on the loan is a function of the short rate, which captures both effects.

[14]Note that here I group all short term assets into the size of the market, including money market funds and cash. Note also that the price elasticity parameter is a reduced-from parameter that captures the underlying production process of the borrower in a more general equilibrium framework.

Next, I describe the simplified demand functions for the loans and long bond. In particular, I assume there exist linear demand functions for each, with downward sloping demand curves.[15] Denote $a = \{\text{Loans, Long Bonds}\}$. There exists an equilibrium rate for loans and bonds which I denote r_{0a}. I denote ΔQ_a to be the demand shock from banks that can move the equilibrium rate away from its starting value r_0. In Appendix B, I micro-found the bond price relationship in a preferred habitat setting (Greenwood and Vayanos (2014), Vayanos and Vila (2021)), while here I adopt a simple reduced form assumption of price impact.

$$r_a = r_{0a} + \Delta Q_a \cdot \alpha_a \tag{10}$$

In reality, the bank can hold securities as available-for-sale and its market value can be updated on the bank's balance sheet. Indeed, the largest banks have to adjust their capital levels for mark-to-market changes in the value of their available-for-sale securities (Fuster and Vickery (2018), Greenwald et al. (2024)). In the calibration I include the mark-to-market share of bonds. In particular, in low rate states the bond would be more valuable (e.g. positive duration) such that its hedging properties would be strengthened. In the high rate states, the value of the available-for-sale securities would go down, covarying positively with loan losses and hence negatively with the value of the loan book. There is a growing literature that studies price inelasticity of asset markets more generally (Vayanos and Vila (2021), Koijen and Yogo (2019), Gabaix and Koijen (2021)), including the price impact estimates in the previous section.

Moving to the loan payoff, the model captures the negative correlation between loan income and bond income to establish the hedging motive. In the model, the borrower pays back the loan in a state contingent fashion, leading the bank to receive a rate of return $\hat{r}_{LS}$. In particular, the loan pays more in the high state and less in the low state, capturing both potential loan repricing and credit losses that are linked to the aggregate state of the economy. I denote the loan rate as

[15] Here downward sloping demand curve means that demand decreases in price. Note that from the perspective of the model, this implies $\alpha_b < 0, \alpha_l < 0$ for bonds and loans, respectively.

a polynomial function of the short rate:

$$\hat{r}_L = \overline{r}_L + \rho_l \cdot r_t + \rho_{l2} \cdot r_t^2 \tag{11}$$

In good times, the central bank raises rates ($r_t > \overline{r}$) and loans have lower losses than expected. In bad times, the central bank is forced to lower rates ($r_t < \overline{r}$) and loan losses are higher than expected. This is motivated by the observation that there is a negative correlation between the level of the short rate and loan losses. For the bank, I assume that there is an increasing marginal cost of providing loans.

$$c_L(L) = \frac{1}{2}\phi_s L_s^2 \tag{12}$$

The value of ϕ_s can be thought to capture the current scale of production for bank of size s.

B. Banks

There exist (representative) banks of each size group that start period 1 with equity capital E_{1s}. The competitive process is such that the large bank moves first and the small bank plays their best response. The large regulated bank internalizes the best response of the small bank when selecting their portfolio today. For the remainder of the toy model, I display the optimization problem of the big bank b and I hold the portfolio of the small bank fixed. The bank chooses deposit rate r_1^d in the first period. The bank chooses a loan quantity L_b and long bond quantity B, with the remainder of their deposits being invested in the short rate. The bank portfolio choice problem is static and held in perperpetuity. In the simple model, there is no capital accumulation problem. In the quantitative model I add a dynamic capital distribution policy. Importantly, the bank faces increasing marginal loan costs ϕ_b, fixed costs c_{fb} and rate-contingent loan losses on their loan book. We can write bank profit in the following way:

$$\pi_{tb}(B_b, L_b, r^d_{bt}|r_t, B_s, L_s, r^d_{st}) = L_b \cdot (r^l(L_s + L_b) - r_t - \rho(r_t) - c_L(L_b)) + B_b \cdot (r^b(B_b + B_s) - r_t) \\ + D(r^d_{tb}|r^d_{ts}, r_t) \cdot (r_t - r^d_{tb}) - c_{fb} \tag{13}$$

Bank equity evolves according to $E_{t+1} = E_t + \pi_t$. In the second period, the bank faces an equity capital constraint[16]:

$$\underbrace{E_{3b}}_{\text{Equity}} \geq \kappa \cdot (\underbrace{D(r^d_{2b}|r^d_{2s}, r_2) + E_{3b}}_{\text{Bank Size}}) \tag{14}$$

After the regulation change, the big bank must maintain an equity capital buffer that is sufficiently large relative to their deposit base. Note that the bank has to pay the fixed costs associated with their deposit franchise in both the high and low rate states. In addition to the fixed costs, the bank may incur loan losses in the second period which can lead it to violate the capital constraint in the second period. In order to bring their book equity back into compliance, bank shareholders must inject costly equity that is a function of the capital shortfall, which I capture with the function $\lambda(E_{3b} - D(r^{d*}_{2b}|r_{2s}, r_2))$. I denote π^*_{2b} to be the realized profits to shareholders.

$$E_{3b} \leq \kappa \cdot (D_b + E_{3b}) \implies \pi^*_{2b} = \pi_{2b} - \lambda \cdot (E_3 - \kappa \cdot (D_b + E_{3b})) \tag{15}$$

If the recapitalization charge is sufficiently large, then it becomes optimal for the bank to hold more long bonds ex-ante in order to hedge against the low rate realization. Now we can formally state the bank's optimization problem in the first period. I remove notation related to the small bank and focus on the big bank's problem holding the small bank's portfolio constant. Having observed the short rate in the first period, the bank chooses a deposit rate r^d_{1b}, long asset quantity B_b, and loan quantity L_b to endure for two periods, and a state-contingent plan for deposit rates

[16]In the model I allow for non-deposit financing R_{tb}, so the bank size can is actually larger if the bank uses it to finance loans or bonds.

in the second period.

$$
\begin{aligned}
\max_{r_1^d, B, L, \{r_2^d | r_2\} | r_1} \quad & \pi_1 + \beta \cdot \mathbb{E}[\pi_2^*] \\
\text{s.t.} \quad & E_3 \geq \kappa \cdot (D(r_2^d | r_2) + E_3) \\
& E_{t+1} = E_t + \pi_t(B, L, r_t^d | r_t) \\
& E_3 < \kappa \cdot (D(r_2^{d*} | r_2) + E_3) \implies \\
& \quad \pi_2^*(B, L, r_2^d | r_2) = \pi_2(B, L, r_2^d | r_2) - \lambda(E_3 - \kappa \cdot (D(r_2^d | r_2) + E_3))
\end{aligned}
\tag{16}
$$

In order to focus on the key friction in the model, let us now focus on the low rate realization of the short rate in the second period for the regulated bank. For simplicity, I assume that $\underline{r} = 0$. Note that deposit rates are bounded at zero such that $r_2^d | 0 = 0$. Taking as given the first period choices, the bank would end with the following equity at the start of the third period.

$$
E_3 = \underbrace{E_1 + \pi_1}_{\text{Starting Equity}} + \underbrace{L(r^l(L) - \rho(0))}_{\text{Loan Income}} + \underbrace{Br^b(B)}_{\text{Bond Income}} - c_F - \frac{\phi}{2} L^2 < \underbrace{\kappa \cdot (D(r_2^{d*} | 0) + E_3)}_{\text{Required Equity}} \tag{17}
$$

Returning to the capital constraint and taking as given the first period choices of B and L, suppose that the values of $\rho(0), c_F$ are such that bank equity falls below the unconstrained threshold. Since the short rate is zero, the bank cannot de-lever.[17] The bank must pay the costly capitalization costs in order to continue. If the recapitalization charge is sufficiently large, then it becomes optimal for the bank to hold more long bonds ex-ante in order to hedge against the low rate realization. Note that the capital constraint is also relevant in the high rate state. If the bank holds too many long bonds and the short rate increases, then the bank can face losses that push the bank toward their capital constraint.

