

Imperfect Pass-Through to Deposit Rates and Monetary Policy Transmission*

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Abstract

I study a monetary model which is consistent with three salient features of the transmission of monetary policy. First, deposit rates adjust partially to changes in the Federal Funds rate. Second, banks substitute deposits with other liabilities in response to contractionary monetary policy changes. Finally, contractionary monetary policy shocks increase credit spreads, and in particular mortgage spreads. In the model, banks have market power in the deposit market, invest in long-duration assets but borrow using short-duration liabilities, and have a dividend-smoothing motive. Moreover, demand for banks' deposits has a dynamic component: it responds gradually to changes in current and past deposit rates, as in the literature on customer markets. I use the model to study the implications of imperfect pass-through to deposit rates for monetary policy transmission and find that the imperfect pass-through to deposit rates amplifies the response of output to monetary policy changes.

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1 Introduction

Standard models of the transmission mechanism of monetary policy assume that banks play no role in the transmission. In these models, interest rates are entirely determined by the policy rate and its expected path. However, there are features of the data that are inconsistent with these models and suggest that banks are relevant for monetary policy transmission.

This paper investigates the monetary transmission mechanism by focusing on the effects of monetary policy changes on real activity through the banking sector and the deposit market. Specifically, I study a general equilibrium monetary model which is consistent with three key facts connected to monetary policy transmission. First, pass-through of the policy rate to deposit rates is imperfect. Since at least [Berger and Hannan \(1989\)](#), it has been noted that deposit rates in the United States adjust partially when other short-term rates change¹. Figure 1 highlights this fact by comparing the path of the Federal Funds rate and the savings deposit rate - the largest class of deposits at US commercial banks - from 1987 to 2013. Second, with imperfect pass-through to deposit rates, the opportunity cost of holding deposits increases when the policy rate increases. Accordingly, depositors withdraw their savings from banks in order to invest them into higher yielding assets, and banks have to compensate the outflow of deposits with other liabilities. This phenomenon is described in Figure 2, where a clear negative correlation emerges between the year-over-year change in the Federal Funds rate and in the share of banks' total liabilities accounted for by transaction and savings deposits². Finally, as shown by [Gertler and Karadi \(2015\)](#), credit spreads, and in particular spreads on mortgages originated by banks, increase in response to contractionary monetary policy shocks.

In this paper, I extend a borrower-saver model with housing in the tradition of [Iacoviello \(2005\)](#) to include banks that intermediate funds between savers and borrowers and have market power in the deposit market. Banks borrow through short-term deposits and bonds from savers and lend in fixed-rate mortgages to borrowers³. Savers value services from deposits in the utility function and perceive deposits at different banks as being differentiated. Borrowers derive utility from housing services and are subject to a borrowing limit. Motivated by evidence that turnover of banks' customers and depositors is limited, implying that the customer and depositor base of banks is persistent⁴, I assume that banks set deposit rates considering that the deposit demand they face has a dynamic component: it depends on current and past deposit rates. In order to

¹Even after interest-rate ceilings on deposits have been phased-out in the 1980's.

²In Section 6 I show that the effect is significant also in response to monetary policy shocks identified through external instruments.

³Maturity mismatch is a standard feature of modern commercial banks' portfolios, as argued by [Begenau et al. \(2015\)](#), [Di Tella and Kurlat \(2017\)](#), and [Drechsler et al. \(2018\)](#). Banks do not appear to use interest-rate derivatives to hedge the corresponding interest-rate risk.

⁴I discuss the evidence concerning deposits in Section 7.

capture the dynamic component of deposit demand, I use “deep habits” following [Ravn et al. \(2006\)](#). Deep habits is a common specification in macroeconomic models to represent persistence in the customer base of firms due to switching costs or repeated purchase in customer markets. Finally, banks are subject to a dividend-smoothing motive, and therefore they are not indifferent about the timing of the cash flows they earn from intermediating funds. The dividend-smoothing motive is captured through a convex cost that banks incur if dividends deviate from a target level, as assumed for instance by [Jermann and Quadrini \(2012\)](#) in a model with firms.

In the first part of the paper, I discuss the novel mechanism that generates imperfect pass-through of changes in the policy rate to deposit rates. The mechanism relies on three main features: i) banks have market power in the deposit market and face a deposit demand with a dynamic component, ii) they manage a maturity-mismatched portfolio, and iii) they are subject to a dividend-smoothing motive. The mechanism is as follows. When the policy rate increases, the cost of banks’ short-term debt increases. While new mortgages originated by banks price-in the higher level of rates, mortgages still on banks’ books, which were issued before the rate change, have their rate locked-in in the short-run. Hence, banks face a trade-off. If they increase the deposit rate as much as the policy rate, they lose current profits. If they keep the deposit rate low, banks experience an outflow of deposits, as depositors prefer to earn a higher rate by investing their savings in other assets than keeping them in low-yielding deposits. This is costly for the bank in an environment where deposit demand has a dynamic component. If the bank loses current deposits, the demand it will face in the future will also be low. Attracting more deposits in the future will then require a higher deposit rate than otherwise. In the end, banks decide to adjust the deposit rate partially, smoothing their profits without losing an excessive amount of deposits. As a result, the increase in the policy rate is passed partially to deposit rates.

I show that each of the three main assumptions - deposit demand with a dynamic component, maturity mismatch, and dividend smoothing - is essential in order to obtain imperfect pass-through to deposit rates in my model. Without deep habits for deposits, or if banks’ assets have the same duration as banks’ liabilities, or yet if banks can costlessly adjust their dividends, then pass-through is full or essentially full.

I provide two validations of the mechanism based on data. First, after calibrating the model to the average pass-through estimated by [Drechsler et al. \(2017\)](#), I compare their estimate of the change in deposit quantities after a change in the policy rate⁵ with the estimate from an analogous regression in my model. [Drechsler et al. \(2017\)](#) find that a 100 bp increase in the Federal Funds rate generates an increase in deposit rates by 39 bp and a 3.23% contraction in deposits after one year. In my model, a 100 bp increase in the risk-free rate is associated with an increase in the deposit rate

⁵Not targeted in the parameterization.

by 39 bp and a decrease in deposits by 5.03% after one year. Second, using panel data, I find that banks that manage a portfolio with a larger gap in duration between assets and liabilities have lower pass-through to deposit rates. Overall, this is consistent with the model implication that, if banks held adjustable-rate mortgages i.e. assets with the same duration as liabilities, then pass-through would be full, while with long duration assets such as fixed-rate mortgages, pass-through is imperfect.

In the second part of the paper, I investigate the implications of imperfect pass-through to deposit rates for monetary policy transmission. I show that, in the baseline version of the model, whether there is full or partial pass-through has no different implications for real variables, to a first order. I find that the lack of real effects from imperfect pass-through relative to full pass-through in the baseline model depends on three main assumptions: i) banks face a supply of non-deposit funding which is infinitely elastic at the risk-free rate, ii) deposits are separable in the utility function, and iii) savers provide both deposits and bonds, earn banks' dividends, and save at the risk-free rate at the margin. While breaking the last assumption gives the counterfactual implication that deposits increase when the policy rate increases, by breaking the other two assumptions I show that persistent monetary policy shocks captured through an inflation target-shock can have larger effects on output under imperfect pass-through than if pass-through is full.

In particular, assumption i) means that banks are able to finance any amount of mortgages at the risk-free rate, up to the borrowing limit faced by borrowers. I break it by assuming instead that savers are subject to a portfolio-adjustment cost which limits arbitrage in the market for banks' bonds. The cost implies that savers require banks to pay a rate on bonds higher than the risk-free rate, and the rate increases if banks want to increase their share of bond financing. This is meant to capture that banks have a limited pool of non-deposit borrowing available, and in particular that this source of funding is less stable than deposits ([Hanson et al., 2015](#)). Therefore, if savers were heterogeneous, those who would consider lending to banks would require a higher compensation for the additional rollover risk the bank takes when it finances a larger share of its assets through non-deposit liabilities.

Under this additional assumption, the trade-off faced by banks when the policy rate increases is more complex. As banks keep the deposit rate low in order to smooth profits, deposits flow out. However, banks still have to finance the assets on their balance sheets, thus they substitute deposits with bonds. The substitution towards bond financing leads to an increase in the bond rate banks have to pay. In turn, banks pass the higher bond rate they face at the margin to the rate on new mortgages originated after the monetary policy shock. As a consequence of the stronger response in the mortgage rate, borrowing demand decreases by more relative to the case with perfect pass-through, where there is no outflow of deposits because their opportunity cost is constant.

Since borrowers have high marginal propensity to consume, as they cut borrowing by more they also cut consumption by more, which in a New-Keynesian setting leads to a larger decrease in output relative to the case with perfect pass-through.

Key elements of the mechanism of amplification of monetary policy transmission due to imperfect pass-through to deposit rates are consistent with the empirical evidence. Using local projections with external instruments for monetary policy shocks, I show that substitution of deposits with non-deposit liabilities in banks' balance sheets in response to contractionary monetary policy shocks is supported by the data. Using different data and identification, [Drechsler et al. \(2017\)](#) also report similar findings. The model generates an increase in the spread between the mortgage rate and the rate on a bond of similar maturity in response to a monetary shock that increases the short term rate. In the data, [Gertler and Karadi \(2015\)](#) find that various spreads, and in particular the mortgage spread over the 10 year government bond rate, increase in the short term after a contractionary monetary policy shock.

Finally, breaking assumption ii) by assuming that deposits and consumption are complements in the utility function amplifies the effects of the monetary policy shock because, with imperfect pass-through, the opportunity cost of holding deposits - the deposit spread - increases with the risk-free rate. Therefore, when the monetary shock raises the risk-free rate, savers want to hold less deposits and more bonds, and due to complementarity between deposits and consumption, they also want to consume less. The nominal rigidity in prices implies that the additional decrease in consumption by savers leads to a deeper fall in output, relative to the case with perfect pass-through where the deposit spread is constant.

Literature

This paper is related to several strands of the economics literature. In proposing a novel mechanism that generates imperfect pass-through to deposit rates, it contributes to the literature that studies deposit pricing, which is for the most part empirical. [Berger and Hannan \(1989\)](#), [Berger and Hannan \(1991\)](#), [Diebold and Sharpe \(1990\)](#), [Neumark and Sharpe \(1992\)](#), [Craig et al. \(2011\)](#), [Driscoll and Judson \(2013\)](#), among others, document the slow adjustment of deposit rates, and some asymmetry in such adjustment, using various panel datasets and econometrics techniques. [Gerlach et al. \(2018\)](#) find no significant asymmetry in the aggregate. In my model, since dividend adjustment costs are symmetric, imperfect pass-through is also symmetric.

Within this literature, [Berger and Hannan \(1991\)](#) and [Driscoll and Judson \(2013\)](#) in particular rationalize the stickiness in deposit rates through static models with fixed cost of adjustment. [Sharpe \(1997\)](#), [Shy \(2002\)](#), [Hannan and Adams \(2011\)](#), [Carbo-Valverde et al. \(2011\)](#) instead focus on switching costs as the key friction that gives banks market power and allows them to slowly

adjust deposit rates in response to the short-term rate. They provide different estimates of such costs and its effects, and use versions of partial-equilibrium (static or multi-period) models with switching costs along the lines of [Klemperer \(1995\)](#) and [Beggs and Klemperer \(1992\)](#) to motivate the empirical analysis. Since deep habits for deposits assumed in my model induce a dynamic pricing problem for the bank which is analogous to that of these models with switching costs, this paper represents the first application of such mechanism to deposit rates in a macroeconomic model.

More recently, [Drechsler et al. \(2017\)](#) find that stronger market power by banks in local deposit markets reduces the degree of pass-through of the policy rate to deposit rates. They find that an increase in the Federal Funds rate generates a larger outflow of deposits and a stronger contraction in lending for banks that raise deposits in more concentrated markets. They also develop a static model of imperfect competition among a finite number of banks to rationalize the facts. In the model, banks' deposits compete against cash in providing liquidity services. Accordingly, banks' market power in setting deposit rates is stronger when holding cash is costlier, i.e. when the policy rate increases, thus banks are increasingly more able to keep deposit rates low as the policy rate increases. [Yankov \(2014\)](#) focuses on dispersion in rates offered by banks on certificate deposits and finds that market power generated by an asset-pricing model with heterogeneous search costs across savers is consistent with the evidence. Among dynamic general equilibrium models, [Gerali et al. \(2010\)](#) assume that changing deposit rates is subject to convex adjustment costs and generate partial pass-through to deposit rates. [Di Tella and Kurlat \(2017\)](#) assume that banks are subject to a binding leverage constraint that requires deposit supply to be a multiple of banks' market value of net worth. Given the assumption that households derive utility from liquidity services provided by deposits, the deposit spread increases with the short-term rate as the market value of banks' long-duration assets and net worth decreases. [Brunnermeier and Koby \(2016\)](#) introduce variation in the degree of pass-through with the level of the short-term rate by assuming that the propensity of depositors to shop for rates across banks decreases with the level of the short-term rate. Relative to these papers, my contribution is to develop a dynamic general equilibrium model that can account for the extent of pass-through and the response of deposit quantities documented by [Drechsler et al. \(2017\)](#), while capturing substitution between deposits and non-deposit liabilities and overshooting of borrowing rates relative to the policy rate, as observed in the data.

Since the mechanism in this paper is based on deep habits, it is related to [Ravn et al. \(2006\)](#) and especially [Gilchrist et al. \(2017\)](#), who combine deep habits and costly external finance in order to generate movements in the optimal markup chosen by firms. The most important difference relative to them is that my mechanism also relies on a peculiar feature of the banking sector, namely maturity transformation, in order to generate fluctuations in profits and induce banks to

change markups in the deposit market.

Deep habits have been applied in dynamic general equilibrium models with a banking sector by [Aliaga-Díaz and Olivero \(2010\)](#), [Aksoy et al. \(2013\)](#), [Ravn \(2016\)](#) and [Melina and Villa \(2018\)](#). However, these papers apply deep habits to the asset side of banks' balance sheets, in order to capture the implications of hold-up problems between firms and banks on the cost of firms' external finance. To my knowledge, my paper is the first to use deep habits to represent a pricing friction on the liability side of the balance sheet of banks.

Finally, even if this paper focuses on pass-through of policy rate changes away from the (effective) zero lower bound on interest rates, there is a literature that documents that imperfect pass-through to deposit rates is a pervasive phenomenon, which occurs even when policy rates fall below zero ([Heider et al. 2018](#), [Eggertsson et al. 2017](#)).

Outline

The rest of the paper is organized as follows. Section 2 develops the dynamic general equilibrium model and discusses the mechanism that generates imperfect pass-through. Section 3 provides further illustration of the mechanism and discusses how the different assumptions are essential to the results. Section 4 describes the baseline parameterization of the model. Section 5 discusses the results on imperfect pass-through to the deposit rate through impulse response functions, it compares the response of deposit quantities in the model and in the data, and highlights the relationship between maturity and pass-through in the data. Section 6 explores the implications of imperfect pass-through for monetary policy transmission. Section 7 discusses the evidence in support of the main assumptions of the model. Section 8 concludes.

2 Model

This section describes the model and discusses some of the agents' main first-order conditions. All equilibrium conditions are listed in Appendix A.

Time is discrete and infinite. There are four types of agents in the economy: two families of households, commercial banks and a production sector.

Each family consists of a continuum of households. One of the main differences between households in the two families is their rate of time preference: one family comprises more patient households ("savers", s) and the other comprises more impatient households ("borrowers", b). The respective measures of the two families are χ and $1 - \chi$.

The economy is populated by a unit measure of banks. Banks intermediate funds between savers and borrowers, engaging in maturity transformation by lending in fixed-rate mortgages to

borrowers and borrowing in short-term deposits and bonds from savers. Because savers perceive deposits at different banks as being differentiated, banks enjoy market power in setting deposit rates. Since there is a continuum of banks, there is no strategic interaction among them in setting deposit rates. A unit measure of monopolistically competitive firms hire labor from households to produce intermediate goods under a nominal rigidity, while a representative final good producer transforms intermediate goods into the final good. Finally, given the assumption of a nominal rigidity, there is a role for a central bank to set the nominal risk-free rate according to a Taylor rule.

Markets are incomplete with respect to aggregate shocks: borrowers can only borrow through fixed-rate mortgages and are subject to a borrowing limit, and savers can only save in banks' deposits and bonds. All these assets are non-contingent with respect to aggregates.

The economy is subject to two aggregate shocks: a total factor productivity (TFP) shock and an inflation-target shock in the Taylor rule, which corresponds to very persistent changes in monetary policy as in [Smets and Wouters \(2003\)](#), [Ireland \(2007\)](#), [Garriga et al. \(2017\)](#) and [Greenwald \(2018\)](#). It allows the central bank to shift long-term nominal interest rates, in addition to short-term rates, in an environment with fixed-rate mortgages.

Preferences

I represent the demand for deposits by savers using a money-in-the-utility function specification⁶. Moreover, I assume that savers are subject to "deep habits" for deposits offered by different banks. Deep habits are a common specification in macroeconomic models to represent persistence in the customer base faced by firms due to switching costs ([Klemperer, 1995](#)) or repeated purchase in customer markets ([Phelps and Winter, 1970](#)), as in [Ravn et al. \(2006\)](#) and [Gilchrist et al. \(2017\)](#) among others.

Accordingly, a saver s derives utility from consumption of the final good C_t^s and deposit holdings at banks $\{d_{jt}^s\}_{j=0}^1$, and disutility from labor N_t^s , based on the period-utility function, separable in all arguments,

$$U^s(C_t^s, N_t^s, D_t^s) = \frac{\left(\frac{C_t^s}{\chi}\right)^{1-\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} + \psi \frac{\left(\frac{D_t^s}{\chi}\right)^{1-\frac{1}{\gamma}} - 1}{1 - \frac{1}{\gamma}} - \zeta_s \frac{\left(\frac{N_t^s}{\chi}\right)^{1+\epsilon}}{1 + \epsilon} \quad (1)$$

where

$$D_t^s = \left[\int_0^1 \left(d_{jt}^s S_{j,t-1}^\theta \right)^{1-\frac{1}{\eta}} dj \right]^{\frac{\eta}{\eta-1}}, \quad \eta > 1 \text{ and } \theta > 0$$

⁶Following [Sidrauski \(1967\)](#), several macroeconomic models have used this specification to capture households' benefits from money-like-assets. [Feenstra \(1986\)](#) shows that models with money-in-the-utility and models with transaction/liquidity costs are functionally equivalent. Demand for liquidity could arise due to exposure to liquidity shocks ([Diamond and Dybvig, 1983](#)) or transaction and liquidity costs ([Baumol, 1952](#), [Tobin, 1956](#)).

is a CES aggregator of utility derived from the continuum of deposits held⁷. This function captures how the saver values deposits at different banks in the utility function. The parameter η governs the elasticity of substitution of deposits across banks, $S_{j,t-1}$ is bank j 's deposit habit stock at the end of period $t - 1$, while θ is the degree of habit formation⁸. The bank-specific habit stock is taken as given by the saver as I assume that habits are external⁹. Its law of motion is described in Section 2.2 when discussing the problem of a bank. In the utility function (1), σ is the elasticity of intertemporal substitution, ψ and γ govern weight and curvature with respect to the CES aggregate of utility from deposits D_t^s , ζ_s is the weight on disutility from labor supply and ϵ is the inverse Frish elasticity of labor supply.

Borrowers have separable preferences over consumption of the final good C_t^b , housing services from houses invested in in the previous period H_{t-1} , and labor supply N_t^b , that take the form

$$U^b \left(C_t^b, N_t^b, H_{t-1} \right) = \frac{\left(\frac{C_t^b}{1-\chi} \right)^{1-\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} + \varphi \log \left(\frac{H_{t-1}}{1-\chi} \right) - \zeta_b \frac{\left(\frac{N_t^b}{1-\chi} \right)^{1+\epsilon}}{1+\epsilon}$$

where the new parameter φ governs the weight on housing services in the utility function.

Financial Assets

There are three nominal assets in the economy: mortgages, banks' deposits and bonds.

The representation of fixed-rate mortgages follows [Greenwald \(2018\)](#). A mortgage is a nominal perpetuity with geometrically decaying payments, as standard in the literature (e.g. [Hatchondo and Martinez 2009](#), [Chatterjee and Eyigungor 2015](#), [Gorea and Midrigan 2017](#)). Letting q_t^* be the equilibrium coupon rate on the mortgage at origination, the bank lends one dollar to the borrower in exchange for $(1 - \nu)^k q_t^*$ dollars in each future period $t + k$ until the mortgage is prepaid, where ν is the fraction of principal paid in each period. Prepayment allows the borrower to repay all remaining principal due on the mortgage, and borrow in a new mortgage - typically at a lower rate. In order to have partial prepayment in any period, it is assumed that any borrower faces an *iid* transaction cost when repaying.

⁷While these preferences represent one saver household as holding deposits at each bank, Appendix C discusses how this can be interpreted as the aggregate outcome of decisions made by individual members of this household to hold deposits each at a single bank, using a discrete choice model ([Anderson et al., 1987](#)) or a characteristics model ([Anderson et al., 1989](#)).

⁸If $\theta = 0$, the habit drops from the saver's problem.

⁹This makes the problem more tractable, as current deposit demand ends up only depending on current rates ([Ravn et al., 2006](#)). As analyzed by [Nakamura and Steinsson \(2011\)](#), if the evolution of the habit specific to each variety is internalized by the customer, a time-inconsistency issue arises. Due to the lock-in effect, when deciding how much to demand, the customer takes into account not only the current price, but also future prices. Thus the price setter has an incentive to promise low prices in the future. However, when the future comes, the price setter will rather prefer to renege on the promise.

