Low Rates and Bank Loan Supply: Theory and Evidence from Japan*

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Abstract

What are the long-run consequences of low nominal interest rates for credit supply? In this paper we (1) provide panel evidence from Japan of the detrimental effects of low rates on long-run bank profitability and loan supply, (2) propose a quantitative macroeconomic model with heterogeneous banks that rationalizes our key empirical findings, and (3) discipline our model using our panel evidence to obtain the aggregate impact on credit supply. Our empirical evidence exploits the differential exposure of banks to nominal rates through their historical liability structure. We show that exposed banks face relatively higher costs of funding, have lower profitability and decrease loan supply as low rates unfold. In the model loans are undersupplied in equilibrium due to financial frictions. Market power banks have on their savings products helps mitigate these frictions by raising bank capitalization, but is sensitive to nominal rates due to the competition from money. This force is stronger for banks with initially more market power, generating heterogeneity that we use to discipline the model. We find that low rates resulted in significantly lower loan growth in Japan. We explore in counterfactuals two commonly discussed policies: tiering bank reserves and taxing cash. Both alleviate the negative effects of low rates on credit supply, although tiering has a limited effect.

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1 Introduction

A striking economic phenomenon of recent decades has been the steady decline of nominal interest rates in developed economies. Negative rates in Japan and Europe as well as the u-turn in the Federal Reserve's latest interest rate cycle suggest that the low-rates environment will persist. Policymakers and practitioners have expressed concerns that this environment threatens monetary policy transmission and financial stability due to the pressure it puts on financial intermediaries' profitability (Coeure, 2016; Lane, 2016; Kuroda, 2017).[1] These concerns are prevalent for banks, whose traditional lines of business rely on generating a sufficiently high spread between returns on assets and fundings costs to cover operating expenses and a profit margin. We complement the literature that seeks to understand the implications for monetary policy transmission by asking: what are the *long-run* consequences of low nominal interest rates for credit supply, and which policiy tools are useful for mitigation?[2]. We argue that understanding the long-term effects is key to comprehend the implications of low rates for monetary and prudential policy, first because an absence of strongly negative long-run effects would alleviate current policy concerns, second because endogenous mitigation such as increases in non-interest income and cost-efficiency are taken into account, and third because short-term factors such as hedging makes short-term identification harder.[3] We focus on two mitigation policies that have been implemented or suggested but not tested in the economic literature: bank reserve tiering and a tax on currency designed to reduce the return on cash holdings.

The first main contribution of the paper is to provide novel empirical evidence on the detrimental long-term effects of low nominal interest rates on bank profits and bank lending, based on the experience of banks in Japan. Japan, as the first economy to enter the "low-for-long" environment, provides a simultaneously interesting and worrying case study. We show first that the aggregate spreads banks earn and bank profitability have significantly decreased

[1] See also Jackson (2015), Bech and Malkhozov (2016), and Claessens et al. (2017).

[2] For implications of low rates for monetary policy cuts see Brunnermeier and Koby (2018), Eggertsson et al. (2019), Wang (2018), and Campos (2018)

[3] Drechsler et al. (2018) show that U.S. banks actively match the short-run interest exposure of their liabilities with that of their assets. We show that this is also true for Japanese banks, but not over the long-run.

since the onset of the low interest rates environment. We then show that banks' exposure to low nominal rates is heterogeneous, and that banks' historical liabilities structure is a strong predictor of this exposure. We argue that this historical exposure is quasi-experimental due to the segmentation of Japan's banking industry prior the 1980s, and exploit it to show that exposure to nominal rates results in losses in overall profitability, bank capitalization, and bank lending.

Our second main contribution is to provide a macroeconomic model with heterogeneous banks that offers an explanation for banks' exposure to low nominal interest rates in both the cross-section and the aggregate. In our model, low nominal interest rates decrease banks' market power on their liabilities permanently, reducing their net worth and increasing lending frictions. Banks have heterogeneous exposure to low rates due to the differing valuation of their products by households, generating variation in market power. Importantly, we show that in our model the effects of low rates on bank intermediation in the aggregate operate through the same channels in our cross-section of banks. Hence, the identified moments we uncover from our panel analysis are informative about the aggregate mechanisms at play, in the spirit of Nakamura and Steinsson (2018). We use the model to quantify the aggregate effects of a long-term decrease in nominal rates and conduct policy counterfactuals.

The third contribution of this paper is show that the frictions we describe generate a significant decline in bank lending and aggregate output and evaluate potential policy solutions. We find that each percent decrease in the long-term (steady-state) nominal rate in the last three decades decreased loan supply by about 1.33%. This result provides empirical support for the idea proposed in Brunnermeier and Koby (2018) and Eggertsson et al. (2019) that very low interest rates induced by monetary policy can be contractionary, especially when "low-for-long". In other words, our evidence suggests that shocks that steepen the yield curve might be preferable to an overall lowering of the yield curve. We then study two policy counterfactuals that have been implemented or suggested as mitigation tools: reserve tiering and a tax on cash savings. For plausible implementation scenarios, we find tiering to be less effective than taxing cash in mitigating the negative effects of low interest rates. These results suggest that there is scope for policy to reduce the negative impact of low nominal rates on financial intermediation and economic activity.

Our empirical results differ from the existing literature in that we focus on the long-run experience of Japan. This long-term focus offers different identification assumptions that analysis using short-term frequency data, and allows us to test for endogenous responses of banks to their lost net interest income.

Our first empirical result is that the aggregate spread between banks' interest expense and the risk-free rate is decreasing in the level of rates in the long-run, and that interest income does not compensate this decrease, resulting in lower overall margins. The spread between what banks pay on their liabilities and the risk-free rate decreases from close to 1.0% in the early 1990s to about 0.0% post 2000s. In contrast, the spread banks earn on assets over the risk-free rate has only slightly increased, by about 0.2%.

We then show that banks are heterogeneously exposed to the long-term level of nominal rates, and that this exposure can be predicted by the historical liability structure of banks. We project banks' individual funding spread on the long-term level of the risk-free rates and show that some banks have no significant exposure while others' margins do. This exposure can be predicted by banks' historical deposits to liabilities ratios. Differences in ratios arose due to regulations segmenting banks' funding instruments prior to 1979 and have proved highly persistent despite deregulation.

Using our historically predicted exposure, we show that exposed banks' margins decrease in the low rates environment, and these effects are not undone by increases in fees, other non-interest income, or decrease in costs. Specifically, our main results compare bank outcomes in 1990-2000 to the years since 2000, and use 1990 deposits-to-liabilities ratios as exposure. Exposed banks do not increase the relative return they earn on their assets enough to compensate their relatively higher interest expenses, generating net interest margins losses. These declines are not compensated by fees, other income components or cost reductions. We also show the robustness of our findings to (1) dynamic specifications, (2) measurable interest rate movements, and (3) alternate measures of market power in deposit markets.

Next we show that the lower net income of exposed banks translates into lower equity, because dividends and capital issuance do not change enough to compensate the losses of net income. Although exposed banks decrease dividends, these reductions are small relative to their losses in net income. Capital issuance by exposed banks does not change. We conclude that exposed banks' internal equity growth has been affected by low rates.

Finally, we show in bank-firm matched loan-level data that firms' bank borrowing grows less from exposed banks, controlling for firm demand through the inclusion of a firm-time fixed effect. To address the identification challenge of separating the effects of low interest rates from those of the underlying macro environment, our main specification includes firm-time fixed effects that absorb the average effect of macroeconomic variables on banks' demand for loans. We can hence rule out stories where high exposure banks lent primarily to borrowers whose businesses were more affected by the economic slowdown.

In addition to our baseline results we provide throughout our results different specifications to control for possible concerns caused by macroeconomic challenges or spurious heterogeneity in exposure. One important identification challenge we face is that Japan's regional banks tend to be more exposed than city banks, a spatial heterogeneity that may correlate with secular trends towards urbanization that benefit the latter group. To address this concern we show that our main results hold when using variations within regional banks alone. Another important identification challenge we face consists of the numerous contemporaneous shocks to the Japanese banking system during the late 1990s and early 2000s, including rising non-performing loans, zombie lending, mergers, nationalizations, recapitalizations, and restructurings.[4]. We work with a post-mergers entities and control for reported non-performing loans. Our results are robust to controlling for mergers, restructurings, nationalizations, and recapitalizations.

To study the aggregate effects of long-term changes in the steady-state level of nominal rates we extend a standard growth model with a banking sector consisting of heterogeneous banks. Banks provide liquid savings products to households, raise equity, and invest in loans and bonds. Firms use bank loans to finance part of their capital purchases. Households provide labor, consume, and save using three assets: bonds, money (currency), and deposits. Money and deposits provide liquidity benefits that increase the effective return on these assets, but are imperfect substitutes in fulfilling that role. Bank products are also imperfect

[4]Zombie lending was most pronounced during the mid-1990s, among banks with low equity and an incentive to evergreen loans rather than report losses that would result in losses to equity. As our results rely on comparing banks' performance since 2000 to the 1990s, zombie loans are likely if anything to bias our empirical results towards zero

substitutes across banks, generating a demand for each bank. This gives rise to upward-sloping supply of bank deposits.

Although banks have market power in providing differentiated liquid savings to households, how much market power they have depends on the relative returns to bank savings versus money. Money becomes more attractive when nominal rates are low. Banks invest liquid savings into bonds at the margin, and hence charge the bond rate minus a mark-down that depends on the elasticity of bank savings supply. When rates are high, that elasticity is essentially constant, the pass-through of a small nominal rate change to interest expenses is 1, and the demand for bank savings stay constant. When rates are low, however, each further rate decrease makes money more competitive, forcing banks to raise the return on their savings products because they face more elastic demand. The effect on quantities is ambiguous, since a decrease in the mark-down bank charge generates an inflow out of bonds and into liquid savings. The effect on the net income banks make in their funding activities, however, is unambiguously negative. Finally, heterogeneity in the valuation of banks' products by households result in heterogeneity in banks' market power.

Bank lending is constrained by financial frictions, which bank market power helps to mitigate by raising banks' net worth. The loan rate has three components in our model: the bond rate, a mark-up, and a (marginal) asset management cost. The bond rate is the opportunity cost of making a loan. Banks' loans are differentiated products, generating a mark-up. The asset management cost generates a spread, which we assume depends on the total amount of lending as well as the capitalization (equity) of banks. Bank equity is raised from households, who require their stochastic discount factor and an additional premium, pinning down the amount of equity. This premium makes the quantity of equity sub-optimal, which limits loan supply as low capitalization leads to higher asset management costs, higher spreads, and sub-optimal lending. Importantly, market power alleviates these frictions by raising the return on equity.

As a consequence of the decline in interest rates, banks' market power falls, decreasing bank profits, equity, and - through capitalization frictions - loan supply.

This mechanism is not only active for the average bank, but also applies in the cross-section of banks. Banks with higher market power in the model (as generated by higher quality bank products, e.g. better customer services) suffer larger shifts in loan supply, validating our empirical approach. The causal chain in the cross-section follows the same path as for the aggregate effects: a bank with higher initial market power charges a higher spread than its competitor, and hence feels the competition from cash savings faster than its competitors, as nominal rates fall. This generates a relative decrease in profits for the exposed bank, which translates into a larger fall in equity, in order to maintain the desired ROE. This larger decrease also generates a relative increase in credit spreads, and a relative decrease in lending.

We discipline the model using banking data before the low rate environment and limited information on the evolution of aggregate funding spreads into the low rates environment. Importantly, we do not incorporate information regarding aggregate changes in equity, lending, or investment following the low-rates environment, or such changes in the cross-section. Instead, the model predicts these aggregate and cross-sectional results, and we compare them with those in both aggregate data and our empirical analysis.

The frictions generated by low nominal rates generate a significant decrease in equilibrium lending and output. We generate a change in the nominal rate from the early 1990s average rate of 3.5% to the post-2000s low rate environment of 0.2%. Inflation adjusts to keep the real rate constant. Bank market power decreases significantly. We find that the change results in a 4% permanent decrease in equilibrium loans and a 0.5% permanent decrease in steady-state output, with effects of similar magnitude on wages and consumption. Households' cash holdings increases, in line with aggregate Japanese data.

Next, we model reserve tiering as closely as possible to the way it was implemented by the Bank of Japan in 2016 and show that it had a small impact on lending and output. Bank reserves at the BOJ were tiered according to outstanding balances in 2015. Effectively, about 80-90% of reserves earned a 0.15% higher rate than marginal balances. We add reserves to banks' investments and apply these subsidies to infra-marginal units. We find that the effects are small: lending increases by 0.25 percent in the low rate steady state, a small amount relative to the overall 4 percent decrease in lending estimated to have been the result of banks' low profitability.

In a second counterfactual experiment, we show that a cash tax – a decrease in the return on cash savings – significantly undoes some of the negative effects of low nominal rates. We follow the proposal pushed forward by Agarwal and Kimball (2015), where currency is replaced by electronic money as the unit of account, and central banks fix an exchange rate between electronic currency and paper currency, effectively controlling the nominal return on money. We test the impact of setting the nominal return on money to negative 0.1 percent. We find that this policy is effective, increasing lending by 1%. Importantly, since currency at the margin is used as a savings device, the liquidity benefits of cash are small, and therefore the cash tax has limited repercussions for households' savings, despite the general equilibrium effect of the loan supply shift.[5]

Outline. The remainder of the paper is structured as follows. Section 2 summarizes the literature. Section 3 describes the empirical tests of the model, sources of data used, and empirical results. Section 4 presents the model. The key mechanisms at play are described in Section 5. The calibration of the economy in general equilibrium is set out in Section 6. The aggregate impact of this channel on lending, as well as our counterfactual experiments, are described in Section 7. The final section concludes.

2 Related literature

A recent literature has emerged that attemps to understand the effects of very low negative interest rates in the short run. Recent theoretical work by Brunnermeier and Koby (2018) demonstrates the existence of a "reversal rate," i.e. the policy rate below which interest rate cuts are contractionary for lending. The reversal rate depends on banks' capitalization and fixed income holdings as well as the degree of interest rate pass through and capital constraints. They provide a New Keynesian closure to their banking model and quantify the reversal rate in European data. Our paper differ in that capital gains have run out and equity dynamics are different in the long run. Our result relate to the idea that the "long-run reversal rate" is essentially high and positive: in the long-run, high nominal rates and high

[5] Our model features homogeneous, representative households. A cash tax could have heterogeneous effects on households if heterogeneity is taken into account, particularly for households that save exclusively using currency or bank savings – a significant share of the Japanese population.

inflation are preferable environments. Eggertsson et al. (2019) provide a macroeconomic model where as policy rates turns negative the usual transmission mechanism of monetary policy breaks down, and provide support from swedish economic data. Wang (2018) argues in a model with perfect (bank) competition that lower equilibrium real rates dampens the sensitivity of output to monetary policy, and estimates the extent of this dampening for different levels of real rates. Wang calibrates his model to the U.S. data and finds the dampening to be significant. He also shows that a decrease in r^* generate higher lending spreads. Campos (2018) estimates reduced welfare benefits of monetary policy in negative territory, and calibrates a model to European data. In contrast to this strand of the literature, our paper focuses on the long-term effects of low nominal interest rates, exploiting the experience of Japan in which nominal rates have been low for long. We also make contributions in adding bank heterogeneity to our macroeconomic model and using it to quantify the model. Finally, we evaluate the impact of plausible policy interventions, in particular an effective tax on cash savings as proposed by Agarwal and Kimball (2015).

Our paper also relates to recent work on banks' market power on deposits, in particular Drechsler et al. (2016). Similar to our model, in Drechsler et al. (2016) the spread that banks' charge for their liabilities is dependent on the nominal rate due to the presence of currency. The decrease in spreads following a decline in rates generates an inflow of deposits, which support lending. In our model this inflow is present but banks are flush with liabilities: the inflow ends up in banks' bond holdings. Drechsler et al. (2018) show that the dependence of the spreads on the nominal rate creates a risk that banks actively hedge using duration matching. Although Japanese banks hedge in a similar manner as described in Drechsler et al. (2018) prior to the low interest rate period, our findings are consistent with their findings in that permanent changes in interest rates cannot be hedged by banks using capital gains from duration mismatch. The same logic is behind the "creeping-up" result in Brunnermeier and Koby (2018). Our results also relate to the work of Egan et al. (2017a) who show that banks have market power on their liabilities and proceed to estimate it structurally. In their setting banks' are heterogeneous and low individual bank profits generate bank runs that disrupt credit supply. Finally, Egan et al. (2017b) document that the heterogeneity in the quality of the provision of banks savings' products is significant.

They show that the cross-section of bank valuations is driven by differences across banks in technology, customer demographics, and market power on the liabilities side of banks, as opposed to asset productivity.