[17] In this simple version of the model, I rule out the bank's ability to shed deposits via a non-price mechanism. The short rate does not necessarily have to be zero for the mechanism to hold.

C. Equilibrium

For a given set of estimated structural parameters, an equilibrium is defined by a vector of prices such that deposit, loan, and bond markets clear and large and small banks solve their dynamic portfolio problem. In particular, the equilibrium includes deposit rates in the current state $\{r^d_{ts}, r^b_{tb}\}$, a state-contingent plan for deposit rates for the next period $\{r^d_{t+1,s}, r^b_{t+1,b}|r_{t+1}\}$ such that the deposit market clears. On the asset side, I focus on the equilibrium that maximizes the joint value of small and large banks.[18] In particular, there exist static portfolios B_s, B_b, L_s, L_b that maximize bank value, producing rates r^b, r^l in bond and loan markets, respectively.

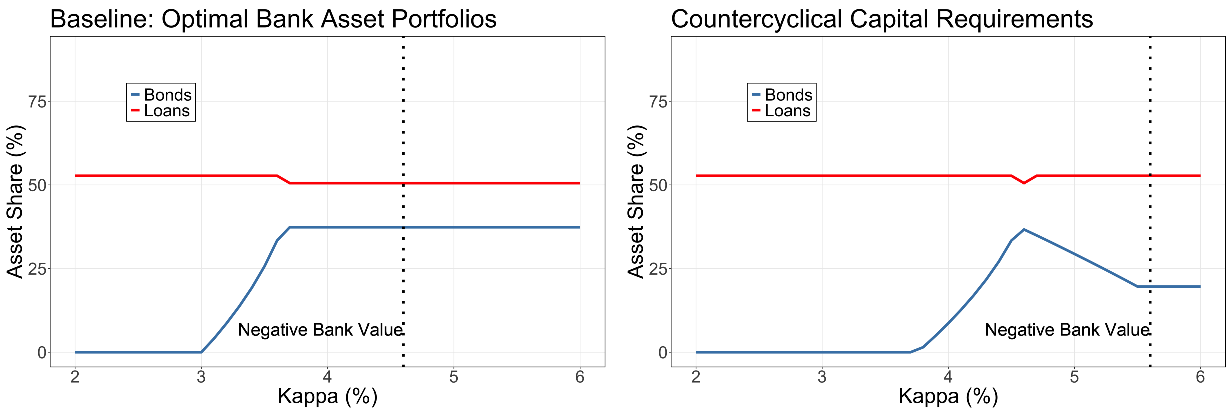
To further clarify the mechanism, I solve the toy model for the regulated bank (holding the portfolio of the less regulated bank constant) by selecting the optimal amounts of loan holdings L bond holdings B such that ex-ante bank equity value is maximized, given parameters that govern the deposit, loan and long bond market elasticities. I present a numerical example of the solution and a macro-prudential counterfactual exercise in Figure 9. On the x-axis I vary the capital requirement. On the y-axis I show the resulting optimal holdings of long bonds and loans, as a percentage of deposits.

First, in the left panel, I show the baseline solution. Focusing on the blue line, we observe that as we increase capital requirements from left to right, the bank increases its holdings of long bonds from 0 to over 30% of their balance sheet. This results from the valuable hedging properties of long bond income as the capital requirement becomes more binding. Next, moving to the red line which captures optimal loan holdings, we observe that there exists an initial region where increase loan holdings are optimal. However, we observe that as capital requirements approach 4%, it becomes optimal for the bank to reduce their loan book size as the loan-losses in the low rate state outweigh the potentially higher baseline income. We note that the bank holds constant portfolio shares as the capital requirement approaches 5%, since increasing holdings leads to inefficient price impact. Last, we observe that bank value becomes negative as capital requirements approach 5%, as the threat of recapitalization costs in the low rate state outweigh

[18] I also solve the model where small banks move second, playing a best response to the large banks. The large bank thus internalizes the small bank's price impact on asset markets. The results are qualitatively similar.

the value of the bank ex-ante. Importantly, the model produces a region where bonds are substituting fully for other floating rate assets, and thus they substitute only partially for loans moving from left to right. This is supported by the reduced form findings which support a less than one-to-one substitution.

Figure 9. Numerical Examples



Next, I consider a scenario where the regulator installs counter-cyclical capital requirements. In particular, I model the capital requirement as decreasing by 25% in the low rate state, and increasing by 25% in the high rate state, leaving its average level unchanged. This greatly reduces banks' incentives for holding long bonds, and allows for a higher level of credit provision in the constrained region. Bank value does not turn negative under the counter-cyclical capital requirement until the requirement is at nearly 6%. Furthermore, there exists a region above 4.5% where increasing the capital requirement actually decreasing the bank's optimal holdings of long bonds. This is due to the fact that income in the high rate state is so low, leading to an incentive to transfer profits back to the low rate state.

IV. Quantitative Exercise

Next I describe the exercise to quantify the effect of the increased in bank capital regulation on long term interest rates and to evaluate counterfactual policy scenarios. I extend the model to an infinite horizon and I parameterize the short rate as a mean-reverting stochastic process:

$$r_{t+1} - \overline{r} = \kappa_r(r_t - \overline{r}) + \sigma_r \epsilon_{t+1} \tag{18}$$

First, we require estimates of $\{\kappa_r, \sigma_r, \overline{r}\}$ that govern the short rate process. Second, we require estimates of the price elasticity of loan, long bond, and deposit markets. Third, we need parameters that capture the size, leverage and expense parameters of the banking system.

As in the simple model, the bank must have enough book equity E_{t+1} to satisfy their leverage constraint in future periods.

$$\underbrace{E_{t+1}}_{\text{Equity}} \geq \kappa \cdot \underbrace{(D(r_t^d | r_t) + E_{t+1})}_{\text{Bank Size}} \tag{19}$$

I extend the simple profit maximization in the simple toy model by adding a dividend policy which captures a standard costly equity issuance friction. In particular, if r_{t+1} realizes and the bank falls below their book equity threshold, then the bank must sell costly bank equity to recapitalize.[19] In particular, denote E^*_{t+1} to be the realized equity position for bank shareholders in time $t+1$. In order to bring their book equity back into compliance, bank shareholders must inject equity that is a multiple of their capital shortfall. The costly equity issuance parameter incentivizes the bank to stay away from their optimal leverage threshold by maintaining sufficient income and is a feature of many corporate finance models (Hennessy and Whited (2005)).

I add an additional constraint on the long bond holdings of each bank. In particular, I add a quadratic holding cost for long bonds in order to allow the portfolio problem to more closely match the data. In particular, I add the parameter ξ_s to capture the quadratic per-period holding costs of long bonds, which I calibrate to match banks' holdings of long bonds as of the pre-SLR

[19] In the simple version of the model, I rule out the possibility for the bank to de-lever to hit their equity constraint. This can be motivating by the signalling value to depositors if the bank deviates from the optimal deposit rate.

data.

$$\pi_{ts}^{*} = \pi_{ts} - \xi_s B_s^2 \tag{20}$$

The parameter can be thought to capture the time-invariant shadow costs of holding long term bonds. Importantly, the parameter is held constant when I compare the baseline result to the counterfactual estimates.

The hedging motive for holding bonds relies on the value of fixed rate cash flows as loan and floating rate cash flows decline as the short rate falls, amid continued rate insensitive expenses. Additionally, the mark-to-market value of available-for-sale securities also affects capital levels as interest rates change. As documented in Greenwald et al. (2024), regulators in 2013 required large US banks to account for unrealized capital gains in their securities portfolios in the calculation of their equity capital levels. Mark-to-market accounting changes the functional form of the bank's optimization problem. In particular, unrealized capital gains act as 'stealth recapitalization' (Brunnermeier and Sannikov (2016)). I augment the optimization problem of the bank to capture the effect of mark-to-market changes in the value of the long bond portfolio. Denote $\hat{B}_t$ to be the market value of the bank's portfolio, where the price is a function of the state variable $P_t^b(r_t)$. I denote ω to be the share of securities marked as available for sale (AFS). Adjusted bank equity can thus be defined similarly:

$$\hat{E}_t = E_t + (\hat{B}_t - B) = E_t + \omega * B \cdot (P_t^b(r_t) - P_0(\bar{r})) \tag{21}$$

At the start of the model, the bonds are assumed to be purchased at par such that the bond-price wedge is zero. If rates fall, the value of the bonds increases further amplifying the hedging value of the bond beyond the cash flow effects in the profit function (17).

