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Olivier Wang Banks, low interest rates, and  
monetary policy transmission

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## Abstract

This paper studies how low interest rates weaken the short-run transmission of monetary policy and contract the long-run supply of bank credit. As U.S. bond rates have fallen, the pass-through of monetary shocks to loan and deposit rates has weakened while the spread on U.S. bank loans has risen. I build a model in which banks earn deposit and loan spreads, deposits compete with money, and banks' lending capacity depends on their equity. The short-run transmission of monetary policy is dampened at low rates, because deposit spreads act as a better hedge for bank equity against unexpected monetary shocks. In the long run, persistent low rates decrease banks' "seigniorage" revenue from deposit spreads, hence bank equity and loan supply contract, and loan spreads increase.

*JEL classification:* E4, E5, G21

*Keywords:* low interest rates, financial intermediation, interest rate pass-through, deposit spread, loan spread

## Non-technical summary

This paper studies how the secular decline in interest rates in advanced economies weakens the short-run transmission of monetary policy and contracts the long-run supply of bank credit. Relative to the fast-growing literature on the monetary transmission mechanism around the zero lower bound, the paper's distinctive argument is to contrast short-run and long-run effects of low interest rates. I document a novel set of relevant facts using data on U.S. banks, and build a macro-finance model to explain these findings and quantify their policy implications.

Empirically, I find that retail deposit and loan rates offered by U.S. banks are less responsive to movements in policy rates at low interest rates. Moreover, while surprise policy rate cuts boost U.S. banks' stock prices on average, this positive effect is muted or even reversed at low rates. In the long run, I show that persistent low nominal rates tighten credit conditions for bank borrowers: over the past 20 years, as U.S. interest rates have declined, the spread between the yield earned by U.S. banks on loans and the yield on Treasury bonds has doubled from around 100 to 200 bps, in spite of stable credit risk and lower operating costs. At the same time, the bond-deposit spread has fallen by the same amount, so that the total spread between loans and deposits has remained remarkably stable.

Motivated by these facts, I provide a unified theory for the short-run and long-run consequences of low interest rates. The key new mechanism is that interest rates affect the *composition* of bank income. Banks generate most of their income from two spreads. On the asset side, banks earn loan spreads (the risk-adjusted difference between loan and bond rates of the same maturity), a form of external finance premium paid by borrowers. On the liability side, banks earn deposit spreads (the difference between bond and deposit rates), a form of liquidity premium paid by savers.

I argue that the level of nominal interest rates determines whether bank net income stems mostly from the loan or the deposit side. Banks are able to pay low rates on deposits in exchange for their liquidity, safety, and associated payment services. But savers can and do substitute between deposits and other liquid assets, such as money market funds and, most importantly, currency. Lower nominal rates make it less costly to hold currency, which means that in effect, bank-issued deposits face a stronger competitive pressure from government-issued currency in a low rate environment. This compresses the income banks can earn from providing liquid deposits. Why is bank lending affected by what happens on the deposit side? Bank capital is a key bottleneck for loan supply, due to regulatory constraints or simply market discipline. As interest rates fall, the lower profits from deposits imply lower overall retained earnings. Banks being famously reluctant to raise new equity or cut payouts, their equity and loan supply end up falling in tandem. At the macroeconomic level, equilibrium loan spreads must then rise to reflect the tighter credit conditions.

Long-run harmful effects of lower rates take time to materialize. In the short run, rate cuts still stimulate lending. But the model can generate the non-linearity that I find in the data: the standard short-run effect of rate cuts is dampened at low rates. This happens because bank equity is more insulated from policy rate shocks at low rates, consistent with the empirical finding on bank stock returns; lending and aggregate output become less sensitive to monetary policy as well. In my baseline calibration, a permanent fall in the steady state nominal interest rate from 500 bps to 100 bps makes U.S. GDP 15% less responsive to monetary policy.

My focus is on aggregates, but the model also raises interesting political economy implications. Low interest rates can trigger conflicts of interest between the financial sector and the rest of the economy regarding what central banks should do. Temporary rate cuts always stimulate total output in the model, so from an aggregate perspective, there is no “reversal” of monetary policy. However, at low rates, bank profits may suffer from a rate cut even though it benefits the economy as a whole.

While monetary policy can be viewed as the primary driver of interest rates in the short run, the long-run level of real interest rates likely reflects fundamental forces such as demographics and productivity growth. Yet a different kind of monetary policy can still help in the long run: the model shows that increasing the inflation target can mitigate the harmful effect of falling natural real interest rates on long-run bank lending. Higher inflation provides banks a steady flow of profits from deposits, which sustains a higher level of capital and lending. This new rationale for a positive trend inflation, based on long-run credit supply considerations, differs from the traditional “wobble room” argument that a higher inflation target allows central banks to cut rates by more during recessions. Of course, there may be alternative and more efficient ways to maintain long-run bank profitability. But inflation has the advantage of also addressing the weakened short-run transmission of monetary policy. Unlike in the wobble room argument, however, the point of a higher inflation target is to let central banks cut policy rates *by less* during recessions, thanks to an improved pass-through to retail rates.

# 1 Introduction

Prolonged low interest rates in advanced economies have spurred concerns about declining bank profitability and its macroeconomic consequences. By compressing banks' net interest margins, low rates might lead to weaker balance sheets that hinder intermediation (Committee on the Global Financial System 2018); but lower bank margins could also benefit banks' customers. Moreover, monetary policy transmission through the banking sector may be impaired at low rates: in the extreme case of negative nominal rates implemented in Europe, the pass-through of policy rates to deposit and lending rates appears limited.<sup>1</sup> While the one-year Treasury rate rose to 2.7% in the U.S. in November 2018, it fell back to essentially zero in March 2020 following the COVID-19 outbreak, and is likely to remain low in the coming years.<sup>2</sup>

This paper studies how the secular decline in interest rates weakens the short-run transmission of monetary policy and tightens the long-run supply of bank credit. Relative to the fast-growing literature on the monetary transmission mechanism around the zero lower bound, the paper's distinctive argument is to contrast short-run and long-run effects of low interest rates. I document a novel set of relevant facts using data on U.S. banks, and build a macro-finance model to explain these findings and quantify their macroeconomic and policy implications. I argue that due to the interaction between the credit and liquidity provision roles of banks, persistently low rates (i) hurt banks' long-run loan supply and shift the costs of financial intermediation from depositors—who pay lower deposit spreads—to borrowers—who pay higher loan spreads; (ii) weaken the short-run transmission of monetary policy, even above the zero lower bound.

I first present two facts on the relation between interest rates and the retail loan and deposit rates offered by U.S. banks. First, using data on bank income from the Call Reports, I find that over the past 20 years, the maturity-adjusted spread between the yield earned by U.S. banks on loans and Treasuries has doubled, in spite of similar credit risk and lower operating costs. Meanwhile, the total spread between the yield banks earn on loans and the yield they pay on deposits has remained stable. In the cross-section, banks whose deposit spread has been most compressed by lower interest rates have experienced lower growth in retained earnings, equity, and lending, and have increased their loan spreads by more. Second, using data from a large panel of U.S. bank branches, I find that the pass-through of market rates to deposit and loan rates is not only incomplete, as previously documented, but also state-dependent: it is lower at low interest rates.<sup>3</sup>

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<sup>1</sup>See among others Heider, Saidi and Schepens (2018) in the Euro area, Eggertsson, Juelsrud and Wold (2017) in Sweden, Basten and Mariathasan (2018) in Switzerland, Hong and Kandarac (2018) in Japan.

<sup>2</sup>For instance, Gourinchas and Rey (2018) predict an average U.S. short-term real rate of -1.37% or -2.35% (depending on the estimation method) for the period 2015-2025. See also Del Negro, Giannone, Giannoni and Tambalotti (2018) for recent estimates of  $r^*$ .

<sup>3</sup>Incomplete short-run deposit pass-through has been studied by Hannan and Berger (1991), Neumark and Sharpe

I then develop a unified theory for the short-run and long-run consequences of low interest rates. The key mechanism is that nominal interest rates affect the *composition* of bank income. Banks earn the sum of two spreads, reflecting the two sides of the balance sheet. On the asset side, banks earn loan spreads—the difference between loan and bond rates not explained by maturity, credit risk and operating costs. On the liability side, banks earn deposit spreads—the difference between bond and deposit rates. Both spreads can persist due to limits to arbitrage in the form of financial constraints or market power.

The level of nominal interest rates comes into play because savers can substitute between private liquidity (deposits) and public liquidity (currency). Since the nominal interest rate is the opportunity cost of public liquidity, a lower nominal rate makes public liquidity more attractive. Under the plausible condition that money and deposits are gross substitutes, the equilibrium deposit spread, which is the opportunity cost of private liquidity, must also fall for deposits to be held. Thus lower nominal rates reduce not only public seigniorage, but also the “private seigniorage” earned by banks from deposit creation. If bank lending capacity is high enough relative to credit demand—the *unconstrained lending regime*—the decline in private seigniorage has no consequences for the credit market equilibrium. If, however, bank lending capacity is already low—the *constrained lending regime*—lower deposit profits spill over to banks’ asset side, and loan spreads must rise to reflect the tighter credit conditions. The process only stops once bank shareholders can obtain the same excess required return on equity as before, when interest rates were high. Whether bank profits come from loans or deposits does not affect shareholders, but it matters very much to the real economy.

To sum up, if private and public liquidity are gross substitutes, then a decrease in the nominal rate compresses deposit spreads, but widens loan spreads in the constrained lending regime. I show theoretically that the behavior of loan and deposit spreads has implications for monetary policy in both the long run, when prices are flexible and the economy reaches its steady state, and in the short run, in the presence of nominal rigidities.

In the long run, for a given inflation target, the economy is in the constrained lending regime if and only if the steady state real rate  $r^*$  is low enough. At high  $r^*$ , banks can sustain their long-run required return on equity (determined by banks’ entry and exit dynamics and their costs of issuing equity) with deposit spreads alone. A classical dichotomy then holds: an increase in inflation inefficiently raises the opportunity cost of liquidity but leaves consumption allocations unchanged. At low  $r^*$ , however, the steady state deposit spread is too low. Banks’ retained earn-

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(1992), and more recently Driscoll and Judson (2013), Yankov (2014), and Drechsler et al. (2017). Incomplete short-run loan pass-through has been widely documented in the U.S. (Berger and Udell 1992) and in Europe (Mojon 2000, De Bondt 2002). A common proxy for loan rates in the U.S. is the “bank prime loan rate” reported in release H.15 by the Federal Reserve. However, as I explain in Section 2.1, the prime loan rate does not reflect the actual rates offered by banks.

ings drop, which depletes their equity. As banks are financially constrained, their lending capacity becomes too low relative to loan demand, and a loan spread opens up to clear the credit market. This process ends when the market-clearing loan spread is high enough to stabilize banks' earnings and substitute for the lower deposit spread. In this regime, a higher inflation target relaxes banks' financial constraints, to the benefit of their borrowers. Hence inflation is not superneutral because it redistributes from depositors, whose opportunity cost of liquidity rises, to borrowers, whose borrowing costs fall.

Turning next to the short run, I add nominal rigidities to explore how incomplete pass-through of bond rates to retail deposit and loan rates also alters the transmission of monetary policy to output.<sup>4</sup> I thereby turn my setting into a tractable heterogeneous agents New Keynesian model with financial frictions. Relative to the standard New Keynesian model, I first clarify when banking frictions matter for monetary policy. The interest-elasticity of output is unaffected by the presence of banks and incomplete deposit pass-through in the unconstrained lending regime, hence banks are irrelevant when  $r^*$  is high enough. By contrast, monetary policy is dampened in the constrained lending regime, and the more so the lower  $r^*$ . As in the long-run analysis, loan and deposit markets are entangled through banks' balance sheets. Lower deposit pass-through, whatever the reason behind it, implies lower loan pass-through, which in turn dampens output sensitivity. Under a mild condition on the substitutability between money and deposits, deposit pass-through is lower at lower nominal rates, consistent with my second motivating fact on short-run pass-through. As a result, loan pass-through and the transmission to output are also weaker at low rates.<sup>5</sup>

I evaluate the quantitative relevance of these mechanisms by calibrating the model to the U.S. banking sector. Two benchmarks are useful to highlight the macroeconomic role of banks. I compare my model to a Modigliani-Miller economy, in which household heterogeneity remains but all assets are perfect substitutes, and to a “credit frictions only” economy where borrowers are still bank-dependent, but deposits provide no liquidity services. In my baseline calibration where  $r^*$  equals 3%, the interest-elasticity of output is 20% lower than in the Modigliani-Miller benchmark, and 8% lower than in the “credit frictions only” benchmark.

I explore how monetary policy transmission depends on the steady state real rate  $r^*$  by changing households' discount factor (changes in productivity growth have the same effect). I find that monetary policy is further dampened at low interest rates, even though the economy is well

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<sup>4</sup>The same forces that yield long-run real effects of monetary policy give rise to short run non-neutrality, even under flexible prices. However, flexible prices imply a counterfactual *negative* pass-through of nominal bond rates to real lending rates.

<sup>5</sup>In Online Appendix D, I use a two-period version of the model to give the key short-run intuitions through closed-form formulas relating deposit pass-through, loan pass-through and the sensitivity of aggregate output to monetary policy.

above the zero lower bound: when  $r^*$  declines from 3% to -1% (assuming a 2% inflation target), the previous 20% dampening grows to 35%. By contrast, the interest-elasticity of output barely changes with  $r^*$  in the two benchmarks, which illustrates that the effect of  $r^*$  stems solely from interactions between loan and deposit markets.

I then study the interaction between steady state policies and monetary policy transmission. As in the long run, a higher inflation target can offset the impact of a lower  $r^*$  because the steady state *nominal* rate is what matters for *real* spreads. Thus increasing the inflation target not only stimulates long-run loan supply, but also enhances monetary policy transmission, at the cost of higher liquidity premia for savers. Second, my model allows to address interactions between financial regulation and monetary policy. I find that holding steady state rates fixed, tighter capital requirements also dampen monetary policy transmission.<sup>6</sup>

In addition to these aggregate predictions, the model sheds light on the conflicts of interest that can arise between banks and the rest of the economy at low interest rates. Rate hikes always contract total output in my model: there is no “reversal” of monetary policy. However, rate hikes do have ambiguous effects on bank profits, because monetary shocks have opposite effects on the two components of bank net interest income, loan spreads and deposit spreads. Which effect dominates depends on both the health of banks and the level of interest rates when the monetary shock happens. As deposit rates are less responsive to policy rates at lower rates, banks suffer less from rate hikes. Consistent with this state-dependent relation between the level of interest rates and the sensitivity of bank profits to monetary shocks, I find using high-frequency data that, while unexpected rate hikes hurt U.S. bank stock returns on average, this negative effect is muted or even reversed at low rates.

## Related literature

While the literature has focused on the short-run transmission of monetary policy around the zero lower bound (ZLB), the first contribution of this paper is to study the *long-run* harmful impact of declining real and nominal rates on bank loan supply. A recent literature studies banks’ exposure to monetary policy in the presence of both maturity mismatch and liquidity premia on deposits (Drechsler, Savov and Schnabl 2018, Di Tella and Kurlat 2017). I propose and document a complementary explanation for the stability of bank profits based on the offsetting behavior of loan and deposit spreads. Accounting for the two kinds of spreads explains why net interest margins are even more stable than in previous work, both empirically and theoretically. Most importantly, studying the two spreads together is key to understand how the secular decline in

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<sup>6</sup>As I abstract from risk, I cannot speak to the trade-off between the benefits of regulation and potential costs in terms of monetary policy transmission. Recent work by Döttling (2019) and Porcellacchia (2020) analyzes the interplay between low interest rates and financial stability.

U.S. interest rates impacts not only banks, but also the non-financial sector, as loan spreads affect the cost of credit faced by banks' borrowers.<sup>7</sup> My long-run results are consistent with a recent body of work that tries to measure the (relative) importance of banks' lending and deposit-taking businesses, in terms of profits, returns or stock market valuations. Egan, Lewellen and Sunderam (2017) apply structural methods from production function estimation to the banking sector and find meaningful synergies between deposit-taking and lending in the cross-section of U.S. banks. Schwert (2018) finds that banks earn a large premium over the market price of credit risk. Begenau and Stafford (2018) take the opposite view and argue that banks make losses on both sides of their balance sheets, while Drechsler (2018) disagrees. My paper takes no stand on the overall profitability of banks; instead, I examine how the composition of bank profits varies with the level of interest rates, and develop the macroeconomic implications of these compositional effects.

I also use the same framework to contribute to the more developed literature on the *short-run* transmission of monetary policy around the ZLB. I offer new evidence on dampened interest rate pass-through at low rates in the U.S., even above the ZLB. The same mechanisms that tie deposit and loan rates together in the long run can help understand these short-run pass-through effects and their consequences for the real effects of conventional monetary policy. My short-run results are most closely related to Drechsler, Savov and Schnabl (2017). In their model, banks with market power over deposits optimally contract deposit supply following a monetary tightening in order to earn a higher deposit spread. If it is costly to replace deposits with wholesale funding, loan supply contracts as a side effect. I follow their lead in putting deposits at center stage, but I highlight a complementary mechanism that matters when financial constraints and thus bank equity affect aggregate bank lending. At low interest rates, rate hikes have a stronger positive impact on the profits earned by banks on deposits because stronger competition between money and deposits makes deposit rates stickier. As a result, these deposit profits are a better hedge against monetary shocks, hence monetary policy has a weaker negative effect on bank equity, and hence the constrained supply of bank loans, at low interest rates. In most of my analysis, incomplete pass-through to loan and deposit rates follows from general equilibrium effects instead of monopoly pricing; Online Appendix E compares and then combines my framework to one with market power.<sup>8</sup>

Eggertsson, Juelsrud and Wold (2017) show how in the presence of credit frictions, negative rates may not be expansionary. Bonds and deposits are perfect substitutes in their model so

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<sup>7</sup>In Section 2.1, I explain why it is not enough to suppose that banks earn income from deposit provision and maturity transformation to match the data.

<sup>8</sup>Within a pure market power framework that ties lending to deposits but features no scarce bank equity, it is difficult to explain why the loan spread is higher at low interest rates in the long run. If anything, low interest rates should erode banks' market power on deposits and therefore lead them to increase both deposit and loan supplies, which would reduce loan spreads. Another mechanism, such as the link between equity and loan supply I emphasize, is thus needed to explain why low profitability on the deposit side may hurt lending.

there is no deposit spread, but the pass-through to loan rates breaks down once deposit rates hit zero. Brunnermeier and Koby (2018) go even further, by arguing that there exists a “reversal rate” under which a marginal decrease in the policy rate becomes contractionary. They emphasize market power in loan markets, noting that “one of the most striking features of [their] reversal result is that it does not rely on stickiness of the deposit rate”. Relative to this literature, my paper puts interactions between incomplete deposit and loan pass-through at its heart to study the less extreme case of positive, but potentially low, nominal rates, consistent with my new facts on the state-dependence of pass-through. Indeed, in section 5.2, I show that despite the rich heterogeneity in the model and the presence of multiple financial frictions, monetary policy works exactly as in a representative agent New Keynesian model (hence banks are irrelevant) as long as deposit pass-through is complete.

The seminal papers on the “bank lending channel” of monetary policy (Bernanke and Blinder 1988; 1992, Kashyap and Stein 1995) relied on reserve requirements. I share Van den Heuvel (2002) and Gertler and Karadi (2011)’s emphasis on scarce bank equity instead. Bianchi and Bigio (2017) show how loan spreads depend on central bank policies, such as the rate paid on reserves, that affect the cost of bank liquidity management. Piazzesi et al. (2019) discuss the interplay between inside money (deposits) that facilitates end-user transactions, as in this paper, and outside money (reserves) used in interbank transactions. They abstract from lending and from the substitution or competition between inside and outside money that is key to my paper. Zentefis (2018) shows that the pass-through of monetary policy to loan rates can break down when banks have too little capital to compete with each other in a Salop model. Wang, Whited, Wu and Xiao (2019) estimate a structural microeconomic model to quantify the effect of loan and deposit market power on monetary policy transmission, in particular at low interest rates.

The current environment has given rise to many empirical studies on the effects of low interest rates on banks, especially in Europe. Claessens et al. (2018) study the relationship between interest rates and net interest margins. Altavilla, Boucinha and Peydro (2017) examine how standard and non-standard monetary policy measures affect European banks’ profitability. Ampudia and den Heuvel (2018) also explore the state-dependent impact of monetary shocks on bank stock prices in Europe. I find similar results for U.S. banks in Section 5.4.

Finally, this paper studies the interplay between inside and outside liquidity. Since Holmström and Tirole (1998), several papers have pointed out the crowding-out effect of higher public liquidity supply on private liquidity provision, e.g., Krishnamurthy and Vissing-Jorgensen (2012), Greenwood, Hanson and Stein (2015), and Nagel (2016). Crowding-out can have social benefits when private liquidity provision entails negative externalities like fire sales. By contrast, I highlight that crowding-out may also have a cost in terms of higher credit spreads.<sup>9</sup>

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<sup>9</sup>Another cost, as argued by Acharya and Plantin (2019), is that low interest rates may induce excessive equity

## 2 Evidence on low interest rates and U.S. banks

In this section, I document two new facts about U.S. banks. First, the secular decline in bond rates has not been fully transmitted to loan rates faced by consumers and firms. The reason is a shift in the composition of bank interest income: deposit spreads have shrunk while loan spreads have widened. Second, the short-run pass-through of policy rates to retail bank rates is state-dependent: it is lower at low rates for both loan and deposit rates.

### Data.

I use three main data sources. I obtain quarterly income and balance sheet data for all U.S. commercial banks from the Call Reports. I use the period 1997Q2-2018Q2, for which the reports contain detailed information on the repricing maturity structure of assets and liabilities. Weekly data on loan and deposit rates are collected across U.S. bank branches by RateWatch. My sample runs from 1998 to 2018 for deposits, and 2000 to 2018 for loans. Following Drechsler et al. (2017), I restrict attention to branches that actively set rates. I use representative products that appear as “liquid assets” in the Survey of Consumer Finances: checking deposits, savings deposits, and money market deposit accounts. For loan rates, I use the two most common short-term loans in my sample: adjustable rate mortgages (with 1 year maturity), and auto loans (36 months). The series for unanticipated monetary shocks are from Nakamura and Steinsson (2018). Shocks are defined as changes in market expectations of the Fed funds rate (over the remainder of the month, because Fed funds futures settle on the average rate over the month) in a 30-minute window around FOMC announcements.<sup>10</sup> The sample is all regularly scheduled FOMC meetings from 01/01/2000 to 3/19/2014, excluding the peak of the financial crisis from July 2008 to June 2009.

### 2.1 Long run: falling deposit spreads, rising loan spreads

I begin by showing that the steady decline in interest rates over the past 20 years has only been partially passed through to loan rates.<sup>11</sup> The reason is a rise in the maturity-adjusted loan spread between loans and bonds, that mirrors a decline in the deposit spread between bonds and deposits.

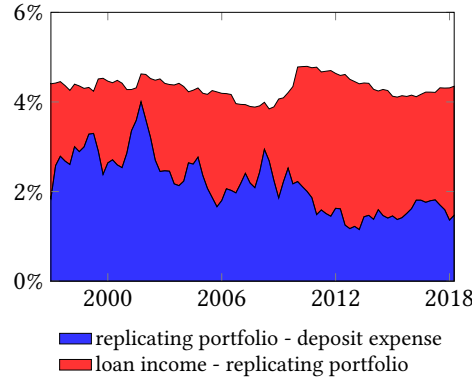
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payouts that crowd out productive investment.

<sup>10</sup>The construction is detailed in Nakamura and Steinsson (2018). The shock is the first principal component of several futures.

<sup>11</sup>A common view is that the “bank prime loan rate”, posted by the Federal Reserve among its selected interest rates in release H.15, is a good indicator of effective lending terms. Figure 9, however, shows that the bank prime loan rate has been mechanically set at a 3% markup over the Fed funds rate since around 1994 (when the Fed started releasing statements about its Federal funds rate target) and is of little relevance for the actual loan rates faced by consumers and firms.

**Figure 1:** Decomposing the difference between the yields earned on loans and paid on deposits.



*Note:* “Loan rate” is loan income divided by total loans. “Deposit rate” is deposit expense divided by total deposits. “Replicating portfolio” is described in the text. The blue area is the difference between the yield on the replicating Treasury portfolio and the deposit yield, and the red area is the difference between the loan yield and the yield on the Treasury portfolio. Sources: Call Reports and Federal Reserve data.

Figure 1 decomposes the difference between loan interest income (as a fraction of total loans) and deposit interest expense (as a fraction of total deposits) for U.S. banks between 1997Q2 (when banks started reporting the repricing maturity of their assets in the Call Reports) and 2018Q2. The left panel shows the realized yields on loans and deposits. These measures do not reflect the rates on *new* loans and deposits, which I will look at in Section 2.2. Instead, they are the interest accruing from past loans and deposits, using book value accounting. The corresponding total spread, shown on the right panel as the sum of the red and blue areas, has been remarkably stable in spite of a large decline in interest rates.