There is a growing body of empirical work that explores the consequences of low interest rates for banks in Europe and the United States. This includes evidence on the pass through of negative interest rates to prices (Jackson, 2015; Claessens et al., 2017; Bech and Malkhozov, 2016) as well as to bank equity and lending (Ampudia and den Heuvel, 2019; Heider et al., 2018; Gropp et al., 2018; Eggertsson et al., 2019). In contrast, we study the long term consequences of a low interest rate environment that is above zero for most of the period under study. In the long run, the effects are less likely to be ambiguous but face other cross-sectional challenges to identification.

Finally, there is substantial evidence on the evolution of the banking system in Japan since the property bubble burst in 1990. Peek and Rosengren (2005) and Caballero et al. (2008) document banks' zombie lending during the 1990s. Amiti and Weinstein (2018) estimate credit supply shocks using matched bank-firm data in Japan, and argue that bank-specific supply shocks are a significant driver to equilibrium lending in Japan. Our work suggests that some of these credit supply shocks are likely to be related to the low interest rate environment. Ono et al. (2018) present evidence that unanticipated reductions in long-term rates increased bank loan supply between 2002 and 2014. In contrast, our findings take the low interest rate environment as implied by both short and long-term rates, relative to the period before the 2000s.

3 Empirical evidence

In this section we first show that the aggregate spread between banks' interest expense and the risk-free rate decreases with the level of rates, resulting in lower aggregate net interest margins. Banks are heterogeneously exposed to the level of interest rates, and their exposure correlates with the historical liability structure of banks. We then project heterogeneous exposures on other outcomes of interest, such as profits, equity, and lending.

3.1 Data

We use three main sources of data for this project.

At the bank level, our data comes from Nikkei NEEDS Financial Quest, which includes all regulatory filings of all listed commercial banks in Japan. Since not all banks report all variables in all quarters, we rely primarily on fiscal year end reporting in March of each year. Our sample starts in 1975 and ends in 2017. During that period, a significant number of mergers and acquisitions occur, and twelve banks fail. For banks involved in mergers, we calculate pro-forma balance sheets for combined entities throughout our sample. For example, to calculate the historical deposits to liabilities ratio of Mizuho Financial Group, we use the sum of the balance sheets of the Industrial Bank of Japan (IBJ), Dai-Ichi Kangyo Bank, and Fuji Bank, which were merged in 2002. This allows us to trace current performance to historical exposure despite substantial merger activity, and allows us to include more banks. In contrast, the unmerged sample of banks has many banks that do not have a clear historical counterpart, causing us to lose observations, or the historical counterpart may not accurately reflect the current business model due to acquiring other banks. Appendix A.1 contains details regarding the exact procedure we use for mergers, and in Appendix A.5 we show that our results hold even when using the unmerged sample of banks. We exclude the Japan Post Bank, due to lack of data prior 2006, and Shinkin credit cooperatives.

In addition to bank level data we use firm-level reporting of borrowing from specific banks to run loan-level regressions. This data is included in listed firms' regulatory disclosures and is collected by the Development Bank of Japan at an annual frequency. Our sample includes the universe of listed firms, which represents about 15% of total lending throughout our sample period. Firms' disclosures include the quantities of long-term and short-term borrowing from all major financial institutions in Japan, as well as firms' annual financial data.

Finally, we supplement our micro data with aggregate data on banks and macroeconomic variables from the Bank of Japan.

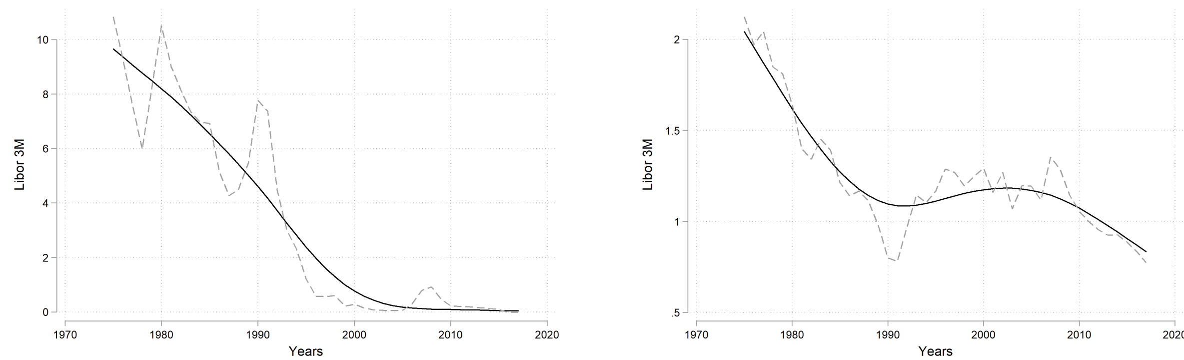
Table 1 shows summary statistics, for the year 2000. There is substantial heterogeneity in bank size within the sample, and banks are very highly dependent on deposits. Loans are

Table 1: Summary statistics (2000)

	Mean	**Median**	**S.D.**
Total assets (tr)	6,055	2,124	17,527
Net Interest Margin	1.85	1.90	0.47
Ordinary Profits / Assets	-0.14	0.21	2.52
Deposits / Liabilities	0.90	0.95	0.14
Loans / Assets	0.70	0.70	0.09
Assets / Equity	29.5	21.7	70.9

Notes: Net interest margin are interest income divided by assets minus interest expense divided by liabilities. Data from Nikkei NEEDS Financial Quest.

Figure 1: Interest rates and bank profitability



(a) Three-month Yen Libor

(b) Bank net interest income per asset

Notes: Panel (a) plots the three-month Yen Libor. Prior to 1986, before the publication of the Libor, we fit the equivalent return on Japanese T-bills. Panel (b) displays aggregate bank net interest income divided by aggregate bank asset for our sample of banks, which excludes Shinkin banks, government banks, and Japan Post Bank. The smoothed line represents the trend component of the respective HP filtered series.

by far the main assets held by banks. Banks are on average highly leveraged.

3.2 Motivating evidence

3.2.1 Aggregate evidence

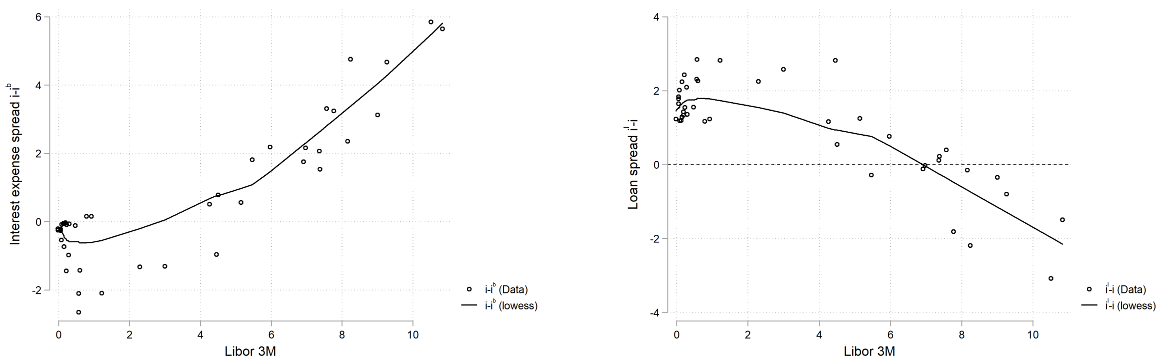
We start by showing that banks' aggregate net interest income per assets has decreased alongside nominal rates over the course of our sample. Figure panel (a) shows that the nominal rates – as measured here by three month Yen Libor – have been on a constant decline from the start of our sample. This decline took a particularly sharp turn in the late nineties following the burst of the real estate bubble, and after that rates essentially stayed close to 0. Figure panel (b) displays banks' total net interest income divided by total assets outstanding. Despite business cycle fluctuations and a decline in the early 1990s related to the real estate crisis, net interest income per asset of Japanese banks has steadily trended down since the mid-1970s.

Next, we show that banks have been unable to fully pass through declines in nominal rates to the rate they pay for their liabilities, while the realized spread between loan rates and nominal rates has steadily increased. Figure 2 panel (a) displays a plot of nominal rates against the aggregate realized interest rate banks pay on their liabilities. As rates fell, banks began paying rates closer to the nominal rate, reducing their margin relative to a risk-free rate investment to close to zero.[6] Importantly, these trends are not driven by business cycle fluctuations, and appear stronger when business cycle components are taken out using an HP filter. Figure 2 panel (b) displays a plot of nominal rates against the aggregate realized spread banks charge on their loans. The low level of nominal rates seem to coincide with a high level of realized loan spreads. As for interest expenses, these trends are not driven by business cycle fluctuations. However, they could reflect secular changes in the provision of credit which coincide with long-run changes in nominal rates. We cannot exclude, for example, that the collapse of the real estate bubble had extremely persistent effects on Japanese banks. For these reasons, in the remainder of our empirical analysis we use variation in the cross-section of banks, to rule out secular trends.[7]

[6]The relevant marginal rate, in our theory, is the risk-free rate, but this empirical fact holds – and is in fact stronger – if rates with higher maturity are used, given the duration of banks' liabilities.

[7]Interest rates in Japan were liberalized over the course of the 1980s. This led banks to charge artificially low interest rates on loans, as reflected by the negative spreads in the lower right portion of Figure 2 panel (b). To compensate, banks sometimes required banks to hold deposits at zero interest. In addition, interest rates on deposits were controlled to provide an implicit subsidy to banks. Through affecting both the numerator and the denominator, this would if anything lead the line in Figure 2 panel (a) to be less steep than would have otherwise been the case. All interest rate controls were lifted by 1992. Our analysis will focus on the period after liberalizations, although our results are robust to using the full sample.

Figure 2: Bank interest rate spreads



(a) Interest expense spread

(b) Loan rate spread

Notes: Panel (a) plots the nominal rate as measure by three month Yen Libor against the spread between the nominal rate and realized aggregate bank interest expense, that is, the ratio of interest expense to total liabilities. Panel (b) plots the nominal rate against the spread between the nominal rate and the aggregate realized bank loan rate, that is, the ratio of interest income from loans to total outstanding loans. The smoothed line is the locally weighted scatterplot smoothing (lowess).

3.2.2 Heterogeneity of exposure

We define bank exposure as bank j's associated parameter β_j estimated from the regression:

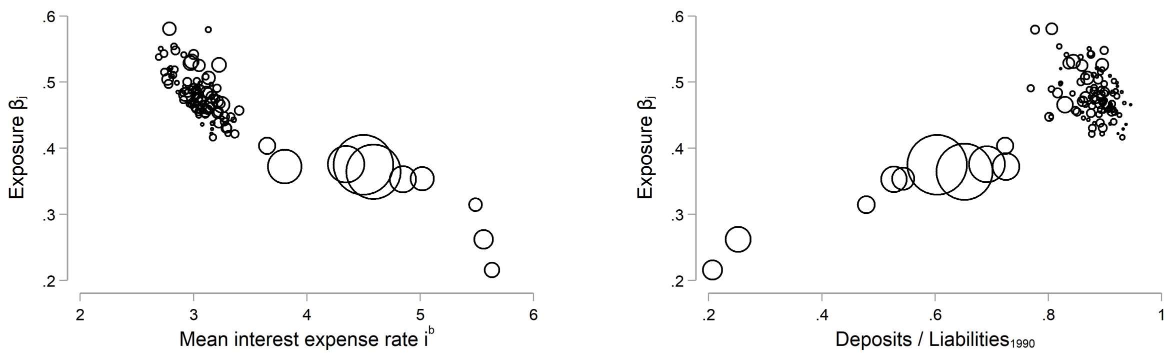
$$i_t - i^b_{jt} = \alpha_j + \beta_j i_t + \varepsilon_{jt}, \tag{1}$$

where i_t is the three month Yen Libor and i^b_{jt} is the realized interest expense of bank j. A large β_j indicates a bank with long-term spreads that are highly dependent on the level of nominal rate, for example because it funds itself with deposits for which it has market power. In contrast, a wholesale funded bank or a money market fund would be expected to have $\beta_j = 0$. Importantly, the interpretation of β_j is different from that of Drechsler et al. (2018), who estimate a similar regression in changes, picking up business cycle frequency fluctuations in both variables. Instead, by running this regression in levels at an annual frequency, we capture the long-run exposure of banks' interest expense spreads to the level of interest rates.[8]

There is significant heterogeneity in the exposure of individual banks to long-run changes

[8] We show that the results of Drechsler et al. (2018) also hold among Japanese banks in Appendix A.3.

Figure 3: Exposure



(a) Rate on interest expenses, 1990 (%)

(b) Exposure

Notes: Panel (a) shows the mean rate of interest expense paid by individual banks over the period prior to persistently low interest rates 1975-2000, against the exposure β_j coefficients estimated from a regression of $i_t - i^b_{jt} = \alpha_j + \beta_j i_t + \varepsilon_{jt}$ run bank by bank, using data since 1975. Panel (b) shows exposure against the deposits to liabilities ratio of individual banks in 1990, which we use in our empirical analysis to predict exposure while alleviating endogeneity concerns. The size of the bubbles indicates bank size in 1990, measured by total assets.

in the aggregate level of interest rates. In our sample, β_j ranges from about 0.2 to 0.6, with a standard deviation of 0.06. A high β_j correlates with large spreads in the high rates environment. Figure 3 panel (a) shows that the variation in β_j is generated by the ability of banks with high β_j to charge large spreads in the high rate environment, which we define broadly as the period 1975-2000.

The heterogeneity we document can be explained by the composition of banks' liabilities, which itself has its sources in historical market segmentation of Japan's banking markets. Historically, different types of banks were restricted to different types of liabilities, and both bank entry and branch expansion were severely limited. This segmentation of markets was a source of market power, leading to persistent differences in D/L as shown in Appendix A.4. Figure 3 panel (b) shows that the deposits-to-liabilities ratio of banks in 1990 strongly correlates with exposure.[9]

[9] This is also true at any point in time between 1975-2000, given its high persistence.

3.3 Regression analysis

3.3.1 Empirical strategy

For the remainder of Section 3 we use the deposits to liabilities ratio of banks in 1990 $\left(\frac{D_{j,1990}}{L_{j,1990}}\right)$ as our main proxy for banks' exposure, and focus on bank performance from 1990 to2017. As argued, the ratio is a good predictor of the interest rate spread banks are able to charge on deposits (i.e. market power) before the low interest rate period. As there were considerable interest rate controls present prior to the 1990s, we use 1990 as our starting point. Not only were banks unable to charge market interest rates on loans, but also common practices such as requiring borrowers to hold compensating balances (i.e. deposits that did not pay interest) also distorts bank income and profitability. In addition, the 1980s were a period of substantial deregulation which we believe to be orthogonal to level of nominal interest rates, but which did affect bank lending.[10]

Our regression specifications test whether banks that are more exposed to long-term changes in nominal rates are differentially affected once Japan enters a low-rate environment. We assess this in regressions of bank outcomes y_{jt} on our measure of bank exposure (the deposits-to-liabilities ratio in 1990), a dummy variable that equals one in the years of the low-rate environment (post), and the interaction of exposure and the post dummy. Our regressions hence take the form:

$$y_{j,t} = \alpha + \beta \,\text{Post}_t + \gamma \frac{D_{j,1990}}{L_{j,1990}} + \delta \,\text{Post}_t \times \frac{D_{j,1990}}{L_{j,1990}} + \text{Controls}_{jt} + \epsilon_{jt}, \tag{2}$$

where we set Post_t equal to 1 for years after 2000. The coefficient of interest δ indicates whether banks that are more exposed have different outcomes in the low rate environment. We add time fixed effects to control for macroeconomic variation, and controls for bank size and non-performing loans. Standard errors are clustered at both the bank and pre/post level, our main sources of variations.

Our data is sufficiently detailed to allow us to decompose these effects into dynamics at an annual frequency. To understand more precisely the timing in which the low rate envi-

[10] For example, see Balloch (2019).

ronment affects banks, we also run dynamic regressions which examine the relative outcomes of exposed banks in each year. These regressions take the form:

$$y_{j,t} = \beta_t + \sum_{s=1990}^{2017} \delta_s \cdot \mathbf{1}_{t=s} \cdot \frac{D_{j,1990}}{L_{j,1990}} + \epsilon_{jt}, \tag{3}$$

where the coefficients of interest $\{\delta_s\}_{s=1990,\ldots,2017}$ are now estimated for each year. This allows us to determine whether changes in outcomes occur gradually or suddenly.

3.3.2 Effect on spreads and net interest margins

Table 2 panel A shows that banks with high deposits-to-liabilities ratios fare less well once Japan enters the low interest rate environment. The estimated coefficient on the interaction term is large and significant, indicating that banks with high deposits to liabilitiess ratio in 1990 are less able to reduce their interest expenses in the low nominal rates period. Column 2 adds year fixed effects, to control for macroeconomic factors. This leaves the coefficients essentially unchanged. Column 3 adds controls for bank size and non-performing loans.