Next I state the Bellman Equation representation of the large bank's problem.

$$
\begin{aligned}
V(B_b, L_b, E_{tb}, r_t | B_s, L_s, r^d_{ts}) = \quad & \max_{r^d_{tb}, \mathrm{Div}_t, B_b, L_b, E_{t+1,b}} \quad \mathrm{Div}^*_{tb} + \beta \mathbb{E}[V(r_{t+1}, B_b, L_b, E_{t+1,b}, r^d_{t+1,b} | B_s, L_s, r^d_{t+1,s})] \\
\text{s.t.} \quad & E_{t+1,b} = E_{tb} + \pi^*_{tb} - \mathrm{Div}^*_{tb} \\
& \mathrm{Div}_{tb} < 0 \implies \mathrm{Div}^*_{tb} = \mathrm{Div}_{tb} \cdot \lambda \\
& \pi^*_{tb} = \pi_{tb} - \xi_b B_b^2 \\
& E_{t+1,b} \leq \kappa_b \cdot (D(r^d_t | r_t, r^d_{ts}) + E_{t+1,b}) \implies \\
& \quad \mathrm{Div}^*_{tb} = \mathrm{Div}_{tb} + \lambda(E_{t+1,b} - \kappa \cdot (D(r^d_{tb} | r_t, r^d_{ts}) + E_{t+1,b}))
\end{aligned}
\tag{22}
$$

The bank takes as given the demand function from depositors, borrowers, and the bond market, in addition to the parameters governing the short rate process. The bank selects deposit rates, a dividend policy, and time-invariant long bond and loan holdings, which pin down a book equity amount in the following period. Note that the model does not feature adjustment costs for dividends (Elenev et al. (2021)). I scale the payout to shareholders by the banks' equity such that the value function is defined over return on equity. This effectively ensures that lower levels of leverage are already penalized as the banks' shareholders value their return per unit of equity.

A. Quantitative Exercise

Next I calibrate the model to quantitatively evaluate the counterfactual scenario referenced in the toy model. I display the parameters in the Table below. I externally calibrate several parameters and combine them with three key estimated parameters.

First, I estimate the relevant parameters for the short rate process, taking the r-star estimates from Holston et al. (2023). I estimate the deposit demand elasticity parameter from the cross-section of banks in Appendix Table 7. I use the GIV estimate for the long bond price elasticity parameter. I obtain the loan elasticity parameter from Diamond et al. (2020). I estimate the correlation between the short rate and loan income across bank sizes using data from the cross-

Category	Parameter	Value	Description	Source
Interest Rate Parameters	$\overline{r}$	0.8	R-star in 2013	Holston et al. (2023)
	κ_r	0.96	Short Rate Reversion	Estimated
	σ_r	0.41	Short Rate Volatility	Estimated
Deposit Parameters	α_d	1	Deposit Elasticity	Estimated
	δ_c	0.53	Cash Quality	Estimated
	δ_{ds}	0.28	Small Deposit Quality	Estimated
	δ_{db}	1.65	Big Deposit Quality	Estimated
Asset Market Parameters	α_b	-2	Bond Rate Elasticity	Estimated
	α_l	-2.3	Loan Rate Elasticity	Diamond et al. (2023)
	β_{MBB}	-0.02	Long Bond Repricing Beta	Estimated, High Frequency
Banking System Paramters	β_r	1.12	Net Loan Income Beta	Estimated
	β_{r2}	-0.05	Net Loan Income Squared Beta	Estimated
	ϕ_b	0.1	Marginal Loan Cost: Big	Calibrated to 2013
	ϕ_s	4.4	Marginal Loan Cost: Small	Calibrated to 2013
	c_{fb}	0.01	Fixed Costs: Big	Calibrated to 2013
	c_{fs}	0	Fixed Costs: Small	Calibrated to 2013
	ξ_b	1	Bond Costs: Big	Calibrated to 2013
	ξ_s	44.4	Bond Costs: Small	Calibrated to 2013
	AFS Share	0.68	AFS Share	Calibrated to 2020
	D	0.91	Deposit Market Size	Calibrated to 2013
	E/A (Big)	0.05	Big Bank Leverage in 2014	Cecchetti & Schoenholtz (2020)
	λ	7	Recapitalization Cost	Elenev et al. (2021)
	β	0.96	Discount Rate	Wang et al. (2022)

section of banks. I calibrate marginal loan cost, bond holding costs, fixed cost, and deposit market size parameters to their level at the time of the regulation. The bond cost parameter captures the fixed shadow costs of holdings bonds revealed by different balance sheet shares before the regulation. I calibrate the share of available for sale securities to match the share for large banks as of 2018 once the regulation is binding. I externally calibrate the three remaining parameters. I obtain large banks' leverage ratio going into the SLR era from Cecchetti and Schoenholtz (2020). I calibrate equity issuance costs from Elenev et al. (2021). I use the discount rate from Wang et al. (2022).

B. Baseline Estimation

I solve for the optimal policy of the bank given alternative capital requirements of 4% (pre-SLR change) and 6%, the amount needed to be well-capitalized according to the SLR. I display large bank value, bank portfolio shares for both large and small banks, and equilibrium asset prices in the columns of each scenario. First, I consider the optimal portfolio under the baseline estimates when capital requirements change. I show the results below.

Scenario	κ	V_b	L_b	B_b	L_s	B_s	r^b	r^l
Pre-SLR	$\kappa = 4\%$	1.00	0.54	0.14	0.87	0.13	3.49	2.30
Post-SLR	$\kappa = 6\%$	0.58	0.49	0.19	0.90	0.10	3.01	2.45

We observe that bank value suffers significantly under the higher capital requirement. Next, for the large bank, we observe that the balance sheet share of loans decreases and the share of bonds increases. Conversely, we observe the opposite effect for small banks. Note that long bond balance sheet share for large banks increases by 5% while the share of small banks decreases by 3%, matching the cross-sectional effect from the reduced form estimate of 8% balance sheet shares. Overall, the quantity purchased by banks drives a decline in the long term rate by 48 basis points. This is lower than the reduced form back of the envelope analysis since the model captures the spillover effect from small banks decreasing their shares. For loans, we observe that the decline in lending volumes is partially offset by increased lending by the unregulated bank, leading total loan rates to increase by 15 basis points.

C. Counterfactual 1: Countercylical Capital Requirements

Next I solve for the optimal portfolio if the regulator installs countercyclical capital requirements as part of the regulation change. I model countercyclical capital requirements as a function of the short rate. If the short rate is below the long term steady state, I decrease capital requirements by 2%. Otherwise, the capital requirement is at the 6% requirement in the post-SLR period. Note that this is similar to the policy enacted by the Federal Reserve in relaxing the SLR in 2020.

Scenario	κ	V_b	L_b	B_b	L_s	B_s	r^b	r^l
Pre-SLR	$\kappa = 4\%$	1.00	0.54	0.14	0.87	0.13	3.49	2.30
Post-SLR	$\kappa = 4\%$ if $r_t < \overline{r}$, else $\kappa = 6\%$	0.75	0.54	0.15	0.87	0.13	3.43	2.29

First, we observe that bank value is higher in the countercyclical requirements scenario as the bank can stay away from their constraint more easily in the down rate state. Second, we see that large banks exhibit a weaker shift in their portfolios toward long bonds, leading to decline of only 6 basis points in the long term rate. Last, we also observe little to no effect on loans.

In summary, if banks expect regulatory forbearance in the low rate state, they can continue to provide additional credit ex-ante and asset prices will reflect the reduced hedging motive.