In order to finance their assets, banks issue riskless one-period nominal deposits and bonds to savers. Bonds issued by different banks are perfectly substitutable, thus they pay the same rate $1 + i_t$ in period $t + 1$ per dollar invested in t . I assume that these bonds are perfectly substitutable with riskless government bonds available in zero-net supply, which are used by the central bank to implement monetary policy. Therefore, in equilibrium, the rate on banks' bonds is the risk-free rate set by the central bank. Furthermore, since bonds represent all non-deposit funding of banks, and large banks in particular are not fully deposit-funded, I assume that only non-negative holdings of bonds are admissible.

Banks' deposits are valued for their services by savers, in addition to the return they earn. One dollar of deposits acquired in period t from bank j generates utility to savers in the same period and pays a rate $1 + i_{jt}^d$ in the following period. This implies a convenience yield on banks' deposits relative to the risk-free rate.

Housing

Since the housing market is not the main focus of the paper, for simplicity I assume that only borrowers obtain a service flow from holding houses and actively trade in the market. In each period, they pay a fraction δ of the market value of their housing stock as maintenance cost. Moreover, housing is in fixed supply \bar{H} , which implies that borrowers' demand for housing determines entirely its price¹⁰.

2.1 Savers

Each saver s chooses consumption C_t^s , labor supply N_t^s , holdings of banks' bonds B_t^s and deposits d_{jt}^s at each bank $j \in [0, 1]$ to maximize the expected present discounted value of utility

$$\mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta_s^t U^s(C_t^s, N_t^s, D_t^s) \right], \beta_s \in (0, 1)$$

subject to a sequence of budget constraints, which in real terms are

$$C_t^s + \int_0^1 d_{jt}^s dj + B_t^s \leq (1 - \tau^y) W_t N_t^s + \int_0^1 \frac{1 + i_{j,t-1}^d}{\Pi_t} d_{j,t-1}^s dj + \frac{1 + i_{t-1}}{\Pi_t} B_{t-1}^s + T_t^s + \Xi_t^s$$

where $\Pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross rate of inflation between $t - 1$ and t , W_t is the real wage, i_{jt}^d and i_t are nominal rates on deposits and bonds respectively, τ^y is a linear tax on labor income rebated to the household at the end of the period through T_t^s , and Ξ_t^s collects real profits from firms and dividends paid by banks, as they are owned by savers.

¹⁰These assumptions are common to [Greenwald \(2018\)](#) and [Faria-e Castro \(2017\)](#).

Defining the saver's discount factor as

$$\Lambda_{t,t+1}^s \equiv \beta_s \frac{U_{C_{t+1}}^s}{U_{C_t}^s},$$

the first-order condition for bond holdings is a standard Euler equation

$$1 = \mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \right] (1 + i_t)$$

The saver's problem also yields an Euler equation for deposits at a bank j , d_{jt}^s , which writes

$$\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \right] \underbrace{(i_t - i_{jt}^d)}_{\equiv m_{jt}^d, \text{ bank } j\text{'s deposit spread}} = \frac{U_{D_t^s}^s \frac{\partial D_t^s}{\partial d_{jt}^s}}{U_{C_t}^s} \quad (2)$$

This equation sets the marginal cost of holding deposits at bank j equal to its marginal benefit in equilibrium. The *lhs* is the opportunity cost of holding one dollar of deposits at bank j , in terms of forgone interest with respect to investing it at the bond rate i_t . This is the deposit spread offered by bank j , m_{jt}^d . Because this cost is nominal and incurred at the beginning of the following period, it is discounted to the beginning of period t using the discount factor for nominal payoffs. The *rhs* in turn is the marginal rate of substitution between consumption and deposits at bank j .

As shown in Appendix D, equation (2) allows to obtain closed-form solutions for deposit demands. Saver s 's deposit demand from bank j has a standard CES form,

$$d_{jt}^s = \left(\frac{m_{jt}^d}{\tilde{m}_t^d} \right)^{-\eta} S_{j,t-1}^{\theta(\eta-1)} D_t^s \quad (3)$$

where $\tilde{m}_t^d \equiv \left[\int_0^1 \left(m_{jt}^d S_{j,t-1}^{-\theta} \right)^{1-\eta} \right]^{\frac{1}{1-\eta}}$ is the (habit-adjusted) average cost of holding deposits in the market. As expected, deposit demand is decreasing in the opportunity cost of holding deposits at bank j , m_{jt}^d / \tilde{m}_t^d , and increasing in the habit stock $S_{j,t-1}$ and aggregate (habit-adjusted) deposit demand D_t^s .

Because there is full insurance across saver households within the family, the solution to the problem aggregates to that of a representative saver. In particular, the saver's discount factor $\Lambda_{t,t+1}^s$ will be unique. Thereafter, I will denote by s all variables that refer to the representative saver, when otherwise confusion would arise with respect to borrowers. Since both deposits and banks' bonds are only held by savers, the index s will be dropped for these two variables.

2.2 Commercial Banks

As highlighted by [Begenau et al. \(2015\)](#) and [Di Tella and Kurlat \(2017\)](#), maturity transformation - that is, investing in long-duration nominal assets, such as fixed-rate mortgages, and borrowing in short-duration nominal liabilities - is at the core of large modern commercial banks' business. These banks are exposed to the corresponding interest-rate risk despite the opportunity of hedging it through interest-rate derivatives.

I capture this feature by assuming that, in each period t , banks have to finance both their book of fixed-rate mortgages issued to borrowers in the past and not yet prepaid, as well as new mortgages issued to borrowers in t , by borrowing in one-period deposits and bonds from savers.

Banks are owned by savers. Each bank $j \in [0, 1]$ enters period t with total principal on outstanding mortgages $M_{j,t-1}$, total payments to be collected from borrowers on outstanding mortgages $X_{j,t-1}$, and a deposit habit stock $S_{j,t-1}$. Letting μ_t be the fraction of mortgages prepaid in period t , and considering that a fraction ν of outstanding principal is repaid in each period by borrowers, the total value of mortgages that the bank has to finance in period t is

$$M_{jt} = \mu_t M_{jt}^* + (1 - \mu_t)(1 - \nu) \frac{M_{j,t-1}}{\Pi_t} \quad (4)$$

where M_{jt}^* are new mortgages originated to prepaying borrowers. This is the law of motion for banks' assets. As the mortgage rate is fixed, the bank operates under another similar law of motion for mortgage payments,

$$X_{jt} = \mu_t q_t^* M_{jt}^* + (1 - \mu_t)(1 - \nu) \frac{X_{j,t-1}}{\Pi_t} \quad (5)$$

where q_t^* is the rate on new mortgages originated in t .

The balance-sheet constraint of the bank requires that in each period the bank collects enough deposits d_{jt} and bonds B_{jt} to finance its book of mortgages M_{jt} ,

$$M_{jt} = d_{jt} + B_{jt} \quad (6)$$

Moreover, the bank has market power in setting its deposit rate i_{jt}^d . It considers that, given the risk-free rate i_t , the deposit demand it faces is increasing in the deposit rate it offers (or equivalently, decreasing in the deposit spread $i_t - i_{jt}^d$ offered, see Equation (3)). It also takes into account that savers are partially locked-in: the deposit habit introduces a link between current and future deposit demand. Specifically, I assume the deposit habit stock at bank j evolves as a moving average of the past stock and current total deposit demand at bank j ,

$$S_{jt} = \rho_s S_{j,t-1} + (1 - \rho_s) d_{jt} \quad (7)$$

The bank's objective is to maximize the expected present discounted value of net real dividends paid to savers. In doing so, the bank is subject to a friction: following e.g. [Jermann and Quadrini \(2012\)](#), [Begenau \(2016\)](#) and [Elenev et al. \(2018\)](#), paying a dividend div_{jt} incurs a cost $f(div_{jt})$ which is quadratic in the deviation of the dividend from a target level¹¹. The total cost of paying out a dividend div_{jt} is thus $div_{jt} + f(div_{jt})$. This assumption makes banks non-indifferent about the timing of cash flows¹². When dividends are below the target level, the cost can capture a precautionary motive to bring profits closer to target in order to avoid expensive equity issuance. When dividends are above the target level, the cost induces the bank to sacrifice some profits in order to pay a higher deposit rate and build a bigger deposit base, that will earn higher profits in the future when short-term rates increase again.

In each period, the bank chooses new mortgage origination M_{jt}^* , deposit and bond issuance d_{jt} and B_{jt} , and the deposit rate to offer i_{jt}^d in order to maximize

$$\mathbb{E}_0 \left[\sum_{t=0}^{\infty} \Lambda_{0,t+1}^s div_{j,t+1} \right]$$

where

$$div_{j,t+1} = \frac{1}{\Pi_{t+1}} \left[X_{jt}(q_t^*) - \nu M_{jt} - (i_{jt}^d + \kappa)d_{jt} - i_t B_{jt} \right] - f(div_{j,t+1}) \quad (8)$$

$$f(div_{jt}) = \frac{\kappa^{div}}{2} \left(div_{jt} - \bar{div} \right)^2$$

subject to laws of motion (4), (5), (7), deposit demand (3) and balance sheet constraint (6).

The term in brackets in (8) is the net interest earned by the bank at the beginning of period $t + 1$ from its intermediation activity carried out in t . Since X_{jt} are total payments on outstanding mortgages, including both principal and interest, $X_{jt}(q_t^*) - \nu M_{jt}$ is the interest income earned by the bank on its book of mortgages¹³. Then, the bank has to pay interest to savers on deposits at rate i_{jt}^d and interest on bonds at rate i_t ¹⁴. The parameter κ is the marginal cost incurred by the bank in offering one dollar of deposits¹⁵.

¹¹When solving the model, the target level will correspond to the steady state level of dividends.

¹²The assumption is similar to the equity-issuance costs assumed by [Gilchrist et al. \(2017\)](#), although my cost is two-sided and does not involve banks being exposed to uninsurable idiosyncratic shocks to their return on assets - which would be the translation of [Gilchrist et al. \(2017\)](#)'s setting into mine.

¹³The implicit assumption is that, in each period, the bank can convert one-for-one the unpaid part of the outstanding principal $(1 - \nu)M_{jt}$ into units of the final good to be used to repay short-term deposits and bonds. This is a necessary assumption in this setting with maturity mismatch where all borrowing and saving happens between two subsequent time intervals. In reality, banks have many maturity options to cover roll-over or shortage of short-term debt, which does not mature all simultaneously.

¹⁴Since I will use an approximation of the solution to the model around the deterministic steady state, the bank does not earn any term premium from managing a maturity mismatched portfolio, as there is no term premium in the deterministic steady state. The profits made by the bank on its intermediation activity come entirely from its market power in the deposit market.

¹⁵This cost is needed in order to have a well-defined problem. Once I assume the saver values deposits in the utility

First-order conditions are listed in Appendix A, but a discussion of the Euler equation for the deposit spread m_{jt}^d set by the bank¹⁶ is in order, as it underpins the mechanism generating imperfect pass-through to deposit rates in the model. In order to simplify the equation while retaining intuition, I assume that the habit stock depreciates fully at the end of the period ($\rho_s = 0$). This means that current deposit demand affects next period's deposit demand only. Then the bank sets the sequence of deposit spreads $\{m_{jt}^d\}_{t=0}^\infty$ to satisfy

$$\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \Omega_{j,t+1} \right] \left(\frac{\eta}{\eta - 1} - \frac{m_{jt}^d}{\kappa} \right) = \theta \mathbb{E}_t \left[\frac{\Lambda_{t,t+2}^s}{\Pi_{t+2}} \Omega_{j,t+2} \frac{m_{j,t+1}^d}{\kappa} \frac{d_{j,t+1}}{d_{jt}} \right] \quad (9)$$

in each period t , where

$$\Omega_{jt} = \frac{1}{1 + f'(div_{jt})} = \frac{1}{1 + \kappa^{div}(div_{jt} - \bar{div})}$$

is the marginal value of profits to the bank, decreasing in dividends¹⁷. The first-order condition equates the marginal cost of attracting one additional dollar of deposits, in terms of forgone profits, to its marginal benefit, in terms of future profits.

Notice that m_{jt}^d / κ is the time-varying markup set by the bank on deposits, as the deposit spread m_{jt}^d is the marginal cost to the saver of holding deposits at the bank and κ is the marginal cost to the bank of supplying deposits (up to time discounting). Since $\eta / (\eta - 1)$ is the optimal markup that maximizes static profits given the CES demand, the *lhs* is forgone profits by the bank to attract the marginal dollar of deposits expressed in terms of deviation of the optimal markup from the markup that maximizes static profits. Given that all terms on the *rhs* are positive, the bank sets a markup below the static markup, a standard result in the deep habits literature. The *rhs* is the marginal increase in future profits expressed in markups from the additional dollar of deposits attracted in period t , which affects period $t + 1$ deposit demand with elasticity θ .

Imperfect pass-through of an increase in the short-term rate i_t to the deposit rate i_{jt}^d is due to the interaction of i) rigidity in banks' interest income earned on long-duration assets relative to the interest paid on short-term debt, ii) the dividend-adjustment cost, iii) the dynamic component in deposit demand from the habit.

Persistence in deposit demand implies that the bank optimally sets a deposit spread below the level that maximizes current profits, as it takes into account the positive effect on future deposit

function, the bank is effectively supplying a good to the saver. Since the bank has market power, the markup would not be well-defined absent such marginal cost. Since this cost represents variable costs including salaries, I rebate it to savers in the term Ξ_t^s . In steady state, the total cost from this source is very small, as it amounts to 0.14% of output.

¹⁶Notice that, since the rate i_t is taken as given by the bank, setting the deposit spread or the deposit rate is equivalent for the bank.

¹⁷As long as $div_{jt} > \bar{div} - \frac{1}{\kappa^{div}}$.

demand. However, when the short-term rate i_t increases, bank's profits and thus dividends from intermediation decrease due to its maturity-mismatched portfolio: legacy assets on bank's balance sheet have a rate which is locked-in in the short term and only new assets originated reflect the new level of rates. At the same time, the bank has to continue financing its asset book. If it is too costly to finance the entire book through deposits given deposit demand¹⁸, the bank will rather keep issuing bonds at the higher rate. The resulting reduction in profits increases the marginal value of current profits $\Omega_{j,t+1}$ relative to future profits $\Omega_{j,t+2}$ in Equation (9). Holding everything else equal, this will be offset by an increase in the optimal markup towards the static markup. Finally, if the deposit spread $i_t - i_{jt}^d$ increases with i_t , it means that the deposit rate does not increase as much as the short-term rate, i.e. there is imperfect pass-through to the deposit rate.

2.3 Borrowers

The problem of the borrowers follows [Greenwald \(2018\)](#). There are two main features in this problem. First, borrowers are subject to a payment-to-income (PTI) constraint - more commonly known as debt-to-income (DTI) limit. It limits the borrowed amount based on interest payments due on the mortgage relative to borrower's labor income. As a result, the mortgage rate enters the constraint directly, amplifying the transmission of shocks that impact this rate.

Second, there is endogenous prepayment by borrowers. At each point in time, borrowers decide whether to prepay their mortgage by comparing their *iid* transaction cost of prepayment with the benefit from prepaying, which depends on the evolution of future mortgage rates. As shown by [Greenwald \(2018\)](#), endogenous prepayment amplifies the transmission of shocks into output¹⁹. Despite the *iid* prepayment cost shocks, thanks to the assumption of perfect insurance within the borrower family, the problem of the borrowers aggregates to that of a representative borrower.

The representative borrower chooses consumption C_t^b , labor supply N_t^b , new housing size H_t^* , new borrowing M_t^{b*} , and the fraction of mortgages to prepay μ_t to maximize the expected present

¹⁸This will be the case near the steady state, as the weight ψ on deposits in the utility function will be calibrated so that equilibrium deposits in steady state match the allocation between deposits and other funding in the aggregate balance sheet of the US banking sector, see Section 4.

¹⁹Given the nominal rigidity, shocks that change borrowing and consumption will affect output only if the change in borrowing and consumption is concentrated in the short run, when firms' prices are still fixed at the pre-shock level for the most part. With endogenous prepayment, an increase in mortgage rates will generate a stronger contraction in borrowing, as borrowers prefer to hold onto the lower rates locked-in into mortgages and wait for rates to go down in the future before prepaying. This effect compounds the tightening of the PTI constraint due to the higher mortgage rate, leading to a larger contraction in borrowing and thus spending by borrowers, who have high marginal propensities to consume, eventually with additional effects on output.

discounted value of utility

$$\mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta_b^t U^b \left(C_t^b, N_t^b, H_{t-1} \right) \right], \beta_b \in (0, 1), \beta_b < \beta_s$$

subject to the sequence of budget constraints

$$\begin{aligned} C_t^b + \frac{(1 - \tau^y) X_{t-1}^b + \tau^y \nu M_{t-1}^b}{\Pi_t} + \mu_t P_t^h (H_t^* - H_{t-1}) &= (1 - \tau^y) W_t N_t^b + \\ &+ \mu_t \left[M_t^{b*} - (1 - \nu) \frac{M_{t-1}^b}{\Pi_t} \right] - \delta P_t^h H_{t-1} - \{\Psi(\mu_t) - \bar{\Psi}_t\} M_t^{b*} + T_t^b \end{aligned}$$

where P_t^h is the house price, δ is the housing maintenance cost, $\Psi(\mu_t)$ is the mortgage prepayment cost aggregated across borrower households²⁰ - rebated lump-sum to the borrower through $\bar{\Psi}_t$ at the end of the period, and T_t^b is the rebate of the labor income tax, net of the tax deduction on mortgage interest payment. To avoid confusion with the analogous variables in bank's problem, I denote with X_t^b and M_t^b the mortgage payments and principal due by the borrower.

The borrower is also subject to the PTI constraint on new borrowing,

$$M_t^{b*} \leq \frac{PTI W_t N_t^b}{q_t^*}$$

Finally, the borrower is subject to laws of motion for mortgage principal and payments analogous to equations (4) and (5) for the bank, in addition to a law of motion for housing

$$H_t = \mu_t H_t^* + (1 - \mu_t) H_{t-1}$$

All Euler equations and equilibrium conditions for the borrower are listed in Appendix A.

2.4 Production Sector

The production sector consists of a perfectly competitive final good producer and monopolistically competitive intermediate goods producers. The final good producer uses a continuum of differentiated inputs indexed by $\omega \in [0, 1]$, purchased from intermediate goods producers at prices $P_t(\omega)$, to operate the technology

$$Y_t = \left(\int_0^1 Y_t(\omega)^{1 - \frac{1}{\xi}} d\omega \right)^{\frac{\xi}{\xi - 1}}, \xi > 1 \quad (10)$$

²⁰The exact form is described in Section 4 when discussing the parameterization.

Optimality requires that the producer minimizes total expenditure $\int_0^1 P_t(\omega) Y_t(\omega) d\omega$ subject to (10), yielding CES demands for each intermediate good ω

$$Y_t(\omega) = \left(\frac{P_t(\omega)}{P_t} \right)^{-\xi} Y_t \quad (11)$$

where P_t is the price of the final good. Intermediate goods producers are owned by savers. They operate a linear production function in labor,

$$Y_t(\omega) = Z_t N_t(\omega)$$

where Z_t is exogenous total factor productivity (TFP) and $N_t(\omega)$ is labor hired to meet the final good producer's demand (11). Each of these producers maximizes profits by choosing price $P_t(\omega)$ subject to its technology, demand and a [Rotemberg \(1982\)](#) quadratic cost of adjusting prices,

$$\frac{\kappa^{adj}}{2} P_t Y_t \left(\frac{P_t(\omega)}{P_{t-1}(\omega) \Pi_{ss}} - 1 \right)^2$$

where κ^{adj} controls the scale of the cost and the producer can costlessly set its price to follow the rate of steady state inflation Π_{ss} . Optimal price setting by intermediate good producers yields a standard Phillips Curve in the symmetric equilibrium, as shown in [Appendix A](#).

2.5 Equilibrium

I focus on a symmetric equilibrium, thus banks and intermediate good producers choose the same deposit rate and price, respectively.

In order to close the model, I assume that the central bank sets the risk-free rate according to the Taylor rule

$$\begin{aligned} \log(1 + i_t) = & \log(\bar{\Pi}_t) + \rho_i \left[\log(1 + i_{t-1}) - \log(\bar{\Pi}_{t-1}) \right] + (1 - \rho_i) \left[\log(1 + i_{ss}) \right. \\ & \left. - \log(\Pi_{ss}) + \phi_{\Pi} (\log(\Pi_t) - \log(\bar{\Pi}_t)) \right] \end{aligned}$$

as specified in [Greenwald \(2018\)](#), where ρ_i captures the degree of interest rate smoothing, ϕ_{Π} captures the extent to which the central bank reacts to deviations of inflation from target, and

$$\log(\bar{\Pi}_t) = (1 - \rho_{\bar{\Pi}}) \log(\Pi_{ss}) + \rho_{\bar{\Pi}} \log(\bar{\Pi}_{t-1}) + \epsilon_t^{\bar{\Pi}}, \epsilon_t^{\bar{\Pi}} \sim N(0, \sigma_{\bar{\Pi}})$$

is an AR(1) stochastic inflation target. As mentioned previously, this shock captures very persistent changes in monetary policy which are able to affect long-term nominal rates by changing short-term rates far into the future, in addition to current short-term rates.

Aggregate TFP follows another AR(1) process

$$\log(Z_t) = (1 - \rho_Z) \log(\bar{Z}) + \rho_Z \log(Z_{t-1}) + \epsilon_t^Z, \epsilon_t^Z \sim N(0, \sigma_Z)$$

A symmetric equilibrium of this model is a sequence of endogenous states $(M_{t-1}, X_{t-1}, H_{t-1}, S_{t-1})$, allocations $(C_t^s, C_t^b, N_t^s, N_t^b)$, mortgage origination and funding decisions (M_t^*, d_t, B_t) , housing and prepayment decisions (H_t^*, μ_t) , and prices $(\Pi_t, W_t, P_t^h, i_t, i_t^d, q_t^*)$ such that ii) given prices and the exogenous stochastic processes, borrower, saver, bank, and firm equilibrium conditions are satisfied, ii) given inflation, past rates, and the inflation target process, i_t satisfies the Taylor rule, iii) the goods, labor, housing and asset markets clear.