Columns 4 and 5 show the same specifications as columns 2 and 3, using only the sample of regional banks. That these effects hold using only the sample of regional banks is a good robustness check, as these banks are most similar in terms of business model. We are encouraged that within this narrow category of bank types, our main results remain statistically and economically significant.

This result is driven by the fact that they pay lower interest rates on liabilities than banks with lower exposure in the high rates environment. In fact, we both groups essentially pay the same price for their liabilities in the post environment. This is most evident in Figure 4 panel (a), which plots the coefficients δ_t of the dynamic specification (3).

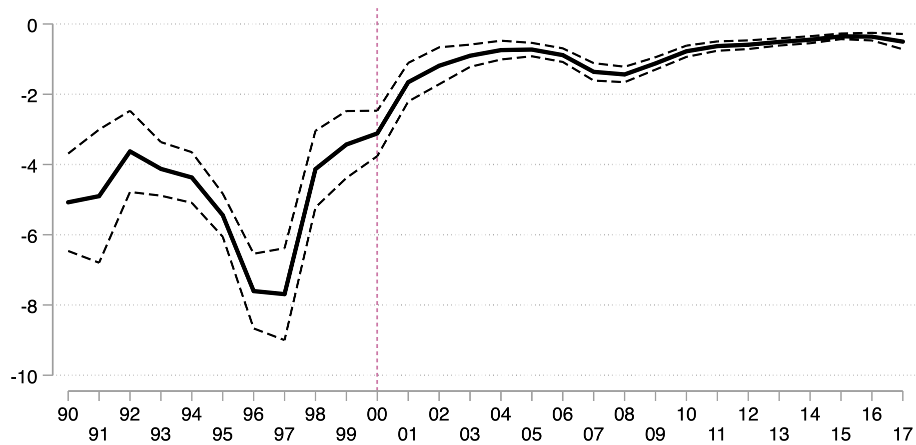
Figure 5 panel (a) provides a visual representation of our baseline result, by plotting the change in the effective interest rate on liabilities against the deposits to liabilities ratio of banks in 1990. This shows that banks with low exposure have reduced their interest expenses significantly, while banks with higher exposure are less capable of reducing their interest expenses. The relationship between the change and exposure appears approximately linear, which supports the implicit linearity assumption in regressions (2) and (3).

Table 2: Interest income and interest expenses

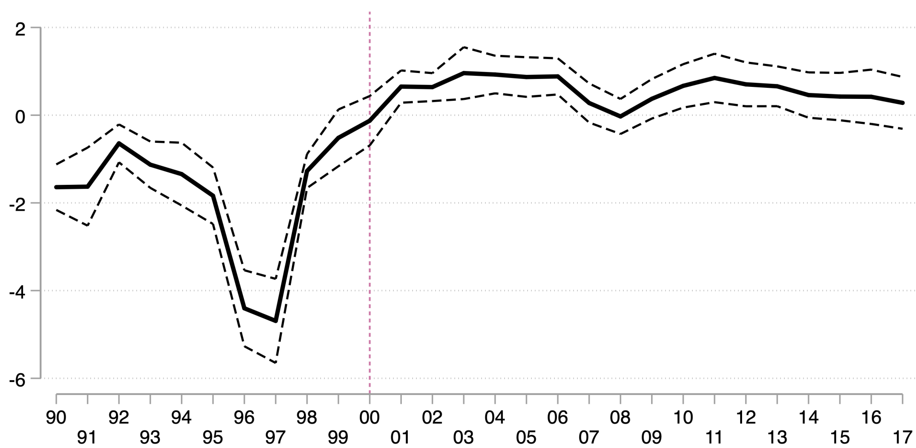
	All banks			Regional banks	
	(1)	(2)	(3)	(4)	(5)
A. Dependent variable: Interest Expense / Liabilities (%)					
Post	-5.61***				
	(0.39)				
D/L 1990	-4.87***	-4.87***	-4.56***	-2.77***	-2.78***
	(0.44)	(0.44)	(0.44)	(0.39)	(0.39)
Post x D/L	4.03***	4.03***	3.97***	2.20***	2.22***
	(0.44)	(0.44)	(0.42)	(0.43)	(0.43)
Constant	6.54***				
	(0.39)				
Observations	3,078	3,078	3,078	2,788	2,788
R-squared	0.60	0.97	0.97	0.99	0.99
B. Dependent variable: Interest Income / Assets (%)					
Post	-4.43***				
	(0.20)				
D/L 1990	-1.75***	-1.75***	-2.54***	-0.85	-0.80
	(0.14)	(0.14)	(0.21)	(0.73)	(0.73)
Post x D/L	2.34***	2.34***	2.41***	0.88	0.63
	(0.24)	(0.24)	(0.25)	(0.95)	(0.92)
Constant	5.60***				
	(0.12)				
Observations	3,078	3,078	3,078	2,788	2,788
R-squared	0.65	0.96	0.96	0.96	0.97
C. Dependent variable: Net Interest Margin (%)					
Post	1.18***				
	(0.42)				
D/L 1990	3.12***	3.12***	2.02***	1.92***	1.97***
	(0.41)	(0.41)	(0.33)	(0.71)	(0.71)
Post x D/L	-1.69***	-1.69***	-1.56***	-1.32	-1.59*
	(0.48)	(0.48)	(0.35)	(0.90)	(0.86)
lConstant	-0.94**				
	(0.36)				
Observations	3,078	3,078	3,078	2,788	2,788
R-squared	0.39	0.60	0.76	0.50	0.54
Controls (all panels):					
Year f.e.s		Y	Y	Y	Y
NPL rate			Y		Y
Bank size			Y		Y

Notes: Regression specification (2), post equals 1 after 2000, and deposits to liabilities ratio is measured in 1990. Standard errors double clustered at the bank and pre/post level. Significance follows * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

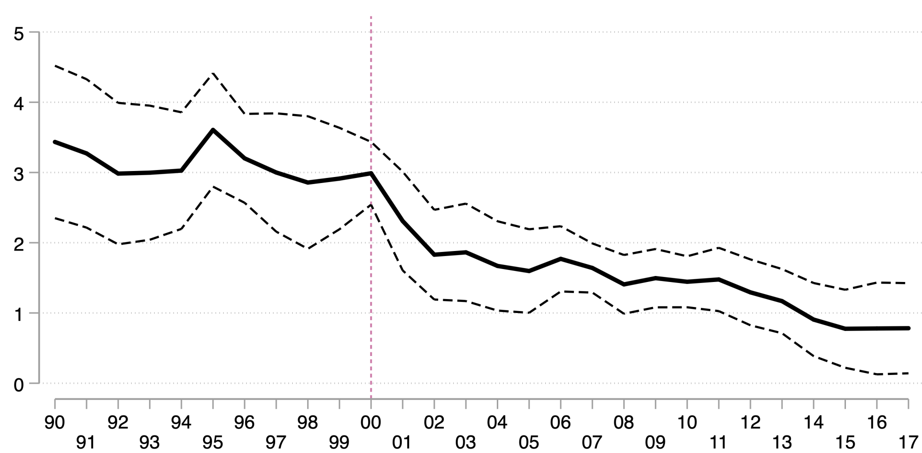
Figure 4: Interest income and interest expense dynamics



(a) Interest Expense / Liabilities



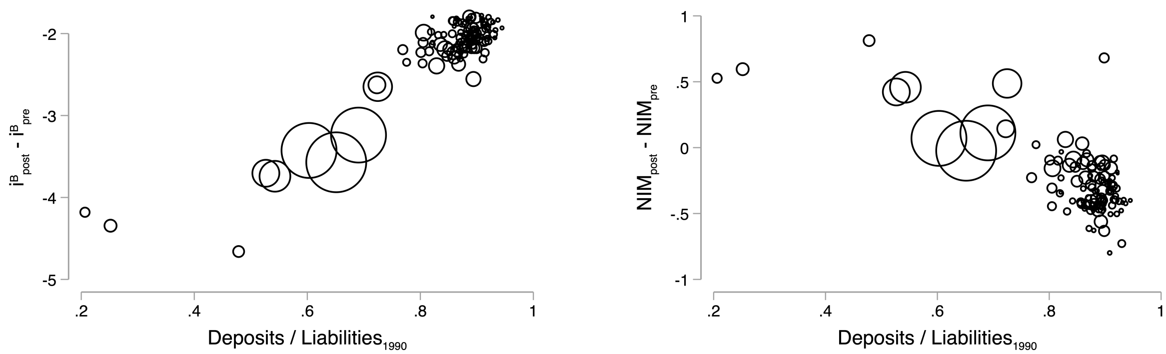
(b) Interest Income / Assets



(c) Net Interest Margin

Notes: Figure shows coefficients δ_t from regression (3), and confidence bands for two-way clustered standard errors (bank, post) at 95 percent levels.

Figure 5: Changes by historical deposit dependence



(a) Δ Interest Expense / Liabilities (b) Δ Net Interest Margin

Notes: The size of the bubbles indicates bank size, measured by total assets.

Next we show that exposed banks do pass through some of their increased interest expenses into rates they charge (or earn) on their assets. Panel B of Table 2 shows the results of regression (2) for interest income. The significant and positive coefficient on the interaction term confirms the relative rise in interest income for exposed banks. Importantly, the size of this change is substantially smaller than the effect of low rates on the pass through of interest expenses: the coefficient on the interaction term is roughly half the size of that in panel A. This contrasts with the results of Drechsler et al. (2018) showing that banks actively hedge their short run interest rate risk. Our results show that in the long run, in a low interest rate environment, this capacity is severely impaired.

It follows from our two previous results that exposed banks' net interest margins must be falling. We define banks' net interest margin is the difference between banks' interest income divided by total assets and interest expenses:

$$\text{NIM}_{j,t} = \frac{\text{Interest income}_{j,t}}{\text{Assets}_{j,t}} - \frac{\text{Interest expenses}_{j,t}}{\text{Liabilities}_{j,t}}$$

Table 2 panel C shows the results of regression (2) with net interest margin as the dependent variable. Figure 5 panel (b) provides a visual representation. In terms of economic magnitudes, the results imply that the net interest margin of the most exposed bank in the sample is 1.7 percentage points lower in the low rate environment, relative to a hypothetical bank without exposure (e.g. a fully wholesale funded bank). As the average bank in the sample in 2000 has a net interest margin of 1.85 percent, this effect is very large. However, the deposits to liabilities ratios of banks in 1990 range from 0.21 to 0.95, so the actual predicted decline for any actual bank is less than the full coefficient predicted in Table 2.

The estimated coefficients of the dynamic regression (3) displayed in Figure 4 panel (c) shows that the effects on net interest margins is gradual and takes almost two decades to fully materialize. Following a decade of stable relative profitability during the 1990s, the relative profitability of exposed banks declines sharply in the early 2000s, and continues to gradually decline, without recovery, until the present. This is an important result, as it suggests that the detrimental effects of negative interest rates may take years before being statistically detectable in financial statements.

3.3.3 Effects on profits and retained earnings

In this section we show that the significant relative decrease in net interest margins of exposed banks is not undone by non-interest sources of income and expenses, such as an increase in fees or a decrease in costs. If banks were able to increase non-interest income or dramatically reduce costs, then the decline in net interest income would not affect net income, retained earnings, or equity. We conclusively rule this out in the Japanese case.

Table 3 shows that the relative decline in exposed banks' profitability remains statistically and economically significant across multiple definitions of profitability. Panel (a) displays the results for net interest income over assets. In the post environment, exposed banks' annual net interest income per asset declines by 1.5-1.6 percentage points. Panel (b) shows that this remains true for net ordinary income per asset, which is inclusive of non-interest income such as fees or trading income as well as expenses such as costs or provision for loan losses. The results consistent across all samples and specifications: exposure predicts strong effects on net ordinary income. Finally, Panel (c) displays the results inclusive of extraordinary income, which includes write-offs. All in all, exposed banks' lower net interest income is not compensated by other income items, decreasing relative net income.

Table 4 provides additional results for specific income statement line items that are commonly cited as helping banks cope with a low interest rate environment: fees, costs and

Table 3: Effects on Net profitability

	All banks			Regional banks	
	(1)	(2)	(3)	(4)	(5)
A. Dependent variable: Net Interest Income over Assets (%)					
Post	1.04***				
	(0.39)				
D/L 1990	2.97***	2.97***	1.90***	1.92***	1.97***
	(0.38)	(0.38)	(0.30)	(0.69)	(0.69)
Post x D/L	-1.62***	-1.62***	-1.49***	-1.35	-1.61*
	(0.45)	(0.45)	(0.32)	(0.88)	(0.84)
Constant	-0.73**				
	(0.33)				
Observations	3,078	3,078	3,078	2,788	2,788
R-squared	0.42	0.61	0.76	0.54	0.57
B. Dependent variable: Net Ordinary Income over Assets (%)					
Post	2.55***				
	(0.54)				
D/L 1990	2.45***	2.45***	2.60***	4.05*	3.95*
	(0.60)	(0.61)	(0.75)	(2.07)	(2.12)
Post x D/L	-2.91***	-2.91***	-2.59***	-4.41**	-3.95*
	(0.61)	(0.61)	(0.72)	(2.15)	(2.26)
Constant	-1.94***				
	(0.53)				
Observations	3,078	3,078	3,078	2,788	2,788
R-squared	0.05	0.15	0.17	0.13	0.16
C. Dependent variable: Net Income over Assets (%)					
Post	1.58***				
	(0.28)				
D/L 1990	1.33***	1.33***	1.28***	4.32**	4.20*
	(0.29)	(0.29)	(0.41)	(2.08)	(2.14)
Post x D/L	-1.81***	-1.81***	-1.35***	-4.03*	-3.49
	(0.30)	(0.30)	(0.42)	(2.32)	(2.45)
Constant	-0.97***				
	(0.27)				
Observations	3,078	3,078	3,078	2,788	2,788
R-squared	0.02	0.13	0.16	0.11	0.15
Controls (all panels):					
Year f.e.s		Y	Y	Y	Y
NPL rate			Y		Y
Bank size			Y		Y

Notes: Regression specification (2), post e quals 1 after 2000, and deposits to liabilities ratio is measured in 1990. Standard errors double clustered at the bank and pre/post level. Net income in panel C includes extraordinary income. Significance follows * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Other income and expenses

	All banks			Regional banks	
	(1)	(2)	(3)	(4)	(5)
A. Dependent variable: Fees / Assets					
Post	-0.07				
	(0.56)				
D/L 1990	-0.76	-0.76	-0.72	-0.25	-0.25
	(0.51)	(0.51)	(0.55)	(0.17)	(0.17)
Post x D/L	0.17	0.17	0.20	-0.23	-0.22
	(0.63)	(0.63)	(0.62)	(0.22)	(0.22)
Constant	0.86*				
	(0.45)				
Observations	3,078	3,078	3,078	2,788	2,788
R-squared	0.19	0.22	0.23	0.42	0.42
B. Dependent variable: General and administrative expenses / Assets					
Post	0.51**				
	(0.22)				
D/L 1990	1.75***	1.75***	0.62***	1.55**	1.59***
	(0.16)	(0.16)	(0.21)	(0.60)	(0.61)
Post x D/L	-0.90***	-0.90***	-0.71***	-0.03	-0.24
	(0.25)	(0.25)	(0.26)	(0.76)	(0.74)
Constant	-0.08				
	(0.14)				
Observations	3,078	3,078	3,078	2,788	2,788
R-squared	0.37	0.49	0.82	0.45	0.48
Controls (all panels):					
Year f.e.s		Y	Y	Y	Y
NPL rate			Y		Y
Bank size			Y		Y

Notes: Regression specification (2), post equals 1 after 2000, and deposits to liabilities ratio is measured in 1990. Standard errors double clustered at the bank and pre/post level. Significance follows * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

branches.

At least to date, exposed banks have been unable to compensate for their relatively higher interest expenses by charging higher fees. Table 4 panel (a) shows the response of fees, exclusive of trading income.Across our main specifications, the response of fees is insignificant. Within the sample of regional banks, the banks most able to increase fee income banks with low exposure, which further worsens the relative position of exposed banks.

Exposed banks decrease their costs in response to their higher interest expenses, and (weaker) evidence suggests that they also decrease investment into their branches, albeit insufficiently to overturn net interest income losses. Panel (b) displays the response of general and administrative expense per asset, which shows a statistically and economically significant reduction in G&A expenditures, suggesting that banks might actively manage their investments into acquiring consumers and providing valuable services. The response, however, is only about a third of the loss in net ordinary income over assets, and hence is unable to overturn the decline in net interest income.

3.3.4 Effects on equity

We evaluate to what extent banks' equity (i.e. capitalization) decreases following the decline in profitability due to the low interest rate environment. As banks' net income decreases, so does retained earnings. Given the documented relative decline described above, we expect bank equity to be affected unless banks can reduce dividend payments or increase equity issuance.[11] In the data, book equity is given by the following accounting identity:

$$\text{Equity}_{j,t+1} = \text{Net profits}_{jt} - \text{Dividends}_{jt} + \text{Equity}_{jt} + \text{Equity Issuance}_{j}.$$

Having shown a decline in net profits, we can examine whether dividends and/or equity issuance have changed by enough to prevent a decline in equity.