To correct for the term premia embedded in loan rates, I construct a Treasury portfolio that replicates the repricing maturity of the loan portfolio, computed from the Call Reports as in English et al. (2018) and displayed in Online Appendix Figure 16. For simplicity, I aggregate the four bins in the Call Reports (less than 1 year, 1 to 3 years, 3 to 5 years, 5 to 15 years and more than 15 years) into two bins: “short-term” (less 1 year) and “long-term” loans (all the remaining loans).<sup>12</sup> The yield on the Treasury portfolio recorded in year  $t$  is then defined as

$$R_t^{Treas} = y_{t-1}^{ST} \omega_{t-1}^{ST} + y_{t-10}^{LT} (1 - \omega_{t-1}^{ST}),$$

<sup>12</sup>It is important to keep track of both short-term and long-term assets in banks’ portfolios. Begenau and Stafford (2018) and Drechsler et al. (2018) approximate the return on bank assets with passive strategies holding only 6-year and 10-year Treasuries, respectively. However, Figure 6 shows that the return on a portfolio with only long-term (10 year) bonds differs significantly from the return on the mixed portfolio I construct with more detailed information. Figure 6 also shows the return on bank securities reported by banks: it is almost identical to the return on my mixed portfolio, even though the mixed portfolio has a shorter average duration than a pure long-term bond and the average repricing maturity of securities is *higher* than that of loans.

where

$$\omega_{t-1}^{ST} = \frac{\text{loans that reprice/mature within a year at } t-1}{\text{total loans at } t-1}$$

and  $y_u^{ST}$  (resp.  $y_u^{LT}$ ) is the yield on a 1-year (resp. 10-year) zero coupon Treasury at date  $u$ .<sup>13</sup> I then decompose the total loan-deposit spread using the Treasury portfolio's interest income, recorded at book value to match the accounting convention on loans. The “loan spread”, in red on the right panel of Figure 1, represents the yield on a strategy that borrows Treasuries to invest in loans with the same maturity. The “deposit spread”, in blue, represents the yield on a maturity mismatched strategy that borrows at the average deposit rate to invest in the Treasury portfolio. The loan spread has widened by around 1%, while the deposit spread has shrunk by the same amount. The repricing/maturity structure of banks' loan portfolio, required to construct the Treasury portfolio, is only available after 1997; however, the stability of the total loan-deposit spread goes back much further, in spite of wide variations in interest rates, as shown in Figure 7.

My findings are consistent with Drechsler et al. (2018)'s work on the stability of the net interest margin (NIM), which also includes interest income from securities and interest expense on wholesale liabilities. In fact, the “loan-deposit spread” has been *more stable* than the NIM, which has fallen from 4.4% in 1997Q2 to a low of 2.95% in 2015Q1, before slightly rebounding to 3.2% in 2018. The reason is that the return on securities has fallen by more than the return on loans, consistent with my theory in which banks are the marginal pricers of loans but not of bonds. Hence the NIM would have fallen by even more than it has, had the loan spread not increased.

**Risk premium, operating costs, and LIBOR.** Figure 11 shows that credit risk and operating costs cannot explain the discrepancy: loss provisions were high during the Great Recession but have reverted (since around 2012) to the same levels as in the 2000-2008 period, while operating costs, measured by non-interest expense, have fallen by around 1% of earning assets. Fees and other sources of non-interest income have also decreased. Even holding credit risk constant, part of the higher excess loan spread I find could be due to a higher risk premium. Figure 8, however, shows the same pattern as in Figure 1 for very short-term, low risk, commercial and industrial loans. This suggests that risk premia are not the full story for bank loans.<sup>14</sup> Finally, the pattern is unlikely to stem from an increase in the marginal cost of wholesale funding relative to Treasuries (or equivalently a higher liquidity premium on Treasuries): the spread between the 3-month LIBOR (the leading maturity) and 3-months T-bills has averaged at 36 bps between 2000 and 2006, and at 29 bps between 2010 and 2019.

<sup>13</sup>There is no canonical way to construct a “replicating Treasury portfolio” because we cannot know exactly when a loan was made, but alternative choices, such as varying the maturity of long-term bonds or using a weighted average of the repricing/maturity structures at dates  $t-1$  and  $t-10$ , yield the same results.

<sup>14</sup>Saunders, Spina, Steffen and Streitz (2019) derive a loan spread measure from the secondary loan market and show that it has increased in the U.S. and in Europe.

**Corporate bonds.** The increase in credit spreads is specific to bank loans. Figure 10 shows the corporate bond spread constructed by Gilchrist and Zakrajsek (2012), updated through August 2016. Its 2010-2016 average equals 2.3%, almost exactly the same value as the 1997-2007 average of 2.2%.

### 2.1.1 Inspecting the mechanism with bank-level data

Simple correlations between changes in the deposit spread and variables of interest such as loan spreads, loan quantities, or equity, could be driven by unobservable demand shocks to deposit and loan demand. For instance, some banks may decide to keep paying relatively high deposit rates in spite of the decline in interest rates if attracting deposits helps them finance positive loan demand shocks. Moreover, trends in aggregate quantities may be dominated by the “growth of finance”, as I discuss in more detail in section 4.2. Cross-sectional data can alleviate both of these endogeneity concerns. To isolate the effect of the decline in interest rates from other contemporaneous shocks, I estimate a measure  $\beta_i$  of bank liabilities’ interest rate exposure by running a separate time-series regression for each bank  $i$

$$\Delta r_{it}^{liab} = \alpha_i + \sum_{\tau=0}^3 \beta_{i,\tau} \Delta FFR_{t-\tau} + \epsilon_{it}$$

in the pre-period 1984-2000 where  $r_{it}^{liab}$  is defined as interest expense over total assets and  $FFR$  is the Fed funds rate. Following Drechsler et al. (2018), the measure  $\beta_i = \sum_{\tau=0}^3 \beta_{i,\tau}$  captures the interest exposure of bank liabilities. I use it to construct the predicted change in the spread on liabilities due to the fall in interest rates between 2000Q4 (before the 2001 recession and interest rate cuts) and 2014Q4 (before the Fed started raising rates again in 2015):

$$\Delta \widehat{\text{liability spread}}_{i,00-14} = \left( 1 - \sum_{\tau=0}^3 \beta_{i,\tau} \right) (FFR_{2014} - FFR_{2000})$$

I then run cross-sectional regressions

$$\frac{y_{i,2014} - y_{i,2000}}{y_{i,2000}} = \alpha + \beta \Delta \widehat{\text{liability spread}}_{i,00-14} + \epsilon_i \quad (1)$$

for different outcomes  $y$ : retained earnings (defined as cumulative retained earnings over initial 2000 equity), equity, loans, and loan spreads (for spreads, the right-hand side is just  $y_{i,2010} - y_{i,2000}$ ). Table 1 shows that a larger fall in the liability spread predicts lower retained earnings, slower equity and loan growth and a larger increase in loan spreads. All these predictions are consistent with the mechanism of the model, which predicts that the fall in the liability spread hurts retained earnings and thus equity growth (because it is not offset by higher equity issuance), which feeds into lower loan growth and higher loan spreads, due to the leverage constraint tying lending to eq-

|                           | (1)                        | (2)                 | (3)                 | (4)                   |
|---------------------------|----------------------------|---------------------|---------------------|-----------------------|
|                           | $\Delta$ Retained earnings | $\Delta$ Equity     | $\Delta$ Loans      | $\Delta$ Loan spread  |
| $\Delta$ liability spread | 0.245***<br>(0.0425)       | 0.577***<br>(0.119) | 0.337***<br>(0.101) | -0.260***<br>(0.0388) |
| Observations              | 4272                       | 4272                | 4254                | 4052                  |

**Table 1:** Effect of the decline in interest rates between 2000 and 2014 in the cross-section of banks. The regression equations are (1). Standard errors are block-bootstrapped to account for the fact that regressors are estimated.

uity. Appendix Table 3 shows that the results remain mostly the same when controlling for banks' 2000Q4 leverage (as high leverage naturally predicts faster equity growth) and deposit-asset ratio, which has proven an important variable to understand the impact of post-2014 negative rates in Europe (Heider et al., 2018).

## 2.2 Short run: state-dependent pass-through of monetary shocks

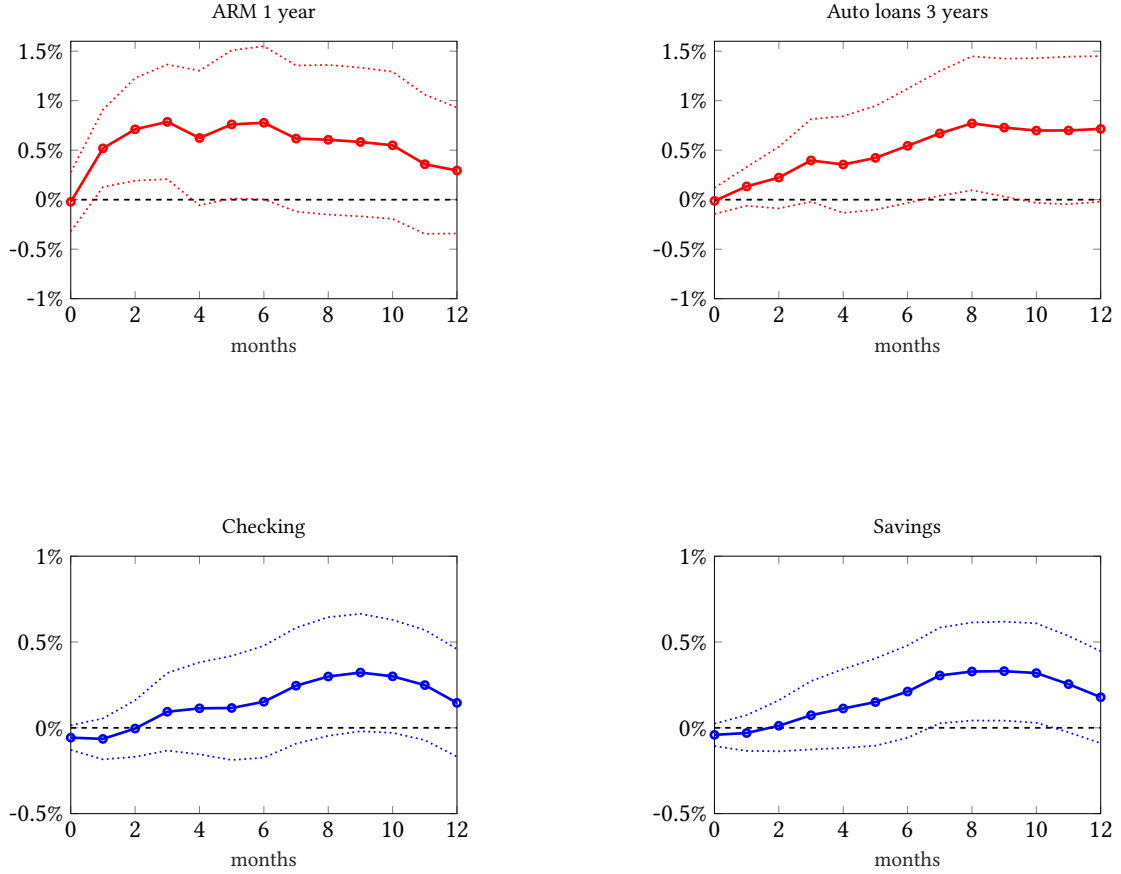
Next, I estimate whether the *short-run* pass-through of monetary shocks to retail rates (at a 1-year horizon) depends on the level of interest rates. I use Jordá (2005)'s local projection method and estimate the following regressions equations at horizons  $h = 0, \dots, 12$  months:

$$y_{b,t+h} - y_{b,t-1} = \alpha_{b,h} + \delta_{1h}\Delta_t + \delta_{2h}i_{t-1} + \beta_h\Delta_t \times i_{t-1} + \gamma_h\text{controls}_{b,t-1} + \epsilon_{b,t+h} \quad (2)$$

Dependent variables  $y_b$  are the branch-level retail rates on various types of deposits and loans. Regressors include branch fixed effects  $\alpha_{b,h}$  for each horizon, monthly monetary shocks  $\Delta_t$  from Nakamura and Steinsson (2018), normalized to have a +100 bps impact effect on the 1-year Treasury rate after 12 months. I control for 4 lags of retail and Treasury rates, and in order to isolate the role of the level of interest rates from that of cyclical conditions, I also interact unemployment with the shock. Since the economy might have been affected by other changes (for instance demographic changes as in Wong 2018, or higher concentration in the banking sector), I control for interactions between linear and quadratic time trends and the shock.

The sequence of estimates  $\{\hat{\beta}_h\}_{h=0,\dots,12}$  traces out the *relative impulse response* of retail rates  $y_{b,t+h}$  to a monetary shock  $\Delta_t$  when the shock takes place at a 100 bps higher interest rate  $i_{t-1}$ . I find that deposit and loan pass-through is lower when the interest rate is lower. Figure 2 displays the results for two types of short-maturity loans ("ARM 1 year" is the fixed rate for the first year on adjustable-rate mortgages; "3-year auto loans" is the rate on auto loans for new vehicles; and two types of deposits, checking and savings deposits). The estimates  $\{\hat{\beta}_h\}_{h=0,\dots,12}$  are above zero

**Figure 2:** Additional pass-through (in percentage points) of a monetary shock to retail rates when the 1-year rate is 100 bps higher.



*Note:* The regression equations are  $y_{b,t+h} - y_{b,t-1} = \alpha_{b,h} + \delta_{1h}\Delta i_t + \delta_{2h}i_{t-1} + \beta_h\Delta_t \times i_{t-1} + \gamma_h \text{controls}_{b,t-1} + \epsilon_{b,t+h}$  for each horizon  $h$ . The figures show the sequences  $\{\hat{\beta}_h\}_{h=0,\dots,12}$  with 90% confidence bands. Standard errors are two-way clustered by branch and month. Sources: Federal Reserve and RateWatch.

in all cases, although the two-way clustered standard errors (by branch and month) are fairly large due to the short sample of my data on retail rates. The pass-through of monetary shocks to retail rates is thus higher at higher rates, for both loans and deposits. These results suggest that the transmission of monetary policy to the rates faced by borrowers and savers is weakened in a low rate environment. In the rest of the paper, I will use the model to provide an explanation for this pattern, and to draw implications for the real effects of monetary policy.

**Robustness.** In Online Appendix A, I conduct several robustness tests. I first show that while the pass-through of policy rates to retail rates is asymmetric (and differently for loan and deposit rates, as we would expect), the results are not driven by asymmetric pass-through, because interest rate hikes are not more likely at low rates in my sample. Second, I show that the same

results hold when using raw changes in the 1-year Treasury rate  $\Delta i_t = i_t - i_{t-1}$  instead of Nakamura and Steinsson (2018)’s monetary shocks as independent variable. It is common in standard pass-through regressions (for instance in the exchange rate pass-through literature, surveyed by Burstein and Gopinath 2014) to use changes in the policy variable of interest instead of identified shocks to this variable, to inform about raw correlations instead of “causal effects”. Third, as emphasized by Nakamura and Steinsson (2018), high-frequency identification may capture not only monetary policy shocks, but also release of the Fed’s information about macroeconomic variables. I show that using Romer and Romer (2004)’s shocks (extended until the end of 2013), constructed as the residuals of a regression of the Fed funds rate on the Fed’s Greenbook forecasts, yields similar results for loans.<sup>15</sup> Fourth, I confirm that the results are not solely driven by the zero lower bound period, by showing that the same results hold when truncating the sample in 2007, although the standard errors are wider since the main source of variation comes from a single recession, in 2001. Finally, I find that in the cross-section of branches, the pass-through of monetary shocks is also higher at branches with higher interest rates  $y_{b,t-1}$ , controlling for variation in national interest rates and other aggregate variables through time fixed effects.<sup>16</sup>

### 3 A model of banks, credit, and liquidity

I now present a model of financial intermediation between heterogeneous agents that can explain the stylized facts described in Section 2. The key idea is that the two sources of bank income, liquidity premia and credit spreads, are entangled through financial constraints, and that falling interest rates affect these two spreads differently.

*Overview of the model.* Time is discrete  $t = 0, 1, \dots$ . Banks are firms that intermediate funds between two types of households, “borrowers” and “savers”. On the asset side, banks can hold bonds or finance loans of arbitrary maturity to borrowers, while on the liability side they can issue bonds or short-term deposits. Households can save in bonds, deposits or cash. Relative to bonds, cash and deposits provide liquidity services. Monetary policy sets the nominal interest rate on bonds, while the rates on loans and deposits adjust endogenously. Spreads between loans and bonds and bonds and deposits can persist because banks are subject to financial constraints.

<sup>15</sup>Recent methods (e.g., Miranda-Agrippino and Ricco, 2018) combine the Romer and Romer (2004) and high-frequency identification strategies by residualizing high-frequency shocks on Greenbook forecasts. Unfortunately my sample is too short and estimates become too imprecise under this combined approach.

<sup>16</sup>The corresponding regression equations are  $y_{b,t+h} - y_{b,t-1} = \alpha_{b,h} + \delta_{t,h} + \beta_h y_{b,t-1} \Delta_t + \gamma_h \text{controls}_{b,t-1} + \epsilon_{b,t+h}$ . The same results within banks, if we use bank-time fixed effects  $\delta_{B,t,h}$  instead. While it is common to use cross-sectional estimates as targeted moments, I will abstract from bank heterogeneity in my theoretical analysis because the large number of ways to make banks heterogeneous makes the mapping from cross-sectional to aggregate effects highly sensitive to misspecification.

### 3.1 Environment

**Firms and technology.** I simplify the non-financial side of the economy as much as possible. Competitive firms produce the final good  $Y$  from labor  $N$  with a linear technology  $A$ :

$$Y_t = A_t N_t.$$

**Assets.** The available assets are short-term bonds with face value  $a_t$ , money  $m_t$ , short-term bank deposits  $d_t$ , and bank loans  $l_{t,t+k}$  with maturity  $k \in \{1, 2, \dots, K\}$ . Let  $R_t$ ,  $R_t^d$  and  $R_{t,t+k}^l$  be the respective real gross returns on bonds, deposits and loans with maturity  $k$ . The corresponding (real) asset prices at date  $t$  are denoted  $q_t = \frac{1}{R_t}$ ,  $q_t^d = \frac{1}{R_t^d}$  and  $q_{t,t+k}^l = \frac{1}{R_{t,t+k}^l}$ . For the special case of short-term loans I simply write  $R_t^l = R_{t,t+1}^l$ . The real return on money  $R_t^m$  is the inverse of inflation,  $R_t^m = \frac{P_t}{P_{t+1}}$ .<sup>17</sup> Net inflation is  $\pi_{t+1} = \frac{P_{t+1}}{P_t} - 1$ . The net nominal rate on bonds is  $i_t = \frac{R_t}{R_t^m} - 1$ . For consistency, I express all rates in real terms.<sup>18</sup>

There is no risk, but assets can be imperfect substitutes for two reasons. First, different assets are associated with different borrowing constraints. For instance, bank-dependent borrowers are able to short loans but not bonds; and households can place their savings in bonds and deposits but not in loans directly—only banks have the expertise to manage loans. Second, money and deposits are not only valued for their pecuniary returns, but also for the transaction services they provide.

**Households.** Households come in two types that differ in their preferences, in the pattern of their labor endowments, and in their financial constraints. “Savers” are unconstrained households that can be viewed as also incorporating all the borrowers in the economy who do not depend on banks. “Borrowers” are *defined* as the bank-dependent borrowers.

*Savers.* There is a mass  $\mu^s = 1$  of infinitely-lived savers. Each saver is endowed with  $\bar{n}^s$  unit of labor in each period, and supplies labor inelastically. Savers have a discount factor  $\beta$ , and value consumption and liquidity services from money  $m$  and deposits  $d$ . They solve

$$\begin{aligned} \max_{c_t, a_{t+1}, m_{t+1}, d_{t+1}} \quad & \sum_{t=0}^{\infty} \beta^t [u(c_t) + v(x(m_t, d_t))] \\ \text{s.t.} \quad & c_t + \frac{a_{t+1}}{R_t} + \frac{m_{t+1}}{R_t^m} + \frac{d_{t+1}}{R_t^d} \leq w_t \bar{n}^s + a_t + m_t + d_t + \text{Div}_t + T_t^s. \end{aligned}$$

<sup>17</sup>Buying  $m_{t+1}$  units of real money maturing at date  $t+1$  at date- $t$  price  $q_t^m$  costs a nominal amount  $M_t \equiv P_t q_t^m m_{t+1}$  at date  $t$  thus  $\frac{M_t}{P_t} = q_t^m \frac{M_t}{P_{t+1}}$ .

<sup>18</sup>Whether financial assets are real or nominal is irrelevant until Sections D and 5.3 where I consider unanticipated monetary shocks.

Every budget constraint will be expressed in real terms.  $w_t$  is the real wage,  $\text{Div}_t$  are aggregate net bank dividends (see below) and  $T_t^s$  are lump-sum transfers from the government. Under flexible prices, non-financial firms make no profits; in Section 5, I will describe the distribution of the profits that arise with nominal rigidities.

A central ingredient of the model is the demand for public liquidity (money  $m$ ) and private liquidity (deposits  $d$ ) that arises from the aggregator  $x$ .

**Assumption 1** (Liquidity). *The aggregator  $x(m, d)$  is strictly increasing, homothetic, differentiable, and concave. There is no satiation in liquidity, i.e.  $v'(x) > 0$  for any  $x$ .*

*Borrowers.* To generate loan demands while limiting the number of state variables, I assume that borrowing from banks is entirely driven by household lifecycle motives.<sup>19</sup> To capture different loan maturities, I use a “preferred habitat” framework: there are overlapping generations of borrowers, who are heterogeneous with respect to the maturity of the loans they need. At each date  $t$ , a mass  $\mu_k$  of borrowers, indexed by their life span  $k \in \{1, \dots, K\}$ , is born. Each borrower of type  $k$  lives only at two dates,  $t$  and  $t + k$ , and is endowed with  $\bar{n}^{y,k}$  units of labor when young, and  $\bar{n}^{o,k}$  units when old. Borrowers of type  $k$  born at date  $t$  have utility

$$u(c_t^{y,k}) + \beta^k u(c_{t+k}^{o,k}).$$

The following financial friction gives a role to banks’ asset side:

**Assumption 2** (Credit frictions). *Borrowers cannot short bonds and must borrow through loans.*<sup>20</sup>

By selling loans  $l_{t+k}$  due when old at  $t + k$ , borrowers receive an amount  $\frac{l_{t+k}}{R_{t,t+k}^l} \geq 0$  when young.<sup>21</sup> They solve

$$\begin{aligned} \max_{c_t^{y,k}, c_{t+k}^{o,k}, l_{t,t+k}} \quad & u(c_t^{y,k}) + \beta^k u(c_{t+k}^{o,k}) \\ \text{s.t.} \quad & c_t^{y,k} \leq w_t \bar{n}^{y,k} + \frac{l_{t+k}}{R_{t,t+k}^l} \\ & c_{t+k}^{o,k} \leq w_{t+k} \bar{n}^{o,k} - l_{t+k} \\ & l_{t+k} \geq 0. \end{aligned}$$

The last constraint states that borrowers can only borrow, and not lend, through loans—only banks can lend. Borrowers could save by buying bonds, but they will not in equilibrium, so

<sup>19</sup>I consider investment in Online Appendix F.3.

<sup>20</sup>Assumption 2 could be relaxed by allowing bond issuance subject to a borrowing constraint. Once the bond constraint binds, marginal borrowing is in the form of loans so nothing changes.

<sup>21</sup>For clarity I switch sign convention for  $l$  between banks and borrowers.

in what follows I ignore this possibility to ease notation. I also shut down any fiscal transfer to borrowers to avoid having the government play the role of a financial intermediary able to alleviate constraints on the flow of funds between private agents.

The total endowment of labor is constant equal to 1:

$$\sum_{k=1}^K \mu_k \left( \bar{n}^{y,k} + \bar{n}^{o,k} \right) + \mu^s \bar{n}^s = 1.$$

**Banks.** I follow closely the workhorse model of banks developed by Gertler and Kiyotaki (2010) with two important differences. First, here banks are not only specialists in credit provision, but also play a role through their deposit claims which are valued for their liquidity. Second, I allow for the long-term loans described above, as maturity mismatch is central to understand the impact of monetary policy on banks. Long-term loans will play no particular role until Section 5.3, but I introduce them now to provide a complete model.