In particular, market clearing in final goods requires

$$C_t^b + C_t^s + \delta P_t^h \bar{H} + f(\text{div}_t) = Y_t \left[1 - \frac{\kappa^{adj}}{2} \left(\frac{\Pi_t}{\Pi_{ss}} - 1 \right)^2 \right]$$

while the labor and housing market clearing conditions are $N_t^b + N_t^s = N_t$ and $H_t = \bar{H}$, respectively.

3 Inspection of the Mechanism

This section illustrates the mechanism that generates imperfect pass-through of the policy rate to the deposit rate using a first-order approximation of the solution around the deterministic steady state.

It is useful to compare the model with deep habits for deposits against a version without habits. This version of the model is identical to the one with habits, except for the degree of habit formation θ which is set to 0²¹. Equation (9) immediately implies that, under this alternative, the markup m_{jt}^d/κ will be equal to the static markup, and the deposit spread will be constant. This is true even in the full model with partial depreciation of the habit stock $\rho_s > 0$. Therefore, with a constant deposit spread $i_t - i_t^d$, changes in the risk-free rate will be passed through to the deposit rate completely.

Figure a shows impulse response functions of interest rates and deposits to a 50 bp annualized increase in the inflation target, which raises the short-term rate persistently²². As i_t increases persistently, the rate on new mortgages q_t^* also increases. However, most of assets on bank's balance sheet pay a rate which was locked-in in the past, so the average rate earned by the bank in

²¹In order to make the two versions comparable, the elasticity of substitution of deposits η across banks in the version without habits is re-calibrated to match the same deposit spread as in the baseline model in steady state.

²²Details on all impulse response functions to this shock are in Figures B.1 and B.2 in Appendix B.

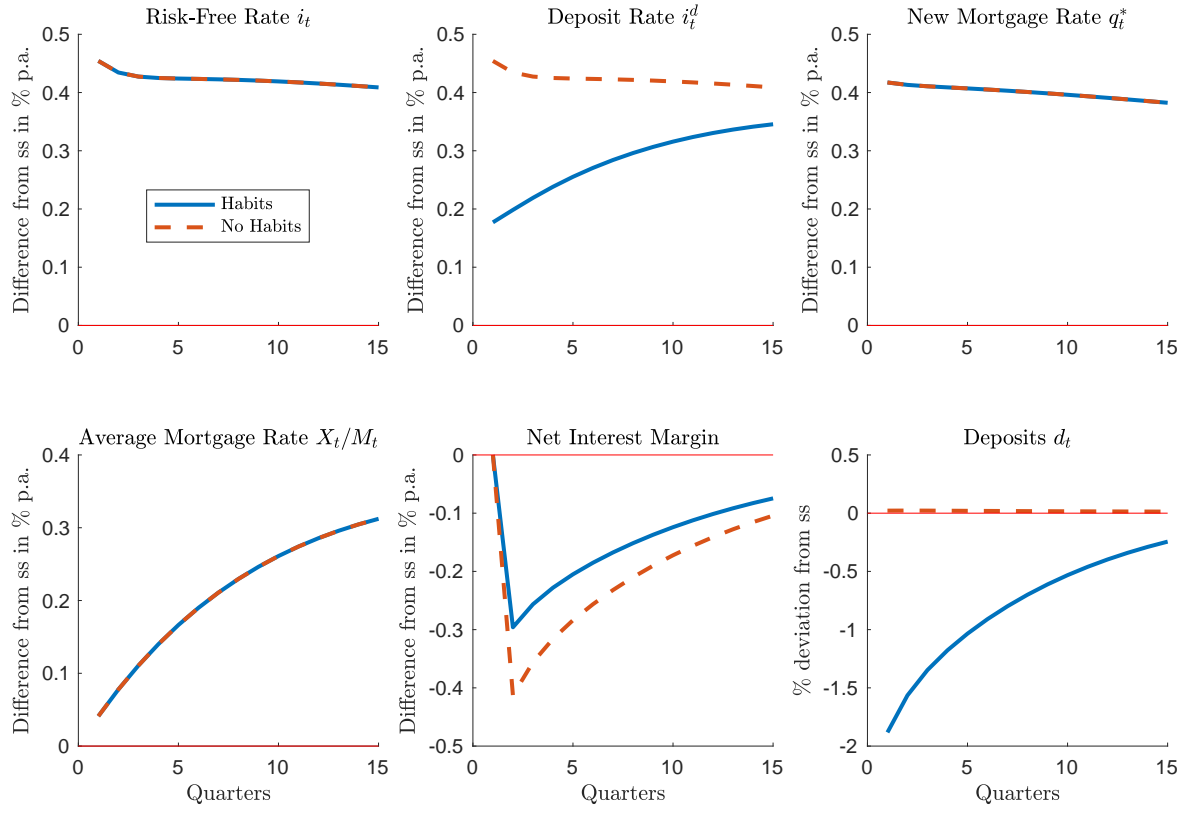


Figure a: Impulse Response Functions to a 50 bp Inflation Target Shock

$t + 1$ on its book of mortgages financed in t , X_t/M_t , increases slowly, as mortgages issued in the past gradually mature or are prepaid and new mortgages are originated at the higher rate.

Since the short-term rate increases and the rate earned on bank's assets adjusts slowly, the bank faces a decrease in its profits from intermediation as shown by the decrease in the net interest margin

$$\left[X_t(q_t^*) - \nu M_t - (i_t^d + \kappa)d_t - i_t B_t \right] \frac{1}{M_t}$$

and its dividends decrease below the steady state level. As a result, the marginal value of profits Ω_{t+1} increases. At this point, the response of the bank under deposit habits differs with respect to the case of no habits ($\theta = 0$). With habits, the bank optimally sets a deposit rate above the rate that maximizes static profits, considering that this will partially increase future deposit demand. However, since the marginal value of profits Ω_{t+1} increases, the bank adjusts its markup on deposits upward - closer to the static markup $\eta/(\eta - 1)$ - by preventing the deposit rate from increasing as much as the risk-free rate. Finally, as the opportunity cost of holding deposits $i_t - i_t^d$ has increased, savers substitute deposits for bonds²³, generating the correlations between deposit

²³As shown in Figure B.1, since bank's balance sheet is defined in real terms, the increase in inflation and the decrease

spread, deposit funding and banks' non-deposit liabilities described empirically by Drechsler et al. (2017).

Linearizing the intertemporal condition for the deposit spread around the steady state²⁴ allows me to disentangle the three forces that affect the response of the deposit spread - or equivalently, of the markup on deposits - in the model. Specifically, the deviation of the deposit spread from steady state can be decomposed as²⁵

$$m_t^d - m^d = \underbrace{\left(m^d - \frac{\eta}{\eta - 1}\kappa\right)}_{< 0} \left(\sum_{j=0}^{\infty} \Gamma^j \mathbb{E}_t \text{discount}_{t+j} + \sum_{j=0}^{\infty} \Gamma^j \mathbb{E}_t \text{marg. value of dividends}_{t+j} \right) + \\ - m^d (1 - \rho_s) \theta \Lambda^s \sum_{j=0}^{\infty} \Gamma^j \mathbb{E}_t \text{deposit demand growth}_{t+j}$$

where

$$\begin{aligned} \text{discount}_{t+j} &= \hat{\Lambda}_{t+1,t+2}^s - \hat{\Pi}_{t+2} + \hat{\Pi}_{t+1} \\ \text{marginal value of dividends}_{t+j} &= \hat{\Omega}_{t+2} - \hat{\Omega}_{t+1} \\ \text{deposit demand growth}_{t+j} &= \hat{d}_{t+1} - \hat{S}_t \\ \Gamma &= \Lambda^s [\rho_s - (1 - \rho_s)\theta] \end{aligned}$$

As usual in the literature on deep habits, a relative increase in the rate at which the price setter discounts the future (i.e. a decrease in the discount factor) increases the current markup towards the static markup, as the price setter values less future profits from accumulating demand. Moreover, if demand is shrinking (i.e. \hat{d}_{t+1} is below the slow moving habit stock \hat{S}_t), the incentive to sacrifice current profits to build future demand is weaker, because any dollar of deposits acquired currently will generate less additional deposit demand in the future under multiplicative habits - as considered here. This contributes to increasing the optimal markup towards the static markup. Finally, if the marginal value of current profits $\hat{\Omega}_{t+1}$ is above the future marginal value $\hat{\Omega}_{t+2}$, this will also raise the optimal markup, as discussed previously.

Figure b shows the relative contribution of each force to the response of the deposit spread $i_t - i_t^d$ following the 50 bp inflation target shock analyzed in Figure a. Except for the effect of the discount factor, the other forces contribute to the increase in the deposit spread with the risk-free rate. However, comparing the magnitudes of the contribution of the different forces, we see that

in mortgage origination M_t^* due to the increase in the mortgage rate q_t^* lead to a decrease in the size of the balance sheet. As a result, bonds decrease below steady state over time, after an initial increase to offset the decrease in deposits. Nevertheless, bonds decrease by less in the case with imperfect pass-through relative to the case with perfect pass-through, as deposits flow out in the former case.

²⁴Equation (9), but with $\rho_s > 0$ as in the full model - see Equation (16) in Appendix A.

²⁵Under the transversality condition imposed by the stationary equilibrium concept.

without the dividend adjustment cost pass-through would be essentially full.

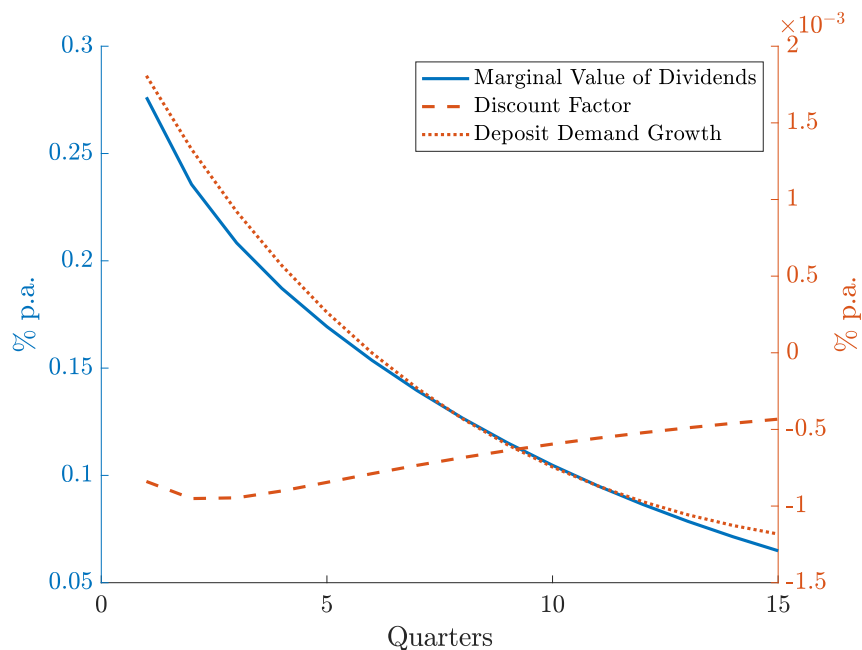


Figure b: Impulse Response of Deposit Spread Broken Up by Component

Hence, both the deep habits for deposits ($\theta > 0$) and the dividend smoothing motive are essential in order to have imperfect pass-through in this model. Section 5.2 below shows that the long duration of banks' assets is also essential for imperfect pass-through in the model.

4 Parameterization

Time is quarterly. I identify the counterpart of deposits in the model with transaction and savings deposits in the data, because these are the two types of deposits with shorter maturity (time deposits typically have costs of early withdrawal), they have the lowest pass-through (e.g. Driscoll and Judson 2013, Drechsler et al. 2017, Gerlach et al. 2018), and they are the largest class of deposits. All parameter values are listed in Table 1.

Commercial Banks and Deposits

I set the marginal cost to the bank of supplying deposits κ at 36 bp per quarter (1.44% annualized), as half²⁶ of the average non-interest expenditures excluding expenditures on premises or rent²⁷ per

²⁶The division by two attributes half of the cost to assets and half to liabilities, and is a rough approximation for the fact that banks' non-interest expenses do not necessarily pertain to deposits only.

²⁷Since this type of expenditures is more fixed relative to the others, such as salaries, marketing, etc.

dollar of assets of commercial banks in the FFIEC Consolidated Reports of Condition and Income (US Call Reports)²⁸ over 1987 to 2013. The share of mortgage principal paid in each period ν is set to match the average duration of banks' assets in the US Call Reports between 1997 and 2013²⁹, equal to 4.26 years, thus $\nu = 0.059$. The degree of habit formation θ is set to a standard value in the literature on deep habits, 0.8 (Ravn et al. 2006, Gilchrist et al. 2017). Since this value has been estimated and used in the context of deep habits in consumption³⁰, I perform a sensitivity analysis reported in Table 2 and explore how the quantitative results of my model described in Section 5.1 vary by changing θ from 0.1 to 0.9, which covers all values for this parameter that I have found in the literature. Results are essentially unaffected. I choose the persistence of the habit stock ρ_s based on an annual attrition rate³¹ of banks' customers. A value of 10% per year is in the middle of the values reported in the literature surveyed in Section 7. Thus $\rho_s = (1 - 0.1)^{0.25} = 0.974$. The elasticity of substitution of deposits across banks is then set in order to have a steady state markdown i^d/i for the deposit rate equal to its average value in the data over 1987-2007 (0.58), where the deposit rate is measured as the average rate on transaction and savings deposits in the US Call Reports. The resulting value of η is 5.930.

Two parameters are set internally based on simulations of the model: the curvature parameter of saver's utility with respect to deposits, γ , which governs the volatility of deposits, and the scale of the dividend adjustment cost κ^{div} , which affects the degree of pass-through. I set them jointly³² to match i) the ratio of the standard deviations of quarterly real deposits to real GDP (3.05)³³ and ii) the average pass-through of the policy rate to deposit rates for the largest 5% of banks estimated by Drechsler et al. (2018), equal to 0.39. As a result, I set $\gamma = 0.119$ and $\kappa^{div} = 476.3$.

Finally, the weight on deposits in the utility function ψ is chosen to yield an average share of deposits to banks' liabilities of 0.43, as its counterpart in the Call Reports over 1987-2013, using transaction and savings deposits. This requires $\psi = 9 \cdot 10^{-5}$.

Borrower and Saver

I set a number of parameters to standard values in the macroeconomics literature. The saver's discount factor β_s equals 0.9975, implying a steady state real rate of 1%. The IES is set to 1 (log-utility)

²⁸I thank Philipp Schnabl for kindly providing the data.

²⁹See Section 7 for details about how duration is estimated.

³⁰Aliaga-Díaz and Olivero (2010) estimate the degree of habit formation parameter in the context of borrowing relationships between firms and banks, and find a value of $\theta = 0.72$.

³¹Interpreting the habit stock as customer base, and the law of motion of the habit stock as a function that maps demand into customer base, then $1 - \rho_s$ would be the rate of attrition of the customer base.

³²I simulate the model 2000 times for 2108 periods, and burn the first 2000 periods to purge the effect of initial conditions, leaving 108 quarters, as the number of quarters in the corresponding data between 1987 and 2013.

³³Deposits are total transaction and savings deposits in the US Call Reports, smoothed using a 4-lag moving average in order to eliminate seasonality and deflated by the GDP deflator. Both deposits and GDP are then logged and HP-filtered.

and I choose an inverse Frish elasticity of labor supply ϵ of 1. The weights on labor disutility in the utility function, $\zeta_b = 7.605$ and $\zeta_s = 5.751$, are set such that both borrower and saver supply the same labor in steady state, equal to $1/3$.

I set the PTI ratio to 0.43, as in the Dodd-Frank act. It should be noted that the mortgage market is not strictly the focus of my paper. The housing maintenance cost δ equals 0.004 to match an annual depreciation rate of 1.5% (Kaplan et al., 2017).

I define borrowers as households in the 2004 SCF who own a house, have a mortgage outstanding, and have less than six months of income in liquid assets, thus I set $1 - \chi = 0.399$ ³⁴. The value of these households' houses relative to their quarterly income is 12.25, and I calibrate the borrower's discount factor β_b to match this ratio, yielding $\beta_b = 0.980$. At the same time, total housing supply $\bar{H} = 4.410$ is chosen in order to get a normalized house price of 1 in steady state and the weight on housing services in the utility function, $\varphi = 0.318$, is set to match the ratio of rent to income ($U_H^b(H)/(WN^b)$) of 0.2 estimated by Davis and Ortalo-Magné (2011).

The *iid* prepayment cost distribution follows Greenwald (2018) and is equal to

$$F_k(k) = \frac{1}{4} \frac{1}{1 + e^{\mu_k - k}}$$

and I set the location parameter $\mu_k = 1.843$ to match an average annual prepayment rate of 15% (Elenev, 2017).

Other Parameters

The remaining parameters concerning the production sector and policies are taken from the literature. In the Taylor rule, interest rate smoothing $\rho_i = 0.81$ (Smets and Wouters, 2007) and inflation reaction $\phi_\pi = 1.5$. The autocorrelation ρ_π and standard deviation σ_π of the inflation target process are set to 0.99 and 0.001, respectively (Garriga et al., 2016), while trend inflation π_{ss} is set to 1.005 (2% annual inflation rate). Steady state productivity $\bar{Z} = 1.099$ is set to normalize steady-state output to 1, while autocorrelation $\rho_Z = 0.948$ and standard deviation $\sigma_Z = 0.007$ are estimated from Fernald (2014) over 1987 to 2013 using utilization-adjusted TFP of non-equipment output.

Finally, the linear labor tax $\tau^y = 0.24$ is set to the average marginal individual income tax estimated by Mertens and Olea (2013) over 1946-2012. The elasticity of substitution across intermediate goods ξ is 10, implying that firms' profits are 10% of output. The scale of the price-adjustment cost κ^{adj} is set to 107.2 - equivalent to an average price reset every year under Calvo price setting.

³⁴The total share of homeowners with a mortgage outstanding in the 2004 SCF is 0.524, while the share of homeowners with a mortgage outstanding who has less than two months of income in liquid assets is 0.308, so my value is a middle ground between the share of actual mortgagors in the data and the share of those more liquidity constrained.

Parameter	Value	Description	Moment / Source / Target
<i>Parameters related to deposits</i>			
ψ	$9 \cdot 10^{-5}$	Weight on deposits in utility	(Transaction + saving deposits) / bank liabilities = 0.43
γ	0.119	Utility curvature in deposits	Std(real deposits) / std(real GDP) = 3.05
η	5.930	CES of deposits across banks	Deposit rate markdown i^d / i = 0.58
ρ_s	0.974	Habit stock persistence	Turnover of bank customers = 10% pa (see text)
θ	0.800	Degree of habit formation	Gilchrist et al. (2017) (see sensitivity)
<i>Bank's parameters</i>			
ν	0.059	Share of mortgage principal repaid	Avg. duration of banks' assets = 4.26 years
κ^{div}	476.3	Scale of dividend adjustment cost	Deposit rate pass-through = 0.39 (Drechsler et al., 2017)
κ	36 bp	Marginal cost of supplying deposits	(see text)
<i>Households' parameters</i>			
β_s	0.998	Saver's discount factor	Real interest rate = 1% pa
β_b	0.980	Borrower's discount factor	Borrowers' house value/income = 12.25 (SCF 2004)
$1 - \chi$	0.399	Fraction of borrowers	(see text) (SCF 2004)
σ	1.000	IES	Log-utility
ϵ	1.000	Inverse Frish elasticity	Standard
ζ_s	5.751	Saver's labor disutility (weight)	Saver's labor supply = 1/3
ζ_b	7.605	Borrower's labor disutility (weight)	Borrower's labor supply = 1/3
φ	0.318	Weight on housing in utility	Rent / income = 0.2 (Davis and Ortalo-Magné, 2011)
<i>Other parameters</i>			
PTI	0.430	Max DTI ratio	Dodd-Frank act
\bar{H}	4.410	Fixed housing supply	Normalize house price to 1
μ_k	1.843	Mean mortgage issuance cost	Average prepayment rate = 15% pa (Elenev, 2017)
δ	0.004	Housing maintenance cost	Depreciation of housing = 1.5% pa (Kaplan et al., 2017)
τ^y	0.240	Income tax rate	Avg. marginal income tax (Mertens and Olea, 2013)
<i>New-Keynesian block parameters</i>			
ζ	10.00	CES of intermediate goods	Profits = 10% of output
κ^{adj}	107.2	Scale of price adjustment cost	Standard avg. price resetting under Calvo = 1/year
ϕ_Π	1.500	Taylor rule: inflation reaction	Standard
ρ_i	0.810	Taylor rule: interest rate smoothing	Smets and Wouters (2007)
<i>Shock parameters</i>			
Π_{ss}	1.005	Trend inflation	Standard, 2% pa
ρ_Π	0.990	Persistence of inflation target	Garriga et al. (2016)
σ_Π	0.001	Standard deviation of inflation target	Garriga et al. (2016)
\bar{Z}	1.099	Steady state productivity	Normalize steady state output to 1
ρ_Z	0.948	Persistence of productivity	Estimate from adj. TFP non-equipment (Fernald, 2014)
σ_Z	0.007	Standard deviation of productivity	"

Targets used to calibrate parameters internally are in **bold**

Table 1: Summary of Parameterization

5 Results on Imperfect Pass-through to Deposit Rates

5.1 Model Assessment

I begin by assessing my model against the estimated response of deposits to changes in the Federal Funds rate in [Drechsler et al. \(2017\)](#). Using panel data, [Drechsler et al. \(2017\)](#) find that a 100 bp increase in the Federal Funds rate generates on average a 39 bp increase in deposit rates among large banks, and a 3.23% contraction in total deposits after one year.