Panel A of Table 5 shows that exposed banks' dividend payments per asset declined relative to banks with low exposure, after 2000. Banks with high deposits to liabilities ratios

[11] Cross-sectional identification is particularly important here, as the implementation of Basel regulations and the collapse of asset prices during our sample period makes aggregate trends in bank capitalization uninformative for our purposes.

Table 5: Bank equity (%)

	All banks			Regional banks	
	(1)	(2)	(3)	(4)	(5)
A. Dependent variable: Dividend payments / Assets					
Post	0.17***				
	(0.02)				
D/L 1990	-0.01*	-0.01	0.04	0.01	0.02
	(0.00)	(0.01)	(0.02)	(0.01)	(0.01)
Post x D/L	-0.17***	-0.17***	-0.18***	-0.21***	-0.21***
	(0.02)	(0.05)	(0.05)	(0.04)	(0.04)
Constant	0.03***				
	(0.00)				
Observations	3,078	3,078	3,078	2,782	2,782
R-squared	0.17	0.19	0.21	0.13	0.13
B. Dependent variable: Equity issuance / Assets					
Post	-0.26				
	(0.18)				
D/L 1990	-0.13	-0.13	-0.07	-0.28*	-0.33*
	(0.09)	(0.16)	(0.14)	(0.16)	(0.17)
Post x D/L	0.26	0.26	0.16	0.30	0.22
	(0.20)	(0.26)	(0.26)	(0.21)	(0.21)
Constant	0.18**				
	(0.08)				
Observations	3,078	3,078	3,078	2,782	2,782
R-squared	0.01	0.05	0.07	0.08	0.09
C. Dependent variable: Δ Equity / Assets					
Post	0.76**				
	(0.38)				
D/L 1990	0.62*	0.62***	0.77***	2.83*	3.04
	(0.32)	(0.07)	(0.14)	(1.64)	(1.83)
Post x D/L	-0.91**	-0.90***	-0.87***	-2.32***	-2.16***
	(0.43)	(0.05)	(0.01)	(0.70)	(0.61)
Constant	-0.35				
	(0.28)				
Observations	3,078	3,078	3,078	2,782	2,782
R-squared	0.00	0.14	0.14	0.15	0.15
Controls (all panels):					
Year f.e.s		Y	Y	Y	Y
NPL rate			Y		Y
Bank size			Y		Y

Notes: Regression specification (2), post equals 1 after 2000, and deposits to liabilities ratio is measured in 1990. Standard errors double clustered at the bank and pre/post level. Significance follows * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

decrease their dividend payments in relative terms, compensating part of their decrease in net earnings. The magnitude of the effect, however, is quantitatively small relative to the losses in retained earnings that exposed banks face.

Panel B of Table 5 shows that banks do not raise additional equity. This is an important result consistent with our theoretical analysis, where banks' lower net profits leads to lower capitalization, allowing banks to maintain a high return on equity despite being less profitable. This lack of capital issuance is likely a specificity of the long horizon of our analysis: at short horizons and for temporary changes in interest rates, banks would have incentives to issue capital in order to take on risk.[12]

Panel C in Table 5 directly computes the change in equity per asset and confirms that banks with high deposits to liabilities ratios' equity declines relative to banks with low deposits to liabilities ratios after 2000. The coefficients on the interaction term are negative and statistically significant in all specifications, and are particularly strong for regional banks, reflecting the higher net income loss coefficients of Table 3.

3.3.5 Effects on lending

We run regressions (2) and (3) at the bank level using lending outcomes, and also conduct regressions at the loan-level to rule out the possibility that our results are driven by demand. Because low interest rates can also be expected to stimulate (in a saving glut) or mitigate (secular stagnation) loan demand, aggregate identification is not possible. Our cross-sectional regressions allows us to make progress. The main threat to identification in this setting is that the macroeconomic environment weighs particularly heavily on banks that have high deposit to liabilities ratios because of how the low rate environment affects these banks' borrowers. This could be the case if borrowers were sorted across bank types and demand fell disproportionately from the borrowers of high D/L banks – for example secular trends in urbanization. We can rule this concern out using loan-level data and firm-year fixed effects to control for demand.

As an initial estimate, Table 6 shows the results of our bank level regression (2) for loan

[12]Models with financial frictions typically assume capital issuance frictions in the short term to maintain a role for the lack of profitability (e.g. Brunnermeier and Koby (2018).

Table 6: Bank lending difference-in-difference results

	All banks			Regional banks	
	(1)	(2)	(3)	(4)	(5)
A. Dependent variable: Δ Loans / Assets					
Post	2.76***				
	(0.73)				
D/L 1990	5.93***	5.93***	4.69***	11.43***	11.16***
	(0.50)	(0.51)	(0.66)	(2.03)	(2.07)
Post x D/L	-4.47***	-4.46***	-2.97***	-14.58***	-13.26***
	(0.85)	(0.85)	(0.89)	(3.18)	(3.28)
Constant	-2.99***				
	(0.42)				
Observations	3,078	3,078	3,078	2,788	2,788
R-squared	0.06	0.39	0.41	0.42	0.44
B. Dependent variable: Interest on loans / Loans					
Post	-3.16***				
	(0.28)				
D/L 1990	-0.07	-0.07	-1.17***	-0.60	-0.53
	(0.15)	(0.15)	(0.26)	(0.86)	(0.87)
Post x D/L	0.78**	0.78**	0.84***	0.83	0.48
	(0.32)	(0.33)	(0.32)	(1.16)	(1.12)
Constant	4.55***				
	(0.12)				
Observations	3,078	3,078	3,078	2,788	2,788
R-squared	0.53	0.95	0.97	0.96	0.96
Controls (all panels):					
Year f.e.s		Y	Y	Y	Y
NPL rate			Y		Y
Bank size			Y		Y

Notes: Regression specification (2), post equals 1 after 2000, and deposits to liabilities ratio is measured in 1990. Δ Loans / Assets is winsorized at the 1 percent level (top and bottom). Standard errors double clustered at the bank and pre/post level. Significance follows * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

growth. Panel A measures growth as loans in time t less loans in $t-1$, divided by bank assets in time t. The results in column (1) imply that loan growth recovered in the 2000s for banks with low deposits to liabilities ratios, while for banks with high deposits to liabilities ratios lending was higher in the 1990s and subsequently declined.

Panel B of Table 6 shows that this is also associated with an increase in loan spreads for banks with high deposit to liabilities ratios after 2000, relative to banks with lower deposits to liabilities in 1990. This increase in loan spreads is consistent with differential rates of loan growth among banks, and suggests that the demand for loans is elastic at the bank level, as in our theoretical model. Importantly, these cross-sectional results are on loan rates are consistent with the aggregate behavior of loan rates documented in Figure 2 panel (a), suggesting that in response to lower bank profitability the spread between bank loan rates and nominal rates increases.

However, the elasticities of lending to equity implied by the coefficients in Tables 5 and 6 are high. This raises questions about the plausibility of our identification assumptions, and whether the full fall in loan growth should be attributed to the effect of the low interest rate environment on equity, or to other factors. Our model provides, through its structure, a partial answer to this question. Empirically, we provide additional results that exploit matched bank-firm loan-level data, which allows us to control for demand.

We find consistent results when projecting exposure to low rates on lending outcomes at the firm level. Our loan level regressions follow the specification:

$$\Delta \log \ell_{ij,t} = \gamma \frac{D_{j,1990}}{L_{j,1990}} + \delta_f \, Post \times \frac{D_{j,1990}}{L_{j,1990}} + \eta_{i,t} + \varepsilon_{ij,t} \tag{4}$$

where $\ell_{ij,t}$ is the loan volume from bank j to firm i in year t, at $\eta_{i,t}$ is a firm-year fixed effect. The coefficient δ_f tests whether firms borrow less from exposed banks, relative to how much they borrow from other banks, post-2000.

These results of regression 4 are shown in Table 7. These tests control for demand by including firm-year fixed effects. These fixed effects absorb variation in lending that is due to firm-specific demand. We still find a persistent effect on exposed banks. Interestingly, the effects grow stronger as we include firm-year fixed effects, suggesting that if anything trends in firm demand benefit exposed banks.

Table 7: Loan-level results (1990-2010)

Sample: 1990-2010	(1)	(2)	(3)
D/L 1990	0.113***	0.119***	0.151***
	(0.006)	(0.017)	(0.021)
Post x D/L	-0.051***	-0.079**	-0.085*
	(0.012)	(0.039)	(0.044)
Firm fixed effects	Y		
Year fixed effects	Y		
Firm-year fixed effects		Y	Y
Bank controls$_{j,t}$			Y
Observations	208,387	208,387	187,835
R-squared	0.04	0.23	0.25

Note: Bank controls include non-interest income, extraordinary income, non-performing loans, and changes to equity due to mergers, acquisitions, and recapitalizations. Robust standard errors. Significance follows * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4 Model

We now present a macroeconomic model with heterogeneous banks that can rationalize the empirical findings presented in Section 3. We use the model to assess the aggregate impact of low nominal rates on bank lending and conduct counterfactual policy analysis.

Time is discrete, infinite, and indexed by t. The model is deterministic. The economy is populated by three types of agents: households, firms, and banks. We first describe these agents and the markets they interact in, and then describe the equilibrium.

4.1 Households

A unit continuum of identical households choose consumption and assets, to maximize their lifetime utility over consumption, which takes the usual form:

$$U_0 = \sum_{t=0}^{\infty} \beta^t u(c_t),$$

where β is the discount factor of households, and c_t is consumption.

Households can save using three asset classes: bonds, bank savings products, and public liquidity (money). We denote by q_t the real price of a bond g that delivers one unit of consumption good in $t+1$. Bond prices reflect real interest rates, i.e. $q_t = \frac{1}{1+r_t} = \frac{1+\pi_t}{1+i_t}$, where r_t is the real rate, i_t is the nominal rate, and π_t is inflation, all between time t and $t+1$. Let $j \in \mathcal{J}$ index bank saving product b_j and $\mathcal{J}$ the set of such products available to households. We denote the price of such a bank product q_{jt}. The price of public liquidity m_t is denoted by q_{mt}. Finally, each household supply one unit of labour inelastically at wage w_t. Given initial savings s_t and transfers T_t, households' budget constraint then reads:

$$w_t + s_t + T_t = c_t + q_t g_t + q_{mt} m_t + \sum_j q_{jt} b_{jt}$$

Next we specify next-period savings s_{t+1} as a function of $g_t, m_t, \{b_{jt}\}_{j \in \mathcal{J}}$. We seek to obtain a simple, parsimonious portfolio choice that reflects the fact that these products offer different non-monetary returns to households. We start by assuming that the savings products offered by banks are differentiated products of heterogeneous quality α_j. These products aggregate into an aggregate bank saving good b_t given by:

$$b_t = N^{-\frac{1}{\varepsilon-1}} \left(\sum_j \alpha_j b_{jt}^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

where ε is the elasticity of substitution across banks and N is the number of banks. When $\varepsilon < \infty$, banks' products are imperfect substitutes in forming the aggregate bank saving good.[13] This CES aggregator can be micro-founded by having a continuum of household members solve a discrete choice problem where each member chooses a bank, given that it wants to invest an amount b_t.

Next we assume in a similar fashion that public liquidity holdings m_t and the bank holding aggregator b_t provide imperfectly substituable services, which yield a liquid savings aggregate $\mathcal{L}_t$:

$$\mathcal{L}_t = 2^{-\frac{1}{\eta-1}} \left(\alpha_b b_t^{\frac{\eta-1}{\eta}} + \alpha_m m_t^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}}$$

[13] Note that if all banks are the same, i.e. $\alpha_j = 1$ for all j, and $b_{jt} = \bar{b}/N$ then $b_t = \bar{b}$.

where η is the elasticity of substitution between bank deposits and money, and α_b, α_m measures the respective quality of bank savings and public liquidity services. Without loss of generality, we normalize $\alpha_b = 1$.

Total household savings is the sum of proceeds from government bonds and a function of liquid savings $\Phi(\mathcal{L}_t)$. The function captures in reduced form the fact that liquid savings provide extra returns by mitigating transactions costs. These extra returns are modelled in units of consumption goods, and are decreasing at the margin with the quantity of liquid savings.[14] That is, we assume that $\Phi(\cdot)$ is increasing and concave, so that marginal benefits of liquidity services are decreasing in the quantity of liquid savings. Summarizing, total household savings available at the beginning of $t+1$ are:

$$s_{t+1} = g_t + \Phi(\mathcal{L}_t) . \tag{5}$$

4.1.1 Solving households' portfolio allocations

We now solve the consumption-saving problem of the households and state the optimal portfolio allocations.

We start with government bonds. Since government bond holdings g_t enters the expression for next-period savings s_{t+1} linearly, a standard Euler equation holds:

$$u'(c_t) = \beta \left(\frac{1}{q_t} u'(c_{t+1}) \right)$$

The (net) holdings of bonds are then given by the household budget constraint.

The price index of liquid savings $q_{\mathcal{L}_t}$ takes a standard CES price index form:

$$q_{\mathcal{L}_t} = \left(\frac{q_{bt}^{1-\eta} + \alpha_m^{\eta} q_{mt}^{1-\eta}}{2} \right)^{1/(1-\eta)}$$

Where q_{bt} is itself a price index that aggregates prices from the banks' differentiated savings

[14] Another common approach is to model these benefits in the utility function.

products:

$$q_{bt} = \left(\frac{1}{N} \sum_j \alpha_j^{\varepsilon} q_{jt}^{1-\varepsilon} \right)^{1/(1-\varepsilon)}$$

Then first order conditions implies that the quantity of liquid assets holdings only depends on its price relative to that of bonds:[15]

$$\Phi' \left(\mathcal{L}_t \right) = \frac{q_{\mathcal{L}_t}}{q_t}$$

From there we can now derive the quantities of cash savings:

$$m_{jt} = \alpha_m^{\eta} q_{mt}^{-\eta} q_{\mathcal{L}_t}^{\eta} \frac{\mathcal{L}_t}{2}$$

Similarly we can obtain the quantity saved in bank savings:

$$b_t = q_{bt}^{-\eta} q_{\mathcal{L}_t}^{\eta} \frac{\mathcal{L}_t}{2}$$

From there we can finally derive the quantity of savings supplied to an individual bank j, as a function of prices:

$$b_{jt} = \alpha_j^{\varepsilon} q_{jt}^{-\varepsilon} q_{bt}^{\varepsilon} \frac{b_t}{N} \tag{6}$$

This expression is taken as given by banks when setting their prices.

4.2 Firms

A continuum of identical firms use labor n_t and capital k_t, and produces output to sell on a competitive market:

$$y_t = A_t \left(k_t^{\alpha} n_t^{1-\alpha} \right)^{\nu},$$

where α is the capital share, and $\nu < 1$ indicates decreasing returns to scale. Labor is paid wage w_t.

Firms live for two periods. First, they borrow their capital and install it. Next, they produce, repay what they borrowed, sell their capital, and close.

[15] This property is particularly useful when computing the elasticity of demand for bank deposits.

Two types of capital are required in production: pledgeable and non-pledgeable, which form k_t according to a Cobb-Douglas function with pledgeable share ρ:

$$k_t = k_{P,t}^{\rho} k_{NP,t}^{1-\rho}$$

Pledgeable capital is borrowed directly from households, at rate r_{t-1}, i.e. the interest rate between $t-1$ and t.[16] Non-pledgeable capital is financed using bank loans, which are differentiated products sold by banks, similar to bank liabilities:

$$\ell_t = \left(N^{-1/\varepsilon^{\ell}} \sum_j \ell_{jt}^{\frac{\varepsilon^{\ell}-1}{\varepsilon^{\ell}}} \right)^{\frac{\varepsilon^{\ell}}{\varepsilon^{\ell}-1}}$$

where ε^{ℓ} is the elasticity of substitution between loans, and each loan ℓ_{jt} offered by bank j has the (real) rate $r_{j,t-1}$. Both types of capital depreciate at rate δ.

The problem of the firm therefore is to choose both capital types, labor, and loans to maximize profits, which are given by:

$$p_t y_t + (1-\delta)(k_{P,t} + k_{NP,t}) - w_t n_t - (1 + r_{t-1})k_{P,t} - \sum_j (1 + r_{j,t-1})\ell_{jt}$$

where p_t is the price of output, and firms' non-pledgeable capital is subject to the constraint:

$$k_{NP,t} \leq \ell_t,$$

which binds in equilibrium.

4.3 Banks

Each bank invests in loans ℓ_{jt} and government bonds g_{jt}, funded by households' bank savings b_{jt} and equity e_{jt}. The balance sheet identity of the banks is given by:

$$\ell_{jt} + g_{jt} = b_{jt} + e_{jt}, \tag{7}$$

and shown graphically in Table 8.