There is a unit mass of banks. Banks are owned by savers but operated by bankers. The vectors  $\mathbf{l}^t$  and  $\mathbf{q}_t^l$  represent respectively the loan portfolio at the beginning of date- $t$  and the price of loans maturing at  $t, t+1, \dots, t+K$ :

$$\mathbf{l}^t \equiv \{l_{t+k}\}_{k=0}^{K-1}, \quad \mathbf{q}_t^l \equiv \{q_{t,t+k}^l\}_{k=0}^K$$

with  $q_{t,t}^l \equiv 1$ . The equity, or capital, of a bank  $i \in [0, 1]$  with a portfolio  $[a_t(i), d_t(i), \mathbf{l}^t(i)]$  at the beginning of period  $t$  is

$$e_t(i) \equiv \mathbf{q}_t^l \cdot \mathbf{l}^t(i) + a_t(i) - d_t(i) \quad (3)$$

$e_t$  is the *marked-to-market book value* of equity (and not the market value, in the sense that it does not capitalize future profits); note that the relevant asset prices to discount future loan payoffs and hence book equity are loan prices, inclusive of potential future spreads. Aggregate bank equity at the beginning of period  $t$  is  $E_t = \int_0^1 e_t(i) di$ . The following assumption determines the process for bank dividends:

**Assumption 3** (Bank dividends). *In each period, a mass  $\rho$  of banks exits and a mass of banks  $\rho$  enters, each of them with exogenous startup equity  $\zeta_t E_t / \rho$ . Each exiting bank sells its loan portfolio to remaining banks and then rebates its equity to the representative saver. Net payouts are high enough for banking to be relevant in steady state:  $\rho - \zeta > 1 - \beta$ .*

Thus aggregate net dividends are

$$\text{Div}_t = (\rho - \zeta_t) E_t.$$

Online Appendix F.1 endogenizes  $\zeta_t$  with a model of costly equity issuance.

In equilibrium, non-satiation of liquidity services from deposits implies that there will be a positive deposit spread ( $R_t > R_t^d$ ) for any finite level of deposits.<sup>22</sup> Therefore in equilibrium it is optimal for banks to only issue the cheapest kind of liability, deposits, and never issue bonds (interpreted as “wholesale funding”). Hence banks’ bond holdings  $a_{t+1}$  will always be non-negative. Moreover, since banks are the only potential “buyers” of loans, equilibrium in the loan market requires banks to hold long positions in loans ( $l_{t+k}^{t+1} \geq 0$  for all  $k$ ).

As long as there is a positive deposit spread, it is optimal for banks to issue more deposits and invest the proceeds in bonds or loans to take advantage this spread. Without any further assumption, there would be no equilibrium when liquidity from utility cannot be satiated, since banks would then want to issue an infinite amount of deposits. There are essentially two ways to rationalize the coexistence of a positive deposit spread and a finite amount of deposits that we observe in the data. One is to assume, as in most of the macro-finance literature, that banks face a leverage constraint that prevents them from increasing the size of their balance sheet as much as they would like. The other is to assume, as in Drechsler et al. (2017), that the deposit market is imperfectly competitive, and banks willingly restrict the supply of deposits in order to earn higher profits. In my baseline model, I focus on the leverage constraint friction. Appendix 4.3 considers the case of deposit market power as well as a hybrid case with both market power and a leverage constraint.

Leverage  $\phi_t$ , defined as the ratio of liabilities over equity:

$$\phi_t = \frac{\sum_k q_{t,t+k}^l \max\{0, -l_{t+k}^{t+1}\} + q_t \max\{0, -a_{t+1}\} + q_t^d \max\{0, d_{t+1}\}}{e_{t+1}}.$$

Active banks take as given the discount factor  $q_t = \frac{\beta u'(c_{t+1}^s)}{u'(c_t^s)}$  and maximize expected discounted dividends, solving:

$$\begin{aligned} V_t(e_t) &\equiv \max_{a_{t+1}, d_{t+1}, l^{t+1}} q_t \{\rho e_{t+1} + (1 - \rho) V_{t+1}(e_{t+1})\} \\ \text{s.t.} \quad & \mathbf{q}_t^l \cdot \mathbf{l}^{t+1} + q_t a_{t+1} = e_t + q_t^d d_{t+1} \\ & e_{t+1} = \mathbf{q}_{t+1}^l \cdot \mathbf{l}^{t+1} + a_{t+1} - d_{t+1} \\ & \phi_t \leq \bar{\phi}_t \end{aligned}$$

where equity  $e_t$  is given by (3) for incumbent banks and  $e_t = \zeta_t E_t / \rho$  for new banks, and  $\bar{\phi}_t$  is the

<sup>22</sup> Adding the possibility of satiation would require considering more regimes, depending on whether the equilibrium amount of deposits is above or below the satiation level. Since I focus on positive nominal interest rates, this complication would bring no further insight. However, the possibility of satiation is an important ingredient when analyzing the case of negative rates, as discussed thoroughly in Rognlie (2016).

maximal leverage ratio. I will assume that the maximal leverage ratio  $\bar{\phi}_t$  stems from a limited pledgeability constraint, either due to a moral hazard problem or a perceived risk of run:

**Assumption 4** (Limited pledgeability). *At date  $t$ , banks can only pledge a fraction  $\theta \in [0, 1]$  of date- $t + 1$  assets to cover their liabilities.*<sup>23</sup>

**Lemma 1.** *In equilibrium, the leverage constraint is always binding,  $\phi_t = \bar{\phi}_t$ , with  $\phi_t = \frac{q_t^d d_{t+1}}{e_t}$  and*

$$\bar{\phi}_t = \frac{\theta R_t^l / R_t^d}{1 - \theta R_t^l / R_t^d}. \quad (4)$$

*Proof.* In the banks' program, loans of different maturities are perfectly substitutable, which implies that the expectation hypothesis for loan rates must hold in equilibrium:  $R_{t,t+k}^l = \prod_{j=0}^{k-1} R_{t+j}^l$ .<sup>24</sup> Since, in addition, deposits are the only liability, leverage simplifies to  $\phi_t = \frac{q_t^d d_{t+1}}{e_t}$ . Since the deposit spread is always positive, i.e.  $q_t^d > q_t$ , the leverage constraint must be binding in equilibrium. Combining this with the expectation hypothesis then gives an expression for the maximal leverage ratio (4) where only the *short-term* loan rate appears.  $\square$

Thus a higher spread between the short-term loan rate  $R_t^l$  and the deposit rate  $R_t^d$  relaxes the bank leverage constraint at  $t$  by making more interest income pledgeable to cover less interest expense at  $t + 1$ . This captures a positive dependence of bank lending capacity in current profits. I discuss banks' constraints in theory and in practice in Section 3.5.

*Banks' excess returns.* The dynamics of bank capital are governed by the return on bank equity  $\text{ROE}_t$ , defined as

$$\text{ROE}_t = \frac{E_{t+1}}{E_t - \text{Div}_t}. \quad (5)$$

If there are excess returns  $\text{ROE}_t - R_t \geq 0$ , as will be the case in equilibrium, it is optimal for banks to delay dividends until exit. We can reexpress banks' budget constraints using the expectation hypothesis for loan rates to obtain the key equation:

$$\text{ROE}_t - R_t = \underbrace{\bar{\phi}_t (R_t - R_t^d)}_{\text{excess return from liquidity provision}} + \underbrace{(1 + \bar{\phi}_t) (R_t^l - R_t)}_{\text{excess return from credit provision}}. \quad (6)$$

The excess return on equity is the sum of two terms, reflecting the two distinct intermediation activities performed by banks. On the one hand, the excess return from deposit liquidity creation

<sup>23</sup>The same pledgeability parameter  $\theta$  applies to all assets; one could assume that bonds are more pledgeable than loans, but this would only introduce an additional wedge between bonds and loans without changing any result below.

<sup>24</sup>Equivalently, asset prices satisfy  $q_t^l = q_{t,t+1}^l q_{t+1}^l$ .

is equal to the spread  $R_t - R_t^d$  leveraged by a factor  $\phi_t$ ; on the other hand, banks can earn an excess return from the spread  $R_t^l - R_t$  on loans, leveraged by a factor  $1 + \phi_t$ .<sup>25</sup> I define loan and deposit spreads as follows, with the convention that both spreads are non-negative:

**Definition 1.** *The date- $t$  loan spread is  $\tau_t^l = \frac{R_t^l - R_t}{R_t}$ , and the date- $t$  deposit spread is  $\tau_t^d = \frac{R_t - R_t^d}{R_t}$ .*

If savers could freely arbitrage between bonds and bank equity, they would demand more equity as long as there are excess returns, bringing down  $ROE_t$  to  $R_t$  in equilibrium. In my baseline model, net dividends are exogenous from Assumption 3, so the return on equity can dominate the real interest rate. Section F.1 will consider the intermediate case of costly equity issuance.

**Monetary and fiscal policy.** The central bank implements uniquely (for instance through a Taylor rule) a sequence of nominal rates  $\{i_t\}_{t \geq 0}$ . I begin with a traditional implementation based on household money demand: given an initial price level  $P_0 > 0$  we can back out the implied sequence of money supply  $\{M_t\}_{t \geq 0}$ .

The seigniorage revenue from outside money creation is rebated lump-sum, in the same period, to savers, who are the ones who pay for it. This ensures that monetary policy does not imply a mechanical redistribution from savers to borrowers. As a result of the transfer rules and the fact that only savers and borrowers hold bonds in equilibrium, Ricardian equivalence holds regarding the timing of transfers  $\{T_t^s\}$ , and I assume without loss of generality that the government runs a balanced budget

$$T_t^s = (1 + \pi_{t+1}) m_{t+1} - m_t, \quad (7)$$

where  $m_t$  are the equilibrium real money balances and  $\pi_{t+1}$  is the net inflation rate from  $t$  to  $t + 1$ . Therefore bonds are in zero net supply.

## 3.2 Equilibrium

I start with a standard equilibrium concept that assumes flexible prices and full employment. The flexible prices equilibrium is suitable for studying long-run issues; I will introduce nominal rigidities in Section 5 to address short-run issues and highlight where the financial frictions interact with or alter the traditional New Keynesian channel of monetary policy transmission.

Let  $\mathbf{L}^t = \{L_{t+k}^t\}_{k=0}^{K-1}$  be the aggregate stock of loans outstanding at the beginning of period  $t$ .  $L_{t+s}^t$  is the sum of individual loan positions  $l_{t+k}$  over banks that are active at  $t - 1$ . The economy has  $K + 2$  aggregate state variables, summarized in the vector  $\mathbf{Z}_t = [a_t^s, D_t, \mathbf{L}^t]$ .

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<sup>25</sup>If the spread  $R_t^l - R_t$  is positive, then banks hold no bonds on the asset side and  $\frac{q_t^l \cdot l_{t+1}^{l+1}}{e_t} = 1 + \bar{\phi}_t$ ; otherwise, if  $\frac{q_t^l \cdot l_{t+1}^{l+1}}{e_t} < 1 + \bar{\phi}_t$ , then the spread is zero and the expression still holds.

**Definition 2** (Flexible prices equilibrium). *Given initial conditions  $Z_0$ , a path for monetary policy  $\{R_t^m\}_{t \geq 0}$  and an initial price level  $P_0 > 0$ , a flexible prices equilibrium is a sequence of allocations  $\{\{c_t^i\}_i, Z_t, m_t\}_{t \geq 0}$ , real wages  $\{w_t\}_{t \geq 0}$  and rates  $\left\{R_t, R_t^d, \left\{R_{t,t+k}^l\right\}_{k=1}^K\right\}_{t \geq 0}$  such that firms, households and banks optimize, and markets for goods and all assets clear.*

The equilibrium is fully characterized by equations (21) to (35) in Online Appendix B.3. From now on, I assume

$$u(c) = \log c, \quad v(x) = \chi \log x$$

to simplify expressions. My results can be obtained with more general CRRA preferences that may differ for borrowers and savers, as long as loan demand curves slope down.<sup>26</sup> I now discuss the two key markets in this model: the market for liquidity, and the market for loans.

### 3.3 Liquidity side: competition between public and private liquidity

In addition to their intertemporal consumption-savings problem, solved by the standard Euler equation  $u'(c_t^s) = \beta R_t u'(c_{t+1}^s)$ , savers face a static optimal liquidity demand problem. The optimal aggregate deposit demand conditional on savers' future consumption  $c_{t+1}^s$  is:

$$\mathcal{D}_{t+1}(s_t^d, i_t, c_{t+1}^s) = \frac{x_d\left(f\left(\frac{s_t^d}{i_t}\right), 1\right)}{s_t^d x\left(f\left(\frac{s_t^d}{i_t}\right), 1\right)} \chi c_{t+1}^s, \quad (8)$$

where the optimal money-deposit ratio  $\frac{m_{t+1}}{d_{t+1}} = f\left(\frac{s_t^d}{i_t}\right)$  increases with  $\frac{s_t^d}{i_t}$ , and  $s_t^d = \frac{q_t^d - q_t}{q_t}$ . From now on, I assume that the two forms of liquidity are sufficiently close substitutes:

**Assumption 5** (Gross substitutes). *Money and deposits are gross substitutes, in the sense that  $\frac{x_d(f,1)}{x(f,1)}$  is non-increasing in  $f$ .*

Under Assumption 5, deposit demand  $\mathcal{D}$  is not only decreasing in the price of deposit liquidity  $s_t^d$ , but also increasing in the price of the competing liquidity, which is the nominal interest rate  $i_t$ .<sup>27</sup> Holding deposit supply fixed, a lower nominal rate thus leads to a decline in  $s_t^d$  and hence a decline in the deposit spread  $\tau_t^d$  that governs banks' excess return in (6). In Section 4, I will show the implications of this competition once we endogenize the supply of private liquidity (through the dynamics of bank capital) and combine it with equilibrium in loan markets.

<sup>26</sup>Calling  $\sigma_b$  borrowers' EIS, the condition is  $\frac{1/\sigma_b - 1}{G^{k/\sigma}} \leq \frac{\gamma^{y,k}}{\beta^k \gamma^{o,k}}$  for all  $k \geq 1$ . A sufficient condition is  $\sigma_b \geq 1$ .

<sup>27</sup>I have expressed the condition when  $v(x) = \chi \log x$ . In the more general case  $v(x) = \chi \frac{x^{1-\frac{1}{\omega}}}{1-\frac{1}{\omega}}$ , money and deposits are gross substitutes if  $\frac{x_d(f,1)}{x(f,1)^{1/\omega}}$  is non-increasing in  $f$ .

**Figure 3:** Bank balance sheet in the two regimes

| Assets                  |          | Liabilities   |
|-------------------------|----------|---------------|
| $(1 + \bar{\phi}_t)e_t$ | Bonds    | Deposits      |
|                         | $k = 1$  |               |
|                         | $k = 2$  |               |
|                         | $\vdots$ | Capital $e_t$ |

(a) Unconstrained lending

| Assets                  |          | Liabilities   |
|-------------------------|----------|---------------|
| $(1 + \bar{\phi}_t)e_t$ | $k = 1$  | Deposits      |
|                         | $k = 2$  |               |
|                         | $\vdots$ |               |
|                         |          | Capital $e_t$ |

(b) Constrained lending

### 3.4 Credit side: two regimes of bank lending

Combining banks' budget and leverage constraints, we have that new equilibrium lending at  $t$  is bounded above by banks' lending capacity  $\Lambda_t$ :

$$\underbrace{\sum_{k=1}^K q_{t,t+k}^l (L_{t+k}^{t+1} - L_{t+k}^t)}_{\text{new loans}} \leq \Lambda_t \equiv (1 + \bar{\phi}_t) (L_t^t - D_t - \text{Div}_t) + \bar{\phi}_t \sum_{k=1}^{K-1} q_{t,t+k}^l L_{t+k}^t. \quad (9)$$

At any date  $t$  the economy can be in one of two regimes. Importantly, in both cases, banks' leverage constraint binds, because banks want to issue as many deposits as possible; the regimes differ through the equilibrium in the loan market.

In the *unconstrained lending* regime, the demand for new loans is lower than banks' lending capacity at date  $t$ . Bonds and loans must then be perfect substitutes from the banks' viewpoint, and there is no credit spread, i.e.,  $R_t^l = R_t$ .

In the *constrained lending* regime, the inequality (9) binds. Date- $t$  credit demand would exceed banks' lending capacity if the ongoing loan rate were  $R_t$ , thus a spread has to open up to clear the credit market, i.e.,  $R_t^l > R_t$ . Bank balance sheets in the two regimes are depicted in Figure 3. All else equal, lower equity will shrink the size of banks' balance sheets and push the economy into the constrained lending regime, which is key to give a macroeconomic role to banks. Indeed, absent binding credit frictions in equilibrium, a classical dichotomy holds:

**Proposition 1** (Classical dichotomy). *Suppose that in equilibrium bank lending is unconstrained at all times. Then equilibrium consumptions are the same as in a model without liquidity frictions, i.e., with  $v(x) = 0$ .*

When bonds and loans are perfect substitutes, the imperfect substitutability between bonds and deposits is irrelevant for consumption allocations. This dichotomy results from two facts:

first, liquidity services  $v(x)$  are separable from consumption utility  $u(c)$ . Second, both public and private seigniorage revenues are rebated lump-sum in proportion to their usage. The private seigniorage from deposits ends up being rebated to savers through bank dividends. It is well known that non-separable liquidity services or redistribution of seigniorage can generate non-neutrality in the long run. I show below that in the constrained lending regime, non-(super)neutrality arises endogenously through the banking sector's dual role as credit and liquidity provider.

### 3.5 Discussion of the main assumptions

**Household demand for liquidity.** Directly putting liquidity services in the utility is the simplest way to generate a demand for assets with dominated return; another route would be to explicitly model transaction frictions, but many such models (e.g., cash-in-advance constraints) are isomorphic to assuming liquidity in the utility (Feenstra 1986). I follow Chetty (1969), Poterba and Rotemberg (1987), and more recently Nagel (2016) and Di Tella and Kurlat (2017) who all incorporate two substitutable forms of liquidity through an aggregator  $x$ . In the background,  $x$  might stand for inattentive depositors or search costs (see Driscoll and Judson 2013, Yankov 2014, Drechsler et al. 2017). In Online Appendix B.2, I provide a cash-credit microfoundation for  $x$  as in Lucas and Stokey (1987).

**Bank leverage constraint.** Limited pledgeability à la Holmström and Tirole (1997) is just one of many possible microfoundations for banks' leverage constraint; but different microfoundations will only differ in the exact form of the cap  $\bar{\phi}_t$  on leverage. For instance, a limited commitment constraint as in Gertler and Kiyotaki (2010) would impose that bankers not wish to run away with a fraction  $\theta$  of the value of assets at  $t$ . This constraint would lead to a maximal leverage ratio  $\bar{\phi}_t = \frac{v_t}{\theta} - 1$  where  $v_t \equiv \frac{V_t}{e_t}$  is the market-to-book ratio, that capitalizes not only current profits, as in the constraint I use, but also the whole stream of future profits. At the other extreme, we could also assume a fixed regulatory leverage ratio  $\bar{\phi}$  that does not depend on profitability.<sup>28</sup>

**Bank balance sheets.** Banks' balance sheets are highly simplified relative to reality: on the liability side, all funding (in particular the marginal funding) is through deposits and there is

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<sup>28</sup>In practice, banks face a wide range of regulatory constraints: Greenwood, Stein, Hanson and Sunderam (2017) list at least ten, with different constraints binding for different banks. Some of those constraints, most clearly the capital charges implied by the Comprehensive Capital Analysis and Review (CCAR) and Dodd-Frank Act stress tests, are directly relaxed by a higher net interest margin through higher "pre-provision net revenue". Finally, capital requirements are based on a mix of market equity values and book equity values (both historical cost book equity and mark-to-market book equity), which means that bank lending capacity indeed depends on the value of long-term assets; see Fuster and Vickery (2018) for a recent discussion.

no wholesale (bond) funding; on the asset side, banks hold no bonds in the constrained lending regime. From the perspective of bank profitability, the balance sheets displayed in Figure 3 can be viewed as netting out securities held on the asset side and wholesale funding on the liability side, as both would pay the same bond rate and earn no excess return. These simplifications allow me to zoom in on the synergies between the lending and deposit-taking businesses, but have two (related) implications at odds with the data: first, in the constrained lending regime, banks only hold loans on the asset side; second, deposit supply shrinks together with bank equity as interest rates fall. Section 4.3 and Appendix E discusses how to make the model more realistic on that front by adding deposit market power a la Drechsler et al. (2017).

**Firm borrowing.** The baseline model assumes that financial flows only take place between households. Another possibility would be to have constrained firms borrowing from households in order to invest.<sup>29</sup> In Online Appendix F.3, I consider a variant of the model where bank loans finance firm investment, thus capital and GDP are affected by financial frictions.

## 4 Low interest rates and long-run intermediation spreads

In this section, I solve for stationary flexible price equilibria and derive comparative statics with respect to long-run trends in interest rates. The main results are that a permanent decline in the nominal interest rate compresses deposit spreads but widens loan spreads due to a fall in bank loan supply. Holding inflation fixed, a lower  $r^*$  can thus explain the incomplete long-run pass-through I documented in Section 2.1, while a higher inflation target can have real effects through the banking sector.

### 4.1 Steady state

I suppose that productivity (hence output) grows at a constant gross rate  $G$  and consider steady states (also known as balanced growth paths). A steady state is defined as an equilibrium where real quantities divided by output  $Y_t$  and asset prices are constant. Quantities without time subscripts are normalized by  $Y_t$ , i.e.,  $x \equiv \frac{x_t}{Y_t}$ . I only consider steady states with positive bank equity and ignore the unstable “financial autarky” steady state with  $E = 0$ . I describe the most important

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<sup>29</sup>I take the household route for several reasons. It allows me to abstract from the dynamics of *physical* capital, in line with the basic New Keynesian model, and maintain an exogenous natural output. Moreover, there is a growing literature on the importance of household borrowing (Mian, Rao and Sufi, 2013); and while small firms are mostly bank-dependent borrowers, large firms have access to liquid corporate bond markets, but no household can issue securities.

steady state equilibrium conditions. Savers' Euler equation pins down the steady state interest rate  $R^* = \frac{G}{\beta}$ . The main steady state equation is then the stationary version of (6):

$$\frac{ROE}{R^*} = 1 + (1 + \bar{\phi}) \tau^l + \bar{\phi} \tau^d. \quad (10)$$

Equation (10) states that the steady state excess return on equity must be sustained by a combination of leverage, loan spreads, and deposit spreads. The terms  $\bar{\phi}$ ,  $\tau^l$  and  $\tau^d$  are all endogenous to the steady state level of bank capital  $E$ . In an unconstrained lending steady state, the deposit spread is high enough that no credit spread is needed to attain the required return on equity, so the right-hand side reduces to  $1 + \bar{\phi} \tau^d$ . In a constrained steady state, a positive credit spread must open up.<sup>30</sup> From (5), the steady state return on bank equity is  $ROE = \frac{G}{1-\rho+\zeta}$  and therefore

$$\frac{ROE}{R^*} = \frac{\beta}{1 - \rho + \zeta}.$$

All else equal, an increase in  $E$  increases the supply of loans. Market clearing for loans then implies a lower credit spread  $\tau^l$ . Similarly, an increase in  $E$  increases the supply of deposits and deposit market clearing implies that the equilibrium price of deposits, i.e., the deposit spread  $\tau^d$ , must be lower as  $E$  increases. As a result, the leverage ratio  $\bar{\phi}$  is also a decreasing function of  $E$ . The right-hand side of (10) is thus a decreasing function of  $E$ , hence (10) uniquely characterizes the steady state capital  $E$ .

## 4.2 The nominal rate and the composition of bank income

I now investigate how the steady state level of the nominal bond rate  $i$  affects intermediation spreads. The nominal rate  $i$  depends on both the real interest rate  $R^*$  and the inflation target. Changes in the real interest rate affect many parts of the economy, so I start with the simpler case of inflation.

**Inflation.** Monetary policy is *superneutral* if steady state consumptions are independent of inflation  $\pi$ . As in any monetary model, monetary policy can directly influence liquidity and its cost in steady state. The question is whether consumption allocations are also affected. In the equilibrium condition (10) that determines  $E$ , the right-hand side is decreasing in  $\pi$  (because the deposit spread  $\tau^d$  is increasing in the nominal rate  $i$ , as explained below). Therefore a higher steady state inflation  $\pi$  shifts the supply of credit up, which results in higher equilibrium bank equity  $E$ . Whether this has an impact on consumptions depends on whether lending is constrained.

<sup>30</sup>Equation (10) is merely an accounting identity that will hold across a wide range of models. Here, there is no risk premium, and the ROE is entirely pinned down by the exogenous exit rate of banks  $\rho$ . But in any model with financial constraints binding in steady state, a similar equation must hold.