While the degree of pass-through is one of my targets in the parameterization, the response

of deposits to changes in the deposit spread is affected by the curvature of utility with respect to deposits (γ), which has been calibrated based on the average relative volatility of real deposits to real GDP in the data - a different moment than the moment estimated by [Drechsler et al. \(2017\)](#). Therefore, I compare the estimated response in their regression against the coefficient from an analogous regression of the change in deposits³⁵ over one year on the change in the risk-free rate over the initial quarter using model-generated data³⁶. I find that a 100 bp increase in the risk-free rate in the model leads to a decrease by 5.03% in deposits after one year, relatively close to the estimated value despite the model being stylized.

Then, I consider a comparison against one of the main macroeconomic models with imperfect pass-through of changes in the policy rate to deposit rates in the literature, [Di Tella and Kurlat \(2017\)](#). The mechanism used in the paper is based on a leverage constraint that binds the supply of deposits by the bank to its marked-to-market net worth. When the short-term rate increases, since banks have a maturity-mismatched portfolio³⁷, the market value of their assets falls, thus their net worth falls and the supply of deposits has to shrink. Because depositors value deposits in the utility function, the reduction in supply of deposits is matched by an increase in the opportunity cost of holding them, i.e. a larger deposit spread. As a result, when the short-term rate increases, the deposit spread increases, thus the deposit rate does not increase one-for-one with the policy rate.

While [Di Tella and Kurlat \(2017\)](#) parameterize the model to match the evolution of the deposit spread in the data and are able to match the response of the deposit rate to the short-term rate (an increase of approximately 34 bp in the deposit rate for a 100 bp increase in the short-term rate), the response of deposit quantities is large. A 100 bp shock to the short-term rate reduces net worth of banks by approximately 30% relative to steady state in their model, on impact, and by 15% at one year³⁸. Equilibrium deposit quantities also decrease by the same amount, given that deposits are a fixed multiple of banks' net worth.

My model implies smaller responses of deposit quantities. Scaling the inflation target shock to get an increase in the short-term rate by 100 bp on impact, deposits would be below steady state by 4.15% on impact, and 2.28% after one year. The productivity shock described below in [Figure c](#), once scaled to give an endogenous change in the short-term rate by 100 bp on impact, implies that deposits would be below steady state by 4.22% on impact, and 4.88% after one year.

³⁵Since [Drechsler et al. \(2017\)](#) use nominal deposits while the model variables are real, I regress $[\log(d_t) + \log(P_t)] - [\log(d_{t-4}) + \log(P_{t-4})] = [\log(d_t) - \log(d_{t-4})] + \log(\Pi_t \Pi_{t-1} \Pi_{t-2} \Pi_{t-3})$ on the change in the risk-free rate $i_{t-3} - i_{t-4}$.

³⁶As in the calibration, I simulate the model 2000 times for 2108 periods, and burn the first 2000 periods to purge the effect of initial conditions, leaving 108 quarters.

³⁷Remarkably, in [Di Tella and Kurlat \(2017\)](#) the choice is endogenous, while in my model it is by assumption.

³⁸This 15% is based on [Figure 1](#), p. 16 of the paper.

5.2 Duration of Banks' Assets

Based on the description of the mechanism that produces imperfect pass-through, it is straightforward to realize that, if all assets of the bank had the same duration as liabilities (either because they are short-term assets, or because their rate is reset every period as in the case of adjustable-rate mortgages), then the pass-through of changes in the short-term rate to the deposit rate would be perfect.

This is illustrated in Figure B.5 in Appendix B, which shows impulse response functions to a 50 bp inflation target shock when all banks' assets are assumed to be adjustable-rate mortgages. As Greenwald (2018) shows in the case without bank, and as shown in Appendix E using the no-arbitrage condition of the bank, in equilibrium the rate on adjustable-rate mortgages q_t^* is equal to $i_t + \nu$, i.e. the mortgage rate and the short-term rate are perfectly correlated. As anticipated, the impulse response of the deposit rate moves essentially one-for-one with the short-term rate³⁹.

Absent the rigidity in rates that the bank earns on its assets, the bank does not experience any perturbation in its profits and dividends from a maturity mismatch⁴⁰. The only other reasons for the bank to not pass changes in the short-term rate completely to the deposit rate are the other motives that affect the decision of the optimal markup (or deposit spread) in Equation (9), namely movements in the discount factor and the growth rate of deposit demand, as discussed in Section 3. These effects however are quantitatively very small⁴¹.

I find support in banks' panel data for the qualitative relationship between duration of banks' assets and pass-through to deposit rates discussed in this section. Table 3 shows that the decrease in pass-through conditional on a longer duration of banks' assets is supported by the data. The table reports bank-level panel regressions using FFIEC Consolidated Reports of Condition and Income (US Call Reports) data where the pass-through of changes in the Federal Funds rate to deposit rates is interacted with either the ex-ante duration of a bank's assets or the ex-ante difference in the duration of its assets and liabilities. Specifically, I estimate

$$\Delta \text{deposit rate}_{i,t} = \alpha_i + \sum_{j=0}^3 \beta_j \Delta \text{FFR}_{t-j} + \sum_{j=0}^3 \delta_j \Delta \text{FFR}_{t-j} * \text{Mat}_{i,t-5} + \Gamma X_{i,t-5} + \epsilon_{i,t}$$

³⁹In this version of the model, while all parameters calibrated internally are set to match the respective targets, I leave the scale of the cost of deviating from the dividend target κ^{div} at its level in the baseline model, given that the ARM version of the model cannot generate enough variation in dividends to come close to the corresponding level in the data, used in the parameterization - even with $\kappa^{div} = 0$.

⁴⁰Variations in the marginal value of profits Ω_t only reflect the fact that the dividend target is defined in real terms, while interest income and expense of the bank are nominal, thus realized inflation will perturb realized real dividends. However, given the low volatility of inflation, I find that this effect on its own is not enough to induce the bank to substantially change its markup and prevent the deposit spread from adjusting with the short-term rate for any scale of the cost of adjusting dividends κ^{div} .

⁴¹I find they cannot generate an increase in the deposit spread larger than 1 basis point in response to the shock considered in Figure B.5.

where $Mat_{i,t-5}$ is either the duration of a bank's assets or the gap between the duration of its assets and liabilities. I follow [English et al. \(2018\)](#), [Di Tella and Kurlat \(2017\)](#) and [Drechsler et al. \(2018\)](#) in measuring the duration of banks' assets and liabilities using US Call Reports data on remaining maturity until payment (for fixed-rate assets/liabilities) or repricing maturity until the next rate reset (for variable-rate assets/liabilities), for different categories of assets and liabilities. Such maturities are then value-weighted in order to estimate an average duration of assets and liabilities of a bank. Since in the model the duration of assets⁴² is not a choice of the bank, I condition on duration before the period over which the pass-through is measured. I measure the deposit rate as the ratio of interest expense on transaction and savings deposits to their respective stocks in the Call Reports, while $\sum_{j=0}^3 \beta_j$ is the average pass-through of the policy rate to the deposit rate offered by the bank over a year, following [Drechsler et al. \(2018\)](#). The vector $X_{i,t-5}$ consists of other ex-ante controls.

The coefficient of interest is $\sum_{j=0}^3 \delta_j$ which describes how much the pass-through decreases with an increase in duration. I estimate it to be approximately -0.016 in the asset-weighted regressions in Table 3, meaning that a duration of bank's assets of 4.3 years (the average aggregate duration of banks' assets) reduces the yearly pass-through by approximately 0.069, or by 21% relative to the estimates of $\sum_{j=0}^3 \beta_j$. This is consistent with the finding in [Drechsler et al. \(2018\)](#) of a negative correlation between the interest expense beta⁴³ of a bank, averaged over time, and the duration of its assets.

5.3 Imperfect Pass-through with Different Shocks

The illustration of the mechanism that generates imperfect pass-through to the deposit rate in Section 3 suggests that the degree of pass-through of changes in the short-term rate implied by the model depends on the response of the long-term rate on mortgages - and banks' interest income - relative to the short-term rate after a shock. Therefore, different shocks can generate different pass-through to the deposit rate.

A comparison of Figures a and c highlights this point. Figure c shows impulse response functions of interest rates and deposits to a negative 1% productivity shock⁴⁴. The decrease in productivity increases firms' marginal costs, and through the nominal rigidity leads to an increase in inflation. Based on the Taylor rule, the central bank increases the short-term rate i_t . While in Figure c the productivity shock implies a relatively fast reversion of the short-term rate to steady

⁴²Or equivalently, the duration gap between its assets and liabilities, since also banks' liabilities in the model have fixed duration.

⁴³The change in a bank's interest expense per 100 bp change in the Federal Funds rate over one year, which includes the effect of imperfect pass-through.

⁴⁴Details on all impulse response functions to this shock are in Figures B.3 and B.4 in Appendix B.

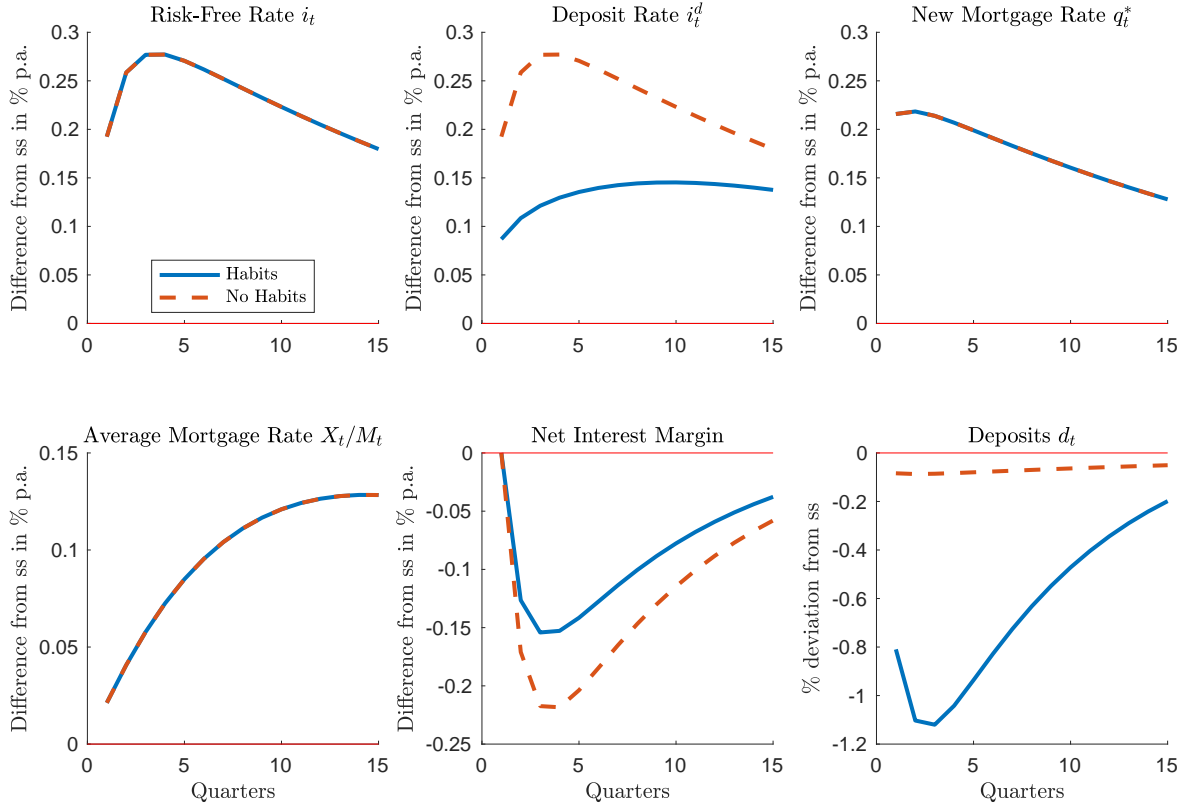


Figure c: Impulse Response Functions to a Negative 1% Productivity Shock

state, in Figure a it remains high for a long period of time. In this second case, given the shift in the term structure, the rate on new mortgages increases almost as much as the short-term rate. Therefore, the deposit rate gradually converges to the higher level of the short-term rate, as the bulk of banks' assets locks in the higher long-term rate.

6 Imperfect Pass-through and Monetary Policy Transmission

The impulse response functions in Figures a and c compare an economy with imperfect pass-through (i.e. with habits, $\theta > 0$) and one with full pass-through (i.e. no habits, $\theta = 0$). Looking at the path of the risk-free rate and the rate on new mortgages, we can see that there is no difference in the response of these variables between the two cases of full and partial pass-through. In Appendix F I show that, for a first-order approximation near the deterministic steady state, the marginal value of profits Ω_t - which appears in the intertemporal condition for the deposit spread (9) and does affect the deposit spread through that equation - drops instead from the no-arbitrage condition linking the marginal cost of funding an additional dollar of mortgages to its marginal benefit. Therefore, the effects of the dividend smoothing motive do not spill over to the mortgage

market.

The same Appendix also discusses how this result, coupled with the assumptions that i) banks face a supply of non-deposit funding which is infinitely elastic at the risk-free rate, ii) deposits are separable in the utility function, and iii) savers provide both deposits and bonds, earn banks' dividends, and save at the risk-free rate at the margin, imply irrelevance of the degree of deposit pass-through for the rest of the economy to a first order⁴⁵.

The following sections describe the outcomes of breaking such irrelevance by changing assumptions i) and ii)⁴⁶. I analyze the responses to the inflation target shock in order to explore how imperfect pass-through matters for monetary policy transmission.

6.1 Incomplete Arbitrage in the Market for Banks' Bonds

Model and Mechanism

The baseline model assumes that banks can finance any quantity of assets at the risk-free rate, up to the borrowing limit that constrains borrower's new debt. In order to break this assumption, I follow [Gertler et al. \(2013\)](#) and assume that savers can trade three assets: deposits which pay the rate i_t^d as before, government bonds A_t - in zero net-supply - which pay the risk-free rate i_t , and banks' bonds B_t which pay the rate i_t^B - different from i_t in general. Savers' holdings of banks' bonds are now subject to an adjustment cost in the budget constraint that takes the form

$$\frac{\kappa^B}{2} \left(\max \left\{ \frac{B_t}{M_t} - \frac{\bar{B}}{\bar{M}}, 0 \right\} \right)^2 M_t$$

where $\frac{\bar{B}}{\bar{M}}$ is the steady-state ratio of bonds in total liabilities (equal to total assets). This cost captures in reduced-form that savers have a limited risk-bearing capacity: they are willing to hold banks' bonds at the risk-free rate only up to a given ratio of total liabilities. Beyond that, as if savers were heterogeneous, some of them become concerned about rollover risk of short-term non-deposit liabilities, which are generally considered a less-stable form of funding than deposits

⁴⁵Figures [B.1](#), [B.2](#), [B.3](#), [B.4](#) in Appendix [B](#) collect all impulse response functions and visualize the result.

⁴⁶I find that, assuming that bondholders and depositors are different agents, tends to give counterfactual responses. In this scenario, depositors can only save in deposits, and value services from deposits exactly as savers do in the baseline model. The decision by the depositor to allocate resources between deposits and consumption depends on the spread between an implicit rate at which the depositor is effectively substituting consumption intertemporally (since she does not face a standard Euler equation as the bondholder does) and the deposit rate. In response to a negative TFP shock which increases the short-term rate, the deposit rate typically increases more than the implicit rate at which the depositor is substituting consumption. Then deposits become relatively less expensive to hold and demand for deposits by the depositor increases, even if the actual deposit spread - i.e. the spread between market rates, $i_t - i_t^d$ - increases. This is the opposite of what we observe in the data. In response to an inflation target shock which increases the risk-free rate, both the actual deposit spread and the implied spread increase. Since the depositor does not have other assets, she substitutes consumption for deposits. Thus depositor's consumption goes up, and this can lead output to increase on impact in this New-Keynesian setting, even in the face of a monetary policy shock that increases the short-term rate.

(Hanson et al., 2015). If savers with higher risk-bearing capacity are not able to fully absorb the excess demand for non-deposit funding by banks, then the rate that banks need to offer on non-deposit liabilities has to increase above the risk-free rate, and arbitrage of asset returns is incomplete.

The budget constraint of the representative saver becomes

$$C_t^s + d_t + A_t + B_t + \frac{\kappa^B}{2} \left(\max \left\{ \frac{B_t}{M_t} - \frac{\bar{B}}{\bar{M}}, 0 \right\} \right)^2 M_t = (1 - \tau^y) W_t N_t^s + \frac{1 + i_{t-1}^B}{\Pi_t} (d_{t-1} + A_{t-1}) + \frac{1 + i_{t-1}^B}{\Pi_t} B_{t-1} + \frac{\tilde{m}_{t-1}^d}{\Pi_t} D_{t-1} + T_t^s + \Xi_t^s$$

Therefore, in equilibrium, the saver's Euler equation for the choice of banks' bonds to hold becomes

$$\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \right] (i_t^B - i_t) = \kappa^B \max \left\{ \frac{B_t}{M_t} - \frac{\bar{B}}{\bar{M}}, 0 \right\}$$

Accordingly, the marginal cost of funds for banks i_t^B can be different than the risk-free rate, and is increasing in the share of bonds in total banks' liabilities. Appendix C shows the first-order conditions from the bank's problem under the new assumption.

I highlight how the Euler equation for the deposit spread set by the bank changes in this version of the model with a bond spread $i_t^B - i_t$. Assuming that the habit stock depreciates after one period for simplicity ($\rho_s = 0$), the equation becomes

$$\begin{aligned} \mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \Omega_{t+1} \right] \left(\frac{\eta}{\eta - 1} \left(1 - \frac{i_t^B - i_t}{\kappa} \right) - \frac{m_t^d}{\kappa} \right) = \\ = \mathbb{E}_t \left[\frac{\Lambda_{t,t+2}^s}{\Pi_{t+2}} \Omega_{t+2} \left[\left(\frac{\eta}{\eta - 1} \left(1 - \frac{i_{t+1}^B - i_{t+1}}{\kappa} \right) - \frac{m_{t+1}^d}{\kappa} \right) \right] \right] \end{aligned} \quad (12)$$

The only difference relative to the baseline model without portfolio adjustment cost is that the static markup $\eta / (\eta - 1)$ is multiplied by the term $1 - (i_t^B - i_t) / \kappa$, which is decreasing in the bond spread. The intuition behind this equation is the following. The marginal cost for the bank of attracting one additional dollar of deposits in terms of forgone profits still depends on the deposit spread m_t^d that the bank offers, as in order to attract deposits the bank has to sacrifice some profits and offer a higher deposit rate - i.e. a lower deposit spread. However, as the bank attracts more deposits, it can save on the additional cost that it pays when financing its marginal dollar of assets at the bond rate, relative to the risk-free rate. Hence, everything else equal, the bank will have a lower overall marginal cost of attracting deposits, the higher the bond rate i_t^B is relative to the

risk-free rate i_t .

I re-parameterize the model to the targets described in Section 4⁴⁷ and in Figure d I report the impulse response functions of key variables to a 50 bp shock to the inflation target⁴⁸. The graphs compare the default case with imperfect pass-through and $\kappa^{div} = 521$ ("low κ^{div} "), ii) perfect pass-through ("no habits"), and iii) imperfect pass-through and $\kappa^{div} = 700$ ("high κ^{div} "). Because the portfolio adjustment cost introduces a kink, I compute a piece-wise approximate solution to the model using the method developed by Guerrieri and Iacoviello (2015).

Faced with an increase in the short-term rate at which it finances its portfolio of mortgages, the bank decides to adjust the deposit rate partially in order to compensate the squeeze in profits from intermediation. As deposits flow out because the opportunity cost of holding them relative to the risk-free rate is higher, the ratio of bonds in total liabilities increases above the steady-state level, leading to an additional increase in the marginal cost of funds i_t^B for the bank. As the bond rate increases above the risk-free rate, the bank passes through part of the additional increase in its marginal cost of funds to the rate on new mortgages q_t^* , which leads to a decrease in new mortgage origination M_t^* , relative to the case of perfect pass-through. As a consequence of the decrease in borrowing, borrower's consumption C_t^b decreases more than in the case of full pass-through, and eventually output falls by more. All these effects are concentrated in the first few periods, as the bank has a strong incentive to bring the ratio of bonds below the steady-state level as soon as possible, given the increase in the cost of funds that it generates.

Comparing the cases with low and high cost of dividend adjustment, we see that there is amplification in the increase in the bond rate with a higher cost of dividend adjustment. This happens because, with a stronger motive to smooth profits, the bank has a stronger incentive to keep the deposit rate from increasing with the risk-free rate. This induces a larger outflow of deposits, which in turn implies banks need to issue relatively more bonds to finance their assets. As banks increase the share of their funding coming from bonds, the interest rate they have to pay on them increases by more. Notice that banks take the bond rate as given and do not internalize the effect of their actions on the bond rate - in contrast with what happens in the deposit market, where banks have market power and internalize the relationship between deposit rate and deposit demand. As a result of the bigger increase in the bond rate, real effects from imperfect pass-through are amplified.

Clearly, starting from steady state, the model has only asymmetric amplification through this channel, given the asymmetry in the adjustment cost. However, if the shock hits the economy outside of the steady state, in the region where the supply of bonds is upward sloping, the ampli-

⁴⁷I normalize the scale of the portfolio adjustment cost κ^B to 1, as the purpose of this exercise is to explore the implications of imperfect pass-through for monetary policy transmission qualitatively.

⁴⁸Details on all impulse response functions to this shock are in Figures B.6 and B.7 in Appendix B.