Banks provide differentiated savings instruments and set the interest rate on their liabilities, taking households' savings supply as given in equation (6). The quality of banks' services is heterogeneous and given by α_j, which alters the appeal of investing at a particular bank.[17] Banks may therefore pay different interest rates on their liabilities. These liabilities are a composite of both deposits and wholesale funds. Similarly, loan products are differentiated. For both liabilities and loans, banks set prices taking demand for loans and households' savings supply as given. Banks take the return on bonds i_t as given.

For a given amount of equity e_{jt}, banks' set the interest rates of loans and liabilities, and choose a quantity of bonds to maximize the net return in each period:

$$\max_{i^{\ell}_{jt}, i^{b}_{jt}, g_{jt}} (1 + i^{\ell}_{jt})\ell_j(i^{\ell}_{jt}, \cdot) + (1 + i_t)g_{jt} - (1 + i^{b}_{jt})b_j(i^{b}_{jt}, \cdot) - c_j(\ell_j(i^{\ell}_{jt}, \cdot), e_{jt})$$

where $c_j(\ell_j(i^{\ell}_{jt}, \cdot), e_{jt})$ is banks' asset management cost, a friction that affects intermediation that is increasing in ℓ and decreasing in e. This captures operating costs that increase with the size of a bank's loan portfolio, but decrease with banks' equity. As a consequence, bank

[16] The rental price is determined by the discount factor of the households, which in steady-state equals $q_t = \frac{1}{1+r_t}$.

[17] We take this as exogenous, but it can also be endogenized as the result of a problem in which banks invest in building their deposit franchise, but have different investment technology.

Table 8: Balance sheet

Assets		Liabilities	
ℓ_{jt}	Loans	Bank Funding	b_{jt}
g_{jt}	Government Bonds	Equity	e_{jt}

equity is important for loan supply. Deposit supply $b_j(i^b_{jt}, \cdot)$ and loan demand $\ell_j(i^\ell_{jt}, \cdot)$ are derived from the household and firm problems described above, respectively.

The balance sheet constraint (7) can be used to solve out g_{jt}. The lending and the funding problems of banks are separable. At the margin, the return on both loans and deposits must equal that of a government bond (an opportunity cost):

$$\underbrace{\max_{i^\ell_{jt}} (i^\ell_{jt} - i_t) l(i^\ell_{jt}, \cdot) - c_j(\ell_{jt}, e_{jt})}_{\text{Lending profits: } \Pi^\ell_{jt+1}} + \underbrace{\max_{i^b_{jt}} (i_t - i^b_{jt}) b_j(i^b_{jt}, \cdot)}_{\text{Funding profits: } \Pi^b_{jt+1}} + (1 + i_t) e_{jt}. \tag{8}$$

and where total profits at $t+1$ in nominal terms are the sum of profits from the lending side and the funding side:

$$\Pi_{jt+1} = i_t e_{jt} + \Pi^\ell_{jt+1} + \Pi^b_{jt+1} \tag{9}$$

Focusing on the lending problem first, we obtain that:

$$1 + i^\ell_{jt} = \underbrace{\frac{\varepsilon_{jt}}{\varepsilon_{jt} - 1}}_{\text{Mark-up}} \left(1 + i_t + \underbrace{c^\ell_j(\ell_{jt}, e_{jt})}_{\text{Asset management costs}} \right)$$

Where the elasticity ε_{jt} is the semi-elasticity of loan demand. The costs $c^\ell_j(\ell_{jt}, e_{jt})$ are decreasing in e_{jt}, making the capitalization of the banks important for loan supply.

From the funding problem, we obtain:

$$1 + i^b_{jt} = \frac{\varepsilon^b_{jt}}{\varepsilon^b_{jt} + 1}(1 + i_t)$$

Where the elasticity is derived from the households' problem and takes the following form:

$$\varepsilon^b_{jt} = (1 - \omega^m_{jt})\varepsilon + \omega^b_{jt}\omega^m_t \eta + \omega^b_{jt}(1 - \omega^m_t)(1 + \varepsilon^{\mathcal{L}}_{q_{\mathcal{L}},t})$$

Where ω^b_{jt} is bank j's market share in the funding market, ω^m_t is the share that households save in cash, and $\varepsilon^{\mathcal{L}}_{q_{\mathcal{L}},t} = \left| \frac{\partial \log \mathcal{L}_t}{\partial \log q_{\mathcal{L},t}} \right|$ is the elasticity of liquid savings with respect to its price.

It is immediate to see that as long as $(\varepsilon - 1) > (\eta - 1)\omega_t^m$, banks with a higher local market share ω_{jt}^b will face a lower elasticity of funding supply and hence larger market power. Banks with higher α_j have higher local market share, and hence larger market power. All types of banks' face decreased market power when ω_t^m rises. However, this is stronger for banks with higher market shares. These forces will be central to replicating our diff-in-diff results.

Finally, banks raise equity directly from households. We assume that bank equity has similar properties as government bonds from the households' perspective, and hence should yield the same return to them by arbitrage. We posit that a friction prevents them from obtaining the full return on banks' profits, so that the return on equity that banks must offer is the risk-free rate plus an additional (real) spread ϱ_E.[18] Hence we have:

$$1 + r_t + \varrho_E = \frac{\Pi_{jt+1} + e_{jt}}{(1 + \pi_t)e_{jt}}$$

where π_t is inflation between period t and $t + 1$. This simplifies to:

$$e_{jt} = \frac{\Pi_{jt+1}}{(1 + \pi_t)\varrho_E}$$

thus determining equity.

4.4 Closure and Equilibrium

Supply of cash and bonds. We assume that the demand for cash pins down the quantity of cash, which is elastically supplied by the government and backed by taxes. We could equivalently assume that a central bank invests cash against bonds, and rebates the proceeds to the government. Similarly, we assume that the government elastically supplies bonds to match banks' demand. The demand for bonds by the households is not pinned down, due to Ricardian equivalence.

Nominal rates and inflation. The path of nominal rates $\{i_t\}_{t=0,1,..}$ is exogenously chosen by the central bank and taken as given by all other agents of the economy. Given these rates,

[18] There is extensive empirical evidence that bank managers target a fixed return on equity above the risk-free rate (see, for example Begenau and Stafford (2019)).

inflation adjusts so that the real rate stays constant. This pins down the price of cash.

Equilibrium. An equilibrium is a set of (a) household decisions rules: portfolio choices for cash, bank savings, bonds, and bank equity; consumption demand; capital supply; (b) firm decision rules: labor demand; capital demand; loan demand; output supply; (c) bank decisions rules: prices of loans and bank savings; demand for bonds; demand for bank equity; (d) government decisions rules: supply of cash and bonds, (e) prices: prices of bonds, cash (inflation); wages; bank equity return; such that (1) households optimize; (2) firms optimize; (3) banks optimize; (4) all markets clear.

5 Determinants of bank loan supply

In this section we characterize the long-term implications of changes in the nominal rates for the economy presented in Section 4. To do this, we compare steady-states for different values of the nominal rate i. We first present aggregate implications and then follow with cross-sectional results that map closely to the empirical results of Section 3. We drop t indices as we discuss steady-state values.

5.1 Aggregate implications

To understand the aggregate implications of a decline in nominal interest rates, we begin by studying a symmetric case, in which all banks are identical. In the symmetric case, each bank has an identical share of households' deposits, and what determines this elasticity is households' propensity to substitute into cash or bonds.

We obtain five formal results.

First, lower nominal rates decrease banks' profitability due to the presence of public liquidity. The inflation decrease caused by the decrease in i makes money more attractive as a saving product. This creates more competition for the banks, who see their revenues decrease. Proposition 1 formally states the result.

Proposition 1 (Funding profits.). *Following a decrease in the nominal rate i, real funding profits $\frac{\Pi^b}{1+\pi}$ decline:*

$$\frac{d\frac{\Pi^b}{1+\pi}}{di} > 0$$

The proof is provided in Appendix B.1 and relies on the envelope theorem. The intuition is straightforward: a decrease in i, from the point of view of banks, has as only effect to decrease the price of public liquidity, an increase in competition that decreases banks' profits.

Next we show in Proposition 2 that part of the profitability losses materializes in higher costs of funding. This occurs under the natural assumption that the elasticity of substitution between the two forms of liquidity in the model – currency and deposits – is larger than the elasticity of substitution between household liquid assets and bonds, part of the profitability losses materializes in higher costs of funding. This assumption holds in our calibration, and hence allows us to rationalize why banks have not pass-through in the long-run some of the decreases in nominal rates into deposit rates.

Proposition 2 (Long-run pass-through.). *Define $\varepsilon^{\mathcal{L}}_{q_{\mathcal{L}}} = \left|\frac{\partial \log \mathcal{L}}{\partial \log q_{\mathcal{L}}}\right|$ to be the elasticity of aggregated liquid savings with respect its price.*

If the elasticity of substitution between cash and bank savings η is larger than one plus that elasticity:

$$\eta > 1 + \varepsilon^{\mathcal{L}}_{q_{\mathcal{L}}}$$

Then the pass-through of a change in i to interest expense rates i^b is incomplete:

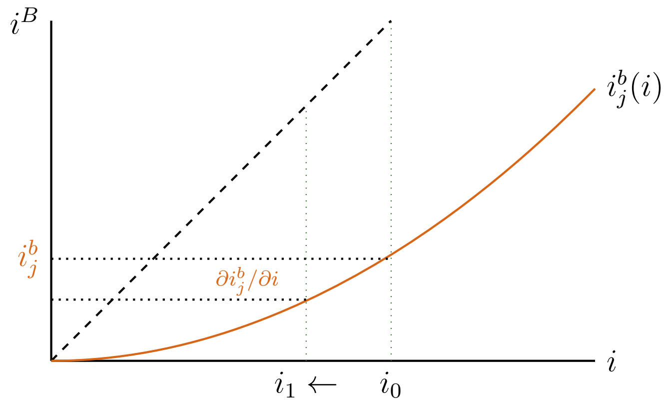
$$\frac{di^b}{di} < 1 \tag{10}$$

The proof is provided in Appendix B.2. The result can be readily seen from remembering that the mark-down banks' charge on their liabilities $\frac{\varepsilon^b_j}{\varepsilon^b_j+1}$ takes the following form:

$$\varepsilon^b_j = (1-\omega^b_j)\varepsilon + \omega^b_j\omega^m\eta + \omega^b_j(1-\omega^m)\left(1+\varepsilon^{\mathcal{L}}_{q_{\mathcal{L}}}\right)$$

where ω^b_j is bank j's market share in the local market, ω^m is the share that households save in cash, and $\varepsilon^{\mathcal{L}}_{q_{\mathcal{L}}} \geq 0$ is the elasticity of liquid savings to the price index of these savings. In the symmetric case, each bank has an identical share of households' deposits: $\omega^b_j = 1/N$

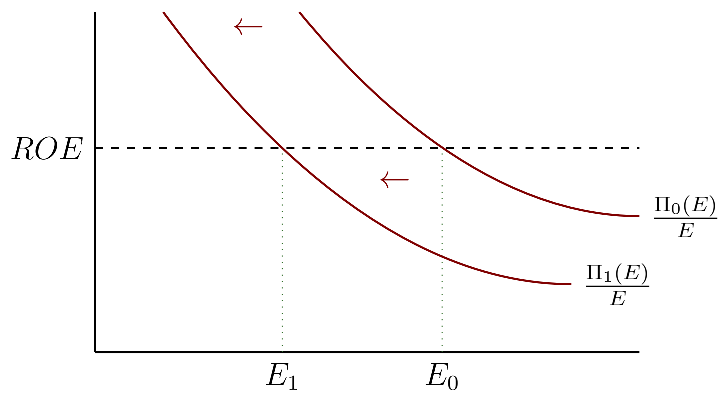
Figure 6: Pass-through to deposits



is constant. The important moving part of the expression is ω^m, the share of households' savings that is invested in cash. When interest rates are high, households save mostly using cash and bank products, as the price of public liquidity is high. The main competition that banks face besides their competitiors comes from government bonds, as encapsulated by the high weight on the elasticity $\varepsilon^{\mathcal{L}}_{q_{\mathcal{L}}}$. As rates decrease, however, banks' main competitor becomes public liquidity, whose price decrease. The elasticity shifts away from $\varepsilon^{\mathcal{L}}_{q_{\mathcal{L}}}$ into η, the elasticity of substitution between cash and bank savings. To the extent that that substitution is larger, banks' market power decreases as they face a more elastic supply of funds, leading to larger costs of funding. Figure 6 shows this graphically.

While our model provides clear predictions for banks' real profits and the behaviour of the spread $i - i^b$, the predictions for the total quantity of bank deposits b are ambiguous. Two opposing forces generate this ambiguity. As nominal rates decline, bonds become less attractive relative to liquid savings under the assumptions of Proposition 2. This generates an increase into bank deposits, which is the basis for the results of Drechsler et al. (2017). However, the price of public liquidity also decreases, bringing the shares of bank savings in total household liquid savings down. When rates are high, the former force tends to generate an increase in bank liabilities, until the latter eventually dominates as nominal rates enter very low or negative territory. We observe both phenomena at play in the Japanese data: Figure 18 in the Appendix shows that the size of bank liabilities to GDP has steadily increased as rates went down, while Figure 16 shows that the share of currency as a percent

Figure 7: Equity effects



of household liquid savings (currency plus deposits) has increased.

In our next result, Proposition 3, we show that the decrease in banks' profits on funding activities translates into losses in total profits, triggering a decrease in equity in order to keep the real return on equity constant.

Proposition 3 (Equity.)**.** *Following a decrease in the nominal rate i, total bank profits $\Pi^l + \Pi^b$ decrease and bank equity e decreases.*

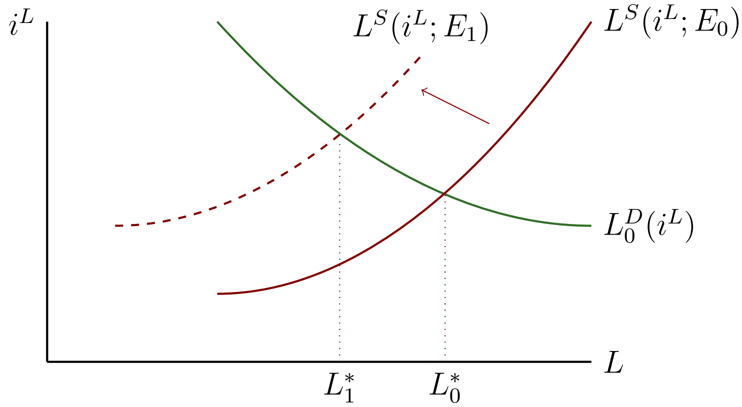
The proof is provided in Appendix B.3. Recall that total banks' profits can be separating in a funding component and lending component (Equation 8). We have show that funding profits decrease. Holding the response of general equilibrium variables (like wages) constant, the change in i has no direct effect of lending profits. Total profits of banks hence go down. To keep the real return on equity constant, bank must then operate with higher leverage, e.g. lower equity. Figure 7 displays this result graphically.

Proposition 4 displays our main result: following a decrease in nominal rates i, the cost of bank loans increase and equilibrium lending supply decreases.

Proposition 4 (Lending.)**.** *Following a decrease in the nominal rate i, the real loan rate r^L increases and the quantity of loans l decreases.*

The proof is provided in Appendix B.4. Since e decreases, asset management costs increase as banks operate with higher leverage. Credit spreads increase and equilibrium lending decreases, as shown in Figure 8. General equilibrium feedback through wages help

Figure 8: Lending effects



to mitigate this effect by supporting loan demand, but does not overturn it. This dampening, however, is quantitatively small.

Finally we show in Proposition 5 that the decline in nominal rates has implications for real quantities: capital, output and wages decrease.

Proposition 5 (Aggregate implications)**.** *Following a decrease in the steady-state i:*

- *Steady-state non-pledgeable capital k_{NP}, pledgeable capital k_P and total capital k decrease.*
- *The ratio of pledgeable capital k_P to non-pledgeable capital k_{NP} increases.*
- *Steady-state output y, wages w and consumption c decrease.*

The proof is provided in Appendix B.5.