From the dichotomy in Proposition 1, we already know that monetary policy is superneutral in an unconstrained lending steady state. In the general case, we have:

**Proposition 2.** *Fixing other parameters and policy  $\pi$ , there exists a threshold  $\bar{\rho}$  such that lending is constrained in steady state if and only if  $\rho > \bar{\rho}$ . If  $x(m, d)$  is not Cobb-Douglas (i.e.,  $m$  and  $d$  are strict gross substitutes), then equivalently there exists a threshold  $\bar{i}(\rho)$  such that lending is constrained if and only if the nominal rate  $i$  is strictly lower than  $\bar{i}(\rho)$ .*

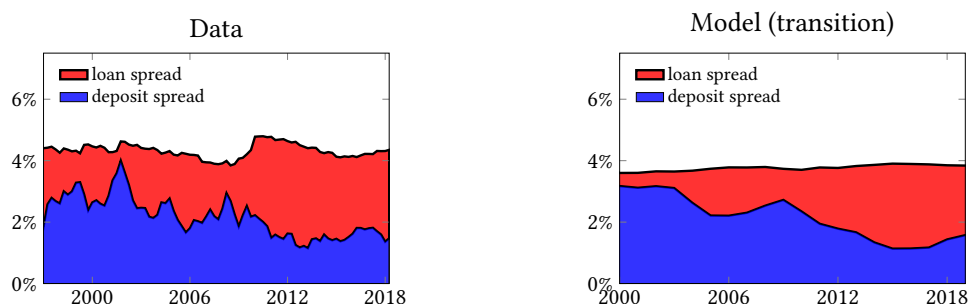
- *When  $i \geq \bar{i}(\rho)$ , monetary policy is superneutral: a local increase in  $\pi$  increases bank capital  $E$  but leaves  $R^*$ ,  $R^d$  and  $R^l$  unchanged.*
- *When  $i < \bar{i}(\rho)$ , a local increase in the inflation target  $\pi$  increases  $E$  and  $\bar{\phi}$ , lowers  $R^d$ , decreases  $R^l$  and leaves  $R^*$  unchanged.*

To understand Proposition 2, we can view the effect of inflation through the lens of public-private competition in liquidity provision. There are two providers: commercial banks and the government. A higher nominal interest rate increases the price of public liquidity, which reduces the competition faced by private liquidity issuers. The steady state private seigniorage earned by banks increases with the nominal interest rate  $i$ . The higher private seigniorage relaxes banks' constraint by boosting retained earnings and fueling a higher bank capital stock, which ends up benefiting bank-dependent borrowers by lowering the loan spread they face. Thus *expected* inflation ends up redistributing from savers to borrowers. Note that superneutrality holds for any  $\rho$  in the knife-edge Cobb-Douglas case because a change in the price of money  $i$  does not affect the total cost of deposits  $s^d D$  paid by savers, so bank balance sheets remain unchanged when the inflation target changes.

The effect of inflation relates to the literature on public liquidity in the form of government bonds. Krishnamurthy and Vissing-Jorgensen (2012; 2015) show that a higher public supply of liquidity in the form of U.S. Treasuries reduces the liquidity premium and crowds out private liquidity creation. Nagel (2016) constructs a measure of the liquidity premium of several near-money assets and shows that it is highly correlated with the nominal interest rate, which indicates a high elasticity of substitution between money and near-money. Greenwood, Hanson and Stein (2015) study the social benefits of this crowding-out when private liquidity creation entails negative pecuniary externalities. Here, public liquidity (currency) also crowds out private liquidity (deposits), but I point out that crowding-out might have a social cost as well, if tighter financial constraints on private liquidity issuers spill over to higher credit spreads.

**Decline in  $R^*$ .** Steady state deposit demand is shifted by the nominal interest rate  $i$ , which depends on both the inflation target and the real interest rate. In practice, central banks target a

**Figure 4:** Model-implied path of spreads from 2000 to 2018.



*Note:* Left panel: Same as figure 1. Right panel: Model-implied loan spread  $\tau^l$  (red) and deposit spread  $\tau^d$  (blue) in response to a 2000 shock to the expected path of real interest rates  $R_t$  that matches the realized rates from 2000 to 2018.

stable level of inflation while the real interest rate  $R^*$  adjusts to changes in the fundamentals of the economy, such as productivity growth and savings rates. Unlike a change in inflation, a change in  $R^*$  also affects  $ROE/R^*$  directly in equation (10), as well as other parts of the economy such as credit demand. If the fall in  $R^*$  is due to lower growth  $G$ ,  $ROE$  and  $R^*$  adjust proportionately, hence  $ROE/R^*$  remains constant. In this case, the shock to  $R^*$  only has an effect on the composition of bank excess returns, exactly as when we varied the inflation target. The response to a change in savings rates, however, depends on banks' payout policy. If the net payout rate  $\rho - \zeta$  adjusts so as to keep  $\frac{ROE}{R^*}$  constant, a discount factor shock has the same effect as a growth shock. Online Appendix F.1 shows that when the net payout rate is endogenous,  $ROE$  indeed falls in response to a lower  $R^*$ .

**Proposition 3** (Lower real rate). *Suppose that either (i) productivity growth  $G$  falls permanently, or (ii) the discount factor  $\beta$  and the rate of retained earnings  $1 - \rho + \zeta$  increase permanently in proportion.*

*Then  $R^*$  falls, and  $ROE/R^*$  is unchanged. In the unconstrained lending regime,  $\tau^d$  and  $\tau^l$  are unchanged. In the constrained lending regime,  $\tau^d$  falls,  $\tau^l$  rises, and leverage  $\bar{\phi}$  falls.*

Figure 4 shows the model-implied paths of loan and deposit spreads in response to a shock to the path of bond rates  $R_t$  taking place in 2000 that matches the realized rates in the U.S. from 2000 to 2018.

**Quantities.** As emphasized by Greenwood and Scharfstein (2013) or Philippon (2015), the U.S. financial sector is not in steady state: bank assets over GDP have been growing steadily from 53% in 1980 to 83% in 2018, likely reflecting a growing demand for intermediation. My model assumes that the economy has reached a balanced growth path with stable intermediation volumes over

GDP, but its predictions regarding these quantities should be interpreted relative to the upward trend due to shifting demand, which can be strong enough to mask the effect of low rates on lending volumes.<sup>31</sup>

For this reason, it is better to focus on the model's predictions about *ratios* of financial stocks (which are closer to being stationary), such as the leverage ratio  $\bar{\phi}$ . The model's results are consistent with U.S. data: the ratio of assets over equity has fallen from 15 in 1990 to 10 in 2006 (and 9 in 2018). Similarly, the ratio of deposits over equity has fallen from 11 in 1990 to 6 in 2006 (and 6.5 in 2018).<sup>32</sup>

### 4.3 Deposit market power

Section E contrasts my model based on scarce equity and a standard model of bank deposit market power and costly wholesale funding that follows Drechsler et al. (2017). I show that such a model cannot generate the same predictions in the short-run (state-dependent pass-through) or in the long-run (rising loan spreads, shrinking deposit spreads), thus for exposition I abstract from imperfect competition in the baseline model. I also study a mixed setting that combines deposit market power and scarce equity: all the main results regarding the behavior of deposit spreads, loan spreads, bank equity and lending remain unchanged. The mixed model is more complex but has the advantage of generating more realistic bank balance sheets than those displayed in Figure 3. In particular, banks can hold bonds or excess reserves even when lending is constrained, in order to target their profit-maximizing deposit supply. This optimal deposit supply increases as low interest rates fall, hence bank balance sheets expand while lending shrinks, which implies that banks' bonds or reserves holdings increase.

### 4.4 The complementarity between deposit-taking and lending

To see why my results depend crucially on the fact that banks are *both* credit and liquidity providers, suppose that instead of having a single institution performing the two functions within the same balance sheet, there are two kinds of intermediaries: specialists in lending such as mortgage companies, with superscript  $l$ , and specialists in liquidity provision such as money market funds or “narrow banks”, with superscript  $d$ . The lending  $l$ -banks finance themselves with bonds at the real interest rate  $R$ , while the  $d$ -banks invest their deposits in bonds. I maintain Section 3's assumptions on banks' limited pledgeability  $\theta$  and payout rate  $\rho$ ; all intermediaries are still owned

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<sup>31</sup>In other countries that have not seen a parallel rise in loan demand as strong as in the U.S., the effects on quantities may be clearer. Indeed, in recent work, Balloch and Koby (2020) find long-run effects of low rates on quantities in Japan consistent with my mechanism: lending volume has declined by more between 1990 and 2017 for banks with a higher 1990 deposit-to-liabilities ratio.

<sup>32</sup>I use 2006 to highlight that these changes have mostly taken place before the post-crisis regulatory reforms.

by savers.<sup>33</sup> Once we decouple the two functions of banks, we recover the classical dichotomy of Proposition 1:

**Proposition 4.** *In the model with two types of banks: (i) both spreads  $\tau^l$  and  $\tau^d$  are higher than with a single bank; (ii) monetary policy is superneutral: steady state spreads  $(\tau^l, \tau^d)$  and consumption allocations are independent of the inflation target; (iii) a change in the growth rate  $G$  has no effect on spreads.*

Lenders  $l$  are insulated from monetary policy and the loan spread only reflects their own required excess return on equity. Since they cannot rely on any private seigniorage earnings to fuel equity accumulation, their equity is lower than the equity of a two-sided bank. A change in the inflation target also leaves the deposit spread  $\tau^d$  unchanged, because the equity of “narrow banks”  $d$  adjusts to completely offset the shift in deposit demand, exactly as in the unconstrained lending regime of Proposition 2.

## 4.5 Extensions

In Online Appendix F I consider several extensions. Section F.1 allows for costly equity issuance. In section F.2, I add operating costs of making loans to capture other components of banks’ return on assets. Section F.3 analyzes the implications of loan spreads when firms use bank loans to finance investment.

## 5 Low interest rates and short-run monetary transmission

The previous section considers how long-run trends in bond rates are passed through to retail rates. In this section, I show how credit and liquidity frictions make the short-run transmission of monetary *shocks* state-dependent. The same forces that yield long-run real effects of monetary policy in Section 4 give rise to short run non-neutrality, even under flexible prices. However, flexible prices imply a *negative* pass-through of nominal bond rates to real lending rates, which is at odds with the data. I therefore add nominal rigidities, thus embedding two-sided banks into a New Keynesian model with heterogeneous agents.

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<sup>33</sup>A more general extension would allow loan providers and deposit issuers to differ in their pledgeability  $\theta$  and net payout rate  $\rho$  parameters; the first part of Proposition 4 would then hinge on a convexity condition involving  $(\theta^l, \rho^l)$  and  $(\theta^d, \rho^d)$ .

## 5.1 Sticky inflation equilibrium

I model nominal rigidities in a tractable way by fixing inflation  $\pi_t$  at some level  $\bar{\pi}$ .<sup>34</sup> With fixed inflation, monetary policy effectively controls the sequence of real bond rates  $\{R_t\}$  by setting the nominal bond rate. Output  $Y_t$  can deviate from its natural level  $Y_t^* = A_t$ , which would prevail if prices were flexible in all periods. Since inflation is sticky, financial assets can be considered as real without loss of generality.

With sticky prices or wages, firms make non-zero profits. The distribution of those profits matters for the consumption behavior of households, and thus for aggregate consumption given the heterogeneity and market incompleteness. Following Werning (2015), instead of separating labor income and profits, I define directly the share  $\gamma_t^i$  of aggregate income  $Y_t$  that accrues to agent  $i$  at date  $t$ . Relative to the baseline model, this amounts to replacing labor endowments  $\bar{n}_t^i$  with  $\gamma_t^i$ . The equilibrium with nominal rigidities is defined as follows:

**Definition 3** (Sticky inflation equilibrium). *Given initial conditions  $Z_0$ , inflation  $\bar{\pi}$ , a path for monetary policy  $\{R_t\}_{t \geq 0}$  and an initial price level  $P_0 > 0$ , a sticky inflation equilibrium is a sequence of allocations  $\{\{c_t^i\}, Z_t, m_t\}_{t \geq 0}$  and rates  $\left\{R_t^d, \left\{R_{t,t+k}^l\right\}_{k=1}^K\right\}_{t \geq 0}$  such that households and banks optimize, and markets for goods and all assets clear.*

## 5.2 When are banks irrelevant for monetary policy transmission?

I begin with two cases showing that it may be justified to ignore the financial sector when studying monetary policy transmission, as in the standard New Keynesian model, even when financial frictions and banks do affect the level and distribution of output.

**Case A: High interest rates.** First, around a steady state with high interest rates, in the sense that  $i \geq \bar{i}(\rho)$  as defined in Proposition 2, we have the sticky prices counterpart of the classical dichotomy result in Proposition 1:

**Corollary 1.** *Around a steady state with unconstrained lending ( $i \geq \bar{i}(\rho)$ ), the response of consumption allocations and hence aggregate output to a sequence of monetary shocks  $\{dR_t\}_{t \geq 0}$  is the same as in a Modigliani-Miller model that features no banks, no credit frictions (i.e., borrowers can freely issue bonds) and no liquidity frictions (i.e.,  $v(x) = 0$ ).*

The standard New Keynesian model used to analyze monetary policy abstracts away from the financial sector and features only a single interest rate, the policy rate  $R_t$  controlled by the central

<sup>34</sup>This can be justified by binding downward nominal rigidity as in Schmitt-Grohé and Uribe (2016); alternatively, as explained in Werning (2015), this equilibrium concept can be viewed as characterizing the “demand-side” of the economy.

bank. Corollary 1 shows that this simplification is justified in a world of high steady state interest rates: when banks earn a sufficiently high private seigniorage, loan rates are equal to bond rates and there is no loss in ignoring what happens within banks to understand the transmission of monetary policy. If, however, the steady state nominal rate falls below the threshold  $\bar{i}(\rho)$ , we must take into account what happens to banks and spreads.

**Case B: Additively separable liquidity services.** Second, in my model, the gross substitutability in Assumption 1 remains crucial to understand how relevant banks are. Even when lending is constrained, the following benchmark provides conditions ensuring that all spreads are independent of monetary policy and thus that there is full pass-through to deposit and loan rates. If, in addition, there are no initial revaluation effects, the aggregate output response is then exactly the same as in a representative agent New Keynesian model (RANK):

**Proposition 5.** *Suppose that (i) the liquidity aggregator  $x(m, d)$  is Cobb-Douglas, (ii)  $u(c)$  and  $v(x)$  are logarithmic, (iii) there are no assets maturing at  $t = 0$ , i.e.,  $L_0^0 = D_0 = a_0^s = 0$ , and (iv) aggregate net dividends are proportional to  $E_t$ , i.e.,  $\zeta_t$  is constant. Then the sequences of spreads  $\{\tau_t^d, \tau_t^l\}_{t \geq 0}$  are invariant to monetary policy, and the aggregate output response is the same as in the RANK model, i.e., for all  $t$ :*

$$\frac{d \log Y_t}{d \log R_t} = -1. \quad (11)$$

Proposition 5 builds on the aggregation results developed in Werning (2015) for heterogeneous agents New Keynesian (HANK) models. These models focus on idiosyncratic risk, household borrowing constraints and precautionary savings, while my setting highlights a different form of market incompleteness—the role of banks in intermediation. In my context, the key departure from Proposition 5 is to discard condition (i) on Cobb-Douglas liquidity in order to match the incomplete pass-through of policy rates to deposit rates that I estimate in Section 2.2.

### 5.3 Quantitative illustration

In the rest of the paper, I focus on parameters that do not satisfy Case A or B above: interest rates are low and liquidity services are not separable. Online Appendix D provides a simple two-period model with analytical results on the state-dependence of monetary policy. In this section, I illustrate the quantitative relevance of the mechanisms by calibrating the dynamic model to the U.S. banking sector and the evidence from Section 2. The model's calibration is described in Online Appendix C.

Monetary policy affects credit supply through three channels. The first, static one, is the endogenous leverage ratio of banks  $\bar{\phi}$  given by (4). With dynamics, there are also flow and stock

effects. The flow effect is that current spreads not only affect the current leverage ratio, but also, through the return on bank equity, the accumulation of bank capital.<sup>35</sup> The stock effect is that monetary policy affects bank lending capacity by revaluating long-term assets (here loans). These long-term assets are priced by intermediaries, just like land is priced by experts in Kiyotaki and Moore (1997); this introduces state-dependence because the impact of monetary policy on the “intermediary stochastic discount factor” will depend on the baseline level of interest rates.

### 5.3.1 Baseline results

Figure 12 displays the impact response of spreads and output to a +100 bps monetary policy shock that lasts for only one period ( $t = 0$ ). The deposit spread increases by 30 bps, or equivalently the deposit pass-through  $\eta_0^d$  is 0.7. The loan spread falls, but only by around 15 bps, which means a relatively high loan pass-through  $\eta_0^l = 0.8$ .

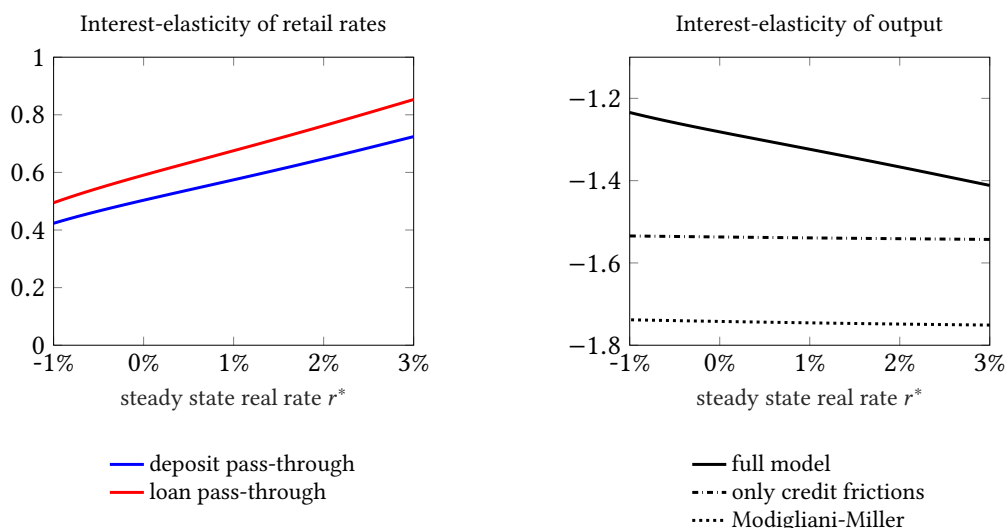
The interest-elasticity of output  $\frac{d \log Y_0}{d \log R_0} = -\eta_0^Y$  is equal to -1.41. This is higher than the RANK value of 1 (the elasticity of intertemporal substitution) due to the revaluation effects studied by Auclert (2019). Borrowers have higher marginal propensities to consume (MPC) than savers, and they have negative “unhedged interest rate exposures”. The negative covariance between MPC and unhedged rate exposures means that redistribution amplifies the output effect of monetary policy.

Two benchmarks help to evaluate the specific role of banks. The first benchmark is a Modigliani-Miller economy where bonds, loans and deposits are perfect substitutes: both deposit and loan spreads are zero and thus there is full pass-through. The Modigliani-Miller case still features heterogeneity and redistribution, hence it allows us to isolate the role of financial frictions. In fact, by Proposition 1, the output response in an economy without loan spreads (but potentially non-zero deposit spreads) is the same as in the Modigliani-Miller benchmark. The second benchmark is a “credit frictions only” economy, that goes further by allowing for banks and constrained lending, but shutting down liquidity frictions (i.e., setting  $v = 0$ ). Comparing the full model to the “credit frictions only” benchmark highlights the interaction between deposit and loan markets.

The interest-elasticity of output is equal to -1.53 in the “credit frictions only” economy and -1.74 in the Modigliani-Miller economy. Thus credit frictions alone dampen the New Keynesian transmission mechanism by 12%, while in the full model the output response is muted by 20% relative to the Modigliani-Miller benchmark.

<sup>35</sup>This flow effect is akin to what Brunnermeier and Sannikov (2016) call the “stealth recapitalization”.

**Figure 5:** Date-0 effects of monetary policy on rates and output as a function of  $r^*$ .



### 5.3.2 Low $r^*$ and monetary policy transmission

I now turn to my key counterfactual exercise, which examines how a lower  $r^*$  affects monetary policy transmission. Figure 5 varies the steady state real interest rate  $r^*$  (by changing  $\beta$ ) from 3% to -1% while keeping the rest of the calibration unchanged. At each steady state  $r^*$ , I compute the response to a date-0 unanticipated +100 bps monetary shock that lasts for only one period. The figures display the impact responses of retail rates and output.

Both pass-through and output sensitivity are lower at lower  $r^*$ . Comparing the full model to the “credit frictions only” and the “Modigliani-Miller” benchmarks shows that this is entirely due to the interaction between deposit and loan rates, as  $r^*$  has no effect on monetary policy transmission to output if there are no frictions, only liquidity frictions, or only credit frictions. When  $r^*$  varies from 3% to -1%, the deposit pass-through falls from 0.7 to 0.4. If there were no credit frictions, this would have no bite on the output effects of monetary policy; but in the full model, loan pass-through drops from 0.8 to 0.5 and, as a result, the output effect falls by 13% (in absolute value), from -1.41 to -1.23. We saw that financial frictions mute the output response by 20% relative to the Modigliani-Miller benchmark in the baseline  $r^* = 3\%$  calibration; the dampening reaches 32% at  $r^* = -1\%$ .

Over the whole range of  $r^*$ , bank lending falls when monetary policy tightens, as shown in Figure 5. In theory, the opposite could happen at very low rates as in Online Appendix D, but under the calibrated maturity structure and elasticity of substitution between money and deposits, deposit pass-through remains high enough and revaluation effects strong enough to prevent any “reversal” of bank lending. I investigate the role of maturity mismatch in the next section. Finally, we can see in Figure 13 that bank value  $V$  is negatively affected by contractionary

monetary shocks, but less so at lower  $r^*$ . Quantitatively, however, the effect of low interest rates is modest, relative to my empirical results in Table 2. One reason is that my model features no risk, and Bernanke and Kuttner (2005) find a significant effect of monetary policy on risk premia. An interesting extension would thus be to incorporate aggregate risk and study how it interacts with deposit and loan spreads.

### 5.3.3 Inflation target and capital requirements

My model can be used to analyze how monetary policy transmission depends on two steady state policies: the inflation target, previously set at  $\pi = 2\%$ , and bank regulation.

**Inflation target.** Recall from equation (8) that deposit demand  $\mathcal{D}$  depends on the nominal interest rate  $i$ . So far I have kept the inflation target fixed and let the steady state real interest rate  $r^*$  vary. We saw in Section 4 that monetary policy is not superneutral in the constrained lending regime because inflation can affect deposit and loan spreads. Similarly, the inflation target can affect monetary policy transmission in the short run by changing the steady state nominal interest rate. Figure 14 varies the inflation target while keeping  $r^*$  fixed at 3%. A higher inflation target improves deposit pass-through, hence loan pass-through. The intuition is exactly as in the previous case where I varied  $r^*$ .

**Capital requirements.** The level of the nominal interest rate has a direct effect on monetary policy transmission through the substitutability between money and deposits, but also an indirect effect working through the endogenous steady state level of bank capital  $E$ : recall from Section 4 that all else equal, a higher steady state nominal interest rate will boost the liquidity premia earned by banks and thus increase  $E$ , with a potential side effect of reducing steady state loan spreads. We can isolate the link between bank capital and monetary policy transmission by holding interest rates fixed and varying either net payouts  $\rho - \zeta$  or the pledgeability parameter  $\theta$ .

I now depict the impact of varying  $\theta$ , as this has an interpretation in terms of capital requirements (see the discussion in Section 3.5 about the banks' financial constraints). Figure 15 shows how bank regulation affects the pass-through of monetary policy to retail rates and output. As  $\theta$  varies, I plot interest-elasticities against the steady state leverage ratio of deposits over equity

$$\bar{\phi} = \frac{\theta R^l / R^d}{1 - \theta R^l / R^d},$$

taking into account all the general equilibrium responses of capital  $E$  and spreads  $\tau^l$  and  $\tau^d$ . The result is that tighter bank regulation hampers monetary policy transmission. Several effects are

at play. First, when banks are more constrained (lower  $\theta$ ), monetary shocks relax banks' lending capacity by less. Second, steady state deposit spreads are higher hence deposit rates are lower, and thus closer to the low nominal rates region where money and deposits are better substitutes. This dampens deposit pass-through, which again translates into lower loan pass-through and weaker output effects of monetary policy.

## 5.4 Evidence from U.S. bank stock returns

I conclude this section by examining empirically the prediction of the model regarding the impact of monetary shocks on bank profitability. For the estimation, I depart slightly from the theory and consider bank stock prices as a measure of profitability because reported measures of the flow of profits, like ROA or ROE, are recorded at a low frequency and are smoothed by book-value accounting conventions. The standard regression to estimate the impact of monetary policy on asset prices is

$$\text{Return}_t = \alpha + \beta \Delta_t + \epsilon_t, \quad (12)$$

where  $\text{Return}_t$  is the intra-day stock return, and  $\Delta_t$  is the monetary shock. Bernanke and Kuttner (2005), Gürkaynak et al. (2005), Gertler and Karadi (2015), and Nakamura and Steinsson (2018) (among others) all estimate equation (12) for various assets (e.g., the market portfolio or long-term bonds), while English et al. (2018) focus on bank stock prices. I estimate instead how this relation changes with the level of the Fed funds rate  $i_{t-1}$  right before the shock, in the regression

$$\text{Return}_t = \alpha + \beta_1 \Delta_t + \beta_2 i_{t-1} + \gamma \Delta_t \times i_{t-1} + \epsilon_t. \quad (13)$$

Table 2 displays my results. The shock  $\Delta_t$  is the same as in Section 2.1. In the standard specification (12), I find a negative (but not significant) effect  $\beta = -4.17$  on the Fama-French bank industry portfolio's return on FOMC announcement days. The point estimate is consistent with English et al. (2018), who find that bank stocks fall by 8% around FOMC announcements in reaction to an unexpected +100 bps shock to the short rate. In my specification (13), I find a negative and significant coefficient  $\gamma = -4.91$  on the interaction term: a Fed tightening hurts bank stocks less (and might even increase them) when interest rates are lower. The standard errors are large, but to interpret the magnitudes of the point estimates, the same +100 bps shock decreases bank stock prices by 13% at  $i = 5\%$ , but increases them by 7% at  $i = 1\%$ . This pattern is consistent with Proposition 8 and with Ampudia and den Heuvel (2018), who perform a similar exercise for European banks by comparing 1999-2008 ("high rates") versus 2012-2017 ("low rates").