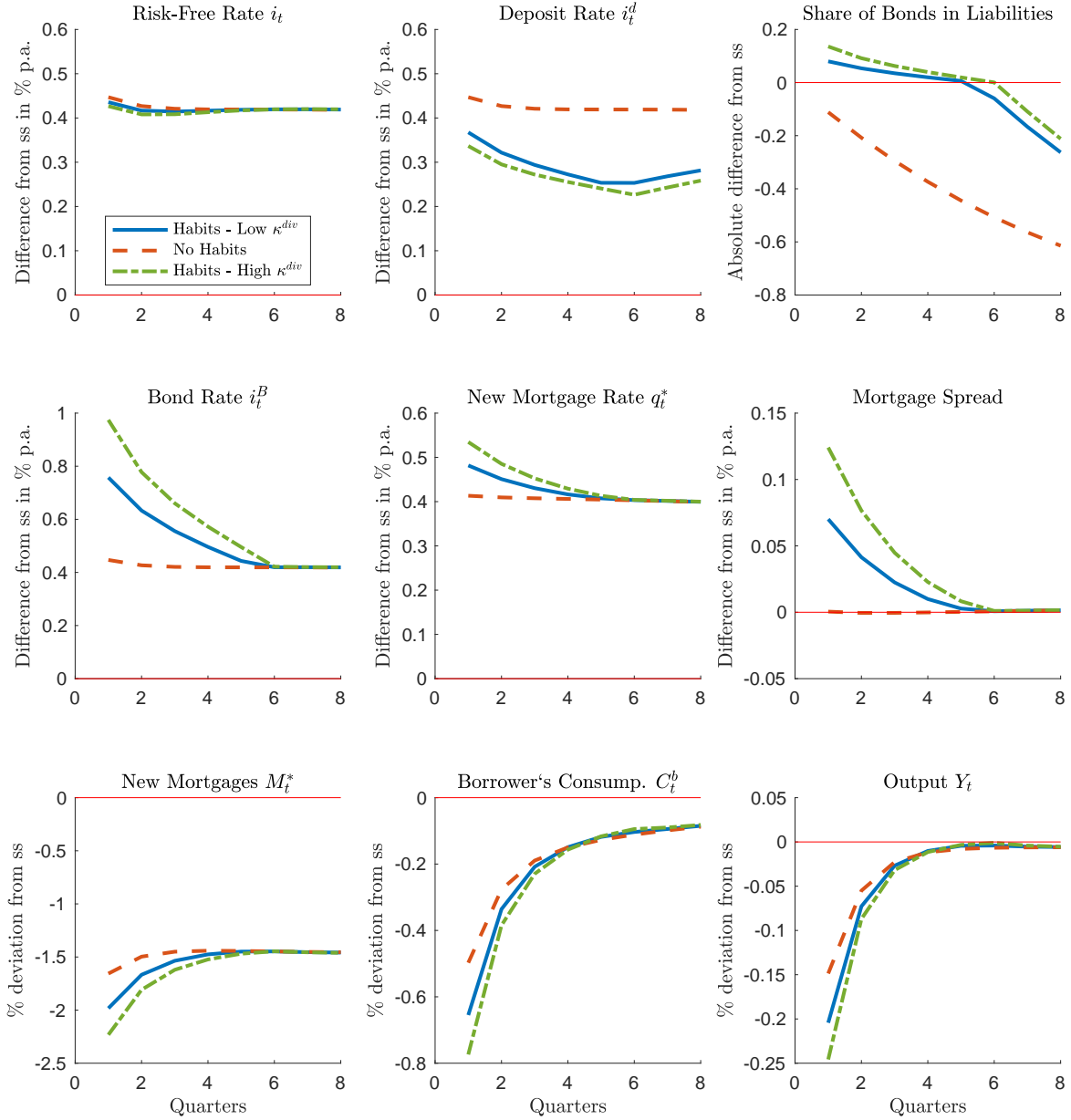


Figure d: IRFs to a 50 bp Inflation Target Shock - Portfolio-Adjustment Cost

fication in the response of borrowing costs for given changes in the policy rate would arise both in response to contractionary as well as in response to expansionary monetary policy shocks⁴⁹.

⁴⁹I verify that this happens through the following experiment. I consider the difference between two simulated paths starting from the steady state, $\{\hat{y}_t^1\}$ and $\{\hat{y}_t^2\}$. The first one corresponds to a one-time +100 bp annualized shock to the inflation target at $t = 0$ that brings the economy in the region where the spread $i_t^B - i_t$ is positive and reverts to steady state. The second one has the same shock at $t = 0$, followed by an expansionary monetary policy shock that reduces the inflation target by -50 bp at $t = 1$. The amplification in the response of output to the expansionary monetary

Evidence

Substitution of deposits with non-deposit liabilities in banks' balance sheets, after an increase in the policy rate, is supported by the evidence. I show this using local projections of banks' liabilities with an external instrument for monetary policy shocks, in the spirit of [Jordà \(2005\)](#) and [Stock and Watson \(2018\)](#). I choose the "policy news shocks" constructed by [Nakamura and Steinsson \(2018\)](#) as the instrument for changes in the Federal Funds rate. These shocks consist of the first principal component of unanticipated changes in prices of five Federal Funds and Eurodollar futures⁵⁰ over 30-minute windows around FOMC announcements, capturing also the effects of "forward guidance". I estimate quarterly⁵¹ local projections between 1995 and 2013 of the form

$$\Delta_h y_{t+h} = \alpha_h + \beta_h \Delta i_t + \Gamma_h X_{t-1} + u_{t+h}^y \quad (13)$$

where y_{t+h} is either i) the ratio of non-deposit liabilities to total liabilities for the aggregate of US commercial banks, ii) the natural logarithm of real total non-deposit liabilities of banks, iii) the natural logarithm of real total deposits, all computed from US Call Reports data⁵². As done before, deposits correspond to transaction and savings deposits. Denoting by ϵ_t^i the shocks constructed by [Nakamura and Steinsson \(2018\)](#), ϵ_t^i is the instrument for the change in the Federal Funds rate over a quarter in Equation (13), Δi_t . Finally, X_{t-1} collects a number of controls. Following [Stock and Watson \(2018\)](#), I use four lags of i) the instrument ϵ_t^i , ii) the change in the policy variable Δi_t , and iii) the change in the response variable Δy_t .

Figure e shows the results⁵³. The first graph describes the response of the Federal Funds rate to the shocks, and highlights the unit effect normalization induced by the two-stage least squares estimation⁵⁴. Thus, all other projections should be interpreted as responses of the variables to a 100 bp shock to the Federal Funds rate. As implied by the model, deposits decrease and the share of liabilities financed through other sources increases⁵⁵. Using different data and identification,

policy shock from the interaction between imperfect pass-through and variation in the bond spread can be seen by looking at the difference between $\{\hat{y}_t^2\}$ and $\{\hat{y}_t^1\}$ starting from period $t = 1$ onwards, separately for the case with deep habits and without habits. I do not report the resulting impulse response functions because, as expected given that the approximate solution is piece-wise linear, they look as the mirror image of the impulse response functions in Figures B.6 and B.7.

⁵⁰Specifically, futures contracts considered target the Federal Funds rate immediately after the FOMC meeting, the expected Federal Funds rate immediately after the next FOMC meeting, and expected 3-month Eurodollar rates at horizons of two, three and four quarters.

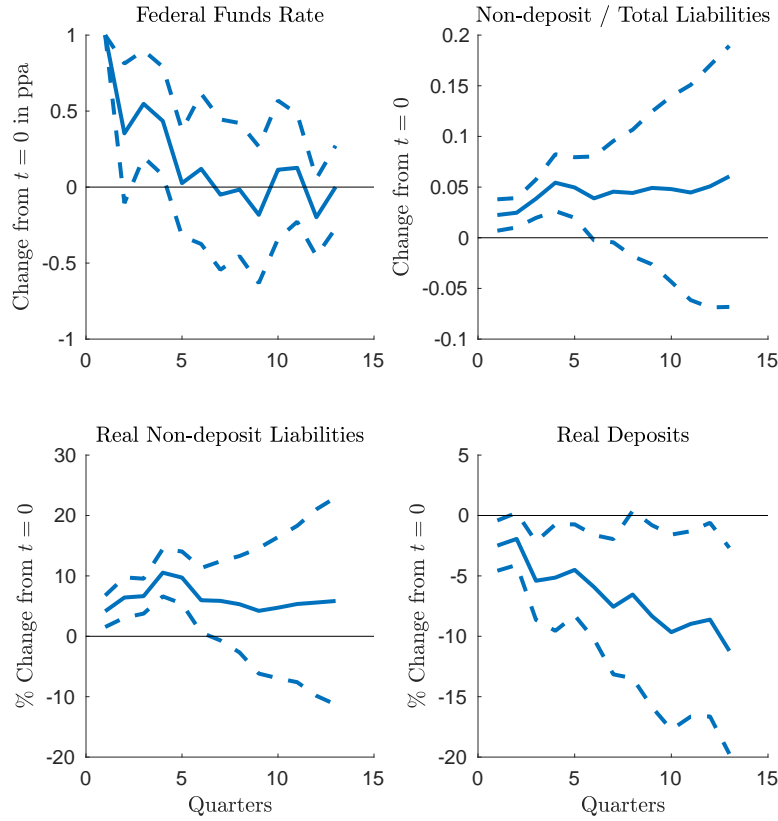
⁵¹Since in a given quarter there can be more than one FOMC announcement, I follow [Wong \(2016\)](#) and [Jeenas \(2018\)](#) and sum all shocks over each quarter.

⁵²Nominal variables are deflated using CPI excluding food and energy. Results are robust to using the GDP deflator.

⁵³Results are robust to i) changing the period to start in Q1 2000 - the preferred period by [Nakamura and Steinsson \(2018\)](#) - and excluding the Financial Crisis; ii) excluding unscheduled meetings; iii) using two instead of four lags of the controls.

⁵⁴In this case, since y_t is i_t , the local projection is $\Delta_h i_{t+h} = \alpha_h + \beta_h \Delta i_t + \sum_{j=1}^4 \Gamma_{h,j}^1 \Delta i_{t-j} + \sum_{j=1}^4 \Gamma_{h,j}^2 \epsilon_{t-j}^i + u_{t+h}^i$.

⁵⁵As discussed previously in Section 3, since bank's balance sheet is defined in real terms, the increase in inflation



Source: US Call Reports, Federal Reserve H.15 Release, [Nakamura and Steinsson \(2018\)](#) “policy news shocks”, Q1 1995 - Q4 2013. Dashed lines correspond to 2 standard errors (Newey-West with $h + 1$ lags). The first stage F-statistic is above 20 in all local projections.

Figure e: Local Projection of Bank Liabilities with Monetary Policy Shock (2 SE bands)

also [Drechsler et al. \(2017\)](#) find evidence of substitution of deposits with non-deposit liabilities after an increase in the policy rate.

Another part of the mechanism which is consistent with the evidence is the overshooting of the mortgage rate in the short run after the monetary policy shock. It is consistent with findings in [Gertler and Karadi \(2015\)](#), who combine a traditional monetary VAR with high frequency identification of monetary policy shocks and find that a monetary policy surprise leads to an amplified response of credit costs due to widening in various spreads, including the mortgage spread over the 10 year government bond rate. In the model, I construct the mortgage spread as the difference between the rate on new mortgages and the rate on a bond with similar maturity⁵⁶, computed

and the decrease in mortgage origination M_t^* due to the increase in the mortgage rate q_t^* lead to a decrease in the size of the balance sheet. As a result, bonds decrease below steady state over time. Nevertheless, bonds decrease by less in the case with imperfect pass-through relative to the case with perfect pass-through, as deposits flow out in the former case, and lead to an increase in the share of bonds in total liabilities.

⁵⁶Since the effective maturity of banks’ assets, i.e. mortgages, is 4.26 years, I consider a 5 year bond.

from current and expected future risk-free rates based on the expectations hypothesis of the term structure⁵⁷. As shown in Figure d, with full pass-through, the mortgage spread in the model is essentially flat. However, with imperfect pass-through, the mortgage spread increases in the short run in response to the contractionary monetary policy shock, as found by Gertler and Karadi (2015)⁵⁸.

6.2 Complementarity between Consumption and Deposits in Utility

In order to break the assumption that consumption and deposits are separable in the utility function, which may not hold in practice if there is a positive correlation between the level of economic activity and demand for liquidity, I follow Piazzesi et al. (2018) and specify the utility function of the saver as

$$U^s(C_t^s, N_t^s, D_t^s) = \frac{1}{1 - \frac{1}{\sigma}} \left[(1 - \psi) \left(\frac{C_t^s}{\chi^s} \right)^{1 - \frac{1}{\gamma}} + \psi \left(\frac{D_t^s}{\chi^s} \right)^{1 - \frac{1}{\gamma}} \right]^{\frac{1 - \frac{1}{\sigma}}{1 - \frac{1}{\gamma}}} - \zeta_s \frac{\left(\frac{N_t^s}{\chi} \right)^{1 + \epsilon}}{1 + \epsilon}$$

With this different assumption, the marginal utility of consumption of the saver becomes

$$\frac{\partial U^s}{\partial C_t^s} = (1 - \psi) \left[(1 - \psi) \left(\frac{C_t^s}{\chi^s} \right)^{1 - \frac{1}{\gamma}} + \psi \left(\frac{D_t^s}{\chi^s} \right)^{1 - \frac{1}{\gamma}} \right]^{\frac{\frac{1}{\gamma} - \frac{1}{\sigma}}{1 - \frac{1}{\gamma}}} \left(\frac{C_t^s}{\chi^s} \right)^{-\frac{1}{\gamma}} \frac{1}{\chi^s}$$

thus the quantity of (habit-adjusted) deposits enters the marginal utility of consumption and then the Euler equation for bonds, allowing for real effects of changes in deposit spreads and quantities. If the curvature parameter γ is smaller than the IES σ , then consumption and deposits are complements and an increase in the deposit spread which reduces demand for deposits, will also reduce consumption by savers.

Figure B.8 in Appendix B shows impulse response functions to the 50 bp inflation-target shock in this version of the model. I re-parameterize internally set parameters to match the targets described in Section 4, including the curvature parameter γ which is set to 0.102 to match the relative standard deviation of real deposits to real GDP. While responses of banks' variables are essentially the same as in the model with separable preferences, Figure B.8 shows that real variables behave differently in the model with imperfect pass-through (habits) relative to the model with full pass-

⁵⁷Notice that the approximation to the solution computed using the method developed by Guerrieri and Iacoviello (2015) has constant risk premia.

⁵⁸Notwithstanding the different types of monetary policy shocks considered, the response of the mortgage spread in the model is actually conservative when compared to the estimate in Gertler and Karadi (2015). They estimate that a monetary policy shock that increases the short-term rate by approximately 15 bp per annum, increases the mortgage spread by 7 bp. Figure d instead shows responses to a monetary policy shock that increases the short-term rate by approximately 45 bp per annum and the mortgage spread by 7 to 12 bp depending on the parameterization.

through (no habits). In particular, saver's consumption increases by less, and as a result output falls by more. As anticipated, the increase in the deposit spread leads to a reduction in deposits demanded by the saver relative to the model with full pass-through. Because deposits are complements with consumption in the utility function, the saver increases consumption by less, and as output is partially demand-determined in this New Keynesian setting, output falls by more. As production is lower, less labor is needed in production, and the lower demand for labor is almost entirely absorbed by the saver.

7 Evidence in Support of Model Assumptions

Two important assumptions in the model are that banks have market power in the deposit market and the deposit demands they face have a persistent component, captured in reduced form through deep habits for deposits.

[Polo and Violante \(2018\)](#) find dispersion in deposit rates offered by different banks in local markets, even after weighting deposit rates offered by banks by their local market shares. This suggests that banks have pricing power and the deposit demands they face are persistent in the sense that banks do not lose deposits, and depositors, quickly if they set a deposit rate which is lower than the rate offered by a competitor in the local market. Using weekly data collected by RateWatch on deposit rates offered by bank branches on new accounts, and combining them with Federal Deposit Insurance Corporation (FDIC) annual data on total deposits at each branch, they find that, for instance, between 2006 and 2007 the average deposit rate offered by banks on money-market deposit accounts (MMDAs), weighted by their market share at the county level, was 1.3% on an annualized basis⁵⁹. The weighted standard deviation of MMDA rates within a county was 0.8% over the period. This amounts to a coefficient of variation of 0.61 - above the level of wage dispersion in labor markets (coefficient of variation of 0.3, [Hornstein et al. \(2011\)](#)), which are typically considered as frictional. Figure 3 shows the path of the average MMDA deposit rate and its standard deviation over time, relative to the Federal Funds rate. Dispersion varies with the level of short term rates, and shrinks significantly during the period of near-zero policy rates

⁵⁹MMDAs include the most common type of non-time deposit product offered by US banks, the \$25,000 money market deposit account ([Drechsler et al., 2017](#)). Rates are aggregated as follows. First, weekly data on deposit rates of each MMDA product offered by a branch are averaged over a month to have a monthly deposit rate for each product. Then monthly MMDA rates of each branch are averaged in order to have an average monthly MMDA rate offered by each bank branch. At this point, annual market shares of each branch in each county from FDIC data are used in order to compute a weighted average MMDA rate of each county. Then the county-level MMDA rates are aggregated across counties based on their share of total deposits, to arrive at a single monthly average MMDA rate across the United States. The aggregation process to compute the standard deviation is analogous. RateWatch data does not cover the universe of bank branches in the US, although coverage has increased over time from approximately 10% of total FDIC-reported deposits in the US in 1999, to 35% in 2006 and 70% after 2008. Markets are defined at the county level also by [Drechsler et al. \(2017\)](#) in their empirical analysis using RateWatch data.

after the Financial Crisis, but even in periods of lower dispersion such as between 2003 and 2004 the coefficient of variation is around 0.35.

Additional evidence in support of a dynamic component in demand for banks' deposits is provided by limited turnover of banks' customers and depositors. [Honka et al. \(2017\)](#) discuss⁶⁰ survey estimates saying that 8.4% of the US population switches primary bank in a year, and 14% opens at least one new account⁶¹ with another bank each year. They also report that "a study conducted by TD Bank in 2013 says that 12% of the study respondents switched primary bank during the last two years" and "a NY Times article published in 2010 mentions that [r]oughly 10 to 15 percent of households move their checking account from one bank to another each year, a figure that hasn't changed substantially in recent years, according to several industry consultants and market researchers". Finally, [Gourio and Rudanko \(2014\)](#) report a customer turnover in online banking accounts of 10 to 20% per year. Overall, these estimates of turnover are similar, if not lower, than for turnover of customers in retail goods markets ([Paciello et al., 2017](#)).

There are also branches of the management and statistics literature which focus on customer valuation and prediction of customer attrition specifically at banks. Even if this includes customers who are not just depositors, it further supports that retail customer relationships are important for banks, including those with depositors. For instance, [Haenlein et al. \(2007\)](#) develop a customer valuation model for retail banking and test it using data of a leading German bank. While data confidentiality prevents them from reporting exhaustive statistics about customer turnover, they say that 1 to 10% of customers aged 37/38 terminate their relationship with the bank in a year - and this provides an upper bound also for depositors' turnover. [He et al. \(2014\)](#) develop a machine learning technique to predict customer attrition for commercial banks, and motivate it precisely based on the difficulty in predicting attrition from a very imbalanced sample between churners and non-churners at the bank.

In order to provide further evidence in support of the assumption that the deposit demand faced by banks is persistent, I look at persistence in the portion of banks' market shares in the deposit market which is not explained by deposit rates or other sources of differentiation across banks suggested in the literature that estimates structural demand models of commercial banks' deposits ([Dick 2008](#), [Egan et al. 2017a](#), [Egan et al. 2017b](#) among others). The procedure is described in Appendix H. I find that the autocorrelation of residuals is high, ranging from 0.995 at one quarter to 0.97 at five years. While [Egan et al. \(2017b\)](#) call these residuals 'productivity', they reflect various unexplained factors, including limited turnover of banks' depositors.

⁶⁰In the notes to the paper.

⁶¹While the types of accounts considered in the main survey in the paper include deposits, credit cards, mortgages and investment accounts, the vast majority of shoppers open deposit accounts (85% checking, 58% saving), and the third most common type of account opened is credit cards (26%).

Other assumptions

Banks are represented in the model as holding only mortgages as assets, earning only interest income, and managing a maturity-mismatched portfolio. These features are motivated by the empirical evidence on the banking sector.

Figure 4 shows that real-estate loans and mortgage-backed securities are the largest asset-category for commercial banks using data from the FFIEC Consolidated Reports of Condition and Income (US Call Reports). The average share of total assets accounted for by this class is approximately 35% over the period 1997-2013, while all other loans and all other securities account for 28% and 11% on average over the period, respectively⁶².

I also find that interest income accounts for most of total (interest and non-interest) income of commercial banks. This is shown in Figure 5 based on US FDIC Historical Statistics on Banking data. While with the decrease in the term premium the share of total income accounted for by interest income has decreased, even in the recent low-interest rate environment the share stands at around 65%-70%.

Regarding maturity mismatch, I follow the same procedure described in Section 5.2 but at the level of the aggregate US commercial banking sector in order to estimate an aggregate average duration of banks' assets and liabilities. The resulting time series are reported in Figure 6. As Drechsler et al. (2018) find, the average duration of the aggregate of banks' assets is approximately 4.3 years during 1997-2013, while for liabilities it stands at 0.4 years. Excluding transaction and savings deposits for which the maturity is assumed to be 0, I find that the average duration of remaining banks' liabilities is approximately 0.9 years - still significantly lower than for assets. Finally, even if commercial banks are sophisticated investors and could hedge the interest-rate risk generated by their maturity-mismatched portfolio through derivatives, Begenau et al. (2015) find that only approximately 50% of bank holding companies use interest rate derivatives⁶³, and most banks use them to take on more interest rate risk. In this sense, the model assumption that banks always manage a maturity mismatched portfolio is justified.