5.2 Cross-sectional implications

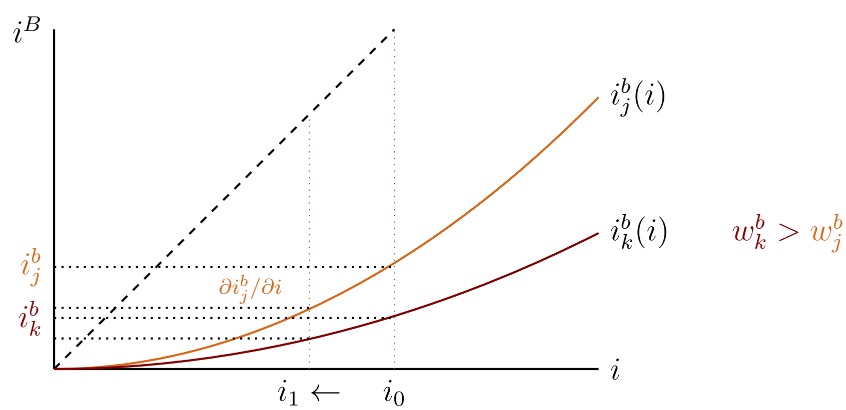
We now show that bank heterogeneity leads some banks to be more affected by a decline in nominal interest rates than others. Due to differences in α_j, which represents quality, additional services, or geographic proximity, for instance, banks effectively have different degrees of market power. This market power exposes banks heterogeneously to a decrease in nominal interest rates, and predicts larger effects on profits, equity and lending. As the cross-sectional effects operate through the same channel as aggregate effects, the cross-section of banks is informative about the aggregate implications of low interest rate environments.

Differences across banks. For simplicity we assume that banks come in two types, regional and national banks, indexed respectively by $j = R$ and $j = N$. There are N_R regional banks and N_C national banks.[19] We assume that regional banks provide products more valuable to households than city banks': $\alpha_R > \alpha_C$. We also assume that city banks' operate with lower (marginal) asset management cost: letting $\zeta_j(l,e) \equiv \frac{\partial c_j(l,e)}{\partial l}$, we assume that $\zeta_C(l,e) < \zeta_R(l,e)$. This can be justified on both efficiency and diversification grounds.

Relative effects of a decrease in i. Starring at Equation 5.1 defining ε_j^b, it is immediate to see that as long as banks' products are sufficiently substitutable (that is, ε is high, which will holds true in all our quantitative applications) banks with a higher market share ω_j^b will face a lower elasticity of funding supply and hence larger market power. All types of banks' face decreased market power when ω^c rises; however, this is stronger for banks with higher market shares.[20] These forces are central in replicating our diff-in-diff results.

Figure 9 shows these results qualitatively. In the high rate environment, regional banks charge a much lower rate for their liabilities, due to the higher quality households perceive from it. However, as rates decrease, regional banks hit the point where currency competes with their products sooner. This reduces their profitability.

Figure 9: Cross-sectional implications



[19]National banks should be thought as city banks in Japan.

[20]In the data, national (city) banks have larger aggregate shares of the market, but importantly they have smaller market shares at the local level.

Relative effect on profits, equity, and lending. Regional banks lose more profitability following a decrease in nominal interest rates, and hence we expect the same causal chain to lead to higher relative loan rates. This is true under the assumption that $\frac{\partial \zeta_C}{\partial e} \leq \frac{\partial \zeta_R}{\partial e}$, that is, the credit spread function for C banks is not steeper at some interest rate i_0. Then, for any interest decrease to $i_1 < i_0$, the increase in lending rates is larger for regional banks than city banks: $i^l_{R,1} - i^l_{R,0} \geq i^l_{C,1} - i^l_{C,0}$, as seen in the data. This increase in prices results in a relative decrease in regional banks' loan supply.

6 Calibration

We calibrate the model at steady-state to hit moments from the beginning of our empirical analysis, 1990. We then conduct experiments where we decrease the equilibrium nominal rates, and let the model adjust.

5.1 Macro parameters

The model is calibrated annually. We normalize labor supply to 1. The span-of-control parameter ν is set to 0.85. The labour share in production is set to 65% $\times$ ν. We set the Cobb-Douglas share of non-pledgeable capital in total capital ρ at 0.5, which yield a loans-to-gdp ratio of 125%. Depreciation for both capital types is set to 8%. We set $\beta = .98$, aiming for a real rate of 2.00%. The initial steady-state nominal rate is set at 3.40%, the value for 1990 of the one-year rate on Japanese government bonds in 1990, filtered out of its business cycle component.[21] Inflation hence is 1.4%. The parameters are summarized in Table 9.

5.2 Bank parameters

We choose the parameters listed in Table 10 to match the empirical moments reported in Table 11. Importantly, none of the moments we target encompass information regarding the long-term aggregate effects of the nominal rates change through bank total profits, equity,

[21] We use a hp filter with smoothing parameter 100.

Table 9: Macroeconomic parameters for initial steady state.

Parameter	Description	Value
$\bar{n}$	HH labor supply	1
δ	Capital depreciation	0.1
α	Capital share	0.35
ν	Scale parameter	0.85
ρ	NP Capital share	0.5
β	Discount factor	0.98
i	Nominal rate	3.4

Table 10: Fitted Parameters.

Parameter	Description	Value
Savings		
$\bar{L}$	Liquid savings shifter	3.5
$\varepsilon_{\mathcal{L}}$	Elasticity of liquid savings	43.0
$\bar{m}$	Minimum cash holdings	0.11
$\frac{1-\alpha_m}{\alpha_m}$	Cash shifter	-0.04%
$\alpha_R - 1$	R bank advantage	0.26%
$\frac{1}{\varepsilon^b-1}$	EOS across bank savings	0.58%
$\frac{1}{\eta-1}$	EOS across bank and cash	0.022%
Lending		
$\bar{\gamma}$	Maximal equity-to-capital ratio	15.87%
κ_L	Asset cost parameter	0.21%
ζ_C	Bank C leverage advantage	0.53
$\frac{1}{\varepsilon^l-1}$	EOS across bank loans (mark-up)	0.7
Equity		
ϱ_E	Return on Equity	7.27%

or lending, which we do not identify in our cross-sectional analysis and hope to recover from the model. Rather, the identified model allows us to identify these aggregate effects through model simulation. Due to non-linearities imposed by the structure of the model, the moments cannot be matched exactly.

Table 11: Calibration targets and Model values.

Moment	**Data**	**Model**
Savings		
$i - i^b$ spread, initial equilibrium	0.87%	1.18%
$i - i^b$ spread, change	0.84%	0.84%
$i - i^b$ spread, relative change	0.56%	0.26%
Cash holdings, initial equilibrium	4.10%	4.83%
Cash holdings, change	7.00%	7.50%
Loans-to-Liabilities	65.0%	60.1%
Bank liabilities to GDP, change	30%	33%
Lending		
$i^l - i$ spread, initial equilibrium	1.64%	1.60%
Loans-to-Assets ratio	58%	53%
Loan market share of C banks	63%	63%
Lending response to equity injection	1.66%	1.42%
Equity		
Return on Equity	8.00%	9.31%

Our first set of parameters govern the properties of the assets that households can invest in. We start by describing the demand for liquid savings. Recall that their demand is a function of the price of bonds q and the price index of such savings q_s, which is independent of the quantity purchased. This yields $\mathcal{L}_t = \Phi'^{-1}\left(\frac{q_{\mathcal{L}}}{q}\right)$. We assume that this function is log-linear in its price, so that $\log \mathcal{L} = \bar{L} - \varepsilon_{\mathcal{L}} \log\left(\frac{q_{\mathcal{L}}}{q}\right)$, yielding a shifter parameter $\bar{L}$ and an elasticity $\varepsilon_{\mathcal{L}}$ to estimate. Next, we describe the demand for cash. To generate a demand for cash even when rates are high, we assume that a subsistence amount $\bar{m}$ must be held. With this the model yields four parameters to estimate: the subsistence amount $\bar{m}$, the quality of cash relative to bank assets α_m, and the elasticity of substitution between cash and bank assets η. Next, we must parametrize the competition between banks through two parameters: the relative quality advantage of regional banks α_R, and the elasticity of substitution between regional banks ε.

To fit these parameters we target corresponding moments from the market for liquid assets. We relate regional banks to their counterparts in Japan and national banks are interpreted as the non-regional banks, which mostly consist of city banks and trust banks. We target the average spread across both groups in the initial equilibrium ($i_0 = 3.4\%$), which stands at 0.87%, and the 0.84% reduction in this spread in the low rate equilibrium ($i_1 = 0.2\%$). We also target the "difference-in-difference" in spreads across both bank groups: the spread across regional banks decreased by 0.56% more relative to the non-regional bank group. Next, we obtain cash holdings from the Japanese flow of funds and estimate that cash holdings represented roughly 4% of household financial asset holdings in 1990, which increased to 11% by the end of our sample. We target hence an initial cash allocation of 4% and an increase of 7% going into the low rate equilibrium. Finally, we target the ratio of bank liabilities relative to bank loans in the initial equilibrium, which is 65%, as well as the growth of bank liabilities as a fraction of GDP, which grew 30%, to gauge the relative attractiveness of bank liabilities vis-a-vis bond holdings.

Our second set of parameters concern the lending market and its frictions. The elasticity of substitution ε_l governs the substituability of bank lending products from firms' perspective. Next, we parametrize the credit spread implied by the asset management costs directly, that is we assume that $\zeta_j(l_j, e_j) = \kappa_l \times \left(\bar{\gamma} - \frac{\zeta_j l_j}{e_j}\right)^{-1}$. This expression is a smooth version of the usual leverage constraints $l_j \leq \frac{\bar{\gamma}}{\zeta_j} e_j$. We normalize $\zeta_R = 1$ and estimate $\zeta_C \leq 1$, capturing the fact that city banks' loan portfolio are more diversified. This gives us four parameters to estimate.

We target moments from the initial equilibrium to inform the four lending parameters. We match an average loan spread over the risk-free rate of 1.64% and an aggregate loans to assets ratio of 58%. The lending shares of the C bank is 63% in the initial equilibrium. Finally, we need to discipline how credit responds to a change in equity – the asset management cost function. For that purpose we collect data on public equity injections conducted in Japan during our whole sample period. We compute the lending response of an equity injection equivalent to 1% in asset, and find an average response of lending of 1.64% (of assets). We target that elasticity directly in the model.

Finally, the last parameter govern the required return on equity of the banks in excess of the return on bonds, ϱ_E, and provides discipline on the equity held by banks. We target a real return on equity of 8%, the long-term average return of Japanese banks.

7 Quantitative results and counterfactuals

Having calibrated the model we now quantitatively analyze the effects of a lower nominal rate as well as the effects of counterfactual policies.

7.1 Recovering aggregate effects

In this section we analyze the aggregate effects of a decrease in the nominal rate across steady-states, which decreases inflation.[22] Our goal is to obtain a quantitative estimate of the changes in loan spreads and aggregate quantities induced by a change in the nominal rate.

Figure 10 shows that lower nominal rates are associated with lower spreads (distance to the 45 degrees line), as cash becomes a stronger competitor to banks' products. Since regional banks always charge a lower spread, the decrease occurs sooner for these banks. Figure 10 (lower panel) shows that net funding profits Π^b are affected, despite the fact that the demand for bank liabilities actually rise in the model.[23] This loss is larger for regional banks. At very low rates, city banks in fact gain loan market shares due to their diversification benefits.

Figure 11 Panel A shows that equilibrium steady-state lending by both types of banks decreases, and Panel B shows that the ratio of pledgeable capital to non-pledgeable capital increases, indicating substitution. The effects are large, amounting to a 4% decrease in steady-state non-pledgeable capital going from the 3.4% nominal rate initial equilibrium to the 0.2% nominal rate for the period 2000-2017. These effects translate to a permanent 0.5% reduction in output.

[22] A shock to the real rate has qualitatively similar effects as a shock to the nominal rate, except that it changes the demand for loans. Due to the non-linearity of the model, this can result in a different quantitative response.

[23] The reduction in the spreads banks charge induce a substitution away from bonds towards bank saving products.

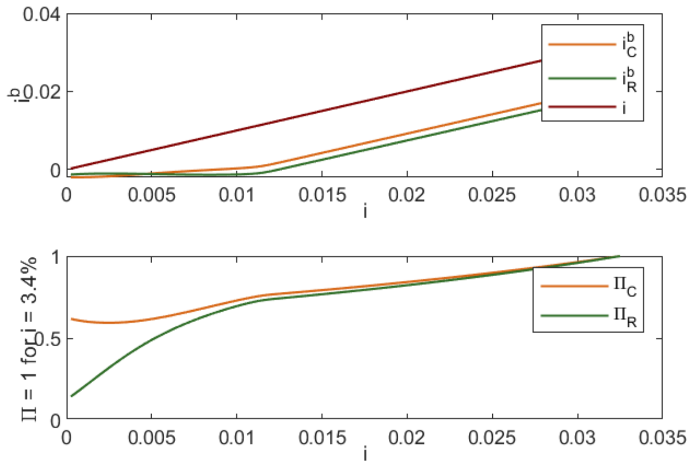


Figure 10: Bank savings rates and Bank profits in calibrated model.

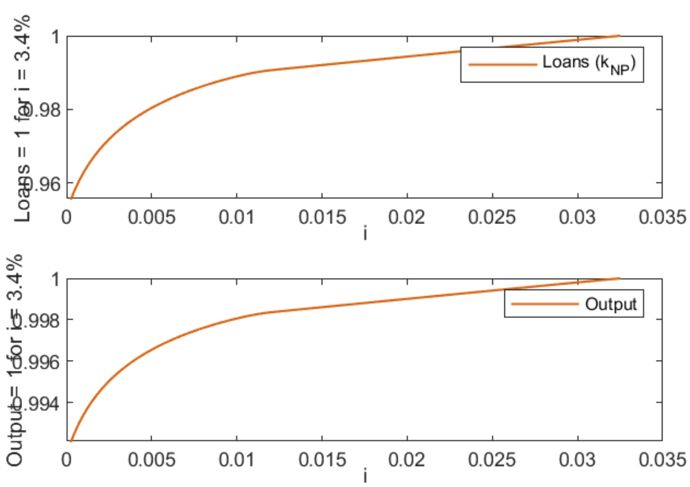


Figure 11: Loans and output in calibrated model.

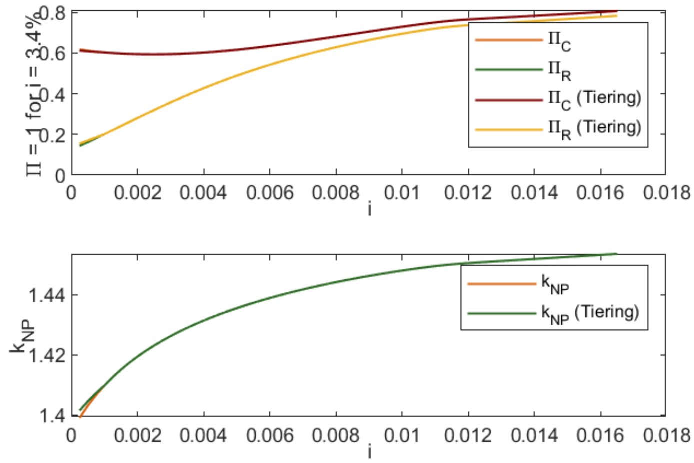


Figure 12: Response of bank profits and bank capital after tiering.

7.2 Tiering

The first counterfactual experiment we implement using the model is to consider tiering the interest rate on reserves. Tiering in Japan was introduced in January 2016. The implemented policy applied different interest rates to different categories of reserves, depending on when they had been initially deposited as reserves. Banks' "basic balance" outstanding in 2015 would continue to earn 0.1%. This represents roughly 50 percent of reserves. An additional 30-40 percent of reserves qualified as part of a "macro add-on" would earn zero. Beyond this, any "excess balance" of reserves would earn negative 0.1 percent. In recent data this is roughly 10 to 20 percent of reserves, depending on the bank.

Using the model, we split banks' bond holdings into government bonds and reserves, and assume that reserves i at the margin but inframarginal units get a subsidized rate i^R.[24] We fix reserves to 20 percent of assets when $i = 0$, and apply a subsidized rate of 0.05% on 80 percent of reserves.

Figure 13 displays the response of bank profits by group as well as capital following the introduction of tiering. This experiment suggests small impact on loan quantities. In the presence of tiering, lending increases by 0.25 percent in the low rate steady state, a small amount relative to the overall 4 percent decrease we document.

[24]Was assume that except for that, government bonds and reserves offer the same returns for banks.

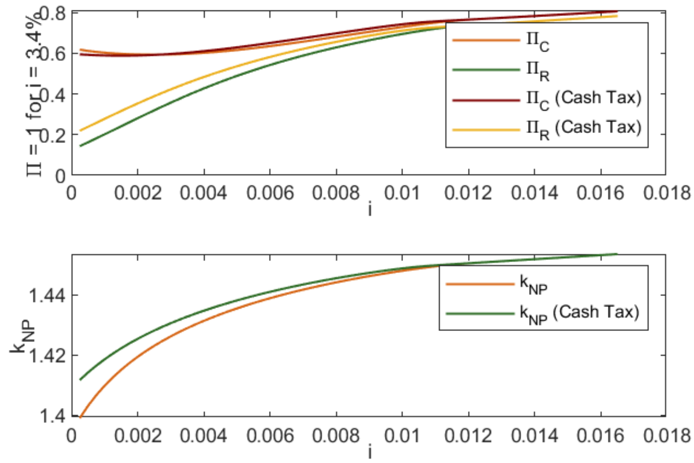


Figure 13: Response of bank profits and bank capital after introduction of a cash tax.