In the Online Appendix, I conduct two robustness exercises. First, even if shocks  $\Delta_t$  are plausibly exogenous,  $i_{t-1}$  can be endogenous in (13); Table 6 shows that the result remains (and becomes even stronger) once controlling for unemployment and inflation. Second, I show that low inter-

**Table 2:** Response of Fama-French’s bank industry portfolio to a +100 bps monetary policy shock.

|                   | (1)             | (2)                |
|-------------------|-----------------|--------------------|
| $\Delta$          | -4.17<br>(5.46) | 11.53<br>(7.41)    |
| $\Delta \times i$ |                 | -4.91***<br>(1.73) |
| Observations      | 151             | 151                |

*Note:* The regression equations are (1)  $\text{Return}_t = \alpha + \beta \Delta_t + \epsilon_t$  and (2)  $\text{Return}_t = \alpha + \beta_1 \Delta_t + \beta_2 i_{t-1} + \gamma \Delta_t \times i_{t-1} + \epsilon_t$ . The dependent variable  $\text{Return}_t$  is the daily return of “Banks” in the 49 Fama-French industry portfolios, taken from Kenneth French’s website.  $\Delta_t$  is the high-frequency Fed funds rate shock from Nakamura and Steinsson (2018) extended until 2019 by Acosta and Saia (2020). The sample is all regularly scheduled FOMC meetings from 01/01/2000 to 9/18/2019, excluding July 2008 to June 2009.  $i_{t-1}$  is the Fed funds Rate on the previous day. All rates are in percentage points. Robust standard errors in parentheses.

est rates have a specific effect on banks, and not just on all industries. I plot the reactions of all 49 Fama-French industries to the same monetary shock, in low and high interest rate subsamples. Table 7 makes the same point: while there is also a significant negative interaction term  $\gamma = -2.19$  for the market portfolio, it is weaker than that for banks. My model also predicts that monetary shocks have a state-dependent effect on the economy as a whole, albeit weaker than on bank values.

## 6 Conclusion

In this paper, I argue that the dual role of commercial banks as credit and liquidity providers has implications for interest rate pass-through in both the long and short runs. Because privately-issued deposits compete with publicly-issued money, the level of the nominal interest rate affects real loan and deposit spreads. A lower nominal rate compresses deposit spreads and widens loan spreads. In the long run, the reaction of spreads explains why the persistent decline in bond rates has not been fully transmitted to loan rates. In the short run, the response of spreads dampens the transmission of monetary shocks to output. Moreover, pass-through is lower at lower rates in the model and in the data, thus monetary policy becomes less potent in a world of low interest rates. Policy can trade-off liquidity frictions against credit frictions: raising the inflation target decreases loan spreads and improves monetary policy transmission, but only at the cost of higher deposit spreads.

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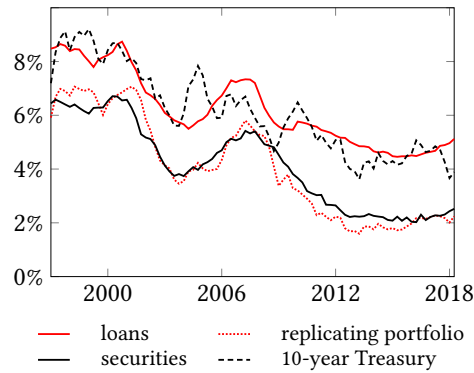
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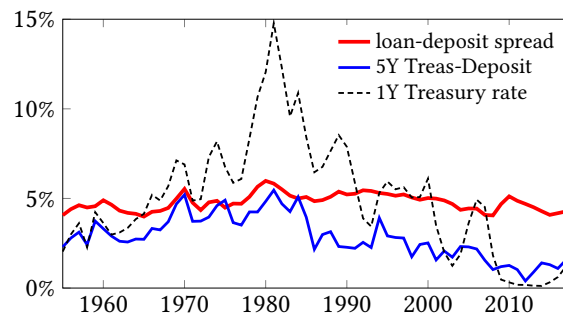
## Figures and tables

**Figure 6:** Realized returns on loans, securities, and Treasury portfolios.



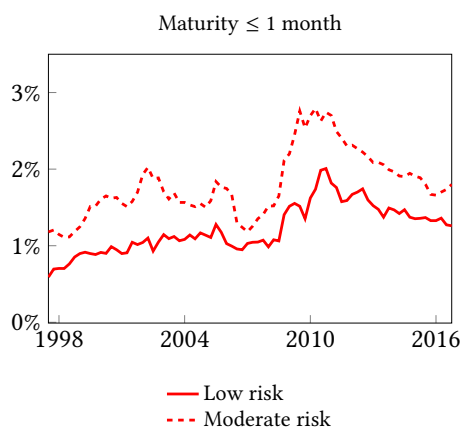
*Note:* This figure shows the average (asset-weighted) realized yields on different assets earned by the U.S. banking sector between 1997Q3 and 2018Q1. The solid lines are the yield on loans and securities from the FDIC. The black dashed line is the yield on a 10-year Treasury bond. The dotted red line is the yield on the replicating portfolio described in Section 2.1. Source: Call Reports, Federal Reserve and author's calculations.

**Figure 7:** Loan-deposit spread, 1955 to 2018.



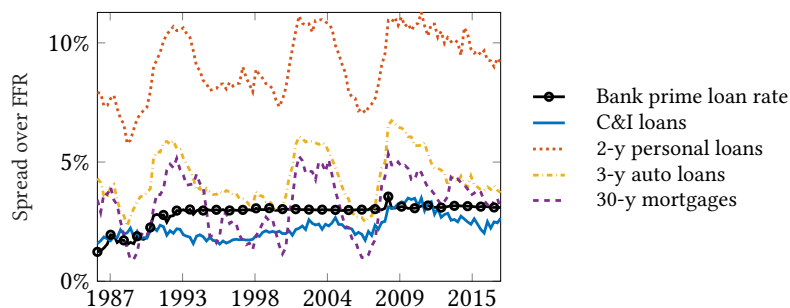
*Note:* The loan-deposit spread is constructed as the difference between loan income divided by total loans and deposit expense divided by total deposits, cf. Figure 1. Sources: FDIC Historical Bank Data and Federal Reserve.

**Figure 8:** Spread between rate on commercial and industrial loans and Fed funds rate. Source: Federal Reserve Release E.2.



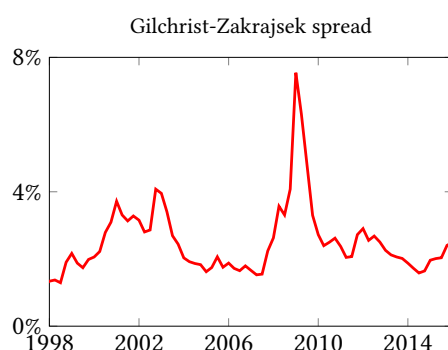
*Note:* This figure shows the spread between commercial and industrial loans with maturity less than 1 month and the Fed funds rate between 1998 and 2016, for loans classified as “low risk” and “moderate risk”. The spread on both types of loans has increased over time by approximately the same amount, which suggests that higher spreads do not reflect higher credit risk premia.

**Figure 9:** Spreads over Fed funds rate. Source: Federal Reserve Board.



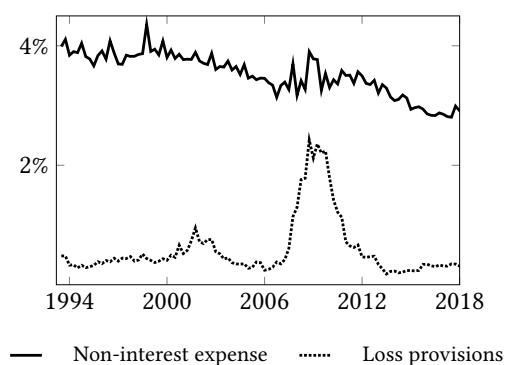
*Note:* This figure shows that the “bank prime loan rate”, which is the main lending rate reported by commercial banks and the Federal Reserve, does not reflect the actual loan rates paid by firms and consumers.

**Figure 10:** Credit spread on corporate bonds from Gilchrist and Zakrajsek (2012), updated through August 2016.



*Note:* This figure shows that unlike the loan spread, the spread on corporate bonds (computed over Treasuries with the same maturity) has not increased with the decline in interest rates. The spread averages at 2.2% between 1997 and 2007, and 2.3% between 2010 and 2016.

**Figure 11:** Components of bank profits, as percentage of earning assets. Source: FDIC.

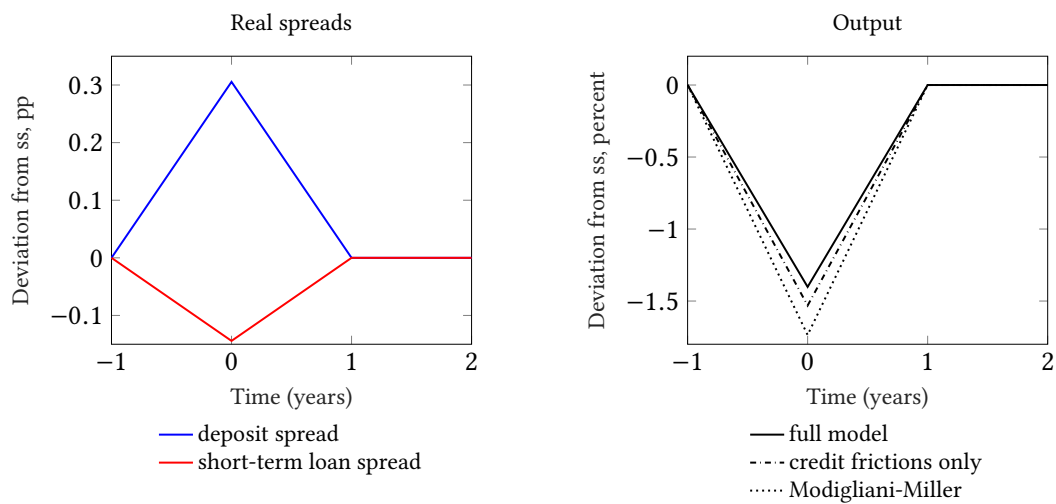


*Note:* This figure shows two components of bank profits: non-interest expense and loan loss provisions. Non-interest expense has declined steadily, driven by a decline in data processing costs. After 2012, loan loss provisions have reverted to levels similar to or lower than pre-2008.

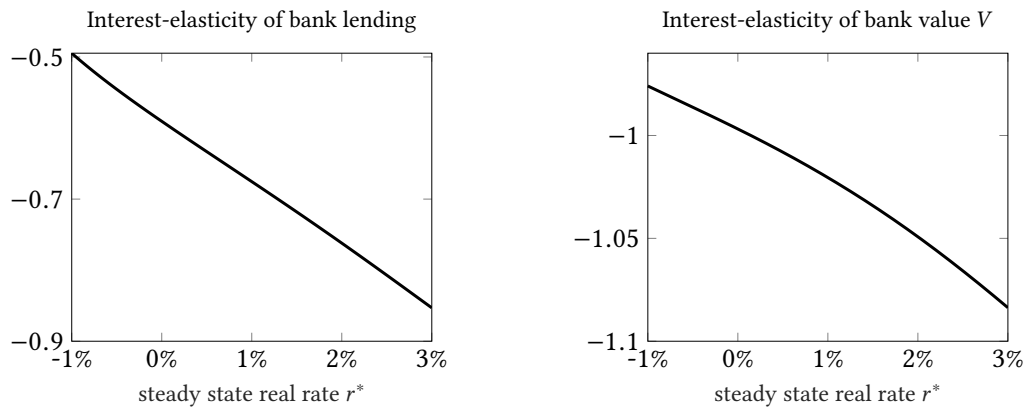
|                       | (1)                        | (2)                 | (3)                 | (4)                   |
|-----------------------|----------------------------|---------------------|---------------------|-----------------------|
|                       | $\Delta$ Retained earnings | $\Delta$ Equity     | $\Delta$ Loans      | $\Delta$ Loan spread  |
| $\Delta$ liab. spread | 0.139***<br>(0.0405)       | 0.362***<br>(0.120) | 0.308**<br>(0.0982) | -0.231***<br>(0.0389) |
| Controls              | Yes                        | Yes                 | Yes                 | Yes                   |
| Observations          | 4189                       | 4187                | 4180                | 3984                  |

**Table 3:** Cross-sectional regression (1) adding 2000 deposit/asset ratio and leverage as controls.

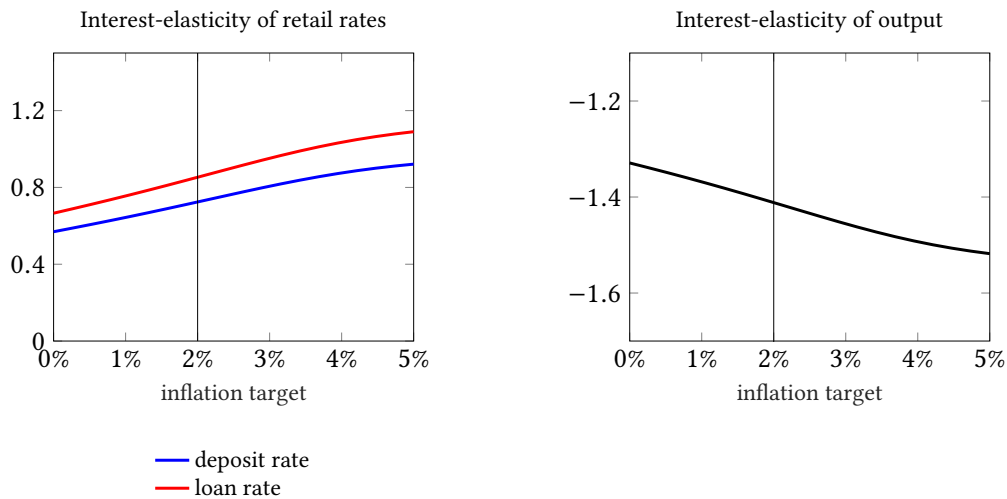
**Figure 12:** Response to a +100 bps monetary shock at  $r^* = 3\%$ .



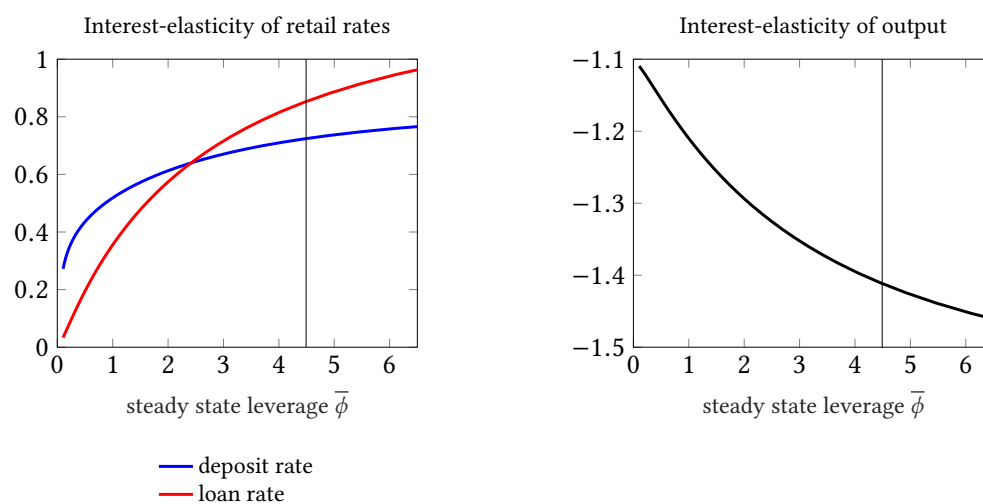
**Figure 13:** Date-0 effects of monetary policy on bank lending and value as a function of  $r^*$ .



**Figure 14:** Date-0 effects of monetary policy on rates and output as a function of the steady state inflation target. Vertical lines denote the baseline calibration.



**Figure 15:** Date-0 effects of monetary policy on rates and output as a function of steady state bank leverage  $\bar{\phi}$ . Vertical lines denote the baseline calibration.

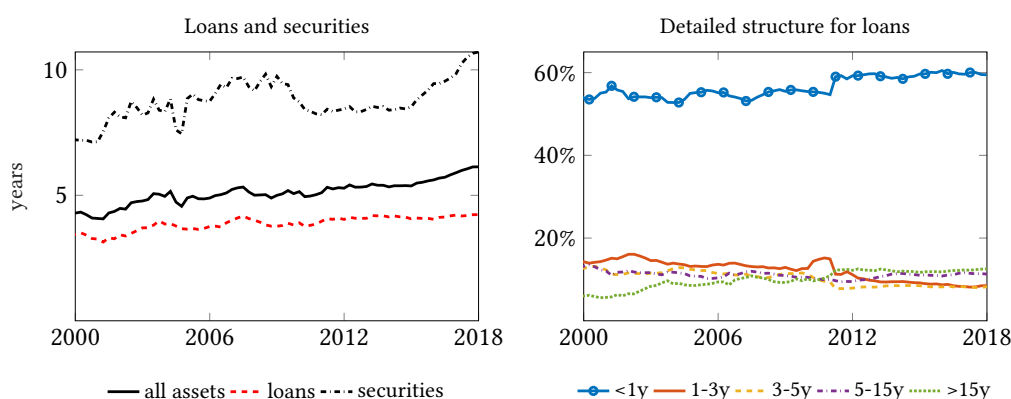


# Online Appendix

For Online Publication

## A Additional figures and tables

**Figure 16:** Repricing maturity structure of U.S. banks' assets.



*Note:* This figure shows the maturity structure of U.S. banks' assets between 1997Q3 and 2018Q1. Left: Value-weighted average repricing maturity period of all assets, loans, and securities. Right: Loan repricing maturities corresponding to the buckets in the Call Reports, expressed as value-weighted shares of total loans. Source: Call Reports.

**Asymmetric pass-through.** Asymmetric pass-through of rate hikes and cuts could explain the state-dependence I find under two conditions: (i) the pass-through of positive policy shocks  $\Delta_t > 0$  is stronger than that of negative shocks  $\Delta_t < 0$ ; and (ii) positive (resp. negative) policy shocks are more likely when  $i_{t-1}$  is low (resp. high). To examine part (i), I estimate state-dependent local projections:

$$y_{i,t+h} - y_{i,t-1} = \mathbb{I}(\Delta_t < 0) \left[ \alpha_{i,h}^- + \beta_h^- \Delta_t + \gamma_h^- \text{controls}_{i,t-1} \right] + \mathbb{I}(\Delta_t > 0) \left[ \alpha_{i,h}^+ + \beta_h^+ \Delta_t + \gamma_h^+ \text{controls}_{i,t-1} \right] + \epsilon_{i,t+h}. \quad (14)$$

**Table 4:** Asymmetric pass-through for various deposit and loan rates.

|                                   | $\hat{\beta}^+$ |   | $\hat{\beta}^-$ |
|-----------------------------------|-----------------|---|-----------------|
| Checking deposits                 | 0.17            | < | 0.59            |
| Saving deposits                   | 0.47            | < | 0.53            |
| Money market deposits             | 0.91            | < | 1.11            |
| Adjustable rate mortgages, 1 year | 2.67            | > | 0.72            |
| Personal loans, 2 years           | 0.73            | > | 0.16            |
| Auto loans, 3 years               | 2.46            | > | 0.25            |

*Note:* Estimates  $\hat{\beta}^+$  (for positive shocks  $\Delta_t > 0$ ) and  $\hat{\beta}^-$  (for negative shocks  $\Delta_t < 0$ ) at horizon  $h = 12$  in equation (14).

Table 4 shows the  $h = 12$  months coefficients  $\{\hat{\beta}_{12}^-, \hat{\beta}_{12}^+\}$  for various products. There is indeed significant pass-through asymmetry. However, while loan rates increase more in response to positive shocks than they decrease in response to negative shocks, the opposite pattern holds for deposit rates. Furthermore, regressing the monetary shocks on the level of interest rates

$$\Delta_t = \alpha + \gamma i_{t-1} + \epsilon_t$$

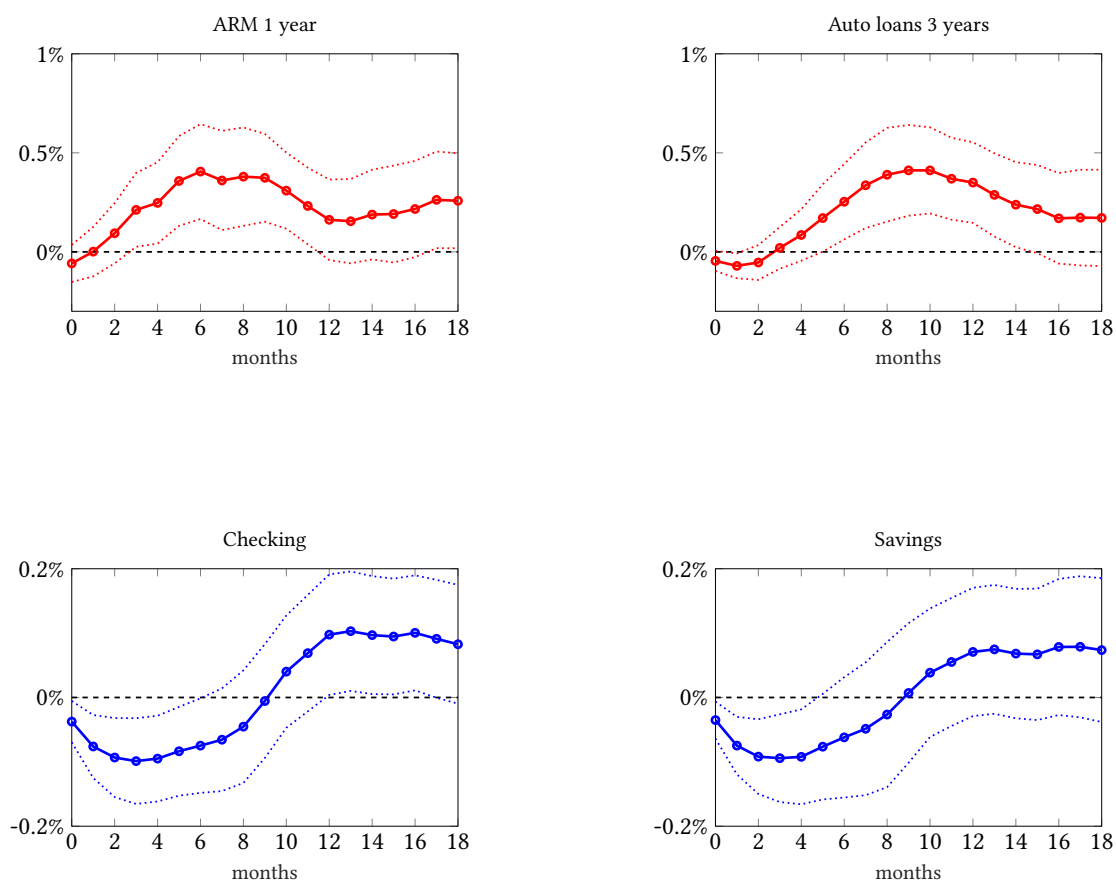
shows that condition (ii) is not satisfied: positive policy shocks are *not* more likely when rates are low. This is consistent with the fact that rate shocks are supposed to be unexpected: were the level of rates a predictor, it would already be incorporated in Fed funds futures before the FOMC announcement. Thus asymmetric pass-through does not appear to drive the results of Section 2.2.