D. Counterfactual 2: State-contingent LSAPs

In the last scenario, I consider the impact of changes in bond supply as interest rates. In particular, I assume that the Fed purchases a larger amount of the long bond to lower the price by 5$ per 100 face value when rates fall to 0. The Fed reverses the purchases when rates rise above 0. I solve for the resulting bank portfolios under the new pricing mapping for both the pre- and post- scenarios.

Scenario	κ	V_b	L_b	B_b	L_s	B_s	r^b	r^l
Pre-SLR	$\kappa = 4\%$	1.00	0.54	0.14	0.87	0.13	3.49	2.30
Post-SLR	$\kappa = 6\%$	0.61	0.52	0.17	0.89	0.11	3.26	2.35

The amplified hedging value of long bonds allows the bank to have a higher value ex-ante (.61 versus .58 in the baseline estimate) as it manages to avoid hitting the capital constraint as frequently. The regulated bank increases bond holdings by less, leading to muted effect of only 23 basis points in the long term rate. The strong state-contingent asset purchase leads the bank to internalize the effect recapitalization, affecting asset prices ex-ante in the steady state.

The coupons associated with the bonds at the time of the banks' purchase are unchanged, so the interaction works through changes in the price of the long bonds (Vayanos and Vila (2021), Greenwood and Vayanos (2014)). Beyond the effect on the value of the bond portfolio, there is an additional channel through bank reserves. QE is financed by an increase in bank reserves which are floating rate assets held by the banking sector. In those states, banks' can be overloaded with reserves which can further amplify the risk management problem in the paper. The key tradeoff when considering whether the level of reserves is binding depends on the degree to which the increases in reserves increases the price of the long bonds, which can offset the cash flow decline associated with larger reserve quantities. Implicitly the model above considers only the scenario where the quantity of reserves is less influential than the corresponding price gains on banks' existing portfolio.

V. Conclusion

Monetary policymakers have expanded their policy tools since the Global Financial Crisis, strengthening bank regulation and engaging in large scale asset purchases, while holding interest rates near zero. In this paper I show that bank capital regulation can influence traditional monetary policy objectives by tilting banks' risk management problem toward holding long maturity government bonds. I provide reduced form evidence that enhanced capital requirements led to a significant portfolio shift toward long bonds within the banking system, functioning as a large scale asset purchase. As policymakers call for a rethinking of the regulatory framework amid bank stability concerns in 2023, this paper highlights the under-appreciated consequence of enhanced bank regulation through the effect on the yield curve. Overall the paper highlights that the separate pillars of monetary policy can interact in a quantitatively important direction. As policymakers pursue quantitative tightening and the "Basel Endgame", the model provides a framework for future research to study the economics of the interaction between interest rates, unconventional monetary policy and banks.

REFERENCES

Admati, Anat R, Peter M DeMarzo, Martin F Hellwig, and Paul C Pfleiderer, 2012, Debt overhang and capital regulation, *Rock Center for Corporate Governance at Stanford University Working Paper* .

Adrian, Tobias, Richard K. Crump, and Emanuel Moench, 2013, Pricing the term structure with linear regressions, *Journal of Financial Economics* 110, 110–138.

Adrian, Tobias, Erkko Etula, and Tyler Muir, 2014, Financial intermediaries and the cross-section of asset returns, *The Journal of Finance* 69, 2557–2596.

Aiyar, Shekhar, Charles W Calomiris, and Tomasz Wieladek, 2015, Bank capital regulation: Theory, empirics, and policy, *IMF Economic Review* 63, 955–983.

Altunbas, Yener, David Marques-Ibanez, Michiel van Leuvensteijn, and Tianshu Zhao, 2022, Market power and bank systemic risk: Role of securitization and bank capital, *Journal of Banking & Finance* 138.

Bauer, Michael, and Glenn D Rudebusch, 2014, The signaling channel for federal reserve bond purchases, *International Journal of Central Banking* .

Begenau, Juliane, 2020, Capital requirements, risk choice, and liquidity provision in a business-cycle model, *Journal of Financial Economics* 136, 355–378.

Begenau, Juliane, Monika Piazzesi, and Martin Schneider, 2015, Banks' risk exposures, NBER Working Papers 21334, National Bureau of Economic Research, Inc.

Brunnermeier, Markus K, and Yann Koby, 2018, The reversal interest rate, Working Paper 25406, National Bureau of Economic Research.

Brunnermeier, Markus K, Sebastian A Merkel, and Yuliy Sannikov, 2022, Debt as safe asset, Working Paper 29626, National Bureau of Economic Research.

Brunnermeier, Markus K, and Yuliy Sannikov, 2016, The i theory of money, Working Paper 22533, National Bureau of Economic Research.

Buchak, Greg, Gregor Matvos, Tomasz Piskorski, and Amit Seru, 2018, Beyond the balance sheet model of banking: Implications for bank regulation and monetary policy, NBER Working Papers 25149, National Bureau of Economic Research, Inc.

Cecchetti, Steve, and Kim Schoenholtz, 2020, Setting bank capital requirements.

Chodorow-Reich, Gabriel, Andra Ghent, and Valentin Haddad, 2021, Asset insulators, *Review of Financial Studies* 34, 1509–1539.

Choi, Dong Beom, Michael R Holcomb, and Donald P Morgan, 2020, Bank leverage limits and regulatory arbitrage: Old question-new evidence, *Journal of Money, Credit and Banking* 52, 241–266.

Christensen, Jens H E, and Signe Krogstrup, 2018, Transmission of Quantitative Easing: The Role of Central Bank Reserves, *The Economic Journal* 129, 249–272.

Di Tella, Sebastian, and Pablo Kurlat, 2017, Why are banks exposed to monetary policy?, Working Paper 24076, National Bureau of Economic Research.

Diamond, Douglas W, and Philip H Dybvig, 1983, Bank Runs, Deposit Insurance, and Liquidity, *Journal of Political Economy* 91, 401–419.

Diamond, William, Zhengyang Jiang, and Yiming Ma, 2020, Monetary transmission through bank balance sheet synergies, *SSRN Electronic Journal* .

Dick, Astrid A., 2008, Demand estimation and consumer welfare in the banking industry, *Journal of Banking & Finance* 32, 1661–1676.

Domanski, Dietrich, Hyun Song Shin, and Vladyslav Sushko, 2017, The hunt for duration: Not waving but drowning?, *SSRN Electronic Journal* .

Drechsler, Itamar, Alexi Savov, and Philipp Schnabl, 2021, Banking on deposits: Maturity transformation without interest rate risk, *The Journal of Finance* 76, 1091–1143.

Du, Wenxin, Benjamin M Hébert, and Wenhao Li, 2022a, Intermediary balance sheets and the treasury yield curve, Working Paper 30222, National Bureau of Economic Research.

Du, Wenxin, Benjamin M Hébert, and Wenhao Li, 2022b, Intermediary balance sheets and the treasury yield curve, Working Paper 30222, National Bureau of Economic Research.

Du, Wenxin, Alexander Tepper, and Adrien Verdelhan, 2018, Deviations from covered interest rate parity, *The Journal of Finance* 73, 915–957.

Duffie, Arvind KrishnamurthyDarrell, Arvind Krishnamurthy, and Darrell Duffie, 2016, Passthrough efficiency in the fed's new monetary policy setting.

D'Amico, Stefania, and Thomas B. King, 2013, Flow and stock effects of large-scale treasury purchases: Evidence on the importance of local supply, *Journal of Financial Economics* 108, 425–448.

Elenev, Vadim, Tim Landvoigt, and Stijn Van Nieuwerburgh, 2021, A macroeconomic model with financially constrained producers and intermediaries, *Econometrica* 89, 1361–1418.

Favara, Giovanni, Ivan Ivanov, and Marcelo Rezende, 2021, Gsib surcharges and bank lending: Evidence from us corporate loan data, *Journal of Financial Economics* 142, 1426–1443.

Fraisse, Henri, Mathias Lé, and David Thesmar, 2020, The real effects of bank capital requirements, *Management Science* 66, 5–23.