8 Conclusion

This paper develops a general equilibrium monetary model with imperfect pass-through of changes in the short-term rate to the deposit rate. I propose a novel mechanism to generate the imperfect pass-through to deposit rates observed in the data. This mechanism relies on three key features: banks' activity of maturity transformation, persistence in banks' deposit demand through deep

⁶²Cash, Federal Funds sold and trading assets essentially account for the remaining part of total assets.

⁶³Drechsler et al. (2018) instead look at holdings of interest-rate derivatives disaggregated by banks - not at the aggregate bank holding company level - and report that only 8% of banks use such derivatives.

habits, and costly dividend adjustment. I argue that each of these three features is essential in order to have imperfect pass-through in this framework, and I validate the mechanism by comparing model and data in two dimensions. First, the response of deposit quantities implied by the calibrated model is in line with the evidence in [Drechsler et al. \(2017\)](#). Second, in the data I find that banks managing a portfolio with a smaller gap between the duration of assets and liabilities have higher pass-through. In the model, if banks were not maturity mismatched, pass-through would be full.

Finally, I investigate the implications for monetary policy transmission of imperfect pass-through relative to full pass-through to deposit rates. Specifically, I find that, if banks face an increase in their cost of borrowing at the margin as they finance a larger share of their assets through non-deposit liabilities, imperfect pass-through can amplify the response of output to persistent monetary policy shocks that shift the term structure. In this form, the model is consistent with three key facts related to monetary policy transmission: partial adjustment of deposit rates to changes in the policy rate, substitution between deposits and other liabilities in banks' balance sheets following monetary policy changes, and increase in mortgage spreads in response to contractionary monetary policy shocks.

This paper opens several exciting avenues for future research. The mechanism can be embedded in a model where the amount of funds that banks can borrow and intermediate is tied to banks' net worth, as for instance in [Gertler and Kiyotaki \(2010\)](#). It would then be possible to explore the macroeconomic implications of changes in the spread that banks earn from their deposit-taking business through the effects on banks' net worth, especially near the zero-lower bound on interest rates. Furthermore, the mechanism could be applied in a model with heterogeneous banks such as [Corbae and D'Erasmus \(2014\)](#) to explore how imperfect pass-through to deposit rates interacts with banks' capital requirements.

References

- AKSOY, Y., H. S. BASSO, AND J. COTO-MARTINEZ (2013): "Lending relationships and monetary policy," *Economic Inquiry*, 51, 368–393.
- ALIAGA-DÍAZ, R. AND M. P. OLIVERO (2010): "Macroeconomic implications of "deep habits" in banking," *Journal of Money, Credit and Banking*, 42, 1495–1521.
- ANDERSON, S. P., A. DE PALMA, AND J.-F. THISSE (1989): "Demand for differentiated products, discrete choice models, and the characteristics approach," *The Review of Economic Studies*, 56, 21–35.
- ANDERSON, S. P., A. DEPALMA, AND J.-F. THISSE (1987): "The CES is a discrete choice model," *Economics Letters*, 24, 139.
- BAUMOL, W. J. (1952): "The transactions demand for cash: An inventory theoretic approach," *The Quarterly Journal of Economics*, 545–556.
- BEGENAU, J. (2016): "Capital requirements, risk choice, and liquidity provision in a business cycle model," .
- BEGENAU, J., M. PIAZZESI, AND M. SCHNEIDER (2015): "Banks' risk exposures," Tech. rep., National Bureau of Economic Research.
- BEGGS, A. AND P. KLEMPERER (1992): "Multi-period competition with switching costs," *Econometrica: Journal of the Econometric Society*, 651–666.
- BERGER, A. N. AND T. H. HANNAN (1989): "The price-concentration relationship in banking," *The Review of Economics and Statistics*, 291–299.
- (1991): "The Rigidity of Prices: Evidence from the Banking Industry," *The American Economic Review*, 81, 938.
- BERRY, S., J. LEVINSOHN, AND A. PAKES (1995): "Automobile prices in market equilibrium," *Econometrica: Journal of the Econometric Society*, 841–890.
- BRUNNERMEIER, M. K. AND Y. KOBAYASHI (2016): "The reversal interest rate: An effective lower bound on monetary policy," *Unpublished paper, Princeton University*.
- CARBO-VALVERDE, S., T. H. HANNAN, AND F. RODRIGUEZ-FERNANDEZ (2011): "Exploiting old customers and attracting new ones: The case of bank deposit pricing," *European Economic Review*, 55, 903–915.

- CHATTERJEE, S. AND B. EYIGUNGOR (2015): "A quantitative analysis of the US housing and mortgage markets and the foreclosure crisis," *Review of Economic Dynamics*, 18, 165–184.
- CORBAE, D. AND P. D'ERASMO (2014): "Capital requirements in a quantitative model of banking industry dynamics," .
- CRAIG, B. R., V. DINGER, ET AL. (2011): "The Duration of Bank Retail Interest Rates (formerly titled: A microeconomic investigation into bank interest rate rigidity)," Tech. rep.
- DAVIS, M. A. AND F. ORTALO-MAGNÉ (2011): "Household expenditures, wages, rents," *Review of Economic Dynamics*, 14, 248–261.
- DI TELLA, S. AND P. KURLAT (2017): "Why are Banks Exposed to Monetary Policy?" Tech. rep., National Bureau of Economic Research.
- DIAMOND, D. W. AND P. H. DYBVIG (1983): "Bank runs, deposit insurance, and liquidity," *Journal of political economy*, 91, 401–419.
- DICK, A. A. (2008): "Demand estimation and consumer welfare in the banking industry," *Journal of Banking & Finance*, 32, 1661–1676.
- DIEBOLD, F. X. AND S. A. SHARPE (1990): "Post-deregulation bank-deposit-rate pricing: The multivariate dynamics," *Journal of Business & Economic Statistics*, 8, 281–291.
- DRECHSLER, I., A. SAVOV, AND P. SCHNABL (2017): "The deposits channel of monetary policy," *The Quarterly Journal of Economics*, 132, 1819–1876.
- (2018): "Banking on deposits: Maturity transformation without interest rate risk," Tech. rep., National Bureau of Economic Research.
- DRISCOLL, J. AND R. JUDSON (2013): "Sticky deposit rates," .
- EGAN, M., A. HORTAÇSU, AND G. MATVOS (2017a): "Deposit competition and financial fragility: Evidence from the us banking sector," *American Economic Review*, 107, 169–216.
- EGAN, M., S. LEWELLEN, AND A. SUNDERAM (2017b): "The cross section of bank value," Tech. rep., National Bureau of Economic Research.
- EGGERTSSON, G. B., R. E. JUELSRUD, AND E. G. WOLD (2017): "Are negative nominal interest rates expansionary?" Tech. rep., National Bureau of Economic Research.
- ELENEV, V. (2017): "Mortgage credit, aggregate demand, and unconventional monetary policy," .

- ELENEV, V., T. LANDVOIGT, AND S. VAN NIEUWERBURGH (2018): “A macroeconomic model with financially constrained producers and intermediaries,” Tech. rep., National Bureau of Economic Research.
- ENGLISH, W. B., S. J. VAN DEN HEUVEL, AND E. ZAKRAJŠEK (2018): “Interest rate risk and bank equity valuations,” *Journal of Monetary Economics*.
- FARIA-E CASTRO, M. (2017): “Fiscal multipliers and financial crises,” *Unpublished manuscript, New York University*.
- FEENSTRA, R. C. (1986): “Functional equivalence between liquidity costs and the utility of money,” *Journal of Monetary Economics*, 17, 271–291.
- FERNALD, J. (2014): “A quarterly, utilization-adjusted series on total factor productivity,” Federal Reserve Bank of San Francisco.
- GARRIGA, C., F. E. KYDLAND, AND R. ŠUSTEK (2016): “Nominal rigidities in debt and product markets,” Tech. rep., National Bureau of Economic Research.
- (2017): “Mortgages and monetary policy,” *The Review of Financial Studies*, 30, 3337–3375.
- GERALI, A., S. NERI, L. SESSA, AND F. M. SIGNORETTI (2010): “Credit and Banking in a DSGE Model of the Euro Area,” *Journal of Money, Credit and Banking*, 42, 107–141.
- GERLACH, J. R., N. MORA, AND P. UYSAL (2018): “Bank funding costs in a rising interest rate environment,” *Journal of Banking & Finance*, 87, 164 – 186.
- GERTLER, M. AND P. KARADI (2015): “Monetary policy surprises, credit costs, and economic activity,” *American Economic Journal: Macroeconomics*, 7, 44–76.
- GERTLER, M., P. KARADI, ET AL. (2013): “Qe 1 vs. 2 vs. 3...: A framework for analyzing large-scale asset purchases as a monetary policy tool,” *international Journal of Central Banking*, 9, 5–53.
- GERTLER, M. AND N. KIYOTAKI (2010): “Financial intermediation and credit policy in business cycle analysis,” in *Handbook of monetary economics*, Elsevier, vol. 3, 547–599.
- GILCHRIST, S., R. SCHOENLE, J. SIM, AND E. ZAKRAJŠEK (2017): “Inflation dynamics during the financial crisis,” *American Economic Review*, 107, 785–823.
- GOREA, D. AND V. MIDRIGAN (2017): “Liquidity constraints in the US housing market,” Tech. rep., National Bureau of Economic Research.

- GOURIO, F. AND L. RUDANKO (2014): "Customer capital," *Review of Economic Studies*, 81, 1102–1136.
- GREENWALD, D. (2018): "The Mortgage Credit Channel of Macroeconomic Transmission," *MIT Sloan Research Paper No. 5184-16*.
- GUERRIERI, L. AND M. IACOVIELLO (2015): "OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily," *Journal of Monetary Economics*, 70, 22–38.
- HAENLEIN, M., A. M. KAPLAN, AND A. J. BEESER (2007): "A model to determine customer lifetime value in a retail banking context," *European Management Journal*, 25, 221–234.
- HANNAN, T. H. AND R. M. ADAMS (2011): "Consumer switching costs and firm pricing: Evidence from bank pricing of deposit accounts," *The Journal of Industrial Economics*, 59, 296–320.
- HANSON, S. G., A. SHLEIFER, J. C. STEIN, AND R. W. VISHNY (2015): "Banks as patient fixed-income investors," *Journal of Financial Economics*, 117, 449–469.
- HATCHONDO, J. C. AND L. MARTINEZ (2009): "Long-duration bonds and sovereign defaults," *Journal of international Economics*, 79, 117–125.
- HE, B., Y. SHI, Q. WAN, AND X. ZHAO (2014): "Prediction of customer attrition of commercial banks based on SVM model," *Procedia Computer Science*, 31, 423–430.
- HEIDER, F., F. SAIDI, AND G. SCHEPENS (2018): "Life below zero: Bank lending under negative policy rates," .
- HONKA, E., A. HORTAÇSU, AND M. A. VITORINO (2017): "Advertising, consumer awareness, and choice: Evidence from the us banking industry," *The RAND Journal of Economics*, 48, 611–646.
- HORNSTEIN, A., P. KRUSELL, AND G. L. VIOLANTE (2011): "Frictional wage dispersion in search models: A quantitative assessment," *American Economic Review*, 101, 2873–98.
- IACOVIELLO, M. (2005): "House prices, borrowing constraints, and monetary policy in the business cycle," *American economic review*, 95, 739–764.
- IRELAND, P. N. (2007): "Changes in the Federal Reserve's inflation target: Causes and consequences," *Journal of Money, credit and Banking*, 39, 1851–1882.
- JEENAS, P. (2018): "Monetary Policy Shocks, Financial Structure, and Firm Activity: A Panel Approach," .

- JERMANN, U. AND V. QUADRINI (2012): “Macroeconomic effects of financial shocks,” *American Economic Review*, 102, 238–71.
- JORDÀ, Ò. (2005): “Estimation and inference of impulse responses by local projections,” *American economic review*, 95, 161–182.
- KAPLAN, G., K. MITMAN, AND G. L. VIOLANTE (2017): “The housing boom and bust: Model meets evidence,” Tech. rep., National Bureau of Economic Research.
- KLEMPERER, P. (1995): “Competition when consumers have switching costs: An overview with applications to industrial organization, macroeconomics, and international trade,” *The review of economic studies*, 62, 515–539.
- MELINA, G. AND S. VILLA (2018): “Leaning Against Windy Bank Lending,” *Economic Inquiry*, 56, 460–482.
- MERTENS, K. AND J. L. M. OLEA (2013): “Marginal tax rates and income: New time series evidence,” Tech. rep., National Bureau of Economic Research.
- NAKAMURA, E. AND J. STEINSSON (2011): “Price setting in forward-looking customer markets,” *Journal of Monetary Economics*, 58, 220–233.
- (2018): “High frequency identification of monetary non-neutrality: The information effect,” *Quarterly Journal of Economics*.
- NEUMARK, D. AND S. A. SHARPE (1992): “Market structure and the nature of price rigidity: evidence from the market for consumer deposits,” *The Quarterly Journal of Economics*, 107, 657–680.
- PACIELLO, L., A. POZZI, AND N. TRACHTER (2017): “Price Dynamics with Customer Markets,” Tech. rep., CEPR Discussion Papers.
- PHELPS, E. S. AND S. G. WINTER (1970): “Optimal Price Policy under Atomistic Competition,” *ES Phelps et al., Microeconomic Foundations of Employment and Inflation Theory*, Norton, New York.
- PIAZZESI, M., C. ROGERS, AND M. SCHNEIDER (2018): “Money and Banking in a New Keynesian Model with Abundant Reserves,” *Working paper*.
- POLO, A. AND G. VIOLANTE (2018): “Product Differentiation in Deposit Markets,” *Working paper*.
- RAVN, M., S. SCHMITT-GROHÉ, AND M. URIBE (2006): “Deep habits,” *The Review of Economic Studies*, 73, 195–218.

- RAVN, S. H. (2016): "Endogenous credit standards and aggregate fluctuations," *Journal of Economic Dynamics and Control*, 69, 89–111.
- ROTEMBERG, J. J. (1982): "Sticky prices in the United States," *Journal of Political Economy*, 90, 1187–1211.
- SHARPE, S. A. (1997): "The effect of consumer switching costs on prices: A theory and its application to the bank deposit market," *Review of Industrial Organization*, 12, 79–94.
- SHY, O. (2002): "A quick-and-easy method for estimating switching costs," *International journal of industrial organization*, 20, 71–87.
- SIDRAUSKI, M. (1967): "Inflation and economic growth," *Journal of political economy*, 75, 796–810.
- SMETS, F. AND R. WOUTERS (2003): "An estimated dynamic stochastic general equilibrium model of the euro area," *Journal of the European economic association*, 1, 1123–1175.
- (2007): "Shocks and frictions in US business cycles: A Bayesian DSGE approach," *American economic review*, 97, 586–606.
- STOCK, J. H. AND M. W. WATSON (2018): "Identification and Estimation of Dynamic Causal Effects in Macroeconomics Using External Instruments," *The Economic Journal*, 128, 917–948.
- TOBIN, J. (1956): "The interest-elasticity of transactions demand for cash," *The review of Economics and Statistics*, 38, 241–247.
- WONG, A. (2016): "Transmission of Monetary Policy to Consumption and Population Aging," Tech. rep., mimeo, April 21, Princeton University, Princeton.
- YANKOV, V. (2014): "In search of a risk-free asset," .

Tables

	Baseline	$\theta = 0.1$	$\theta = 0.9$
Drechsler et al. (2017) regression			
Change in deposits for 100 bp increase in i_t	-5.03%	-5.38%	-4.98%
Productivity shock that raises i_t by 100 bp			
Decrease in deposits after 1 year	-4.88%	-5.05%	-4.85%
Inflation target shock that raises i_t by 100 bp			
Decrease in deposits after 1 year	-2.28%	-2.51%	-2.25%

Table 2: Sensitivity to Parameterization of the Degree of Habit Formation θ

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	$\Delta \text{deposit rate}_t$						
$\sum_{j=0}^3 \Delta FFR_{t-j}$	0.338*** (0.0272)	0.339*** (0.0263)	0.341*** (0.0257)	0.341*** (0.0257)	0.331*** (0.0246)	0.332*** (0.0247)	0.332*** (0.0247)
$AMat_{t-5}$	-0.002 (0.0050)	-0.003 (0.0050)	-0.002 (0.0048)	-0.002 (0.0048)			
$\sum_{j=0}^3 \Delta FFR_{t-j} * AMat_{t-5}$	-0.017** (0.0072)	-0.017** (0.0070)	-0.016** (0.0071)	-0.016** (0.0071)			
$LMat_{t-5}$		-0.042 (0.0382)	-0.057 (0.0428)	-0.057 (0.0428)			
$DepShare_{t-5}$			-0.066 (0.0425)	-0.066 (0.0427)		-0.034 (0.0299)	-0.034 (0.0300)
$\log(Assets)_{t-5}$				-0.002 (0.0028)			-0.003 (0.0026)
$MatGap_{t-5}$					-0.002 (0.0048)	-0.001 (0.0046)	-0.001 (0.0046)
$\sum_{j=0}^3 \Delta FFR_{t-j} * MatGap_{t-5}$					-0.016** (0.0072)	-0.016** (0.0072)	-0.016** (0.0072)
Constant	0.005 (0.0211)	0.023 (0.0247)	0.054 (0.0416)	0.085** (0.0381)	0.001 (0.0185)	0.014 (0.0263)	0.060* (0.0315)
Bank FE	Y	Y	Y	Y	Y	Y	Y
N	431,340	431,306	431,306	431,306	431,306	431,306	431,306
R2	0.195	0.195	0.196	0.196	0.195	0.195	0.195

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Data is from US Call Reports and Federal Reserve H.15 Release, Q1 1997 - Q4 2013. The dependent variable is the change over a quarter in the deposit rate on transaction and saving deposits of a bank, computed as the ratio of interest expense to stock. $\sum_{j=0}^3 \Delta FFR_{t-j}$ is the pass-through over 1 year, following Drechsler et al. (2018). $AMat_{t-5}$, $LMat_{t-5}$, $MatGap_{t-5}$ are weighted average repricing maturity of a bank's assets, liabilities, and the difference between the two, respectively. The variables are lagged before the period over which pass-through is measured. Maturities are computed as the midpoint of each maturity bin reported in the Call Reports, for each asset/liability category, weighted by the respective share of assets/liabilities for each bank-quarter (English et al., 2018). Federal funds sold and purchased, non-time deposits and cash are assumed to have maturity 0, subordinated debt is assumed to have a maturity of 5 years as in Drechsler et al. (2018). On average, 95% of assets and liabilities of a bank are accounted for. $DepShare_{t-5}$ is the share of liabilities accounted for by transaction and saving deposits. Bank variables are winsorized at the 1% level. Standard errors are clustered by bank. Observations are weighted by the share of total assets in each quarter accounted for by each bank.