**Table 5:** No asymmetry in monetary shocks.

|              | $\Delta_t$      |
|--------------|-----------------|
| $i_{t-1}$    | -0.00<br>(0.00) |
| Constant     | 0.00<br>(0.01)  |
| $R^2$        | 0.057           |
| Observations | 155             |

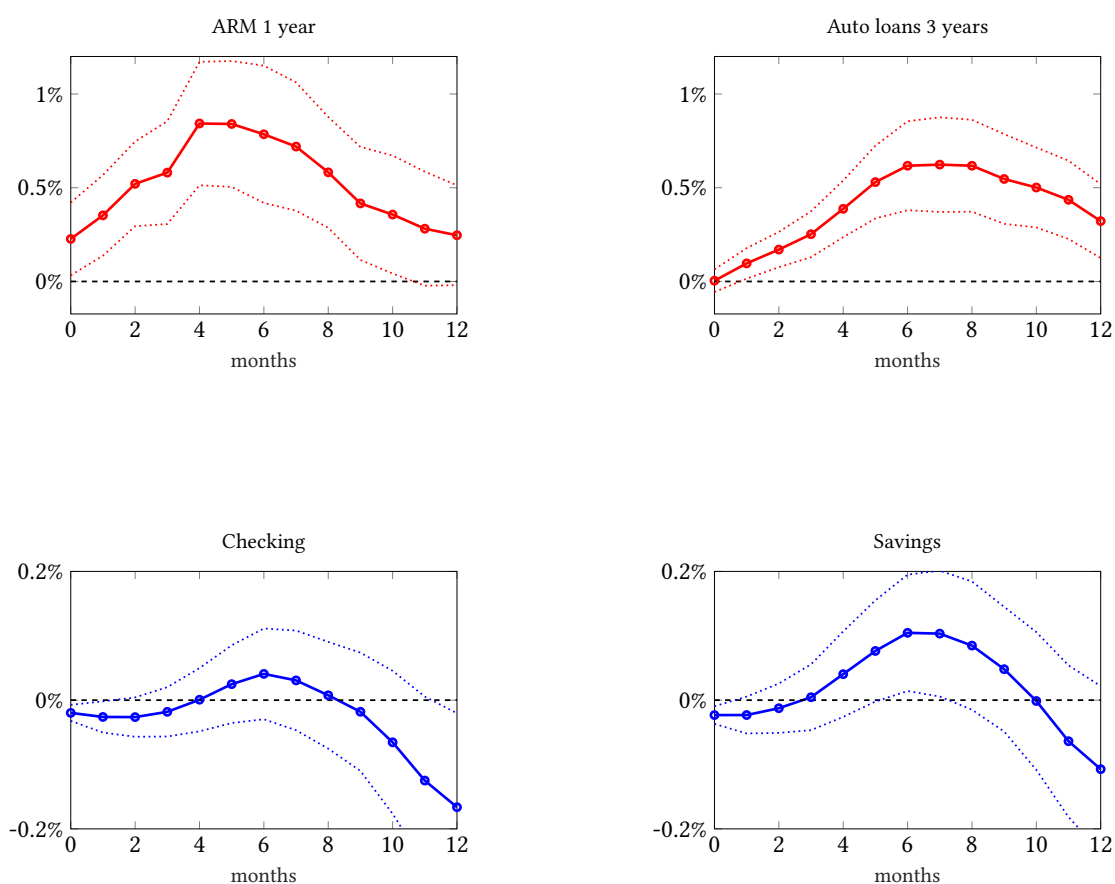
*Note:* The regression equation is  $\Delta_t = \alpha + \gamma i_{t-1} + \epsilon_t$ . Robust standard errors in parentheses.

**Figure 17:** Additional pass-through of a raw +100 bps change in the 1-year Treasury rate  $i_t$  to deposit and loan rates when  $i_{t-1}$  is 100 bps higher.



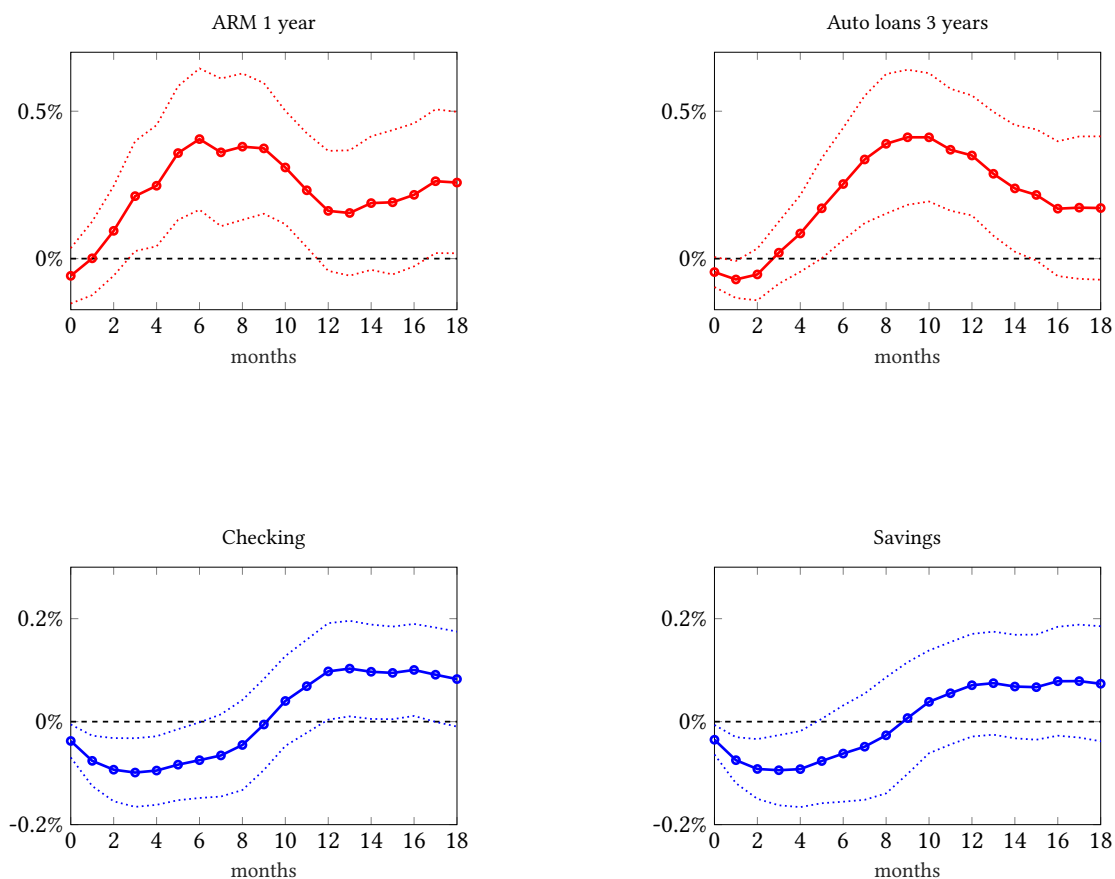
*Note:* The regression equations are  $y_{b,t+h} - y_{b,t-1} = \alpha_{b,h} + \delta_{1h}\Delta i_t + \delta_{2h}i_{t-1} + \beta_h\Delta i_t \times i_{t-1} + \gamma_h \text{controls}_{b,t-1} + \epsilon_{b,t+h}$  for each horizon  $h$ . The figures show the sequences  $\{\hat{\beta}_h\}_{h=0,\dots,12}$  with 90% confidence bands. Standard errors are two-way clustered at the branch-month level. Sources: Federal Reserve and RateWatch.

**Figure 18:** Additional pass-through of the monetary shock from Romer and Romer (2004) (extended until the end of 2013) to deposit and loan rates when  $i_{t-1}$  is 100 bps higher.



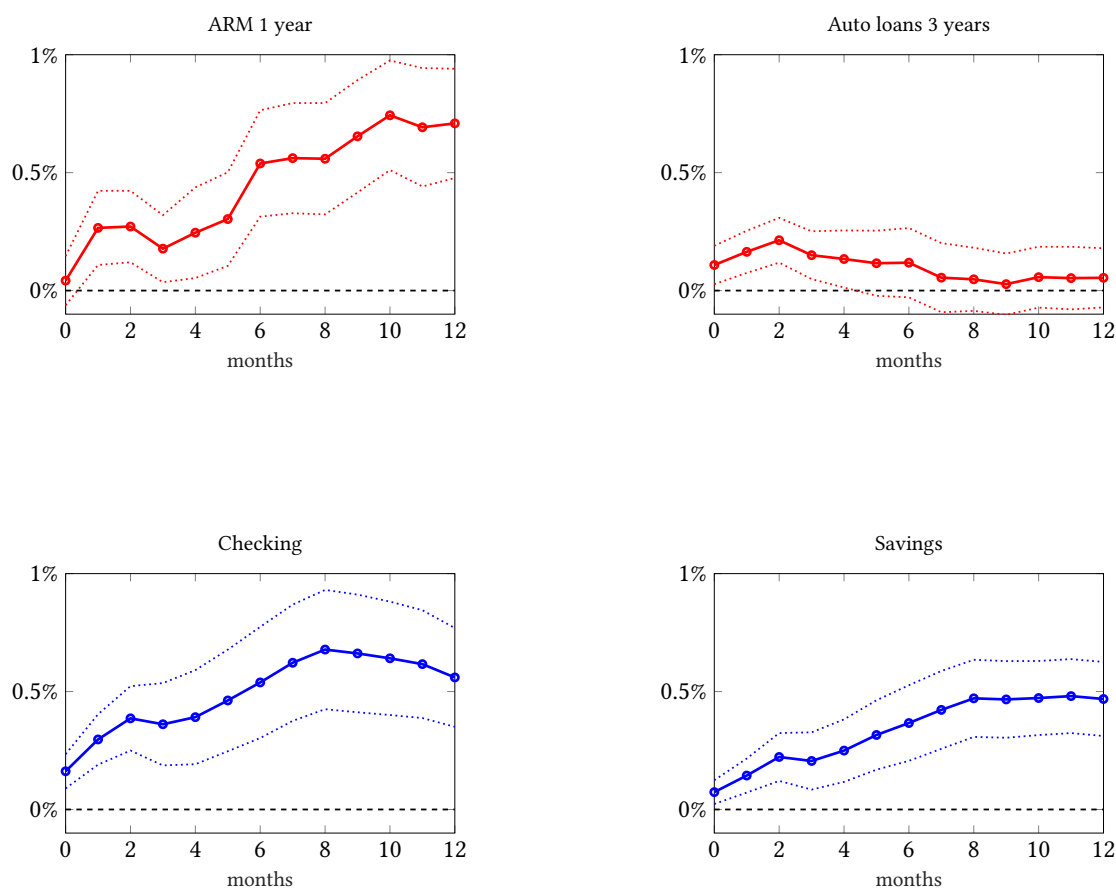
*Note:* The regression equations are  $y_{b,t+h} - y_{b,t-1} = \alpha_{b,h} + \delta_{1h}\Delta_t + \delta_{2h}i_{t-1} + \beta_h\Delta_t \times i_{t-1} + \gamma_h\text{controls}_{b,t-1} + \epsilon_{b,t+h}$  for each horizon  $h$ . The figures show the sequences  $\{\hat{\beta}_h\}_{h=0,\dots,12}$  with 90% confidence bands. Standard errors are two-way clustered at the branch-month level. Sources: Federal Reserve and RateWatch.

**Figure 19:** Additional pass-through of the monetary shock from Nakamura and Steinsson (2018) to deposit and loan rates when  $i_{t-1}$  is 100 bps higher. Only using the 1998-2007 sample.



*Note:* The regression equations are  $y_{b,t+h} - y_{b,t-1} = \alpha_{b,h} + \delta_{1h}\Delta_t + \delta_{2h}i_{t-1} + \beta_h\Delta_t \times i_{t-1} + \gamma_h\text{controls}_{b,t-1} + \epsilon_{b,t+h}$  for each horizon  $h$ . The figures show the sequences  $\{\hat{\beta}_h\}_{h=0,\dots,12}$  with 90% confidence bands. Standard errors are two-way clustered at the branch-month level. Sources: Federal Reserve and RateWatch.

**Figure 20:** Additional pass-through of the monetary shock from Nakamura and Steinsson (2018) to deposit and loan rates  $y_{b,t+h}$  when the relevant branch rate  $y_{b,t-1}$  is 100 bps higher, with time fixed effects.



*Note:* The regression equations are  $y_{b,t+h} - y_{b,t-1} = \alpha_{b,h} + \delta_{t,h} + \beta_h \Delta_t \times i_{t-1} + \gamma_h \text{controls}_{b,t-1} + \epsilon_{b,t+h}$  for each horizon  $h$ . The figures show the sequences  $\{\hat{\beta}_h\}_{h=0,\dots,12}$  with 90% confidence bands. Standard errors are two-way clustered at the branch-month level. Sources: Federal Reserve and RateWatch.

**Table 6:** Effect of a 100 bps monetary policy shock on Fama-French's bank industry portfolio.

|                   | (1)             | (2)                | (3)                 |
|-------------------|-----------------|--------------------|---------------------|
| $\Delta$          | -4.17<br>(5.46) | 11.53<br>(7.41)    | 59.16<br>(35.74)    |
| $\Delta \times i$ |                 | -4.91***<br>(1.73) | -11.75***<br>(3.66) |
| Controls          | No              | No                 | Yes                 |
| Observations      | 151             | 151                | 151                 |

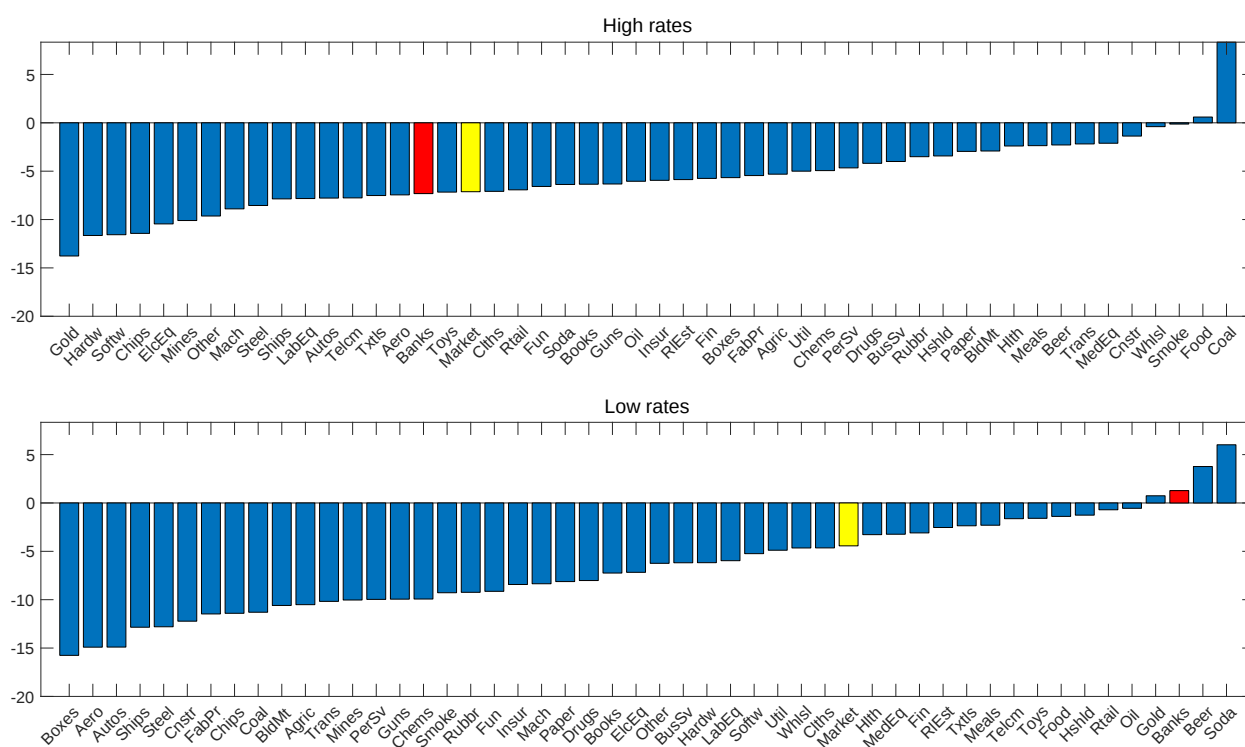
*Note:* See Table 2 for description of the data and regression equations. Column (3):  $\text{Return}_t = \alpha + \beta_1 \Delta_t + \beta_2 i_{t-1} + \gamma \Delta_t \times i_{t-1} + \Gamma' \Delta_t \times \text{controls}_{t-1} + \epsilon_t$  where controls are the unemployment rate and CPI inflation. Robust standard errors in parentheses.

**Table 7:** Effect of a 100 bps monetary policy shock on Fama-French's bank industry portfolio vs. market portfolio.

|                   | (1)<br>Banks    | (2)<br>Banks       | (3)<br>Market     | (4)<br>Market     |
|-------------------|-----------------|--------------------|-------------------|-------------------|
| $\Delta$          | -4.17<br>(5.46) | 11.53<br>(7.41)    | -6.22**<br>(3.06) | 0.76<br>(4.51)    |
| $\Delta \times i$ |                 | -4.91***<br>(1.73) |                   | -2.19**<br>(1.04) |
| Observations      | 151             | 151                | 151               | 151               |

*Note:* See Table 2 for description of the data and regression equations. The dependent variables  $y$  are the daily return of "Banks" in the 49 Fama-French industry portfolios, and the daily return on the market portfolio, taken from Kenneth French's website. Robust standard errors in parentheses.

**Figure 21:** Response of Fama-French's 49 industry portfolios and market portfolio to a 100 bps shock to the Fed funds rate.



*Note:* Each bar shows the coefficient  $\beta_j$  in the regression  $y_{j,t} = \alpha_j + \beta_j \Delta_t + \epsilon_{j,t}$  where  $y_{j,t}$  is the daily return for industry  $j$ . The bank industry portfolio is highlighted in red and the market portfolio in yellow. The top (resp. bottom) panel shows results when the Fed funds rate is above (resp. below) its median level in the sample of 1.64%.

## B Theoretical Online Appendix

### B.1 Gross substitutability: functional forms

The most common specification for  $x$  is a CES aggregator:

$$x(m, d) = \left[ \alpha m^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha) d^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}. \quad (15)$$

Following Chetty (1969), who first introduced the CES aggregator (15), a large literature has estimated high elasticities of substitution between money and “near-monies” such as deposits. For instance, Poterba and Rotemberg (1987) estimate an elasticity of substitution between currency and savings deposits that lies between 1.2 and 100, depending on the set of instruments.<sup>36</sup> Another tractable specification is the *hierarchical CES* aggregator:

$$x(m, d) = \left[ \gamma m^{\frac{\epsilon-1}{\epsilon}} + (1-\gamma)(m+d)^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}. \quad (16)$$

(16) ensures that nominal deposit rates are always non-negative, because money  $m$  is a strictly better form of liquidity than deposits  $d$ . The interpretation of (16) is that some transactions can only be made in cash (for instance to evade taxation) while for others, cash and deposits are perfect substitutes.<sup>37</sup> If  $x$  is CES as in (15), then Assumption 5 is equivalent to  $\epsilon \geq 1$ ; if  $x$  is hierarchical CES as in (16), then a sufficient condition for Assumption 5 to hold is  $\epsilon \geq \gamma$ . The share  $\gamma$  of pure cash transactions can be very small. Intuitively, the gross substitutes assumption becomes very natural once we account for the fact that money and deposits are not just two arbitrary goods.

Suppose  $x$  is CES as in (15):

$$x(m, d) = \left[ \alpha m^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha) d^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}.$$

Then

$$\frac{x_d(f, 1)}{x(f, 1)} = \frac{1}{\frac{\alpha}{1-\alpha} f^{\frac{\epsilon-1}{\epsilon}} + 1},$$

which is non-increasing in  $f$  if and only if  $\epsilon \geq 1$ .

<sup>36</sup>See Ball (2012), Lucas and Nicolini (2015), and Ireland (2015) for more recent discussions. Cysne and Turchick (2010) provide a survey of post-Volcker estimates of  $\epsilon$ , with most of them well above 1. One central question in this literature, since at least Barnett (1980), is actually whether money and deposits should be treated as perfect substitutes.

<sup>37</sup>In Online Appendix B.2, I show how (16) can arise from cash-in-advance constraints à la Lucas and Stokey (1987).

Suppose  $x$  is hierarchical CES as in (16):

$$x(m, d) = \left[ \gamma m^{\frac{\epsilon-1}{\epsilon}} + (1-\gamma)(m+d)^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}.$$

Then

$$\frac{x_d(f, 1)}{x(f, 1)} = \frac{1}{\frac{\gamma}{1-\gamma} f \left( \frac{1+f}{f} \right)^{1/\epsilon} + 1 + f},$$

and the denominator is non-decreasing in  $f$  if

$$\gamma \left[ \frac{1+f}{f} \right]^{1/\epsilon} \left[ 1 - \frac{\gamma}{\epsilon(1+f)} \right] + 1 - \gamma > 0$$

hence a sufficient condition (given  $f \geq 0$ ) is

$$\epsilon \geq \gamma.$$

## B.2 Cash-in-advance foundations for liquidity demand

In this section, I describe one potential microfoundation for the liquidity-in-utility model. Following Lucas and Stokey (1987), suppose that there are three types of consumption goods: a “credit good”  $c_1$ , a “cash good”  $c_2$  that can only be purchased with cash and a “deposit good”  $c_3$  that can be purchased only with deposits. Given an initial portfolio, savers maximize

$$\sum_{t \geq 0} \beta^t U(c_{1t}, c_{2t}, c_{3t})$$

subject to flow budget constraints

$$c_{1t} + c_{2t} + c_{3t} + q_t [\Omega_{t+1} + i_t m_{t+1} + s_t^d d_{t+1}] \leq \Omega_t + \gamma_t^s Y_t \quad (17)$$

where  $\Omega_t = a_t + m_t + d_t$  denotes total wealth, and cash-in-advance constraints

$$c_{2t} \leq m_t \quad (18)$$

$$c_{3t} \leq d_t \quad (19)$$

As Lucas and Stokey (1987), each period should be thought of as split in two subperiods, but I use a different timing to be consistent with the convention in Section 3: in the first subperiod, the household separates into workers and shoppers subject to the cash-in-advance constraints, while in the second subperiod there is a centralized securities market for bonds, money and deposits.

The first-order conditions imply

$$\frac{U_{c_2,t+1} - U_{c_1,t+1}}{U_{c_1,t+1}} = i_t$$

$$\frac{U_{c_3,t+1} - U_{c_1,t+1}}{U_{c_1,t+1}} = s_t^d$$

Since (18) and (19) must bind in any equilibrium with positive liquidity premia  $i_t$  and  $s_t^d$ , we can define total consumption as

$$c_t \equiv c_{1t} + c_{2t} + c_{3t}$$

and rewrite utility as<sup>38</sup>

$$U(c_t - c_{2t} - c_{3t}, c_{2t}, c_{3t}) = U(c_t - m_t - d_t, m_t, d_t)$$

Note that the hierarchical CES model described in 3.3 can also be nested if the third good  $c_3$  can be purchased with money or deposits, by replacing (19) with  $c_{3t} \leq m_t + d_t$ .

### B.3 Equilibrium conditions

Denote the vector of state variables  $\mathbf{Z}_t = [a_t^s, D_t, L_t^t, \dots, L_{t+K-1}^t]'$  (setting  $L_{t+K}^t = 0$ ).  $L_{t+k}^t$  captures the amount maturing at  $t+k$  at the beginning of period  $t$ . Given monetary policy, at each date  $t$  we need to solve for  $11 + 4K$  variables:  $q_t$  (in flexible prices equilibrium) or  $Y_t$  (in sticky inflation equilibrium), together with

$$q_t^d, \left\{ q_{t,t+k}^l \right\}_{k=1}^K, a_{t+1}^s, a_{t+1}^B, D_{t+1}, \left\{ L_{t+1+k}^{t+1} \right\}_{k=0}^{K-1}, C_t^s, C_{t+1}^s, \left\{ c_{t,t+k}^{y,k}, c_{t,t+k}^{o,k} \right\}_{k=1}^K, \lambda_t, \nu_t, \zeta_t \quad (20)$$

where  $L_{t+k}^{t+1}$  is the amount maturing at  $t+k$  outstanding at the beginning of period  $t+1$  and  $\lambda_t, \nu_t, \zeta_t$  are Lagrange multipliers defined below. I separate the full equilibrium conditions into “blocks”:

- Savers block: The three equations of “savers’ block” are

$$D_{t+1} = \frac{1}{x \left( f \left( \frac{s_t^d}{i_t} \right), 1 \right)} (v')^{-1} \left( \frac{s_t^d u' (C_{t+1}^s)}{x_d \left( f \left( \frac{s_t^d}{i_t} \right), 1 \right)} \right) \quad (21)$$

$$q_t^d D_{t+1} + q_t a_{t+1}^s + C_t^s = \gamma_t^s Y_t + D_t + a_t^s + (\rho - \zeta_t) E_t \quad (22)$$

$$q_t u' (C_t^s) = \beta u' (C_{t+1}^s) \quad (23)$$

<sup>38</sup>The separable specification  $u(c_t) + v(x(m_t, d_t))$  also requires  $U_{c_1 c_2} = U_{c_1 c_1}$  and  $U_{c_1 c_3} = U_{c_1 c_1}$ .

where  $E_t = a_t^B - D_t + \sum_{k=0}^{K-1} q_{t,t+k}^l L_{t+k}^t$ . (21) is optimal deposit demand combined with deposit market clearing, (22) is savers' binding budget constraint, and (23) is the standard Euler equation. Note that even when savers only hold deposits in equilibrium ( $a_{t+1}^S = 0$ ), their marginal rate of intertemporal substitution is the bond rate  $R_t$ , not the deposit rate  $R_t^d$ , because they are not constrained to save in deposits. Thus in the short-run analysis, incomplete deposit pass-through does not mechanically translate into incomplete pass-through of monetary policy to savers' consumption. In fact, allowing for unconstrained substitution between bonds and deposits is crucial to *generate* the incomplete deposit pass-through.