Fuster, Andreas, and James Vickery, 2018, Regulation and risk shuffling in bank securities portfolios, Staff Reports 851, Federal Reserve Bank of New York.

Gabaix, Xavier, and Ralph S. J Koijen, 2021, In search of the origins of financial fluctuations: The inelastic markets hypothesis, Working Paper 28967, National Bureau of Economic Research.

Gagnon, Joseph E., Matthew Raskin, Julie Remache, and Brian P. Sack, 2011, Large-scale asset purchases by the Federal Reserve: did they work?, *Economic Policy Review* 17, 41–59.

Granja, Joao, 2023, Bank fragility and reclassification of securities into HTM, *SSRN Electronic Journal* .

Greenwald, Daniel, John Krainer, and Pascal Paul, 2024, Monetary transmission through bank securities portfolios, Working Paper 32449, National Bureau of Economic Research.

Greenwood, Robin, Samuel G. Hanson, Jeremy C. Stein, and Adi Sunderam, 2017, Strengthening and Streamlining Bank Capital Regulation, *Brookings Papers on Economic Activity* 48, 479–565.

Greenwood, Robin, and Dimitri Vayanos, 2014, Bond Supply and Excess Bond Returns, *The Review of Financial Studies* 27, 663–713.

Haddad, Valentin, and David Sraer, 2020, The banking view of bond risk premia, *The Journal of Finance* 75, 2465–2502.

Hanson, Samuel G., 2014, Mortgage convexity, *Journal of Financial Economics* 113, 270–299.

Hanson, Samuel G., and Jeremy C. Stein, 2015, Monetary policy and long-term real rates, *Journal of Financial Economics* 115, 429–448.

He, Zhiguo, and Arvind Krishnamurthy, 2013, Intermediary asset pricing, *American Economic Review* 103, 732–70.

He, Zhiguo, and Arvind Krishnamurthy, 2018, Intermediary asset pricing and the financial crisis, *Annual Review of Financial Economics* 10, 173–197.

Hennessy, Christopher A., and Toni M. Whited, 2005, Debt dynamics, *The Journal of Finance* 60, 1129–1165.

Hirtle, Beverly, and Sarah Zebar, 2023, Bank profits and shareholder payouts: The repurchases cycle Federal Reserve Bank of New York Liberty Street Economics, January 9, 2023.

Holston, Kathryn, Thomas Laubach, and John C. Williams, 2023, Measuring the natural rate of interest after covid-19, *SSRN Electronic Journal* .

Hutchison, David E., and George G. Pennacchi, 1996, Measuring rents and interest rate risk in imperfect financial markets: The case of retail bank deposits, *The Journal of Financial and Quantitative Analysis* 31, 399–417.

Jansen, Kristy A.E., 2021, Long-term investors, demand shifts, and yields, *SSRN Electronic Journal* .

Jiang, Erica Xuewei, Gregor Matvos, Tomasz Piskorski, and Amit Seru, 2023, Limited hedging and gambling for resurrection by u.s. banks during the 2022 monetary tightening?

Jiang, Erica Xuewei, Gregor Matvos, Tomasz Piskorski, and Amit Seru, 2024, Monetary tightening and u.s. bank fragility in 2023: Mark-to-market losses and uninsured depositor runs?, *Journal of Financial Economics* 159, 103899.

Kekre, Rohan, Moritz Lenel, and Federico Mainardi, 2024, Monetary policy, segmentation, and the term structure, Working Paper 32324, National Bureau of Economic Research.

Koijen, Ralph S. J., and Motohiro Yogo, 2019, A demand system approach to asset pricing, *Journal of Political Economy* 127, 1475–1515.

Koont, Naz, and Stefan Walz, 2021, Bank credit provision and leverage constraints: Evidence from the supplementary leverage ratio.

Krishnamurthy, Arvind, and Annette Vissing-Jorgensen, 2011, The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy, *Brookings Papers on Economic Activity* 42, 215–287.

Li, Lei, Elena Loutskina, and Philip E Strahan, 2019, Deposit market power, funding stability and long-term credit, Working Paper 26163, National Bureau of Economic Research.

Ludvigson, Sydney C., and Serena Ng, 2009, Macro Factors in Bond Risk Premia, *The Review of Financial Studies* 22, 5027–5067.

McPhail, Lihong, Philipp Schnabl, and Bruce Tuckman, 2023, Do banks hedge using interest rate swaps?, Working Paper 31166, National Bureau of Economic Research.

Modigliani, Franco, and Richard Sutch, 1966, Innovations in interest rate policy, *The American Economic Review* 56, 178–197.

Paul, Pascal, 2023, Banks, maturity transformation, and monetary policy, *Journal of Financial Intermediation* 53, 101011.

Peek, Joe, and Eric Rosengren, 1995, Bank regulation and the credit crunch, *Journal of Banking & Finance* 19, 679–692, The Role of Capital in Financial Institutions.

Rodnyansky, Alexander, and Olivier M. Darmouni, 2017, The Effects of Quantitative Easing on Bank Lending Behavior, *The Review of Financial Studies* 30, 3858–3887.

Sundaresan, Suresh M., and Kairong Xiao, 2022, Liquidity regulation and banks: Theory and evidence, *SSRN Electronic Journal* .

Van den Heuvel, Skander J, 2008, The welfare cost of bank capital requirements, *Journal of Monetary Economics* 55, 298–320.

Vayanos, Dimitri, and Jean-Luc Vila, 2021, A preferred-habitat model of the term structure of interest rates, *Econometrica* 89, 77–112.

Wang, Yifei, Toni M. Whited, Wu Yufeng, and Kairong Xiao, 2022, Bank market power and monetary policy transmission: Evidence from a structural estimation, *The Journal of Finance* 77, 2093–2141.

Williams, John, 2014, Monetary policy at the zero lower bound: Putting theory into practice, *Hutchins Center on Fiscal and Monetary Policy* .

Xiao, Kairong, 2019, Monetary Transmission through Shadow Banks, *The Review of Financial Studies* 33, 2379–2420.

APPENDIX

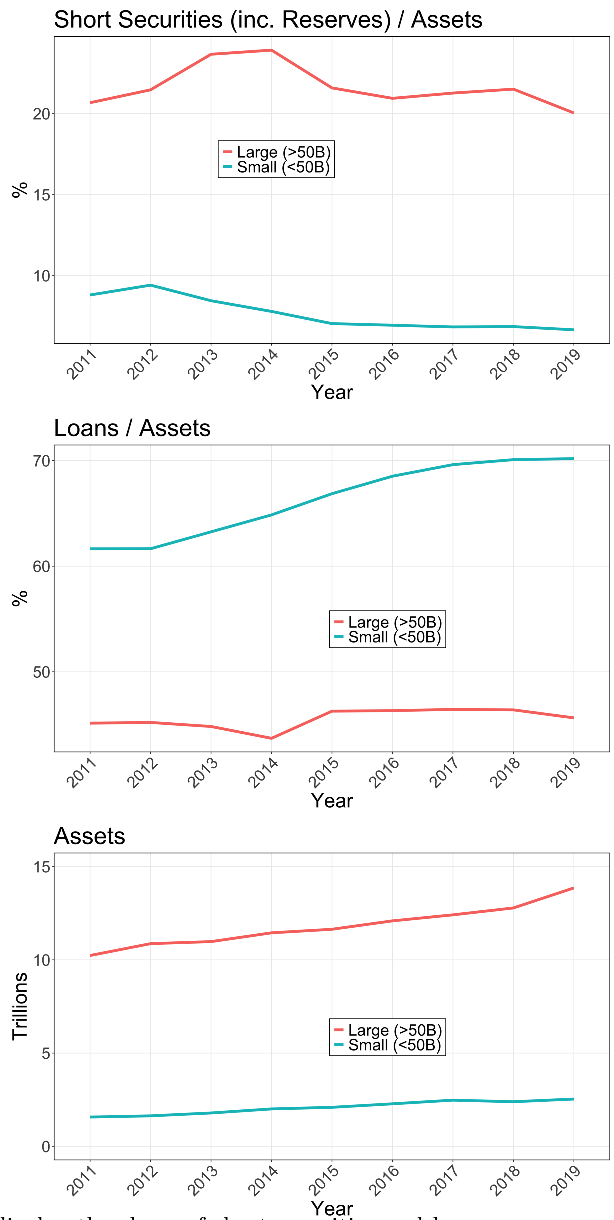
Appendix A. Tables and Figures

Table 4 Summary Statistics

Statistic	N	Median	St. Dev.	Pctl(25)	Pctl(75)
Assets (BHC)	18,058	3.65	242.18	1.78	9.70
Assets (Bank)	15,824	2.97	165.14	1.58	7.64
Tier 1 Equity/Assets	17,994	9.41	3.32	8.43	10.56
Tier 1 Equity/RWA	17,728	12.82	4.39	11.41	14.98
Long Bonds/Assets (BHC)	18,058	15.81	11.08	10.20	23.32
Long Bonds/Assets (Bank)	15,824	12.32	10.01	7.52	18.77