7.3 Cash Tax

Our second counterfactual experiment considers a cash tax. This idea follows the proposal of Agarwal and Kimball (2019), in which electronic money is established as the unit of account, and central banks establish establish an exchange rate at the cash window between electronic currency and paper currency. We test the impact of setting the nominal return on money ζ_m to negative 0.1 percent.

Figure 13 displays the response of bank profits by group as well as capital following the introduction of a cash tax. This increases lending by 1 percent.

8 Conclusion

That low interest rates affect bank profitability is a subject of high importance and continued debate. In this paper, we demonstrate this empirically in the case of Japan, where interest rates have been at low levels since the mid 1990s. This channel has had a quantitative impact on bank lending, both in aggregate and in particular on banks whose historical dependence on deposits makes it relatively difficult for them to pass interest rate cuts through to their expenses. While policies such as tiering the interest rate help to mitigate the effects of low rates on bank profitability, it appears more effective to implement cash taxes to prevent households from substituting bank deposits for cash.

Taken together, this evidence highlights a potential cost of low nominal interest rates which reduces the effectiveness of monetary policy, particularly when rates remain low for long periods of time. Although banks may hedge interest rate risk in general, this becomes more difficult in low interest rate environments. Banks may also not expect low interest rate environments to remain long-lived, for example due to over-optimism in the potential for recovery or risk shifting returns.

There are a number of further questions which are not addressed in the current paper, which we believe are important areas for future work. We assume that banks' assets include loans and securities, and that there is no risk in banks' securities portfolios. As loan demand declines, banks with growing deposits increase investing in securities, and may "reach for yield" to increase their income. This poses a potential risk.

In addition, little is known about the behavior of economic agents in a negative rate environment. Many banks are loathe to charge depositors a negative interest rate on small deposit accounts, but are more open to the idea of 'fees.' Similarly, whether negative interest rates distort firm borrowing and investing decisions in some yet unknown ways remains to be seen. Our results depend on a calibration that seems to match Japan's experience while rates were low but positive, and how exactly agents react to negative rate environments is an area where more research is necessary.

Overall, these findings raise questions for policymakers in selecting the optimal level and path of policy rates, and to what extend other policies such as tiering, targeted long term refinancing operations, or other central bank lending facilities can help to compensate banks for the lost profits in a low interest rate setting.

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A Empirical Appendix

A.1 Details on mergers

We manually track the mergers, acquisitions, and failures of all banks in our sample. Where banks merge, we add together the historical balance sheet components of the post-merger bank to compare the post-merger performance to a pro-forma sum of parts, before the merger.

The list of mergers accounted for in this way is summarized in Table A1.

For example, Kyowa Bank and Saitama Bank merge in 1991 to form Asahi Bank, which merges with Daiwa Bank in 2002. The combined bank is then reorganized into Saitama Resona and Resona Holdings. We do not assess the reorganization but rather combine all the pre-merger banks and post merger banks into a single entity for the entire sample.

Our results are robust to using individual banks, without adjusting for mergers.

Twelve banks fail and their assets cannot be clearly traced to a single entity. We remove these from the analysis. For reference, these are listed in Table A2.

A.2 Covariate balance

In Table A3, we sort banks into two groups: high deposits-to-liabilities ratio in 1990 vs. low deposits-to-liabilities ratio in 1990, with each group representing 50% of the total market share for bank liabilities. These groups differ particularly along two dimensions: bank size and the share of regional banks. To address these concerns, we include (lagged) bank size as a control in our specifications, and also study specifications that use only variation within regional banks.

A.3 Relation to Drechsler et al. (2017, 2018)

We can show that the findings of Drechsler et al. (2018) hold in our setting, by estimating the expense and income beta from a regression:

$$\Delta i_{jt}^{k} = \alpha + \beta_{kj} \Delta i_{jt} + error \tag{A11}$$

Table A1: Mergers and Acquisitions

Acquiror	Bank acquired	Date
Fukuoka Financial Group	Kyushu-Shinwa Holdings	2007q2
Hokuto Bank	Akita Akebono Bank	1993q1
Juroku Bank	Gifu Bank	2012q1
Kansai Urban Banking	Biwako Bank	2009q4
Kanto Tsukuba Bank	Tsukuba Bank	2003q2
Kinki Osaka Bank	Bank Of Kinki	2000q1
Kirayaka Bank	Yamagata Shiawase Bank	2007q1
Kirayaka Bank	Kirayaka Holdings	2008q3
Kiyo Bank	Wakayama Bank	2006q3
Kiyo Bank	Kiyo Holdings	2013q3
Kumamoto Bank	Higo Family Bank	1992q1
Kyushu Financial Group	Kyushu Bank	2003q1
Michinoku Bank	Hirosaki Sogo Bank	1976q3
Minato Bank	Hyogo Bank	1995q3
Minato Bank	Midori Bank	1999q1
Mitsubishi UFJ	Bank Of Tokyo	1996q1
Mitsubishi UFJ	Tokai Bank	2001q3
Mitsubishi UFJ	Nippon Trust Bank	2001q3
Mitsubishi UFJ	UFJ Holdings	2005q3
Mitsubishi UFJ	Toyo Trust Bank	2005q3
Mitsubishi UFJ	Sanwa Bank	2005q4
Mizuho Financial Group	Industrial Bank Of Japan	2002q1
Mizuho Financial Group	Dai-Ichi Kangyo Bank	2002q1
Mizuho Financial Group	Fuji Bank	2002q1
Namihaya Bank	Bank Of Naniwa	1998q3
Namihaya Bank	Fukutoku Bank	1998q3
Nishi-Nippon City Bank	Takachiho Sogo Bank	1984q1
Nishi-Nippon City Bank	Fukuoka City Bank	2004q3
North Pacific Bank	Sapporo Bank	2008q3
North Pacific Bank	Ibaraki Bank	2009q4
North Pacific Bank	Sapporo Hokuyo Holdings	2012q3
Kyowa Bank	Saitama Bank	1991q1
Resona (Daiwa)	Asahi Bank (Kyowa)	2002q4
Resona	Nara Bank	2005q4
Resona	Resona Trust & Banking	2009q1
San-In Godo Bank	Fuso Bank	1991q1
Senshu Ikeda Bank	Senshu Bank	2010q1
Sumitomo Mitsui Financial Group	Heiwa Sogo Bank	1986q1
Sumitomo Mitsui Financial Group	Taiyo Kobe Bank	1990q1
Sumitomo Mitsui Financial Group	Sakura Bank (Mitsui)	2001q1
Sumitomo Mitsui Financial Group	Sumitomo Banking	2002q3
Sumitomo Mitsui Trust Bank	Mitsui Trust And Banking	2000q1
Sumitomo Mitsui Trust Bank	Chuo Mitsui Asset Trust & Bank	2012q1
Sumitomo Mitsui Trust Bank	Chuo Mitsui Trust & Banking	2012q1
Tokyo Star Bank	Tokyo Sowa Bank	2001q1
Yamaguchi Financial Group	Setouchi Bank	2004q1
Yamaguchi Financial Group	Momiji Holdings	2006q3

Notes: When banks merge, we list as the acquirer the bank with a financial reporting identifier that is used by the combined entity after the merger. Where bank names are changed we list the previous name in parentheses.

Table A2: Failures

Bank name	Date
Toho Sogo Bank	1992q1
Taiheiyo Bank	1996q1
Hanwa Bank	1997q1
Hokkaido Takushoku Bank	1998q1
Tokuyo City Bank	1998q1
Kyoto Kyoei Bank	1998q3
Namihaya Bank	2000q1
Kofuku Bank	2000q1
Kokumin Bank	2000q1
Niigata Chuo Bank	2001q1
Ishikawa Bank	2002q3
Chubu Bank	2002q3

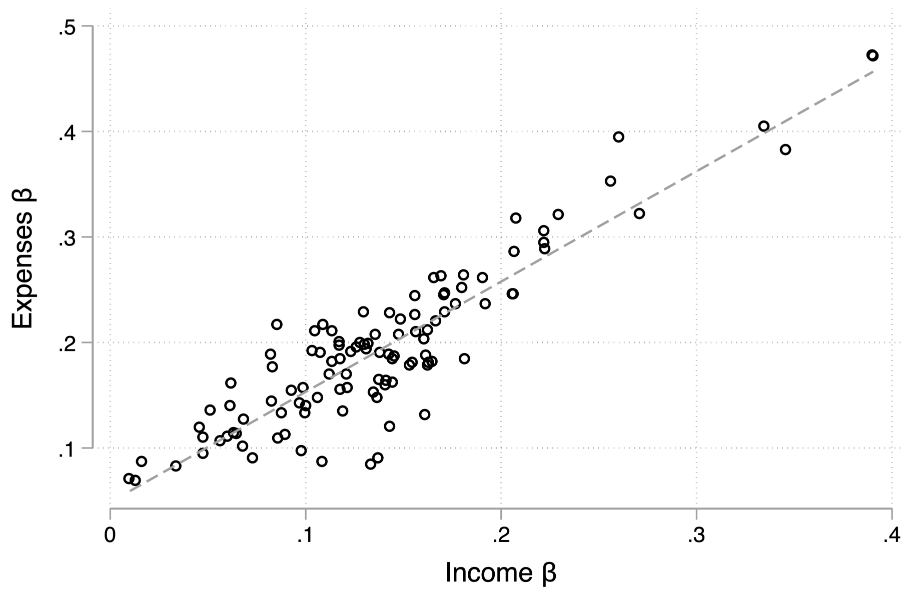
Table A3: Balance of covariates (2000)

	Low D/L	High D/L
Assets (tr)	18,713	2,021
median:	*5,531*	*1,654*
NIM (%)	2.08	2.30
NII/Assets (%)	1.67	1.95
Deposits / Liabilities (DD)	0.82	0.94
Expense β	0.17	0.03
Income β	0.12	0.01
Loans to Assets	0.71	0.70
Fee income / Assets	0.24	0.21
Regional banks (%)	75	99
Total number of banks	28	85

Notes: Each group represents roughly 50% of the market share of aggregate bank liabilities (assets).

The resulting estimates of interest income betas and interest expense betas are shown in Figure 15, which line up close to the 45 degree line. This shows that in Japan, banks hedge and equalize their income, expense betas. While this is true in a stable environment, we focus in our results on the long term β, rather than the short term, and look at the level of interest rates rather than banks' reactions to changes. In the low interest rate environment, banks are no longer able to hedge effectively.

Figure 14: Banks hedge



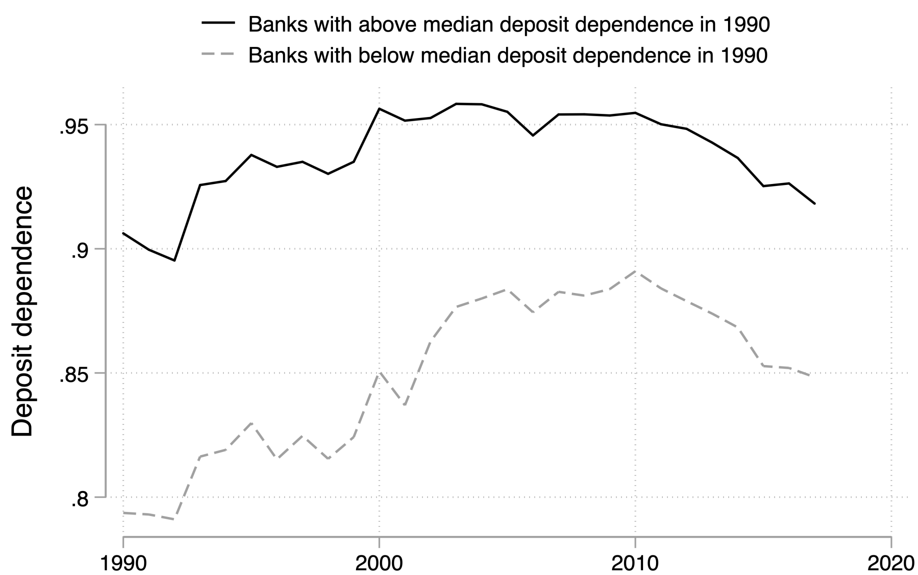
Notes: Each data point represents one bank. The y-axis plots coefficients of bank-level regressions of the change in interest expenses scaled by liabilities on changes in the 1 year JGB interest rate, for 1975-2017. The x-axis is the corresponding coefficient from a regression of interest income scaled by bank assets.

A.4 Persistence of D/L

In our mechanism, banks with large market power are more exposed to low nominal interest rates. One such measure of market power, we hope to have shown convincingly, is the deposits-to-liabilities ratio, which we fix at its 1990 value and use to conduct long-term comparisons across groups. A maintained assumption of this setting is that banks' market power is very persistent (in the model, permanent). Figure 15 shows that banks with high deposits to liabilities ratio in 1990 kepe this status throughout our whole sample, even though the deposits-to-liabilities ratio of both groups gets shifted around due to macroeconomic developments.

Table A4 below also shows that our main results are robust to using the deposits-to-liabilities ratio of banks in 1975 instead of 1990, consistent with the idea that the ratio is highly persistent.

Figure 15: Persistence of historical deposit dependence



A.5 Robustness checks

A.5.1 Alternative regressions

We show here that our results are robust to alternative measures of banks' exposure to low interest rates.We re-run regressions corresponding to column (2) of the regression results tables in the main text. As outcomes, we consider (1) the mark-down $\mu^b_{ijt} = i_t - i^b_{jt}$ where i^b_{jt} is the measured interest expense and where μ^b_{ijt} has its business cycle component removed, the interest expense i^b_{jt}, the net interest margin, net operating income, and the realized loan rate. Table A4 compares the results of:

A. the baseline specification in the main text, using D/L in 1990

B. the unmerged sample of banks,

C. the deposits-to-liabilities ratio of bank in 1975 and the baseline sample (1990-2017)

D. the deposits-to-liabilities ratio of bank in 1975 and the full sample (1975-2017)

E. the exposure β_j computed in Section 3.2.2

F. the "expense beta" as computed by Drechsler et al. (2017, 2018), which proxies for market power

G. the level of the spread between the risk-free rate i_t and the rate banks pay on their liabilities i^b_{jt} in 1990, as a proxy of banks' market power in 1990, and[25]

H. a specification which uses nominal rates instead of a post variable.

Unmerged sample of banks. Table A4 panel B shows the results. When we do not consolidate banks, we find very similar point estimates as in our main sample.

Deposits to Liabilities in 1975. Table A4 panel C displays our robustness results when setting the deposits to liabilities ratio in 1975 as an exposure variable. They are consistent with our main analysis, supporting the idea that the market power embedded in D/L is highly persistent due to historical reasons.

Table A4 panel D displays the robustness results when setting the deposits to liabilities ratio in 1975 as an exposure variable and using the full sample of data, from 1975 to 2017. They are consistent with our main analysis, giving support to the idea that banks that charge high initial spreads – banks we interpret have high market power – lose these advantages in the post low rates era.

Direct exposure β_j. Unsurprisingly our results hold when directly using our measure of exposure β_j defined in equation (1). Table A4 panel E shows the results. Banks with large β_j suffer larger drop in their mark-ups, pay higher interest expenses, haver lower net interest margins, lower net ordinary income, and charge higher loan rates.

[25]We remove the business cycle component of this measure bank-by-bank in order to avoid contamination from business cycle fluctuations

Drechsler et al. 2017, 2018 β. Table A4 panel F displays our robustness results when setting DSS β as computed in section A.3 as an exposure variable. They are consistent with our main analysis, supporting the idea that DSS's expense β captures banks' market power on their liabilities, with low values indicating a larger market power.

Using rates instead of pre/post. Table A4 panel G shows that the results hold when instead of using pre/post we use the level of short term interest rates to obtain an interpretable elasticity. We use the three month Yen Libor, from which we remove the business cycle component.[26] Following a decrease in rates, banks with a high deposits-to-liabilities ratio at the beginning of the sample experience lower spreads, higher interest expenses, lower net interest margins, lower net ordinary income (although the coefficient is less significant), and higher loan rates.

[26] We use a standard HP filter to do so.