Table 3: Banks' Pass-through by Repricing Maturity of Assets - Asset-weighted

Figures

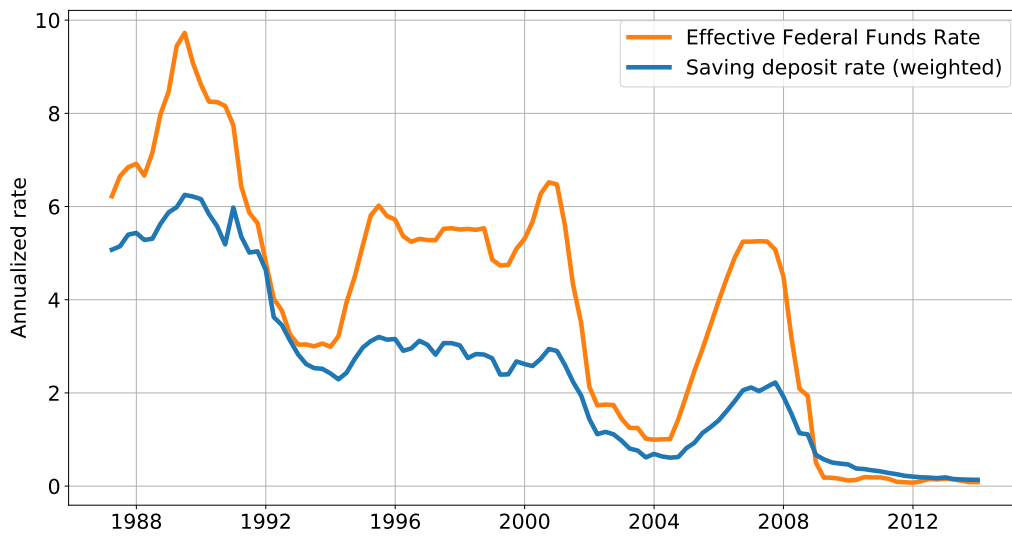


Figure 1: Federal Funds Rate vs. Savings deposit Rate

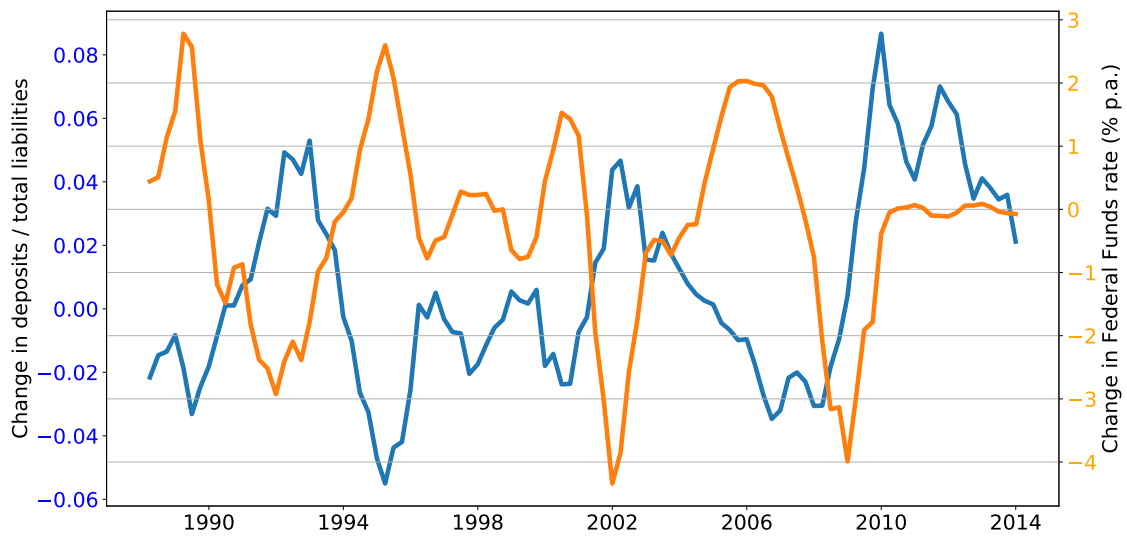


Figure 2: Δ Ratio of Non-deposit Liabilities to Total Liabilities vs. Δ Federal Funds Rate

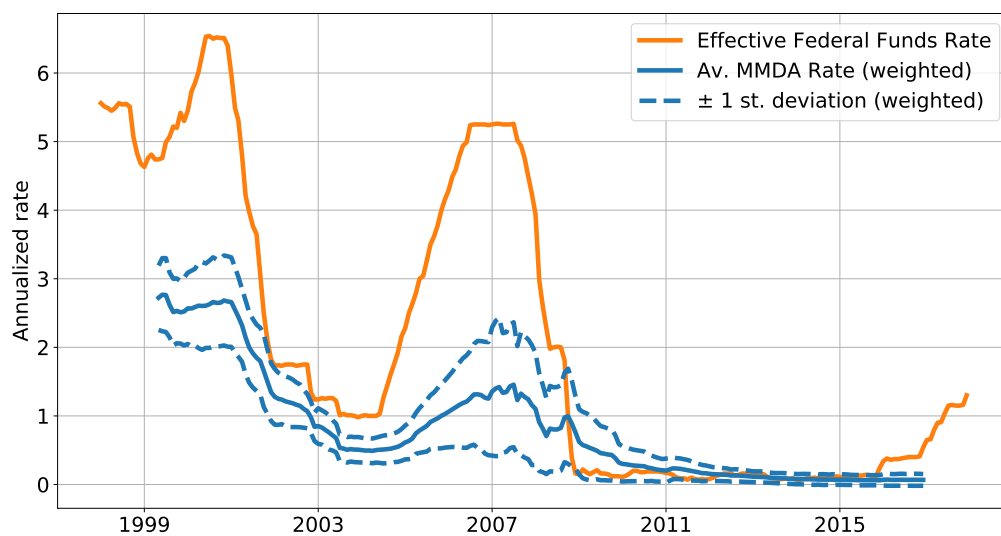


Figure 3: Dispersion in Money-Market Deposit Account Rates (Polo and Violante, 2018)

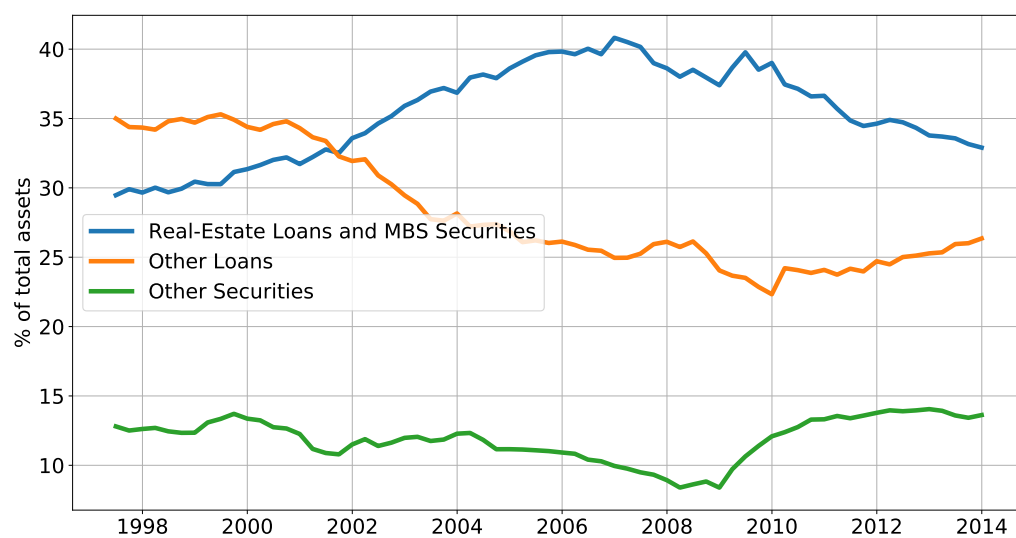


Figure 4: Shares of Banks' Assets by Asset Class

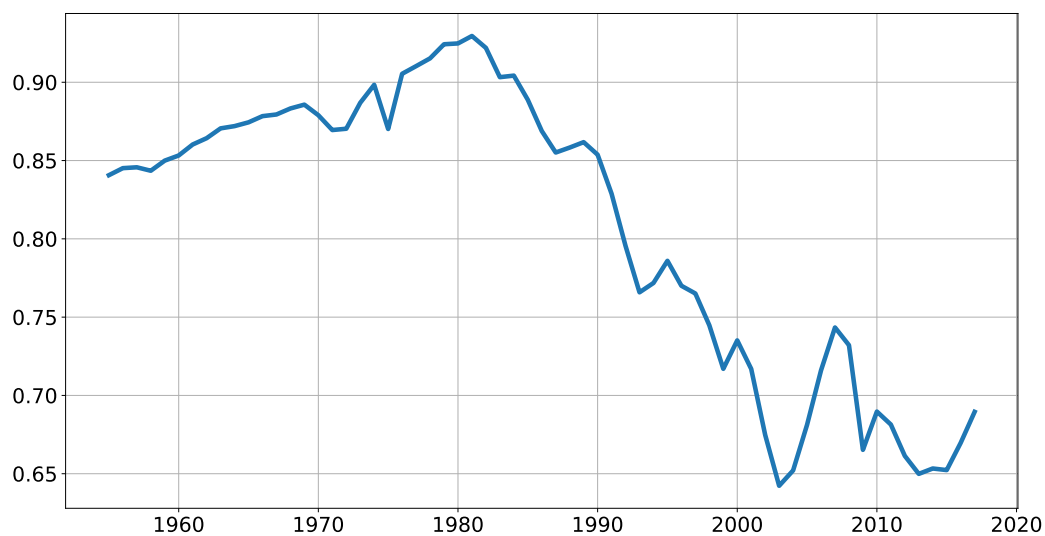


Figure 5: Banks' Interest Income Share of Total Income

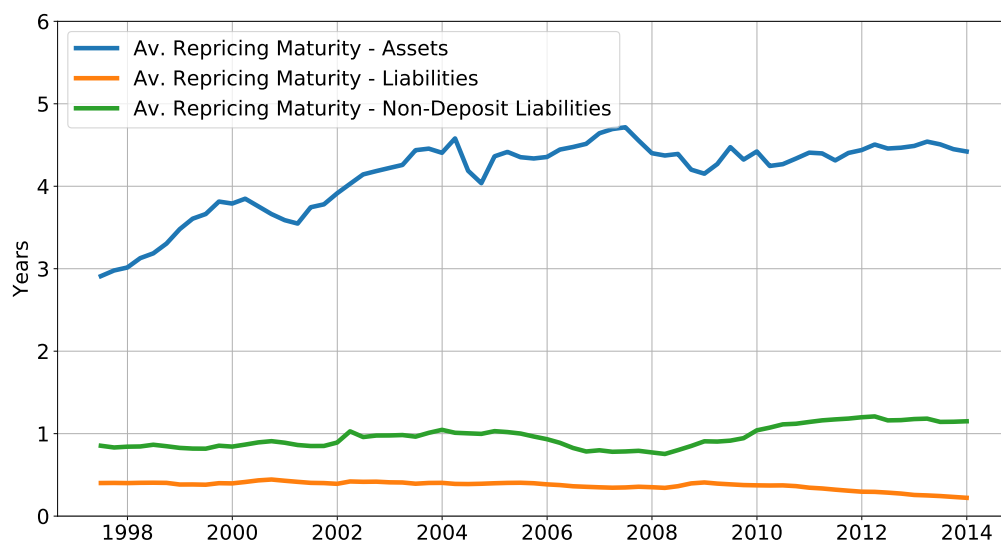


Figure 6: Repricing Maturity of Banks' Assets and Liabilities

Appendix

A List of Equilibrium Conditions

Saver

Euler equation

$$1 = \mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \right] (1 + i_t) \text{ where } \Lambda_{t,t+1}^s = \beta_s \frac{U_{C_{t+1}}^s}{U_{C_t}^s}$$

Intratemporal condition

$$-U_{N_t^s} = U_{C_t}^s W_t (1 - \tau^y)$$

Euler equation for deposits

$$\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \right] (i_t - i_t^d) = \frac{U_{D_t}^s S_{t-1}^\theta}{U_{C_t}^s} \quad (14)$$

Budget constraint (redundant by Walras' law)

$$C_t^s + d_t + B_t = (1 - \tau^y) W_t N_t^s + \frac{1 + i_{t-1}}{\Pi_t} (d_{t-1} + B_{t-1}) - \frac{\tilde{m}_{t-1}^d}{\Pi_t} D_{t-1}^s + T_t^s + \Xi_t^s \quad (15)$$

where

$$\begin{aligned} D_t^s &= d_t S_{t-1}^\theta \\ T_t^s &= \tau^y W_t N_t^s \\ \Xi_t^s &= \underbrace{div_t + \frac{\kappa}{\Pi_t} d_{t-1} + Y_t \left[1 - \frac{\kappa^{adj}}{2} \left(\frac{\Pi_t}{\Pi_{ss}} - 1 \right)^2 \right]}_{\text{profits from firms}} - W_t N_t \\ \tilde{m}_t^d &= m_t^d S_{t-1}^{-\theta} \end{aligned}$$

Bank

Euler equation for deposit spread

$$\begin{aligned} &\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \Omega_{t+1} \right] \left(\frac{\eta}{\eta - 1} - \frac{m_t^d}{\kappa} \right) = \\ &= \mathbb{E}_t \left[\frac{\Lambda_{t,t+2}^s}{\Pi_{t+2}} \Omega_{t+2} \left[\rho_s \left(\frac{\eta}{\eta - 1} - \frac{m_{t+1}^d}{\kappa} \right) + (1 - \rho_s) \theta \frac{m_{t+1}^d}{\kappa} \frac{d_{t+1}}{S_t} \right] \right] \end{aligned} \quad (16)$$

No-arbitrage condition

$$\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \Omega_{t+1} \right] i_t = \mathbb{E}_t \left[\Lambda_{t,t+1}^s (\Omega_{t+1}^X q_t^* + \Omega_{t+1}^M) \right]$$

where

$$\begin{aligned} \Omega_t^M &= -\mathbb{E}_t \left[\Lambda_{t,t+1}^s \Omega_{t+1}^X \right] \frac{q_t^*(1-\nu)(1-\mu_t)}{\Pi_t} - \nu \frac{\Omega_t}{\Pi_t} \\ \Omega_t^X &= \mathbb{E}_t \left[\Lambda_{t,t+1}^s \Omega_{t+1}^X \right] \frac{(1-\nu)(1-\mu_t)}{\Pi_t} + \frac{\Omega_t}{\Pi_t} \end{aligned}$$

Marginal value of profits

$$\Omega_t = \frac{1}{1 + \kappa^{div}(\bar{div}_t - \bar{div})}$$

Dividends

$$div_t = \frac{1}{\Pi_t} \left[X_{t-1} - \nu M_{t-1} - (i_{t-1}^d + \kappa) d_{t-1} - i_{t-1} B_{t-1} \right] - \frac{\kappa^{div}}{2} (div_t - \bar{div})^2 \quad (17)$$

Balance-sheet constraint

$$M_t = d_t + B_t \quad (18)$$

Law of motion of deposit habit stock

$$S_t = \rho_s S_{t-1} + (1 - \rho_s) d_t \quad (19)$$

Law of motion of mortgage principal

$$M_t = \mu_t M_t^* + (1 - \mu_t)(1 - \nu) \frac{M_{t-1}}{\Pi_t}$$

Law of motion of mortgage payments

$$X_t = \mu_t q_t^* M_t^* + (1 - \mu_t)(1 - \nu) \frac{X_{t-1}}{\Pi_t}$$

Borrower

Intratemporal condition

$$-U_{N_t^b}^b = U_{C_t^b}^b \left[W_t(1 - \tau^y) + \mu_t \lambda_t \frac{PTIW_t}{q_t^*} \right]$$

Euler equation for new housing

$$P_t^h = \mathbb{E}_t \left[\Lambda_{t,t+1}^b \left\{ \frac{U_{H_t}^b}{U_{C_{t+1}^b}^b} + P_{t+1}^h(1 - \delta) \right\} \right]$$

where $\Lambda_{t,t+1}^b = \beta_b U_{C_{t+1}}^b / U_{C_t}^b$ and λ_t is multiplier on borrowing constraint
Euler equation for new borrowing

$$1 = \Omega_{Mt}^b + \Omega_{Xt}^b q_t^* + \lambda_t$$

where

$$\Omega_{Mt}^b = \mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^b}{\Pi_{t+1}} \{ \nu \tau^y + (1 - \nu) \mu_{t+1} + (1 - \mu_{t+1})(1 - \nu) \Omega_{M,t+1}^b \} \right]$$

$$\Omega_{Xt}^b = \mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^b}{\Pi_{t+1}} \{ 1 - \tau^y + (1 - \mu_{t+1})(1 - \nu) \Omega_{X,t+1}^b \} \right]$$

Euler equation for prepayment

$$\mu_t = F_k \left((1 - \Omega_{Mt}^b - \Omega_{Xt}^b q_{t-1}) \left[1 - \frac{(1 - \nu) M_{t-1}}{M_t^* \Pi_t} \right] - \Omega_{Xt}^b (q_t^* - q_{t-1}) \right)$$

where $q_t \equiv \frac{X_t}{M_t}$ and F_k is cdf of iid idiosyncratic cost of taking new loan after prepayment
Law of motion of housing stock

$$H_t = \mu_t H_t^* + (1 - \mu_t) H_{t-1}$$

Borrowing limit

$$M_t^* = \frac{PTIW_t N_t^b}{q_t^*}$$

Budget constraint

$$C_t^b + \frac{(1 - \tau^y) X_{t-1}^b + \tau^y \nu M_{t-1}^b}{\Pi_t} + \mu_t P_t^h (H_t^* - H_{t-1}) = (1 - \tau^y) W_t N_t^b +$$

$$+ \mu_t \left[M_t^* - (1 - \nu) \frac{M_{t-1}}{\Pi_t} \right] - \delta P_t^h H_{t-1} - \{ \Psi(\mu_t) - \bar{\Psi}_t \} \mu_t M_t^* + T_t^b$$

where

$$T_t^b = \tau^y \left(W_t N_t^b - \frac{X_{t-1}^b - \nu M_{t-1}^b}{\Pi_t} \right)$$

$$\bar{\Psi}_t = \Psi(\mu_t)$$

Producers

Production function

$$Y_t = Z_t N_t$$

Phillips curve

$$\kappa^{adj} \frac{\Pi_t}{\Pi_{ss}} \left(\frac{\Pi_t}{\Pi_{ss}} - 1 \right) + \xi \left(\frac{\xi - 1}{\xi} - \frac{W_t}{Z_t} \right) = \kappa^{adj} \mathbb{E}_t \left[\Lambda_{t,t+1}^s \frac{Y_{t+1}}{Y_t} \frac{\Pi_{t+1}}{\Pi_{ss}} \left(\frac{\Pi_{t+1}}{\Pi_{ss}} - 1 \right) \right]$$

Market Clearing

Final goods

$$C_t^b + C_t^s + \delta P_t^h \bar{H} + f(div_t) = Y_t \left[1 - \frac{\kappa^{adj}}{2} \left(\frac{\Pi_t}{\Pi_{ss}} - 1 \right)^2 \right] \quad (20)$$