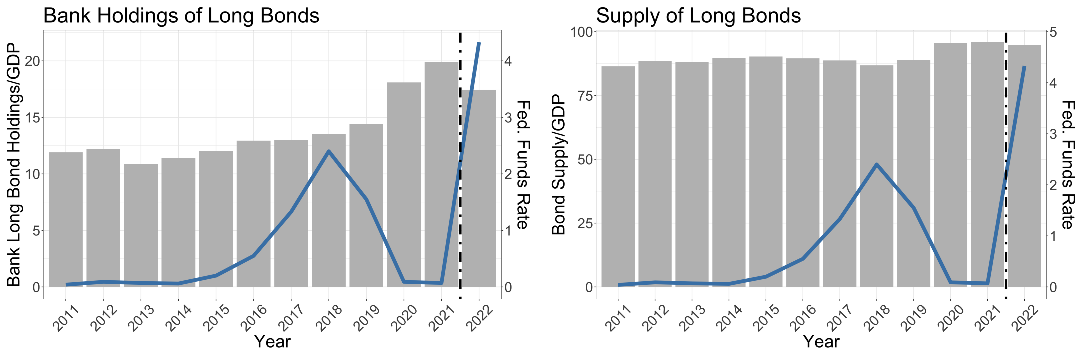
This table presents the summary statistics of the sample of banks from 2010 to 2022. The data is quarterly and includes data for the largest 500 banks in each period.

Figure 10. Balance Sheet Variables: Big and Small Banks



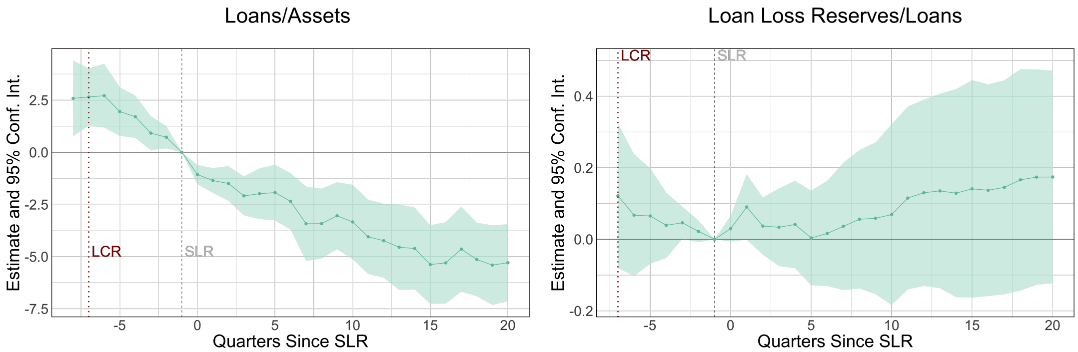
In the first two panels I display the share of short securities and loans as a percentage of the total balance sheet for big and small banks. In the bottom panel I show the total assets of large and small banks. I keep only the largest 500 banks.

Figure 11. Changing Composition of Government Bond Holdings



In the left panel I show estimates for the amount of long Treasuries and Agencies (greater than 1-year maturity) that are held by the banks. In the right panel I show the total supply of long bonds. I obtain the holdings data from the Flow of Funds. I show the evolution of the federal funds rate on the right axis of each panel. I obtain the maturity structure of banks' holdings from the Call Reports.

Figure 12. Loan Dynamics



The two panels show the results of estimating regression (2) on loan shares and loan loss reserves.

Table 5 Bank Regulation and Long Bond Holdings: Triple-Difference

	Long Sec./Assets	Long Sec./Assets
SLR Bank x Post	5.63^{***}	2.15
	(0.72)	(1.41)
SLR Bank x Low Equity x Post		4.40^{***}
		(1.42)
SLR Bank x LCR Gap x Post		-0.56^{*}
		(0.29)
SLR Bank x Low RWA Ratio x Post		0.70
		(1.11)
LCR Gap x Post		0.76^{***}
		(0.21)
Low Equity x Post		−1.20
		(0.74)
Low RWA Ratio x Post		0.62
		(0.72)
Bank Controls	Yes	Yes
Bank FE	Yes	Yes
Date FE	Yes	Yes
Num. obs.	18058	13906
R^2	0.84	0.82

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

The table shows the complete set of triple difference coefficients referenced in the main text. Post corresponds to 2013 for the LCR and 2014 for the SLR. Both specifications include log assets and the deposits' share of assets as time-varying controls. Standard errors are clustered at the bank level.

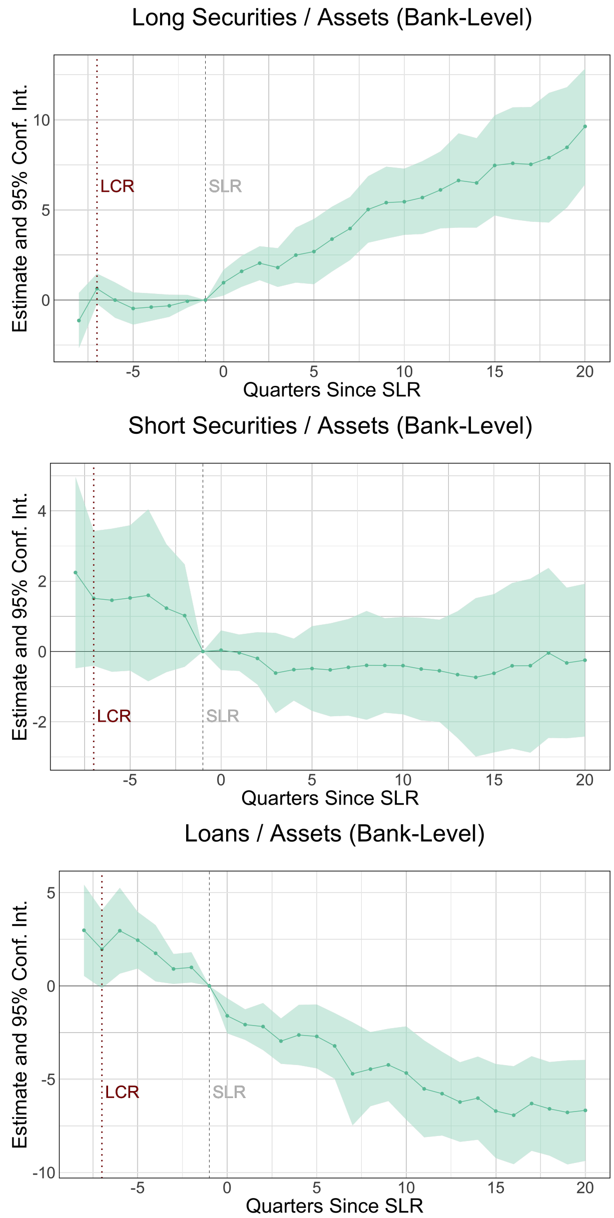
Table 6 Bank-Level Data: Portfolio Choice