Table A4: Robustness regressions

Dependent variable:	μ^b_{jt} (1)	i^b_{jt} (2)	NIM_{jt} (3)	NOI_{jt} (4)	i^l_{jt} (5)	Dependent variable:	μ^b_{jt} (1)	i^b_{jt} (2)	NIM_{jt} (3)	NOI_{jt} (4)	i^l_{jt} (5)
A. Baseline results						B. Unmerged banks					
D/L 1990	4.49**	-4.87**	3.12*	2.45***	-0.07	D/L 1990	4.36**	-4.64**	3.34**	1.88**	0.17
	(0.13)	(0.12)	(0.26)	(0.01)	(0.15)		(0.13)	(0.10)	(0.22)	(0.11)	(0.14)
Post x D/L	-3.46***	4.03***	-1.69**	-2.91***	0.78**	Post x D/L	-3.29**	3.76***	-1.70**	-2.11*	0.71*
	(0.05)	(0.05)	(0.11)	(0.03)	(0.06)		(0.05)	(0.04)	(0.09)	(0.26)	(0.06)
Observations	3,051	3,078	3,078	3,078	3,078	Observations	3,513	3,616	3,616	3,616	3,616
R-squared	0.85	0.97	0.60	0.15	0.95	R-squared	0.80	0.96	0.63	0.10	0.95
C. Exposure measure: D/L in 1975 (1990-2017)						D. Exposure measure: D/L in 1975 (1975-2017)					
D/L 1975	3.88**	-4.19**	2.57*	1.96**	-0.13	D/L 1975	3.71**	-3.80**	2.70*	2.64*	-0.53
	(0.18)	(0.17)	(0.31)	(0.10)	(0.15)		(0.13)	(0.12)	(0.26)	(0.25)	(0.16)
Post x D/L 1975	-2.95***	3.45***	-1.27**	-2.29*	0.74**	Post x D/L 1975	-2.78***	3.05***	-1.40**	-1.41**	1.14**
	(0.03)	(0.03)	(0.05)	(0.18)	(0.02)		(0.03)	(0.03)	(0.06)	(0.06)	(0.04)
Observations	3,036	3,063	3,063	3,063	3,063	Observations	4,562	4,603	4,603	4,603	4,603
R-squared	0.73	0.96	0.51	0.14	0.96	R-squared	0.96	0.96	0.65	0.69	0.97
E. Exposure measure: β_j						F. Exposure measure: DSS β					
β_j	7.66*	-8.15*	5.18*	2.53	0.15	DSS β	-4.07**	4.60**	-3.60**	-2.10*	-0.42
	(0.68)	(0.65)	(0.64)	(0.68)	(0.52)		(0.22)	(0.21)	(0.27)	(0.23)	(0.27)
Post x β_j	-6.28**	7.06**	-2.57**	-2.89	1.94**	Post x DSS β	3.03**	-3.74**	1.93**	3.05	-0.61
	(0.12)	(0.12)	(0.12)	(1.23)	(0.09)		(0.11)	(0.10)	(0.13)	(0.58)	(0.11)
Observations	3,051	3,051	3,051	3,051	3,051	Observations	3,051	3,078	3,078	3,078	3,078
R-squared	0.66	0.95	0.49	0.12	0.95	R-squared	0.52	0.94	0.48	0.12	0.95
G. Exposure measure: $\mu^b_{j,1990}$						H. Nominal rate elasticity					
$\mu^b_{j,1990}$	0.89**	-0.95**	0.62**	0.59**	0.00	D/L 1990	1.14***	-1.15***	1.50***	0.51	0.78**
	(0.02)	(0.01)	(0.02)	(0.01)	(0.03)		(0.20)	(0.23)	(0.25)	(0.62)	(0.33)
Post x $\mu^b_{j,1990}$	-0.70***	0.80***	-0.34**	-0.32**	0.17**	Rate i_t x D/L	1.22***	-1.24***	0.57***	0.17	-0.37**
	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)		(0.19)	(0.21)	(0.07)	(0.17)	(0.15)
Observations	3,051	3,051	3,051	3,051	3,051	Observations	3,051	3,078	3,078	3,078	3,078
R-squared	0.93	0.98	0.65	0.65	0.95	R-squared	0.82	0.96	0.59	0.11	0.95
Controls (all panels):						Controls (all panels):					
Year f.e.s	Y	Y	Y	Y	Y	Year f.e.s	Y	Y	Y	Y	Y

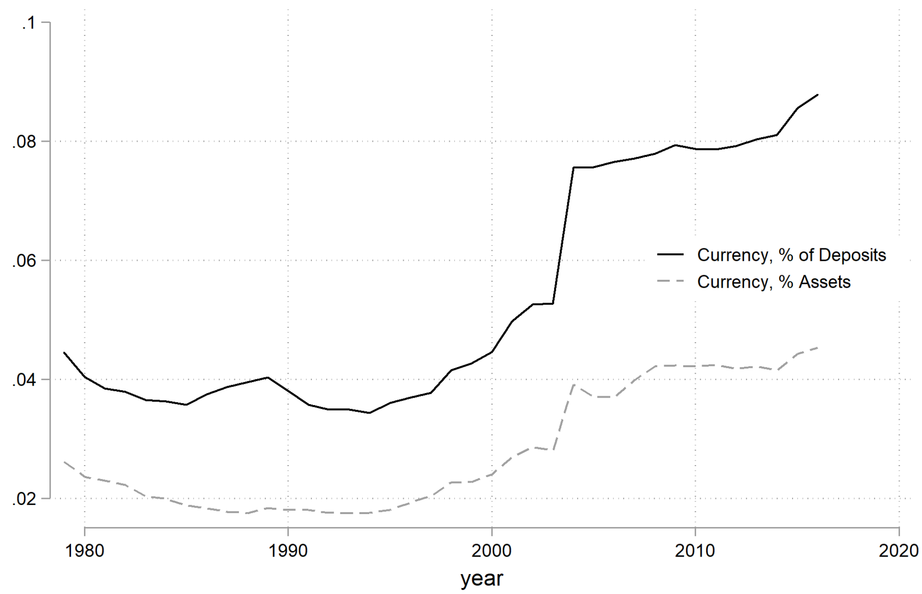
Notes: Significance follows * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are double clustered at the bank and pre/post level. $\mu^b_{jt} = i_t - i^b_{jt}$ where i^b_{jt} are interest expense rate and i_t is the three-month libor. We extract the business cycle component of μ^b_{jt} bank-by-bank using an HP filter and remove it. NIM is interest income rate minus the interest expense rate. NOI is net ordinary income, the sum of net interest income and net non-interest income. i^l_{jt} is the realized loan rate.

A.6 Additional aggregate trends of interest

A.6.1 Household currency holdings

Figure 16 show the currency holdings of households as a percent of all deposits and currency as well as a percent of total financial assets of households. This graph shows that the amount of cash holdings have steadily increased as rates went low.

Figure 16: Currency holdings of households.



Notes: Holdings data from the flow of funds, nominal GDP from Bank of Japan.

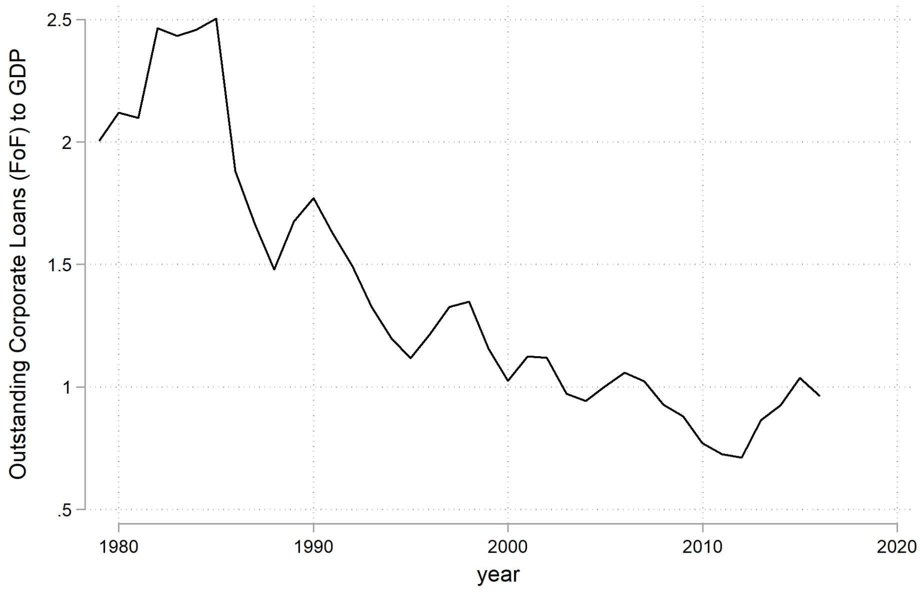
A.6.2 Bank Loans to GDP

Figure 17 shows the total bank loans as a percent of GDP.

A.6.3 Bank Liabilities to GDP

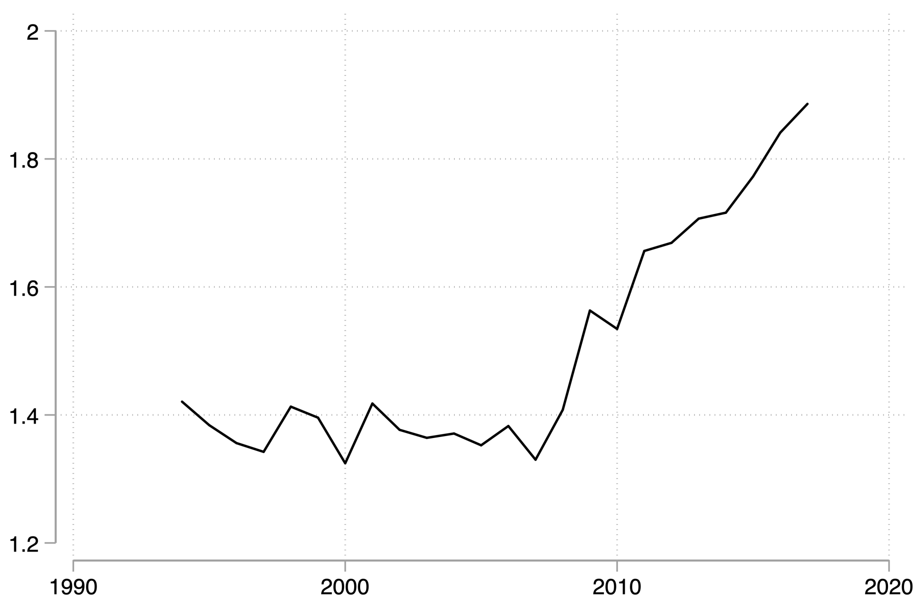
Figure 18 shows total bank liabilities as a percent of GDP.

Figure 17: Oustanding loans to corporations (FoF), % of GDP



Notes: Aggregate lending data from the flow of funds, nominal GDP from Bank of Japan.

Figure 18: Bank liabilities, % of GDP



Notes: Aggregate liabilities data and nominal GDP from Bank of Japan.

A.7 Additional cross-sectional results

A.7.1 Effect on Total Assets

One concern, particularly regarding our liability results, is the scenario in which bank profits is growing yet bank assets is growing faster, resulting in potentially lower profitability metrics but still positive outlook for bank loans-to-equity ratios, the relevant measure of leverage in our model. Table A5 shows these results.

Table A5: Effects on Log Total Assets

	All banks			Regional banks	
	(1)	(2)	(3)	(4)	(5)
Post	-0.92*				
	(0.49)				
D/L 1990	-6.51***	-6.51***	-6.77***	-8.56***	-8.72***
	(0.40)	(0.41)	(0.42)	(0.65)	(0.66)
Post x D/L	1.30**	1.30**	2.22***	0.22	0.98
	(0.56)	(0.57)	(0.55)	(0.84)	(0.84)
NPL rate			-0.31***		-0.24***
			(0.02)		(0.02)
Constant	20.11***				
	(0.36)				
Observations	3,078	3,078	3,078	2,762	2,762
R-squared	0.30	0.31	0.36	0.14	0.19

Notes: Significance follows * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are double clustered at the bank and pre/post level.

A.8 Public equity injections

In this section we show that equity is an important component of bank loan supply by showing that public equity injections into (distressed) banks result in increase in bank lending. Our goals are both to show that equity matters and to use the resulting elasticity to calibrate the strength of the lending frictions in our model. When the government injects new equity into banks, capital constraints faced by the banks relax, facilitating additional lending. Importantly, the public injections in the data occurred during different periods of time – notably the end 90s, the early 2000s, and around the great recession – and affected both large and small banks.

We start by gathering data on public equity injections collected manually on the Deposit Insurance Corporation of Japan website. We then run a regression:

$$\frac{\Delta L_{jt+1}}{A_{jt}} = \alpha_j + \alpha_t + \beta \frac{\Delta E_{jt}}{A_{jt}} + Controls_{jt} + \varepsilon_{jt} \tag{A12}$$

Where L_{jt} is lending, ΔL_{jt+1} is the change in loans $L_{jt+1} - L_{jt}$, E_{jt} is the book equity at period t (and hence at the start of period $t+1$, $\Delta_{E_jt} = E_{jt} - E_{jt-1}$, and controls include public bond injections, non-performing loans at the bank level, and bank size (log total assets).

Table A6 shows the estimated coefficients for β when β is instrumented by public equity injections.

A more conservative estimate of the elasticity of lending to equity can be obtained by using equity injections to banks as an instrument for changes to bank equity.

Table A6: Bank lending, instrumenting for bank equity using recapitalizations

	All banks				Regional banks
	(1)	(2)	(3)	(4)	(5)
DEA	1.7***	1.5***	1.3***	0.8*	1.3***
	(0.5)	(0.5)	(0.5)	(0.5)	(0.6)
Bond injections	Y		Y	Y	Y
NPL rate	Y	Y	Y	Y	Y
Bank size	Y	Y	Y	Y	Y
Year f.e.s	Y	Y	Y		Y
Bank f.e.s	Y	Y		Y	Y
Observations	3,013	3,013	3,015	3,015	2,739
R-squared	0.13	0.33	0.37	0.34	0.38

Notes: Significance follows * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

B Model Appendix

B.1 Proof of Proposition 1

The funding problem of the bank is defined as:

$$\frac{\Pi^b}{1+\pi} = \max_{i_j^b} \frac{1+i-1+i_j^b}{1+\pi} b_j(i_j^b;\cdot)$$

Where $b_j(i_j^b;\cdot)$ is the demand for bank j's product by households. Importantly, $b_j(\cdot)$ also depends on the prices of competing saving products, q_m and q, the respective prices of inflation and real bonds. These prices are taken as given by the bank. We can apply the envelope theorem following a change in i. Note first that because inflation adjusts to keep the real bond rate constant, q stays unchanged. Hence, banks do not face more competition from bond rates. This is not true for for public liquidity: indeed, as i decreases and inflation decreases, its relative price q^m decreases, decreasing $b_j(\cdot)$ and hence Π^b.

B.2 Proof of Proposition 2

From the banking problem recall that the rate changed by banks is given by:

$$1+i_j^b = \frac{\varepsilon_j^b}{\varepsilon_j^b+1}(1+i)$$

Where $\frac{\varepsilon_j^b}{\varepsilon_j^b+1}$ takes the following form:

$$\varepsilon_j^b = (1-\omega_j^b)\varepsilon + \omega_j^b\omega^m\eta + \omega_j^b(1-\omega^m)\left(1+\varepsilon_{q_{\mathcal{L}}}^{\mathcal{L}}\right)$$

where ω_j^b is bank j's market share in the local market, ω^m is the share that households save in cash, and $\varepsilon_{q_{\mathcal{L}}}^{\mathcal{L}} \geq 0$ is the elasticity of liquid savings to the price index of these savings. In the symmetric equilibrium $\omega_j^b = 1/N$. From the household's problem we see that ω^m is an increasing function of the relative price of bank liquidity versus public liquidity,

$\omega^m = \omega^m(q^b/q^m)$. Clearly, q^b/q^m increases as nominal rates fall, as q^m falls.[27] The result then immediately follow from the assumption that $\eta > 1 + \varepsilon^{\mathcal{L}}_{q_{\mathcal{L}}}$.

B.3 Proof of Proposition 3

First note that, holding equity e constant and general equilibrium quantities constant, a change in i has no impact on banks' profits on lending, as the elasticity of loan supply faced by banks does not depend on the nominal rate i, only the real loan rate. Next, note that holding equity e and general equilibrium quantities constant has no impact on this result: by the envelope theorem a decrease in e decrease the profits that banks make, and general equilibrium responses can only depend the response of a loan supply in the first place, but not overturn it, by contradiction. Hence, total bank profits must decrease, following our first result in Proposition **??**.

Recall now that equity is the solution to:

$$e = \frac{\Pi^l(e) + \Pi^b}{(1+\pi)\varrho_E}$$

Hence clearly if Π^b decreases then so does e. Since $\Pi^l(e)$ is increasing in e, the decrease is further amplified by losses on the asset side of banks.

B.4 Proof of Proposition 4

The proof is straightforward: a decrease in e increases the spread $c_l(l, e)$ for any l, by assumption. The real loan rate increases and the demand for loans decrease. General equilibrium participates in dampening the response, by raising loan supply.

B.5 Proof of Proposition 5

These results are immediate from the increase in the real loan rate, which is essentially a permanent negative supply shock to the economy.

[27] q^b also falls, but by contradiction to the result this cannot offset the fall in q^m.