- Borrowers block: for each type  $k$  we have

$$q_{t,t+k}^l u'_b(c_t^{y,k}) = \beta^k u'_b(c_{t+k}^{o,k}) \quad (24)$$

$$c_{t+k}^{o,k} = \gamma_{t+k}^{o,k} Y_{t+k} - \frac{c_t^{y,k} - \gamma_t^{y,k} Y_t}{q_{t,t+k}^l} \quad (25)$$

(24) is type  $k$  borrowers' Euler equation and (25) is their binding budget constraint.

- Bank block:

$$q_t^d D_{t+1} = \bar{\phi}_t (1 - \rho + \zeta_t) E_t \quad (26)$$

$$q_t a_{t+1}^B + \sum_{k=1}^K q_{t,t+k}^l L_{t+k}^{t+1} = (1 - \rho + \zeta_t) E_t + q_t^d D_{t+1} \quad (27)$$

(26) is banks' binding limited pledgeability constraint and (27) is their binding budget constraint. Calling  $\lambda_t$ ,  $v_t$ , and  $\xi_t$  the Lagrange multiplier on, respectively, the budget constraint, the leverage constraint, and the  $a_{t+1}^B \geq 0$  constraint, the optimality conditions of banks are

$$\lambda_t q_t^d = v_t q_t^d + q_t \left\{ \rho + (1 - \rho) (\lambda_{t+1} + \bar{\phi}_{t+1} v_{t+1}) \right\} \quad (28)$$

$$\lambda_t q_{t,t+k}^l = q_{t+1,t+k}^l q_t \left\{ \rho + (1 - \rho) (\lambda_{t+1} + \bar{\phi}_{t+1} v_{t+1}) \right\} \quad \forall k \geq 1 \quad (29)$$

$$q_t - q_{t,t+1}^l = \frac{\xi_t}{\lambda_t} \quad (30)$$

$$a_{t+1}^B \geq 0 \quad (31)$$

$$a_{t+1}^B (q_t - q_{t,t+1}^l) = 0 \quad (32)$$

Lending is unconstrained at  $t$  if  $\xi_t = 0$ .

- Bond market clearing

$$a_{t+1}^S + a_{t+1}^B = 0 \quad (33)$$

- Loan market clearing

$$\forall k = 1, \dots, K \quad L_{t+k}^{t+1} - L_{t+k}^t = \mu_k \left( \gamma_{t+k}^{o,k} Y_{t+k} - c_{t+k}^{o,k} \right) \quad (34)$$

- Goods market clearing

$$Y_t = C_t^s + C_t^B + \sum_{k=1}^K \mu_k c_t^{y,k} + \left[ \sum_{k=1}^K \mu_k \gamma_t^{o,k} Y_t - L_t^t \right] \quad (35)$$

Given a guess for  $\lambda_t$ , there are  $4K + 11$  equations, hence we can solve for all variables (including  $\lambda_{t+1}$ ) in terms of  $\lambda_t$ . Given a sequence  $\{q_t^m\}$  that converges to some  $q_\infty^m$ , we can solve for the steady state and then search for  $\lambda_0$  such that iterating forward leads  $\lambda_t$  to converge to its steady state value.

## B.4 Proofs and derivations

**Proof of Proposition 1.** Combining banks' leverage and budget constraints (26)-(27), we have

$$q_t a_{t+1}^B + \sum_{k=1}^K q_{t,t+k}^l L_{t+k}^{t+1} = \left(1 + \bar{\phi}_t\right) (1 - \rho + \zeta_t) E_t. \quad (36)$$

Combining banks' budget constraint (27) and savers' budget constraint (22), we have, after simplifying with bond-market clearing (33),

$$\begin{aligned} \sum_{k=1}^K q_{t,t+k}^l L_{t+k}^{t+1} + C_t^s &= \gamma_t^s Y_t + a_t^s + D_t + E_t \\ &= \gamma_t^s Y_t + a_t^s + a_t^B + \sum_{k=0}^{K-1} q_{t,t+k}^l L_{t+k}^t \\ \sum_{k=1}^K q_{t,t+k}^l L_{t+k}^{t+1} + C_t^s &= \gamma_t^s Y_t + \sum_{k=0}^{K-1} q_{t,t+k}^l L_{t+k}^t, \end{aligned} \quad (37)$$

where the second line follows from the definition of  $E_t$  and the third line from the previous date's bond-market clearing.

Consider now an equilibrium such that  $q_t^l = q_t$  for all  $t$  (for instance around a steady state with unconstrained lending). Then the system is block-recursive, because we do not need to solve for bank capital  $E_t$ . We can replace (27) with the consolidated budget constraint (37) and solve for

$$q_t, a_{t+1}^s, a_{t+1}^B, \{L_{t+1+k}^{t+1}\}_{k=0}^{K-1}, C_t^s, C_{t+1}^s, \{c_t^{y,k}, c_{t+k}^{o,k}\}_{k=1}^K$$

without any reference to the deposit market, and then back out deposit prices and quantities from (21) and (26). In an equilibrium with constrained lending, we must instead keep track separately of capital  $E_t$  and (27) to solve for loan prices  $q_t^l$ .

**Proof of Propositions 2 and 3.** Let  $\mathcal{L}(R^l)$  be the value of the end-of-period stock of loans across all maturities for a given steady state short-term loan rate  $R^l$

$$\mathcal{L}(R^l) = \sum_{k=1}^K (R^l)^{-k} \left[ \sum_{j=k}^{K-k} \frac{\mu_j x_j}{G^{j-k}} \right],$$

where each  $x_k$  solves type  $k$  borrowers' Euler equation

$$u' \left( \gamma^{y,k} + (R^l)^{-k} x_k \right) = (\beta R^l)^k u' \left( \gamma^{o,k} G^k - x_k \right).$$

$\mathcal{L}$  is a decreasing function of  $R^l$  if  $\sigma \geq 1$ , as assumed in the text.

Steady state equilibrium conditions in the deposit, loan, and goods markets imply:

$$\frac{x_d \left( f \left( \frac{s^d}{i} \right), 1 \right)}{x \left( f \left( \frac{s^d}{i} \right), 1 \right)} = s^d \times \frac{E}{\gamma^s - \mathcal{L}(R^l(E))} \times \frac{\theta (1 + \bar{\phi}) (1 - \rho + \zeta)}{\chi}. \quad (38)$$

(38) gives us a solution

$$s^d(i, E)$$

Under strict gross substitutability, the right-hand side of (38) is increasing in  $s^d$  and in  $E$ : as  $E$  increases,  $R^l(E)$  decreases so  $\mathcal{L}$  increases.  $s^d(i, E)$  is non-decreasing in  $i$ . To see this, recall that we always have, from the strict concavity of  $x$ , that  $f$  is increasing. Then, from Assumption 5, the left-hand side of (38) is a decreasing function of  $s^d$ , and a higher nominal rate  $i$  decreases  $f \left( \frac{s^d}{i} \right)$ , which shifts the left-hand side of (38) up. The solution  $s^d(i, E)$  must then increase. As a result, the deposit spread  $\tau^d$  also increases. Going back to (10), we then have two possibilities:

- suppose that in equilibrium  $\bar{\phi}$  increases with  $i$ : then  $\bar{\phi} \tau^d$  increases with  $i$ , and  $(1 + \bar{\phi}) \tau^l$  must decrease, hence  $\tau^l$  decreases;
- suppose that in equilibrium  $\bar{\phi}$  decreases with  $i$ . This means that  $\frac{1+\tau^l}{1-\tau^d}$  must fall, hence  $d\tau^l + d\tau^d < d\tau^l + \frac{1+\tau^l}{1-\tau^d} d\tau^d < 0$ . Since  $\bar{\phi}(\tau^l + \tau^d) + \tau^l$  must be constant,  $\tau^l$  must increase with  $i$ , which contradicts the fact that  $\bar{\phi}$  decreases.

Thus it must be that following an increase in the steady state nominal rate  $i$ ,  $\bar{\phi}$  increases and  $\tau^l$

increases. The same proof applies for Proposition 3, as  $\frac{ROE}{R^*} = \frac{\beta}{1-\rho+\zeta}$  is constant and aggregate loan demand  $\mathcal{L}$  scales with  $1/R^*$  holding  $\tau^l$  fixed.

A knife-edge case happens when  $f \mapsto \frac{x_d(f,1)}{x(f,1)}$  is constant: the nominal rate  $i$  is then irrelevant for  $s^d$  conditional on  $E$ . I now show that this only arises in the case of Cobb-Douglas liquidity  $x$ . For superneutrality in both regimes, we need  $\frac{x_d\left(f\left(\frac{s^d}{i}\right),1\right)}{x\left(f\left(\frac{i^d}{i}\right),1\right)}$  to be constant in the inflation target  $\pi$ . Rewriting  $u = f\left(\frac{s^d}{i}\right)$  we have

$$x_d\left(1, \frac{1}{u}\right) = \text{constant} \times ux\left(1, \frac{1}{u}\right),$$

or, denoting  $z = 1/u$  and  $\varphi(z) = x(1, z)$ ,

$$z\varphi'(z) = \text{constant} \times \varphi(z).$$

The solution of this differential equation is

$$\log \varphi(z) = A + B \times \log z,$$

for some constants  $A$  and  $B$ , which implies Cobb-Douglas liquidity

$$x(1, z) = e^A z^B,$$

as  $x$  is homogeneous of degree 1.

**Proof of Proposition 5.** Following Werning (2015), we can first solve for the “flexible prices” equilibrium with constant output  $Y_t = 1$ . This gives us a sequence of natural interest rates  $\{R_t^n\}$ , implied allocations  $\{\hat{z}_t\}$  and loan and deposit spreads  $\{\tau_t^l, \tau_t^d\}$ . We can then guess that for a given sequence of policy rates  $\{R_t\}$  the equilibrium is

$$Y_t = \frac{R_t^n}{R_t} Y_{t+1},$$

while  $L_t^t, D_t$  are proportional to  $Y_t$

$$L_t^t = \hat{\ell}_t^t Y_t, \quad D_t = \hat{d}_t Y_t$$

and spreads are the same as under  $Y_t = 1$ . The guess works because we can rewrite the optimality of deposit holdings (focusing on short-term loans  $K = 1$  to simplify notation) as

$$\begin{aligned}
s_t^d \hat{d}_{t+1} Y_{t+1} &= (1 - \alpha) \chi \underbrace{\left[ \gamma_{t+1}^s Y_{t+1} + L_{t+1}^{t+1} - q_{t+1}^l L_{t+2}^{t+2} \right]}_{=C_{t+1}^s} \\
&= (1 - \alpha) \chi \left[ \gamma_{t+1}^s Y_{t+1} + \hat{\ell}_{t+1}^{t+1} Y_{t+1} - \frac{q_{t+1}}{1 + \tau_{t+1}^l} \hat{\ell}_{t+2}^{t+2} Y_{t+2} \right] \\
&= (1 - \alpha) \chi \left[ \gamma_{t+1}^s Y_{t+1} + \hat{\ell}_{t+1}^{t+1} Y_{t+1} - \frac{1}{1 + \tau_{t+1}^l} \hat{\ell}_{t+2}^{t+2} R_{t+1}^n Y_{t+1} \right]
\end{aligned}$$

which holds by definition of hat allocations, and similarly for the other equilibrium condition

$$\begin{aligned}
\gamma_t^s Y_t + L_t^t - q_t^l L_{t+1}^{t+1} &= \frac{1}{\beta R_t} \left( \gamma_{t+1}^s Y_{t+1} + L_{t+1}^{t+1} - q_{t+1}^l L_{t+2}^{t+2} \right) \\
\gamma_t^s Y_t + \hat{\ell}_t^t Y_t - \frac{q_t}{1 + \tau_t^l} \hat{\ell}_{t+1}^{t+1} Y_{t+1} &= \frac{1}{\beta R_t} \left( \gamma_{t+1}^s Y_{t+1} + \hat{\ell}_{t+1}^{t+1} Y_{t+1} - \frac{q_{t+1}}{1 + \tau_{t+1}^l} \hat{\ell}_{t+2}^{t+2} Y_{t+2} \right) \\
\gamma_t^s + \hat{\ell}_t^t - \frac{1}{R_t^n (1 + \tau_t^l)} \hat{\ell}_{t+1}^{t+1} &= \frac{1}{\beta R_t^n} \left( \gamma_{t+1}^s + \hat{\ell}_{t+1}^{t+1} - \frac{\hat{\ell}_{t+2}^{t+2}}{R_{t+1}^n (1 + \tau_{t+1}^l)} \right)
\end{aligned}$$

which also holds by definition of hat allocations.

## C Calibration

The model period is 1 year. This choice allows for a higher effective duration of deposits and short-term loans, to capture the fact that those rates adjust not only partially but also sluggishly, see Figure 2. My baseline calibration fits the period 2000-2008 and starts with an annual steady state real rate of  $r^* = 3\%$ , that is approximately the Laubach and Williams (2015) estimate for the period. Table 8 summarizes the calibration.

Liquidity services from money and deposits are combined using the CES aggregator (15).  $\epsilon$  is the elasticity of substitution between money and deposits.  $u$  and  $v$  are logarithmic to remain as close as possible to the neutrality conditions of Proposition 5. I allow for two loan maturities: 60% of short-term loans with maturity  $k = 1$  year and 40% of long-term loans with maturity  $K = 10$  years. This approximates the loan repricing maturity structure from the Call Reports, shown in Figure 16. Short-term credit is meant to capture both small business lending and consumer credit, e.g., adjustable-rate mortgages or unsecured credit in response to health shocks as in Chatterjee et al. (2007). Long-term loans are closer to mortgages.

I set the average deposit spread at 2.5% and the short-term loan spread at 1%. Average “core

**Table 8:** Calibration. Sources: see text.

| Parameter        | Description        | Value | Target                   |
|------------------|--------------------|-------|--------------------------|
| $\beta$          | Discount factor    | 0.97  | $r^* = 3\%$              |
| $\pi$            | Inflation target   | 2%    |                          |
| <i>Savers</i>    |                    |       |                          |
| $\chi$           | Liquidity services | 0.02  | 2.5% deposit spread      |
| $\alpha$         | Weight on money    | 0.97  | money-deposit ratio      |
| $\epsilon$       | Elasticity $m, d$  | 8     | 70% deposit pass-through |
| $\gamma^s$       | Income share       | 52%   | 38% loans/GDP            |
| <i>Borrowers</i> |                    |       |                          |
| $\gamma^{o,1}$   | Income share       | 45%   | 1% loan spread           |
| $\gamma^{o,K}$   | "                  | 3%    | 40% long-term loans      |
| <i>Banks</i>     |                    |       |                          |
| $\rho$           | Net payout rate    | 17%   | 30% deposits/GDP         |
| $\theta$         | Pledgeability      | 0.79  | bank leverage            |

deposits” defined as checking plus saving deposits at commercial banks, represent 30% of GDP. The stock of loans to GDP averages at 38%. There are multiple ways to achieve these quantities; I set  $\gamma^{y,1} = \gamma^{y,K} = 0$ , which implies  $\gamma^s = 52\%$ ,  $\gamma^{o,1} = 45\%$ , and  $\gamma^{o,K} = 3\%$ . The corresponding target leverage ratio  $\phi = 3.8$  is achieved with a pledgeability parameter  $\theta = 0.79$ . This target leverage is lower than typical numbers because I do not count securities on the asset side or wholesale funding on the liability side. The payout rate  $\rho - \iota$  is then set at 17% to ensure the implied bank equity/annual GDP ratio  $E$  of 8%.

The remaining parameters are related to liquidity. Over a grid for  $\epsilon$ , I set  $\alpha(\epsilon)$  and  $\chi(\epsilon)$  to target the deposits/GDP ratio already mentioned and a 12% money-deposit ratio, which corresponds to half of currency component of M1 (approximately the share held domestically, see, e.g., Schmitt-Grohé and Uribe 2012) divided by core deposits. I then solve for the steady state and compute the reaction of the deposit rate to a 100 bps monetary shock under sticky inflation. The elasticity of substitution  $\epsilon$  is set to match my estimates of the 1-year deposit pass-through estimated over 2000-2008 as in Section 2.2. I aggregate over checking deposits, saving deposits and money market deposit accounts according to the weights in the 2004 Survey of Consumer Finances, which yields a 70% pass-through and thus a value  $\epsilon = 8$ . This yields values  $\alpha = 0.97$  and  $\chi = 0.02$ , close to those in Di Tella and Kurlat (2017).

## D Incomplete pass-through in a two-period example

I use a two-period version of the model to illustrate analytically the main forces driving the response of output, spreads, bank lending and profits to monetary policy shocks. Proofs are available upon request.

**Setup.** There are two dates  $t = 0$  and  $t = 1$ , and prices are sticky only at  $t = 0$ . Thus  $Y_1$  is fixed at its natural level  $Y_1^*$ , but  $Y_0$  depends on monetary policy  $R_0$  or, equivalently,  $i_0$ . I consider monetary shocks around an arbitrary baseline allocation determined by the policy rate  $R_0$  (not necessarily the natural rate that implements  $Y_0 = Y_0^*$ ). All households have log-utility ( $u = v = \log$ ) and the same discount factor  $\beta$ . Savers have no income at date 1, so I use  $\gamma^s$  and  $\gamma^b = 1 - \gamma^s$  without time subscripts to denote the shares of income  $Y_0$  accruing to savers and borrowers, respectively.

**Proposition 6.** *There exists a decreasing function  $R^*(E_0)$  such that lending is constrained if and only if  $R_0 < R^*(E_0)$ . Output is given by*

$$Y_0 = \begin{cases} \frac{Y_1^*}{\beta R_0} & \text{if } R_0 \geq R^*, \\ \frac{Y_1^*}{\beta R_0} \times \Gamma(\tau_0^l) & \text{if } R_0 < R^*, \end{cases} \quad (39)$$

$$(40)$$

where  $\Gamma \leq 1$  is decreasing in  $\tau_0^l$ . Fixing  $R_0$ , a negative shock to  $E_0$  or  $\theta$  increases  $\tau_0^l$  if  $R_0 < R_0^*$ .

The proof gives the closed form for  $\Gamma$ . In the unconstrained lending regime, output is given by the standard dynamic IS curve (39), that exactly matches the RANK model, as in Proposition 5. Thus liquidity frictions alone are irrelevant for aggregate output, which reflects Proposition 1's dichotomy between consumption and liquidity allocations in the unconstrained lending regime. In the constrained lending regime, the new term  $\Gamma$  captures credit frictions. The loan spread  $\tau_0^l$  appearing in (40) is an equilibrium object, but a negative shock to bank capital  $E_0$  or pledgeability  $\theta$  increases  $\tau_0^l$  all else equal. A higher loan spread  $\tau_0^l$  hurts borrowers but benefits savers, who receive higher dividends from banks at  $t = 1$ . The proof of Proposition 6 shows that the total effect on output is negative, and thus an increase in  $\tau_0^l$  acts as a negative aggregate demand shifter.

**The pass-through of monetary shocks.** Equation (40) makes apparent that a monetary shock (a change in  $R_0$ ) has two effects in the constrained regime: the standard RANK effect on the first term  $\frac{Y_1^*}{\beta R_0}$ , and a new effect on the second term  $\Gamma(\tau_0^l)$  if the shock affects the spread between loan and bond rates. I now describe how loan rates are, in turn, related to deposit rates. Let

$$\eta^Y \equiv -\frac{d \log Y_0}{d \log R_0}, \quad \eta^l \equiv \frac{d \log R_0^l}{d \log R_0}, \quad \eta^d \equiv \frac{d \log R_0^d}{d \log R_0}$$

denote the interest-elasticities, or *pass-through*, of monetary policy to output (with a minus sign to have positive numbers), loan rates and deposit rates, respectively. These three elasticities are tied together by the fact that banks are both the issuers of deposits and the providers of loans:

**Proposition 7.** *In the constrained lending regime, loan pass-through  $\eta^l$  and the interest-elasticity of output  $\eta^Y$  are both increasing in deposit pass-through  $\eta^d$ .  $\eta^Y$  is positive but smaller than in the unconstrained lending regime (where  $\eta^Y = 1$ ); more precisely, in the constrained lending regime  $\eta^Y$  is bounded by*

$$1 - \frac{(1 + \bar{\phi}) \Gamma}{1 + \bar{\phi} + \frac{(1 - \epsilon^\Gamma) \beta_Y^b Y_0}{Y_1^*/R_0^l - \beta_Y^b Y_0}} \leq \eta^Y \leq 1 - \frac{\Gamma}{1 + \bar{\phi} + \frac{(1 - \epsilon^\Gamma) \beta_Y^b Y_0}{Y_1^*/R_0^l - \beta_Y^b Y_0}},$$

where  $\epsilon^\Gamma = \frac{d \log \left( 1 + \tau_0^l \left[ 1 - Y^s \beta \left( \frac{1 + \tau_0^l}{1 + \beta + \tau_0^l} \right) \right] \right)}{d \log (1 + \tau_0^l)} \in (0, 1)$ .

The proof contains closed-form formulas mapping  $\eta^d$  to  $\eta^l$  and  $\eta^Y$ . The intuition behind Proposition 7 is as follows. In this two-period setting, equity  $E_0$  is fixed and loan supply only depends on the leverage ratio  $\bar{\phi}_0$ , which increases in the loan-deposit spread  $R_0^l/R_0^d$  because higher profits relax banks' pledgeability constraint.<sup>39</sup> The size of banks' balance sheet  $(1 + \bar{\phi}_0) E_0$  ties together the deposit and loan markets. All else equal, a higher deposit pass-through  $\eta^d$  means that an interest rate hike contracts credit supply by more, because the profits banks make on deposits fall by more. The loan rate must then increase by more to clear the credit market, that is, loan pass-through  $\eta^l$  must be higher. Since the fall in credit supply acts as a deleveraging shock, the more credit supply contracts, the more output falls in response to the rate hike. Thus a higher deposit pass-through leads to a stronger effect of monetary shocks on output  $\eta^Y$  through a "bank lending channel" whose strength depends on deposit pass-through.<sup>40</sup> Next, I show how low nominal interest rates can dampen deposit pass-through.

**Low interest rates and low pass-through.** Proposition 7 takes deposit pass-through  $\eta^d$  as given, but it is itself an equilibrium object, that depends in particular on the level of interest rates. The following result shows how low rates can dampen deposit pass-through:

---

<sup>39</sup>Recall that  $\bar{\phi}_0 = \frac{\theta R_0^l/R_0^d}{1 - \theta R_0^l/R_0^d}$ .

<sup>40</sup>The interest-elasticity of output depends on the deposit rate only indirectly, through the loan rate. Although savers do hold deposits that pay  $R_0^d$  and thus earn an *average* return between  $R_0^d$  and the bond rate  $R_0$  (and in fact exactly  $R_0^d$  in the constrained regime), their relevant *marginal* rate of intertemporal substitution remains  $R_0$ , hence there is always full pass-through of monetary policy to savers' consumption. Assuming that savers can only save in deposits would mechanically imply incomplete pass-through even absent credit frictions. However, in my model, allowing for savers' portfolio choice between bonds, deposits and money is crucial to generate incomplete deposit pass-through.

**Lemma 2.** *If*

$$\frac{d^2}{df^2} \left[ \frac{x_d(f, 1)}{x(f, 1)} \right] \leq 0, \quad (41)$$

*then the deposit pass-through  $\eta^d$  is increasing in the nominal rate  $i_0$ . If  $x$  is CES as in (15), then a sufficient condition for (41) to hold is*

$$\epsilon > \frac{2 - 2\alpha}{1 - 2\alpha}.$$

In Section 2.2, I show that deposit pass-through is lower at lower rates in U.S. data. This suggests that condition (41) is satisfied for U.S. deposit rates. Gross substitutability implies that the money-deposit ratio is a decreasing function of the nominal rate  $i$ . The intuition behind (41) is that there is more scope for substitution between money and deposits when the money-deposit ratio  $f = \frac{m}{d}$  is higher, which happens at lower  $i$ . Within my framework, this assumption on  $x$  is the simplest way to capture the state-dependence of deposit pass-through, but there could be other reasons for deposit pass-through to depend on the level of interest rates, for instance in models that feature depositor search (Yankov 2014).

Together with Proposition 7, condition (41) implies that the loan pass-through  $\eta^l$  and the interest-elasticity of output  $\eta^Y$  are also lower when the nominal interest rate  $i_0$  is lower. In my model, the fact that loan pass-through is lower at lower rates, as we also see in Section 2.2, is therefore *a consequence of the lower deposit pass-through* at lower rates. Deposit and loan markets are connected because the same intermediaries are providing loans and deposits within the same balance sheet. In a narrow banking system where different intermediaries specialize in lending or liquidity provision, low interest rates would still decrease deposit pass-through, but would have no reason to affect loan pass-through.