	Long Sec./Assets	Short Sec./Assets	Loans/Assets
SLR Bank x Post	6.34***	−2.42	−7.39***
	(1.01)	(2.01)	(1.36)
Net Long Hedge / Assets	21.51	169.49	−180.06
	(119.90)	(119.53)	(176.61)
Bank Controls	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
Date FE	Yes	Yes	Yes
Num. obs.	15592	15592	15592
R^2	0.85	0.77	0.90

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

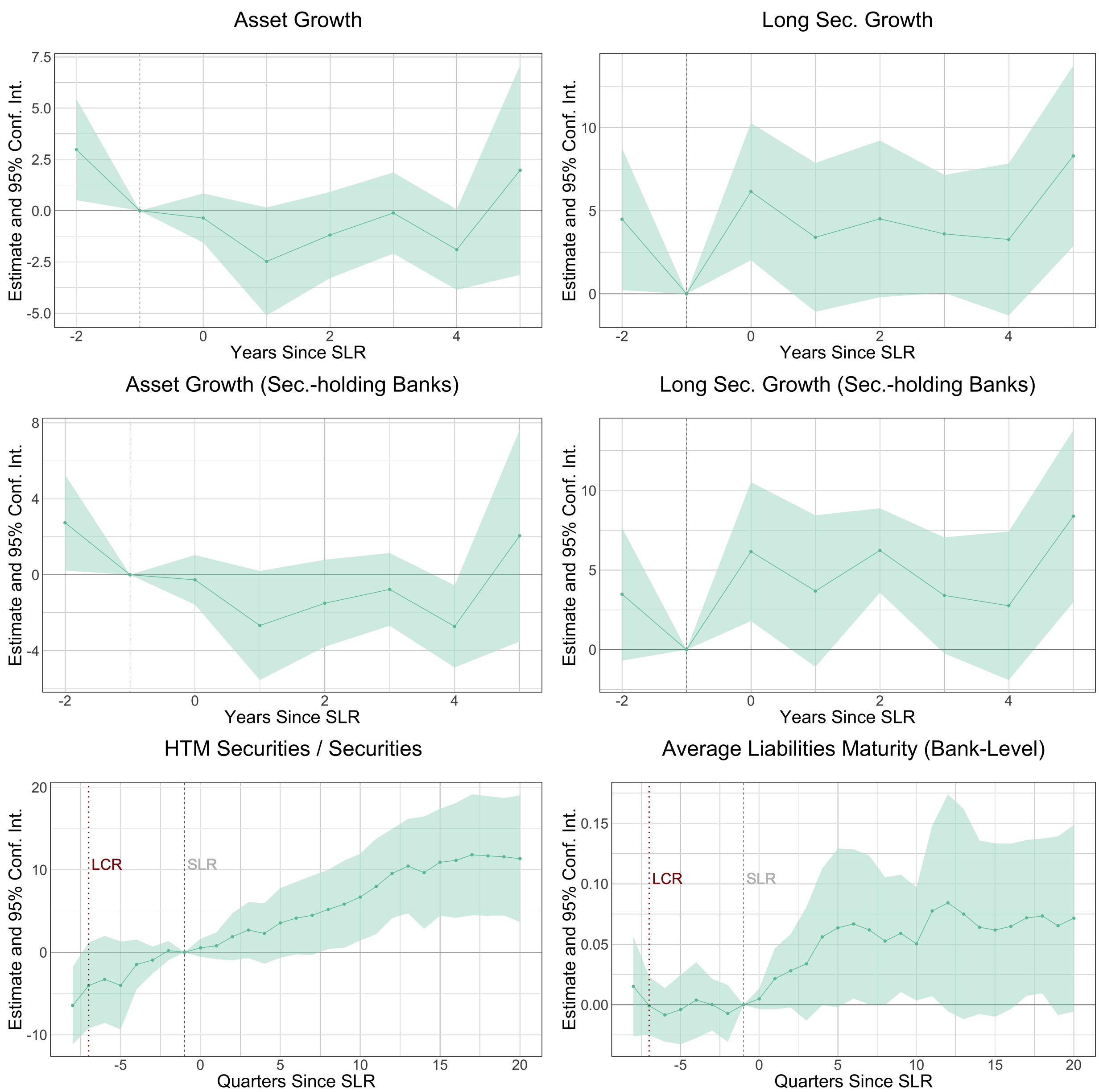
The table shows the results of estimating the baseline regression at the bank-level (rather than BHC level). All specifications include log assets, the deposits' share of assets, and the net long interest rate swap exposure as a share of assets as time-varying controls. Standard errors are clustered at the bank level.

Figure 13. Bank-level Dynamics



The two panels show the results of estimating regression (2) on long securities and loans balance sheet shares using data at the bank level, rather than BHC level.

Figure 14. More Balance Sheet Variables



The top two panels show the results of estimating regression (2) on asset growth and short long security holding growth. The middle two panels focus on banks that held at least 10% of their balance sheet in securities. The bottom two panels show the effect on the share of securities marked as HTM and on the average maturity of bank liabilities.

Appendix B: Government Bond Elasticity Micro-foundation

Next I present a micro-foundation of government bond inelasticity studied in the model. In particular, I augment a traditional preferred habitat model of the term structure (e.g. Vayanos and Vila (2021)) where banks and non-banks are counterparties in the trade of government bonds. There are two key differences between the original setting in Vayanos and Vila (2021) and the current environment. Trade in the original model occurs over a continuous yield curve of zero-coupon bonds, while the simplified environment in this paper includes a single long duration coupon bond. The key to the model is that banks remove interest rate risk from the portfolio of non-banks, which can lower the price of interest rate risk. In the baseline model, banks are institutionally distinct from traditional investors in the model as they hold their bonds to maturity while non-banks maximize the mark-to-market value of their securities. There is a supply θ_t^τ outstanding of bond of maturity τ. I denote non-bank holdings by X_t^τ and bank holdings $B^\tau(\bar{r}, \kappa)$ as a function of the long-run rate and the level of capital requirements.[20] The short rate r_t is the source of risk in the economy and follows a mean-reverting stochastic process with mean $\bar{r}$, persistence κ_r and volatility σ_r.

$$dr_t = \kappa_r(\bar{r} - r_t)dt + \sigma_r dB_t \tag{23}$$

The model contains default-free zero coupon bonds denoted by their maturity $\tau \in (0, ..., T]$.[21] The price of each bond of maturity τ in time t is denoted P_t^τ. The par value of each zero coupon bond is denoted X_t^τ. As in Vayanos and Vila (2021), I conjecture that bond prices are affine in the risk factor r_t:

$$P_t^\tau = e^{-[A(\tau)r_t + C(\tau)]} \tag{24}$$

[20] The model can be extended by making bank demand and the supply of government debt contingent on the level of short rates.

[21] Note that there is a complication where the model assumes bonds are zero-coupon bonds while in reality investors hold coupon bonds.

Next I apply Ito's lemma to obtain the instantaneous return on the bond with maturity τ:

$$\frac{dP_t^\tau}{P_t^\tau} = \mu_t^\tau dt - A(\tau)\sigma_r dB_t, \quad \text{where} \quad \mu_t^\tau = A'(\tau) r_t + C'(\tau) + A(\tau)\kappa_r(r_t - \overline{r}) + \frac{\sigma_r^2}{2}A(\tau)^2 \tag{25}$$

Risk-averse arbitrageurs have wealth W_t which they allocate at each maturity τ with holdings denoted by X_t^τ. Non-bank arbitrageur wealth thus evolves following:

$$dW_t = [W_t r_t + \int_0^\infty X_t^\tau(\mu_t^\tau - r_t)d\tau]dt - [\int_0^T X_t^\tau A(\tau)d\tau]\sigma_r dB_t \tag{26}$$

The arbitrageur has mean-variance preferences over wealth changes:

$$\max_{X_t^\tau} \quad \mathbb{E}_t[dW_t] - \frac{\gamma}{2}\mathbb{V}_t[dW_t] \tag{27}$$

The arbitrageur's first-order condition is:

$$\mu_t^\tau - r_t = A_r(\tau)\gamma\sigma_r^2 \times [\int_0^T A(\tau)X_t^\tau d\tau] \tag{28}$$

Next, as in Vayanos and Vila (2021), I impose market clearing $X_t^\tau = \theta^\tau - F^\tau - B^\tau(\overline{r},\kappa)$.

$$\mu_t^\tau - r_t = A_r(\tau)\gamma\sigma_r^2 \times [\int_0^T A(\tau)(\theta^\tau - F^\tau - B^\tau(\overline{r},\kappa))d\tau] \tag{29}$$

The remainder of the solution follows from Vayanos and Vila (2021). The solution involves solving for $A_r(\tau), C(\tau)$ that solve the two first-order differential equations implied by Equation 29. Gathering terms related to r_t, we can solve for $A(\tau)$:

$$A_r(\tau) = \frac{1 - e^{-\kappa_r\tau}}{\kappa_r} \tag{30}$$

Solving for the constant terms produces the following term for $C(\tau)$:

$$C(\tau) = (\kappa_r\overline{r} + \sigma_r^2\gamma\int_0^T A_r(\tau)(\theta^\tau - F^\tau - B^\tau(\overline{r},\kappa)d\tau)\int_0^\tau A_r(u)du - \frac{\sigma_r^2}{2}\int_0^\tau A_r(u)^2 du \tag{31}$$

Next I make the key simplifying assumption to map the VV setting into the model environment of this paper. I assume there exists a single default-free coupon bond that follows the same pricing relationship. This assumption effectively requires that movement the τ-year zero coupon rate can be reasonably mapped into the τ-year coupon bond. The assumption of a single coupon bond allows for a tractable mapping into the rest of the model. Solving for the slope and intercept terms, we find:

$$A_r \approx \frac{1 - e^{-\kappa_r \cdot \tau}}{\kappa_r} \qquad C \approx A_r \kappa_r \overline{r} + \sigma_r^2 \gamma A_r^2 \cdot (\theta - F - B(\overline{r}, \kappa)) - \frac{\sigma_r^2}{2} A_r^2 \tag{32}$$

We can thus write the τ-year yield in the following way:

$$y_t^\tau = \frac{1}{\tau}\left(A_r r_t + A_r \kappa_r \overline{r} - \frac{\sigma_r^2}{2} A_r^2 + \sigma_r^2 \gamma A_r^2 \cdot (\theta - F) - \sigma_r^2 \gamma A_r^2 \cdot B(\overline{r}, \kappa)\right) \tag{33}$$

The sensitivity coefficient in this case is:

$$\frac{\partial y_t^\tau}{\partial \kappa} = \frac{\partial y_t^\tau}{\partial B(\overline{r}, \kappa)} \cdot \frac{\partial B(\overline{r}, \kappa)}{\partial \kappa} = -\frac{1}{\tau} \sigma_r^2 \gamma A_r^2 \frac{\partial B(\overline{r}, \kappa)}{\partial \kappa} \tag{34}$$

The key parameter that determines the sensitivity is the risk-aversion of non-banks γ, given the model framework that estimates the sensitivity of bank bond demand as capital requirements κ change.

A. Dynamic Supply and Bank Demand

In reality, both the net supply and bank demand for bonds can change as interest rates change. Allowing for dynamic trading will be priced into the shape of the supply curve available to banks in the first period. For example, as decline in the short rate can be associated with a decrease in the supply of government debt as the central bank engages in QE which may be greater than the corresponding increasing government debt supply. Banks' interest rate exposure can also vary as a function of the level of interest rates, similar to Haddad and Sraer (2020) who show that banks' duration exposures forecast subsequent Treasury returns.

For tractability reasons to enable a closed for solutions, suppose the non-bank sector hypothesizes that net supply and bank demand functions are linear in the short rate:

$$\theta_t^\tau(r_t) = \theta^\tau + \xi_\theta(r_t - \bar{r}) \qquad B_t^\tau(r_t, \bar{r}, \kappa) = B^\tau(\bar{r}, \kappa) + \xi_B(r_t - \bar{r}) \tag{35}$$

Now, returning to Equation 29, we can substitute the dynamic terms and once again solving for $A_r(\tau), C(\tau)$.

$$\mu_t^\tau - r_t = A_r(\tau)\gamma\sigma_r^2 \times [\int_0^T A_r(\tau)(\theta^\tau + \xi_\theta(r_t - \bar{r}) - B^\tau(\bar{r}, \kappa) - \xi_B(r_t - \bar{r}))d\tau] \tag{36}$$

First, solving for $C(\tau)$, the static supply remains the same (except for demeaning supply terms around the long term rate):

$$C(\tau) = (\kappa_r\bar{r} + \sigma_r^2\gamma \int_0^T A_r(\tau)(\theta^\tau - B^\tau(\bar{r}, \kappa) - (\xi_\theta - \xi_B)\bar{r})d\tau) \int_0^\tau A_r(u)du - \frac{\sigma_r^2}{2}\int_0^\tau A_r(u)^2 du \tag{37}$$

Next, returning to the r_t terms, we have the following ODE:

$$A_r'(\tau) + A_r(\tau)\kappa_r - 1 = A_r(\tau)\gamma\sigma_r^2 \int_0^T A_r(\tau)(\xi_\theta - \xi_B)d\tau \tag{38}$$

Solving for $A_r(\tau)$ yields:

$$A_r(\tau) = \frac{1 - e^{-\kappa_r^*\tau}}{\kappa_r^*} \quad \text{where: } \kappa_r^* = \kappa_r - \gamma\sigma_r^2 \int_0^T A_r(\tau)(\xi_\theta - \xi_B)d\tau \tag{39}$$

We observe in Equation 39 that κ_r^* increases in ξ_B and decreases in ξ_θ. Haddad and Sraer (2020) argues that $\xi_B > 0$, as banks increase their holdings of long bonds as rates increase and subsequently mean-revert. As $\bar{r}$ decreases, banks' holdings of long bonds increases following the cash-flow hedging argument in this paper. The sign of ξ_θ is unclear ex-ante. During the 2010s, $\xi_\theta > 0$ as the Fed conducted QE (QT) beyond the supply increase from the fiscal authority. However, during the COVID crisis in 2020, the fiscal authority increased their issuance of long term debt, increasing the net supply (beyond Fed purchases), leading to $\xi_\theta < 0$. Now, I make the same simplifying assumption that the pricing process for the 10-year coupon bond can be approximated by the process for the 10-year zero coupon bond implied by the model. Next I write out the yield as a function of the parameters:

$$y_t^\tau = \frac{1}{\tau}(A_r r_t + A_r \kappa_r \overline{r} - \frac{\sigma_r^2}{2} A_r^2 + \sigma_r^2 \gamma A_r^2 \cdot (\theta - (\xi_\theta - \xi_B)\overline{r}) - \sigma_r^2 \gamma A_r^2 \cdot B(\overline{r}, \kappa)) \tag{40}$$

We can now represent the yield of the long bond as a function of dynamic bank portfolio flows. In particular, the main condition is that the parameter ξ_B has to be consistent with banks' actual purchases of long bonds along the cycle.

$$y_t^\tau = A(\xi_\theta, \xi_B) r_t + C(\xi_\theta, \xi_B) \tag{41}$$

Appendix C. Deposit Demand Elasticity Estimation

I use a set of cost shifters to the instrument for deposit rates (Xiao (2019)). The instruments include the ratio of salaries over assets and expenses on fixed assets over assets. I include the squared amount of each variable as additional instruments. The second stage of the regression takes the following form, where $\widehat{r}_{bt}$ denotes the cleaned deposit rate which is assumed to be exogenous to other demand channels.

$$\log(s_{bt}) = \alpha_d \widehat{r_{bt}} + \alpha_t + \epsilon_{bt} \tag{42}$$

I present the estimation results below in Table 7.

Table 7 Deposit Demand Elasticity

	Log Share
Deposit Rate (IV)	1.00^{***}
	(0.25)
Method	IV
Date FE	Yes
SE Cluster	Bank
Num. obs.	54174

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$