**Bank profitability and lending.** So far I have studied how banks affect the transmission of monetary policy to households and aggregate output. I conclude this section by focusing on the impact of monetary policy on banks themselves, looking at bank lending and bank profitability. I show in particular how the interest-elasticity of bank profits depends on the level of interest rates, and provide evidence from the response of U.S. bank stock prices to monetary shocks.

One measure of banks' profits is the return on equity

$$\text{ROE} = \frac{E_1}{E_0} = R_0^l \times \frac{1 - \theta}{1 - \theta \frac{R_0^l}{R_0^d}}. \quad (42)$$

ROE has two components. One is the loan rate  $R_0^l$ ; the other is the loan volume, which is increasing in leverage hence in the spread  $R_0^l/R_0^d$ . In the unconstrained lending regime, bank profits always increase with  $R_0$  as both the loan rate and the loan volume increase. In the constrained

lending regime, an increase in  $R_0$  is partially passed through to  $R_0^l$ , but it can also decrease the loan-deposit spread and hence the volume of lending.

**Proposition 8** (Bank profits and lending). *Suppose that the liquidity aggregator  $x$  satisfies condition (41). Then there exist  $\underline{\underline{R}}, \underline{R}$  such that  $\underline{\underline{R}} \leq \underline{R} \leq R^*$  and*

- *for  $R_0 \in (\underline{R}, R^*)$ , bank lending and profits fall with a monetary tightening  $dR_0 > 0$ ;*
- *for  $\underline{\underline{R}} \leq R_0 \leq \underline{R}$ , bank lending falls but bank profits rise with a monetary tightening;*
- *for  $R_0 \leq \underline{\underline{R}}$ , both bank profits and lending rise with a monetary tightening.*

The intuition behind Proposition 8 is that the strength (but not the sign) of the output response depends on the loan rate pass-through  $\eta^l$ , while the response of bank loans depends on the *difference between loan and deposit pass-through*  $\eta^l - \eta^d$ . Holding deposit pass-through  $\eta^d$  fixed, a higher loan pass-through  $\eta^l$  would indeed be reflected in a positive correlation between the output response and the loan response, as in Bernanke and Blinder (1992). But crucially, in general equilibrium we cannot hold  $\eta^d$  fixed, as  $\eta^l$  and  $\eta^d$  are jointly determined through banks' balance sheets.

The model sheds light on the alignment of incentives between banks and the rest of the economy regarding the conduct of monetary policy. When bank lending is unconstrained, banks always benefit from rate hikes, in the sense that an increase in the policy rate boosts their return on equity. When bank lending is constrained, banks might instead benefit from accommodative monetary policy: this “central bank’s put” was widely discussed in the early stages of the financial crisis (Farhi and Tirole 2012, Diamond and Rajan 2012). However, if either banks get recapitalized back to the unconstrained regime, or if rates reach ultra-low levels and bank lending remains constrained, then banks may start benefiting from rate hikes, which would nevertheless hurt output, albeit not necessarily bank lending.

## E Relation with deposit market power

In this section, I compare the predictions of a model of bank market power over deposits and wholesale funding frictions a la Drechsler et al. (2017), and those of the baseline model with scarce equity. I then consider a mixed model with both market power and equity frictions.

## E.1 Deposit pricing under market power

I first solve savers' static portfolio choice and the bank's resulting optimal deposit pricing policy. Consider a slightly more general version of Section 3.3, where the utility of a saver at date  $t$  is

$$U(c_t^s, x(m_t, d_t))$$

The date- $t$  first-order conditions with respect to next period liquidity holdings  $m_{t+1}$  and  $d_{t+1}$  are

$$\begin{aligned} \frac{U_{x,t+1} x_{d,t+1}}{U_{c,t+1}} &= \frac{q_t^d - q_t}{q_t} \equiv s_t^d \\ \frac{U_{x,t+1} x_{m,t+1}}{U_{c,t+1}} &= \frac{q_t^m - q_t}{q_t} \equiv i_t \end{aligned} \quad (43)$$

As in Section 3.3, if  $x$  is homothetic and concave we get

$$\begin{aligned} \frac{x_d(m_{t+1}, d_{t+1})}{x_m(m_{t+1}, d_{t+1})} &= \frac{s_t^d}{i_t} \equiv z_t \\ \Rightarrow \frac{m_{t+1}}{d_{t+1}} &= f(z_t) \end{aligned}$$

where  $f$  is increasing. Plugging back into (43):

$$\frac{U_x(c_{t+1}^s, d_{t+1} \cdot x(f(z_t), 1))}{U_c(c_{t+1}^s, d_{t+1} \cdot x(f(z_t), 1))} x_d(f(z_t), 1) = z_t i_t \quad (44)$$

defines a deposit demand function

$$\mathcal{D}_{t+1}(z_t, i_t, c_{t+1}^s)$$

Suppose now that a monopolist bank maximizes revenue taking  $c_{t+1}^s$  as given. This simplifying assumption can be justified in several ways:

1. This setup is isomorphic to a model in which  $d$  represents an aggregator of deposits  $d_b$  from a large number of horizontally differentiated banks  $b$  in monopolistic competition: each individual bank will then take total consumption  $c_{t+1}^s$  as given.
2. Alternatively, under a Greenwood et al. (1988) specification for  $U$

$$U(c, x) = \tilde{U}(c + v(x)) \quad (45)$$

deposit demand is independent of consumption  $c_{t+1}^s$ ; however, this justification is less appealing once we think of microfoundations for liquidity in the utility (e.g., Online Appendix B.2).

3. A third route is to follow Drechsler et al. (2017): in the limit of vanishing liquidity services  $U_x \rightarrow 0$ ,  $c_{t+1}^s$  becomes exogenous.

Taking  $c_{t+1}^s$  as given, the bank solves

$$\max_{s_t^d} s_t^d \mathcal{D} \left( \frac{s_t^d}{i_t}, i_t, c_{t+1}^s \right) \Leftrightarrow \max_{z_t} z_t \mathcal{D} (z_t, i_t, c_{t+1}^s)$$

and thus sets

$$\frac{\partial \log \mathcal{D}_{t+1}}{\partial \log z_t} = -1 \quad (46)$$

Denote

$$G(x, c) = \frac{U_x(c, x)}{U_c(c, x)}$$

Differentiating (44), we get the elasticity

$$\frac{\partial \log \mathcal{D}_{t+1}}{\partial \log z_t} = \frac{1 - \frac{\mathcal{D}_{t+1}(z_t, i_t) x(f(z_t), 1) G'(\mathcal{D}_{t+1}(z_t, i_t) x(f(z_t), 1))}{G(\mathcal{D}_{t+1}(z_t, i_t) x(f(z_t), 1))} - \frac{\partial \log x_d(f(z_t), 1)}{\partial \log z_t}}{\frac{\mathcal{D}_{t+1}(z_t, i_t) x(f(z_t), 1) G'(\mathcal{D}_{t+1}(z_t, i_t) x(f(z_t), 1))}{G(\mathcal{D}_{t+1}(z_t, i_t) x(f(z_t), 1))} z_t f'(z_t) x_m(f(z_t), 1)}$$

Hence if  $x \mapsto \frac{x G_x(x, 1)}{G_x(x, 1)}$  is constant, the elasticity  $\frac{\partial \log \mathcal{D}_{t+1}}{\partial \log z_t}$  does not depend on  $i_t$ . This is the case under the following assumption, which I maintain in the rest of the section:

**Assumption 6.** *There exist  $\gamma$  and a function  $\varphi$  such that*

$$\frac{U_x(c_{t+1}^s, x_{t+1})}{U_c(c_{t+1}^s, x_{t+1})} = \varphi(c_{t+1}^s) x_{t+1}^{-\gamma} \quad (47)$$

The following result generalizes the case of CES  $x$  and vanishing liquidity  $U_x \rightarrow 0$  studied by Drechsler et al. (2017):

**Proposition 9.** *The monopolist bank sets a constant  $z^*$  (that does not depend on  $i_t$ ), hence deposit pass-through is incomplete, but “constant”.<sup>41</sup>*

$$\eta_t^d = \frac{d \log R_t^d}{d \log (1 + i_t)} = 1 - \frac{d \log (1 + s_t^d)}{d \log (1 + i_t)} = 1 - z^* R_t^d \approx 1 - z^*$$

Importantly, assumption 6 only involves the outer utility  $U(c, x)$  and not the aggregator  $x$  that is just assumed to be homothetic and concave. Thus  $x$  can be CES as in Drechsler et al. (2017), hierarchical CES as in (16), or even a more general aggregator. Assumption 6 is satisfied for instance if  $U(c, x) = u(c) v(x)$  or  $U(c, x) = u(c) + v(x)$  where  $u$  and  $v$  are CRRA sub-utilities. It also holds with the non-separable Greenwood et al. (1988) specification (45).

<sup>41</sup>In this discrete time formulation, pass-through still depends slightly on the level of rates through  $R_t^d$  but the effect is negligible and would disappear in continuous time.

Proposition shows that while deposit pass-through is incomplete under market power, it is not state-dependent: it is as incomplete at low interest rates as it is at high rates. However,  $z_t = s_t^d / i_t$  can indeed increase as  $i_t$  falls in the case of financially constrained banks. For instance, suppose deposits supply is fixed at  $\bar{D}$ . Then rewriting (44) as

$$\varphi(c_{t+1}) \bar{D}^{-\gamma} x \left( f \left( \frac{s_t^d}{i_t} \right), 1 \right)^{-\gamma} \cdot x_d \left( f \left( \frac{s_t^d}{i_t} \right), 1 \right) = s_t^d \quad (48)$$

shows the following:

**Corollary 2.** *Holding deposit supply fixed at  $\bar{D}$ , the ratio  $z_t = \frac{s_t^d}{i_t}$  is a decreasing function of  $i_t$ .*

## E.2 Long-run spreads with deposit market power

I now show that deposit market power and equity constraints have different implications for *long-run* lending. Suppose to simplify that the monopolist bank considered above cannot issue any wholesale funding, so that its lending is an increasing function of deposit supply; it is straightforward to generalize the argument to costly wholesale funding as in Drechsler et al. (2017). Then in a steady state with lower nominal rate  $i$ , the monopolist bank will optimally supply more deposits. The equilibrium quantity of deposits  $\mathcal{D}(z^*, i, c^s)$  is decreasing in  $i$  by (44). Therefore, the resulting deposit spread is lower (since  $s^d = z^* i$  falls). Lending increases without any shift in loan demand, thus loan spreads also fall:

**Corollary 3.** *With a monopolist bank and no wholesale funding, both the steady state deposit spread  $\tau^d$  and the steady state loan spread  $\tau^l$  are lower when  $i$  is lower.*

This result contrasts with the first fact in Section 2.1 and the stability of the total loan-deposit spread, with  $\tau^l$  and  $\tau^d$  moving in opposite directions.

## E.3 Combining deposit market power and scarce equity

Suppose now that we combine bank market power on the deposit side, while maintaining the assumption that lending is tied to bank equity. But unlike in Drechsler et al. (2017), wholesale funding is costless; and unlike in my baseline model, deposit supply is unconstrained, but chosen optimally by the monopolist bank. Lending is still tied to equity as in the baseline model through  $L = (1 + \bar{\phi}) E$ . Recall that under assumption (47), the optimal choice of  $z = s^d / i$  is constant hence deposit supply is simply  $D^* = \mathcal{D}(z^*, i, c^s)$ . There are then two cases:

- If  $D^* \geq \bar{\phi} E$ , then banks hold bonds or reserves on the asset side (in addition to their loans) to back their optimal deposit supply  $D^*$ .

**Figure 22:** Bank balance sheets with deposit market power and constrained lending when  $D^* > \bar{\phi}E$ .

|                     | Assets | Liabilities    |
|---------------------|--------|----------------|
|                     | Bonds  |                |
| $(1 + \bar{\phi})E$ | Loans  | Deposits $D^*$ |
|                     |        | Capital $E$    |

- If  $D^* < \bar{\phi}E$ , then banks issue wholesale funding paying  $R$  on the liability side to earn loan spreads without expanding deposit supply beyond  $D^*$ .

In both cases, the main steady state equation (10) now becomes

$$\frac{ROE}{R^*} = 1 + \frac{D^*}{E} \times \tau^d + \underbrace{\frac{L}{E} \times \tau^l}_{=1+\bar{\phi}}$$

The only difference is that the ratio  $\frac{D^*}{E}$  can now differ from  $\bar{\phi}$ . This extension yields the exact same proposition as my main long-run results (Propositions 2 and 3):

**Proposition 10.** *Suppose  $m, d$  are gross substitutes (assumption 5). In response to a permanent decline in  $i$ , due to a lower  $R^*$  or a lower inflation target  $\pi$ :*

- *deposits  $D^*$  increase,*
- *the deposit spread  $\tau^d$  falls and the loan spread  $\tau^l$  increases,*
- *bank equity  $E$  and lending  $L$  fall.*

The intuition is exactly as in the baseline model. Lower nominal rates compress the deposit spread  $\tau^d$ , since  $s^d = z^*i$  falls and  $\tau^d = \frac{s^d}{1+s^d}$ . As a result, retained earnings fall, which leads to lower equity, lower lending, and higher loan spreads. The mixed model adds some complexity but it has the advantage of generating more realistic bank balance sheets than those displayed in Figure 3. In particular, banks can hold bonds or excess reserves even when lending is constrained, in order to target their profit-maximizing deposit supply. This optimal deposit supply increases as low interest rates fall, hence bank balance sheets expand while lending shrinks, which implies that banks' bonds or reserves holdings increase.

## F Other extensions

### F.1 Costly equity issuance

In the main text I assumed an exogenous net dividend policy governed by the entry and exit dynamics in Assumption 3. I now show that endogenizing banks' equity issuance and required return on equity ROE reinforces the results.

**Bank profitability.** Let us first take ROE as given, as in the baseline setup. Monetary policy affects banks' book equity and thus market value, even when it is superneutral in terms of consumption. The total market capitalization  $V$  of the banking sector is proportional to the book value of equity  $E$ . More precisely, let  $v_t = \frac{V_t}{E_t - \text{Div}_t}$  be the market-to-book ratio, defined as the net present value of dividends over book equity. The law of motion of  $v$  is  $v_t = \frac{\text{ROE}_t}{R_t} [\rho + (1 - \rho) v_{t+1}]$ , thus in steady state

$$v = \frac{\rho \text{ROE}/R^*}{1 - G(1 - \rho) \text{ROE}/R^*} \geq 1. \quad (49)$$

In both the constrained and unconstrained lending regimes, book equity  $E$  increases in reaction to a higher inflation target. Therefore, the market value of banks  $V$  also increases. The intuition is that when inflation is higher, banks earn more private seigniorage for a given level of capital, which increases  $\tau^d$  and  $\bar{\phi}$ . But since the required return on equity is invariant to inflation,  $(1 + \bar{\phi}) \tau^l + \bar{\phi} \tau^d$  must remain constant. In an unconstrained lending steady state, this can only be achieved by keeping  $\bar{\phi} \tau^d$  constant through higher capital. Part of the extra earnings from private seigniorage is consumed as dividends, and the rest is kept as retained earnings, which ends up increasing  $E$ , until the point where the levered excess return from liquidity provision falls back to its initial level. In a constrained lending steady state, a similar process takes place, but part of the adjustment falls on the (lower) credit spread.

**Equity issuance.** Suppose next that in each period, banks can issue equity  $e$  at a convex cost  $C(e)$  instead of having an exogenous startup equity. Without loss of generality, only entering banks issue equity. Given the equilibrium market-to-book ratio  $v$ , entrants issue  $e$  to maximize  $ve - C(e)$  which yields an endogenous startup equity in each period:

$$\zeta E = \rho (C')^{-1}(v).$$

The only difference with the previous section is that the long-run required return on equity is now endogenous. From (49), ROE solves

$$\frac{\text{ROE}}{R^*} = \frac{\beta}{1 - \rho \left[ 1 - \frac{(C)^{-1} \left( \frac{\rho \text{ROE}/R^*}{1 - G(1 - \rho) \text{ROE}/R^*} \right)}{E} \right]}. \quad (50)$$

Equation (50) generalizes the Modigliani-Miller case where  $\text{ROE}/R^*$  is constant at 1.

**Proposition 11.** *Suppose that entrants can issue equity subject to a positive, increasing and convex cost  $C$ . Then, in the constrained lending regime, a fall in the real interest rate  $R^*$  due to either lower productivity growth  $G$  or higher discount factor  $\beta$  lowers the deposit spread  $\tau^d$  and bank capital  $E$ , and raises the loan spread  $\tau^l$ .*

The required return on equity ROE adjusts with  $R^*$  because when  $R^*$  falls, new banks issue more equity in response to the higher market-to-book ratio  $v$ , bringing down ROE closer to  $R^*$ .

## F.2 Operating costs

To ease exposition, I have focused on banks' net interest income. To map the model to the data, we need to take into account other components of bank profits, in particular operating costs as measured by “non-interest expense” in the Call Reports. In this section, I argue that accounting for these costs only strengthens my results.

The before-tax return on assets ROA is defined as

$$\text{ROA} = \text{NIM} + \text{non-interest income} - \text{non-interest expense} - \text{loan loss provisions}$$

where all terms are defined as percent of earning assets. Equation (6) only considers the net interest margin, setting the last three terms to zero. Figure 11 shows that loan loss provisions soared during the financial crisis, but then reverted to pre-2008 levels in 2012 and have been stable since. Meanwhile, mostly thanks to lower data-processing costs, non-interest expense has declined from 4% to 3% of earning assets. I can accomodate non-interest expense by introducing a cost  $\kappa$  of operating loans in the model. The return net of operating costs on a short-term loan is then  $\frac{R_t^l}{1 + \kappa_t}$ . There is some ambiguity regarding how to attribute non-interest expense to the deposit and lending businesses, because a large part of operating costs simply comes from the costs of maintaing branches that are useful both for making loans and deposits. One common choice in the literature is an equal split that attributes 50% of reported non-interest expenses to the loan side (e.g., Greenwood et al. 2017 or Begenau and Stafford 2018). For exposition, I attribute all the non-interest expense to loans, but it is straightforward to attribute part of the costs to the deposit

side with additional notation  $(\kappa^l, \kappa^d)$ . My argument is unchanged as long as the non-interest expense attributed to loans is increasing in total non-interest expense.

In the presence of operating costs, the accounting identity (6) becomes  $ROE_t = (1 + \bar{\phi}_t) \times ROA_t$  where

$$ROA_t = \underbrace{R_t^l - \frac{\bar{\phi}_t}{(1 + \bar{\phi}_t)} R_t^d}_{\text{NIM}} - \underbrace{\frac{R_t^l \kappa_t}{1 + \kappa_t}}_{\text{non-interest expense}}.$$

In the unconstrained lending regime, banks' no-arbitrage condition between bonds and loans requires  $R_t^l = R_t(1 + \kappa_t)$ . We then have, in steady state:

**Proposition 12.** *A permanent decrease in  $\kappa$  is fully passed through to lower loan rates in the unconstrained lending regime  $\frac{d \log R^l}{d \log(1+\kappa)} = 1$ , but only partly passed through in the constrained lending regime:  $0 < \frac{d \log R^l}{d \log(1+\kappa)} \leq 1$ .*

The two components of banks' "marginal cost" of lending, the real interest rate and non-interest expense, have fallen, yet the loan spread  $\frac{R_t^l}{R_t}$  has been stable or increasing. My model can explain this pattern through the combination of a lower real rate  $R^*$  that pushes up the loan spread, and an offsetting decrease in operating costs.

### F.3 Investment and firm borrowing

I now turn to an alternative setting in which bank loans also finance firm investment, so that flexible prices (or "natural") output is affected by financial frictions. I take a minimal model to illustrate how liquidity frictions can affect the economy's productive capacity: the result will generalize to more realistic models of investment. Instead of having households borrowing from banks, consider in each period a unit continuum of new penniless firms producing the final good from capital and labor

$$y_t = A_t k_t^\alpha n_t^\alpha$$

where  $k_t$  is chosen at  $t - 1$ . As in Gertler and Karadi (2011), all firms are bank-dependent and face the rental rate  $R_t^l$ ; this can easily be generalized to allow for unconstrained firms able to issue bonds and thus facing a rental rate  $R_t$ . Given that total labor supply is equal to 1, equilibrium output is given by

$$Y_t = A_t^{\frac{1}{1-\alpha}} \left[ \frac{\alpha}{R_t^l} \right]^{\frac{1}{1-\alpha}}.$$

The only difference with Section 4 is that the demand for loans is now

$$\mathcal{L}(R_t^l) = \left[ \frac{\alpha A_t}{R_t^l} \right]^{\frac{1}{1-\alpha}}.$$

In this setting with endogenous output, a real rate shock also affects the marginal productivity of capital directly. To isolate the effect of low nominal rates, I focus on inflation. We then have the exact counterpart of Proposition 2:

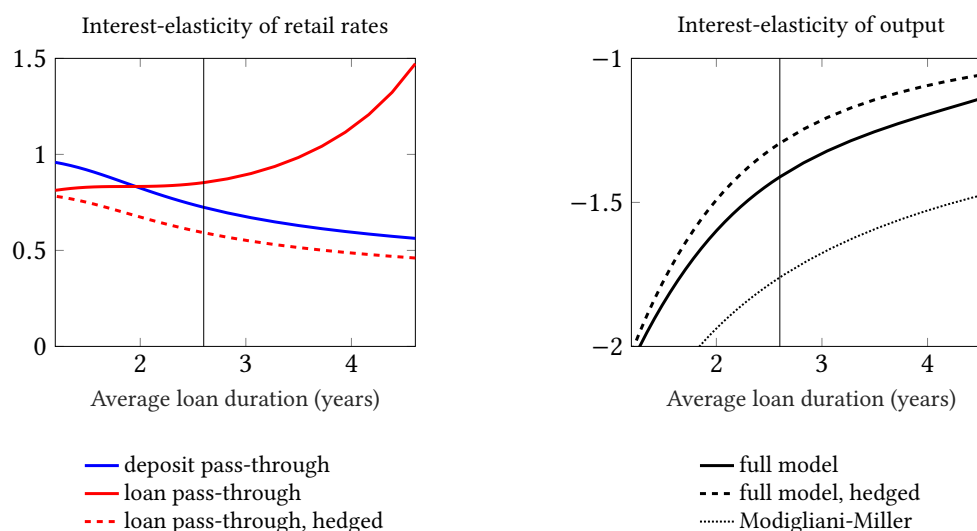
**Corollary 4.** *In the constrained lending regime, a lower inflation target increases the steady state loan spread  $\tau^l$  and thus reduces investment and output.*

## F.4 Maturity mismatch and hedging

Revaluation effects are thought to be an important channel through which monetary policy affects bank lending (Van den Heuvel 2002, Brunnermeier and Koby 2018). I now investigate how banks' maturity mismatch affect the transmission of monetary policy to rates and output in general equilibrium. Recall that bank lending capacity is given by (9). Monetary policy can affect credit supply in two ways: by changing bank leverage  $\bar{\phi}_t$  or by changing the value of long-term assets  $\sum_{k=1}^{K-1} q_{t,t+k}^l L_{t+k}^t$ .

To isolate the role of maturity mismatch, I introduce another benchmark, the “hedged banks” model: bank equity  $E_t$  is fully hedged and remains equal to its steady state value after monetary policy shocks. Interest rate risk is shifted to savers. Figure 23 shows how maturity mismatch affects pass-through and the output effect of monetary policy. Total loans and deposits are kept fixed (at respectively 38% and 30% of GDP), and the model is recalibrated to vary only the share of short-term loans (equal to 60% in the baseline calibration). The left panel of Figure 23 shows how pass-through depends on maturity mismatch. As average loan duration grows, so does the difference between the full model and the “hedged” economy. Loan pass-through increases with duration due to a stronger revaluation effect on banks, and it can even exceed 1 when duration is high enough. By contrast, loan pass-through actually declines with maturity in the “hedged” benchmark.

**Figure 23:** Date-0 effects of monetary policy on rates and output as a function of average bank loan duration.



*Note:* Vertical lines denote the baseline calibration. The "hedged" benchmark is an economy where bank equity remains at its steady state value and interest rate risk is fully shifted to savers.

The right panel of Figure 23 shows that output sensitivity decreases with loan duration. This is due to the force described in Auclert (2019), as illustrated by the “Modigliani-Miller” benchmark in the right panel. Even absent banking frictions, longer loan durations imply smaller unhedged rate exposures for borrowers, and thus a smaller redistribution channel of monetary policy. The “hedged” model controls for the Auclert (2019) redistribution channel, so that comparing the full model to the hedged economy isolates the pure effect of the revaluation of bank equity. Output effects of monetary policy are higher when banks do *not* hedge: when the central bank tightens, bank lending capacity  $\Lambda$  falls, which amplifies the contractionary effect of the rate hike. Quantitatively, the absence of bank hedging increases output sensitivity from by 9% at the baseline duration of 2.6 years.

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