Labor

$$N_t^b + N_t^s = N_t$$

Housing

$$H_t = \bar{H}$$

B Details on Impulse Response Functions

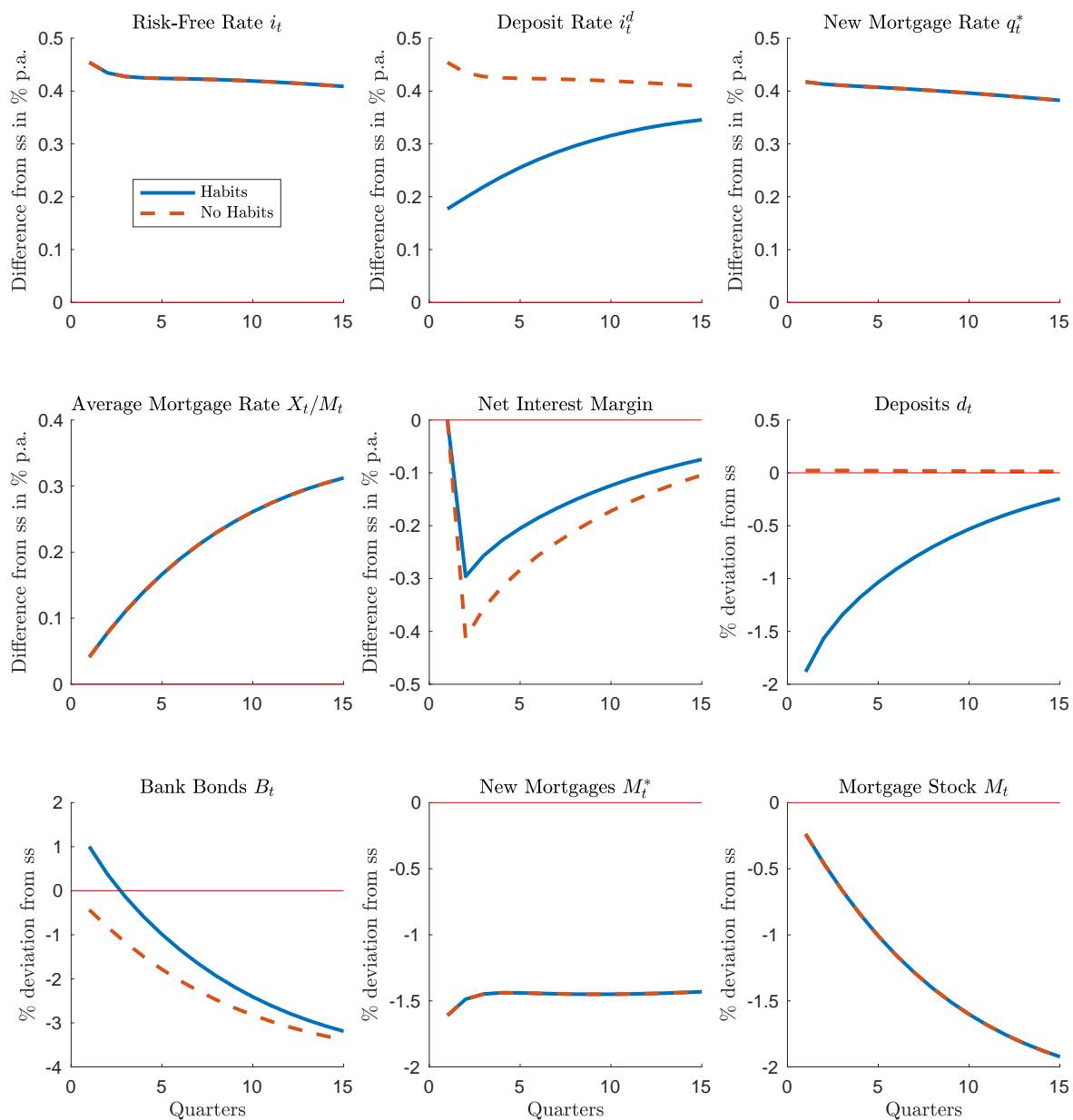


Figure B.1: IRFs to a 50 bp Inflation Target Shock
Bank's Variables

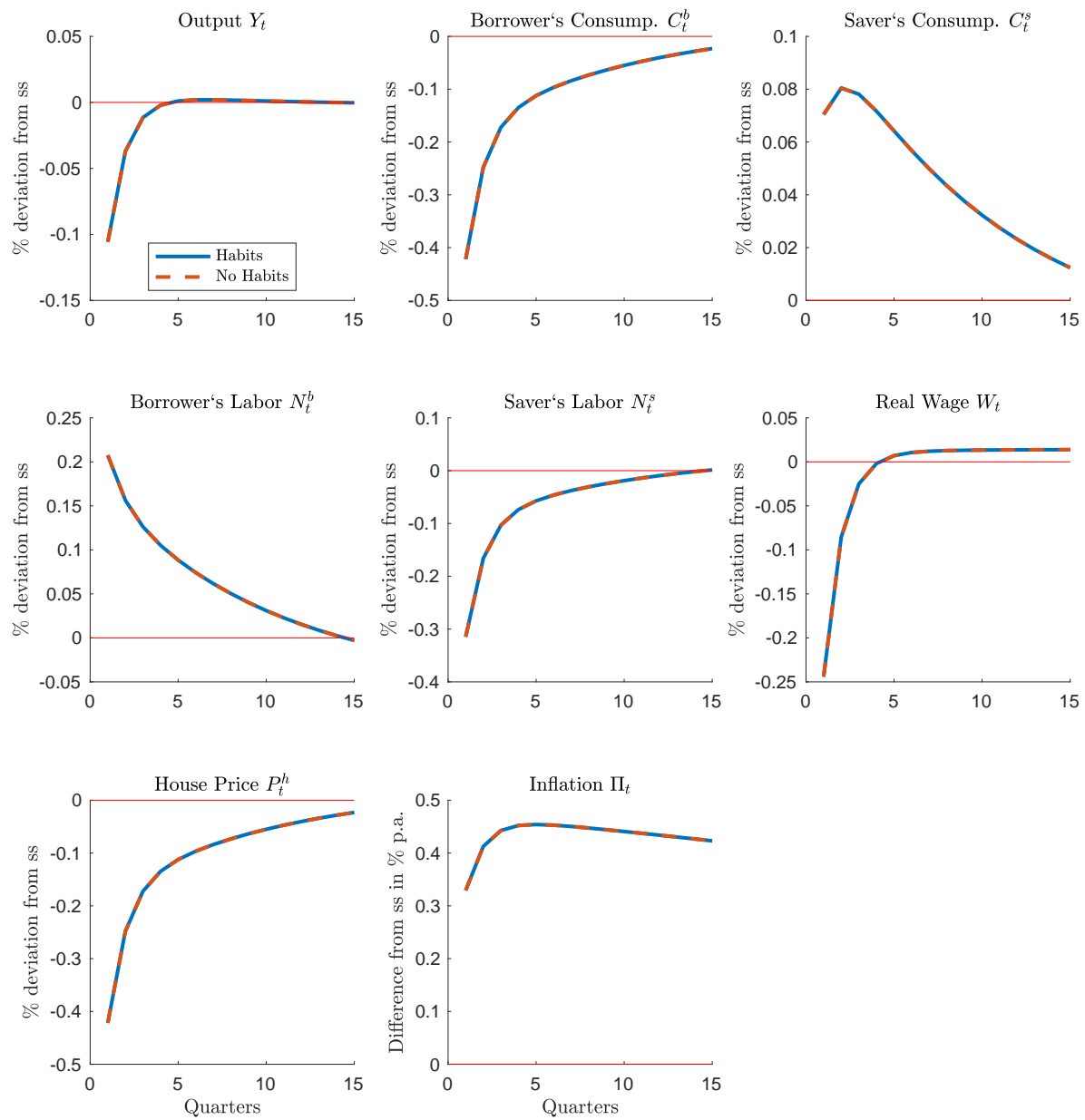


Figure B.2: IRFs to a 50 bp Inflation Target Shock
Real Variables

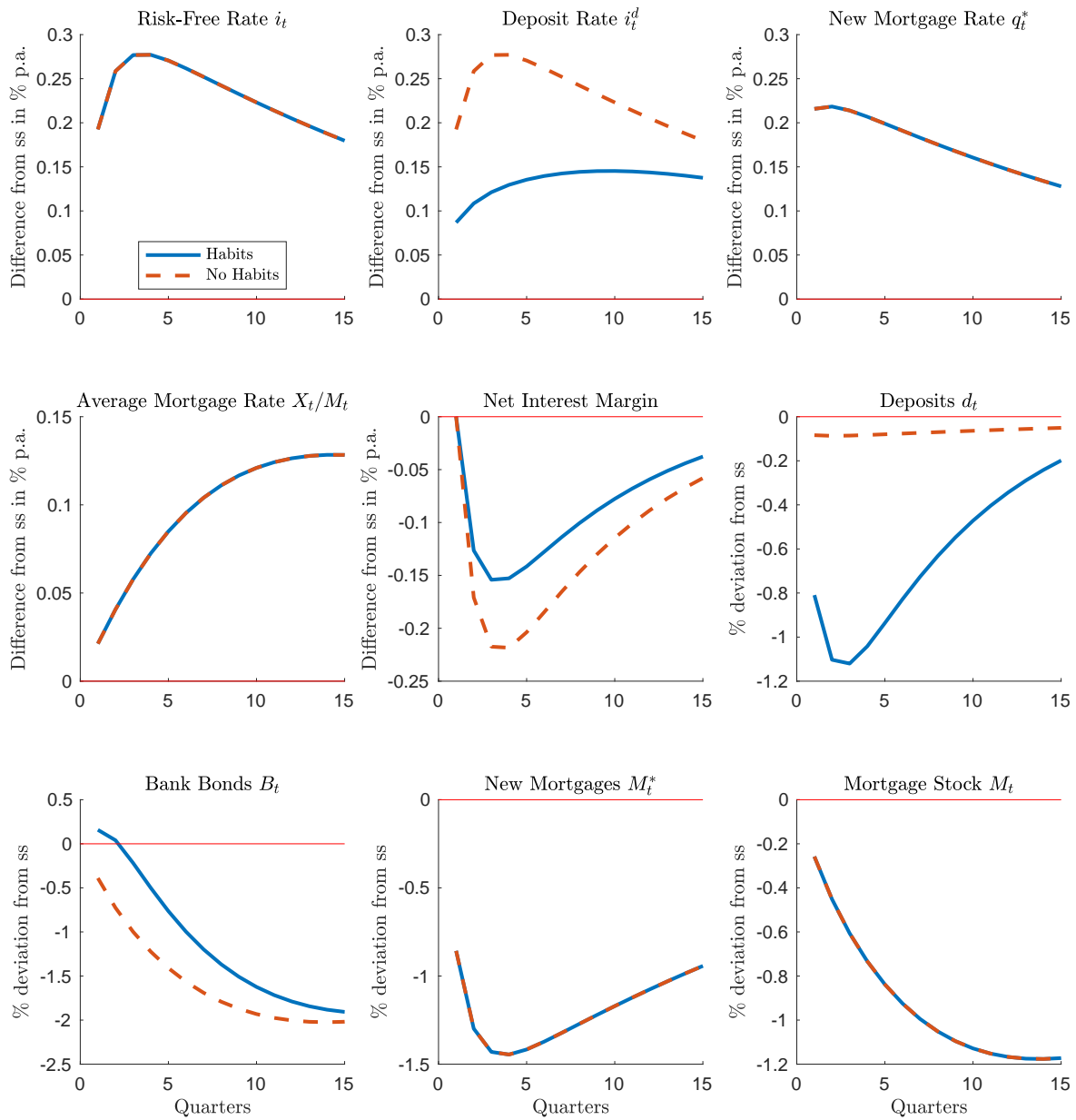


Figure B.3: IRFs to a Negative 1% Productivity Shock
Bank's Variables

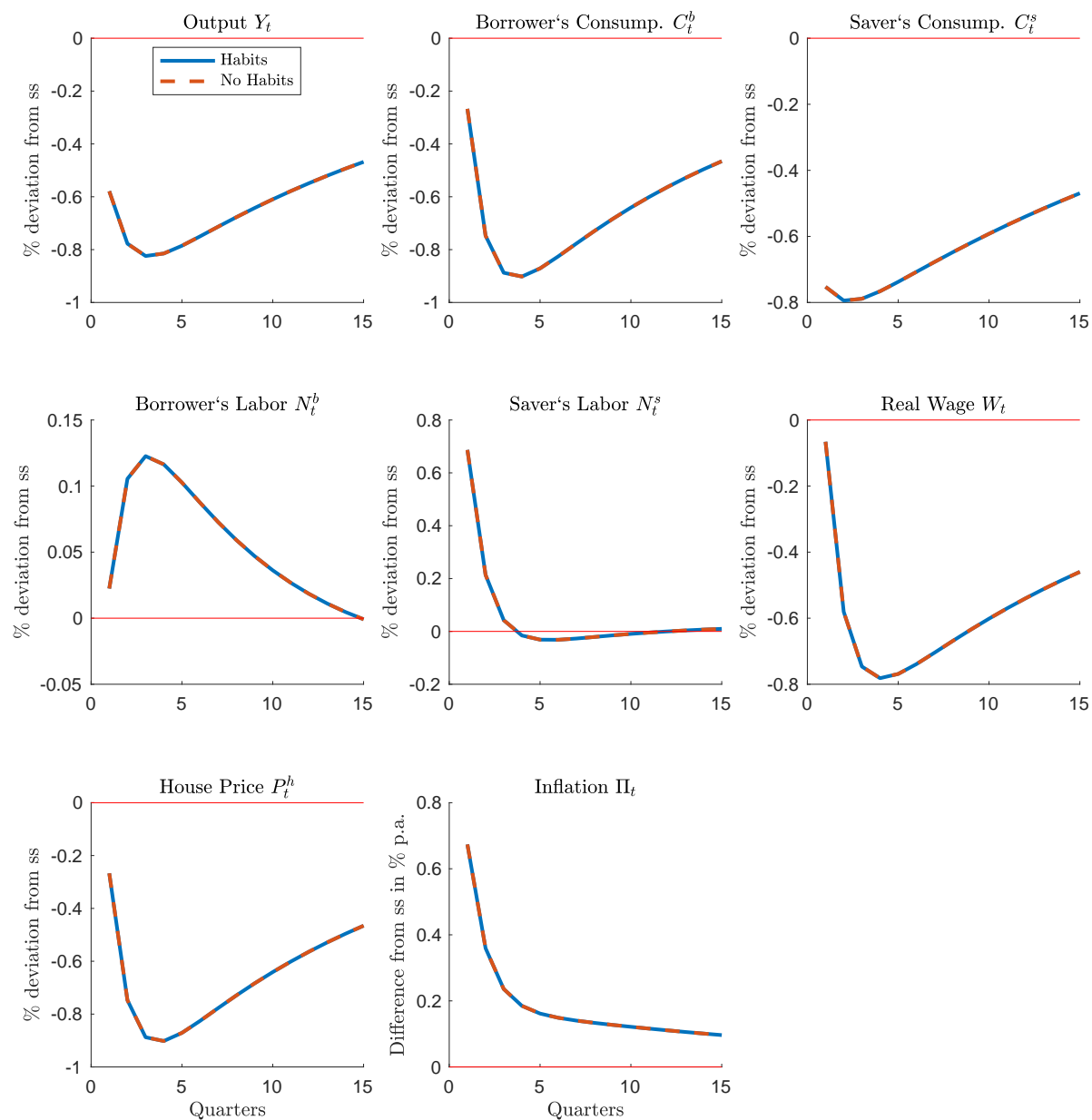


Figure B.4: IRFs to a Negative 1% Productivity Shock

Real Variables

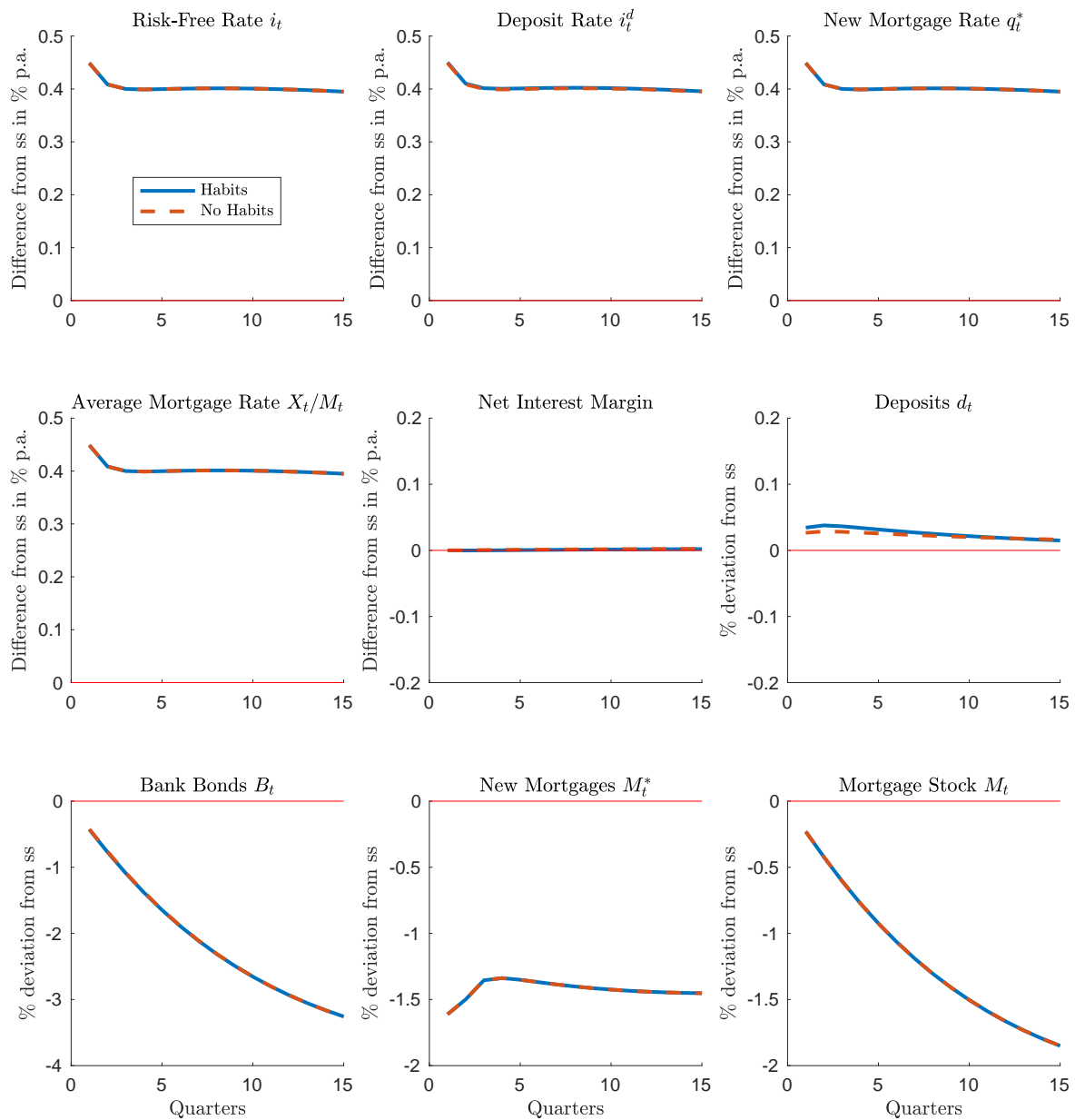


Figure B.5: IRFs to a 50 bp Inflation Target Shock - Adjustable Rate Mortgage Case
Bank's Variables

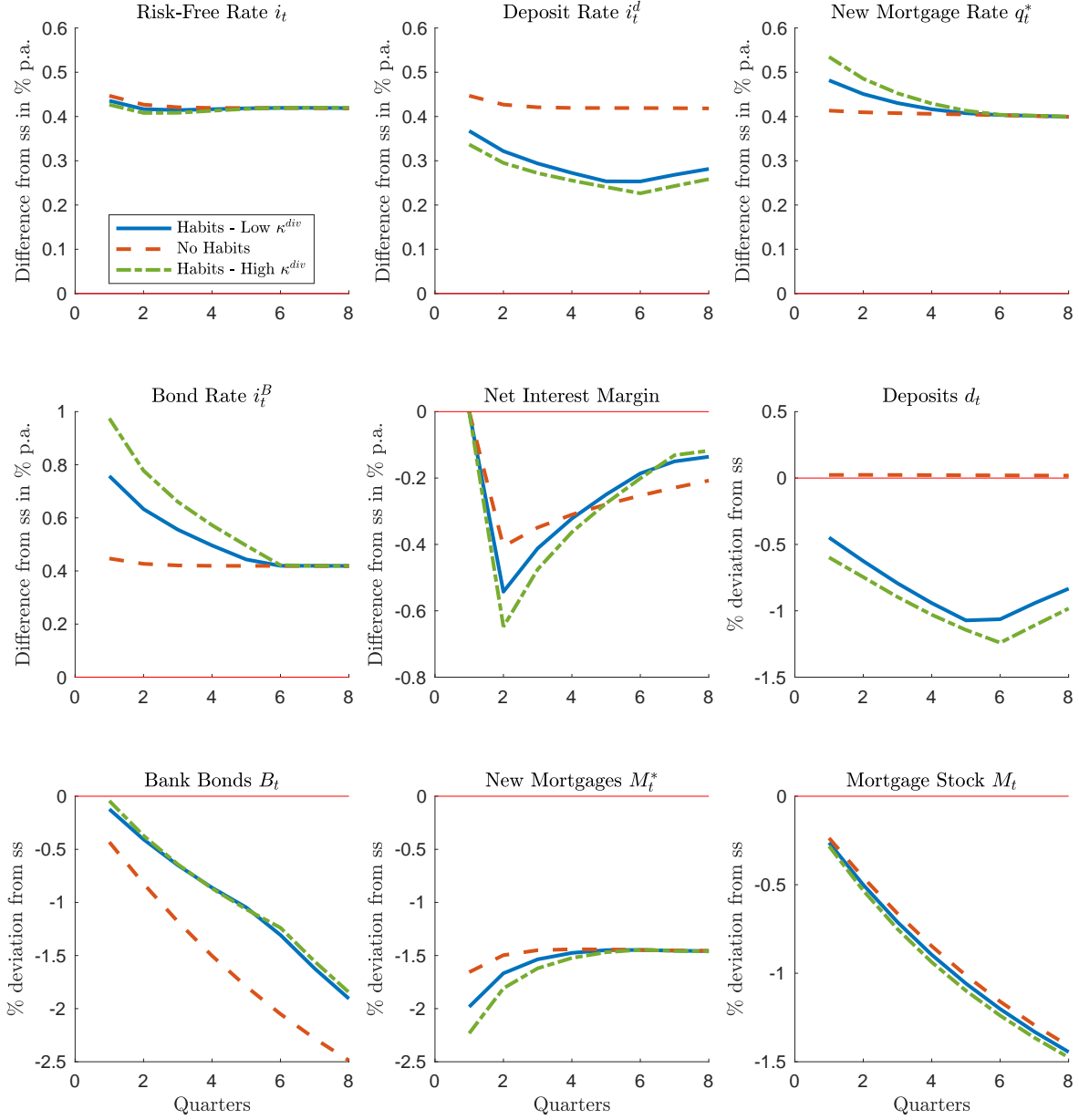


Figure B.6: IRFs to a 50 bp Inflation Target Shock - Portfolio-Adjustment Cost
Bank's Variables

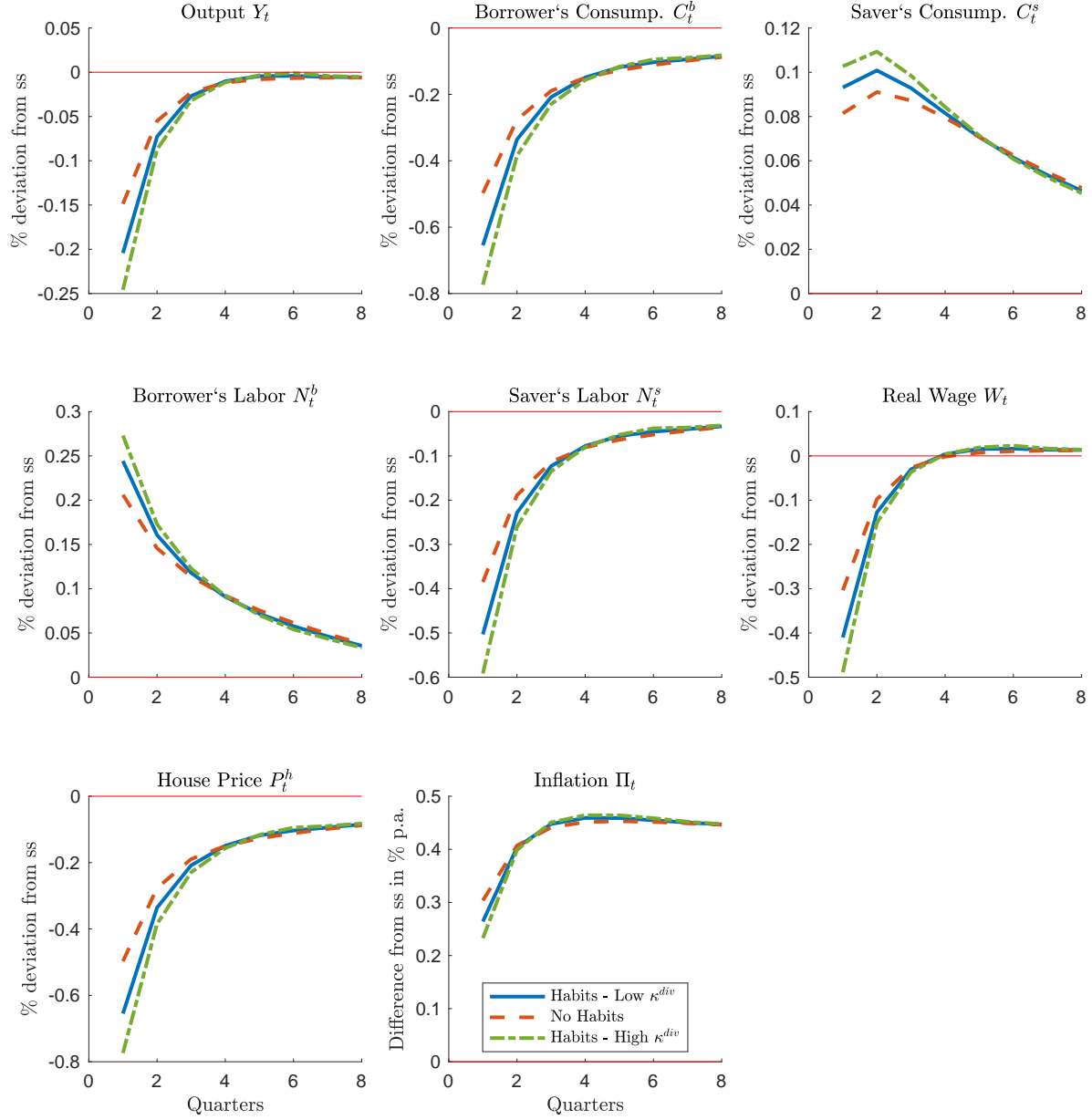


Figure B.7: IRFs to a 50 bp Inflation Target Shock - Portfolio-Adjustment Cost
Real Variables

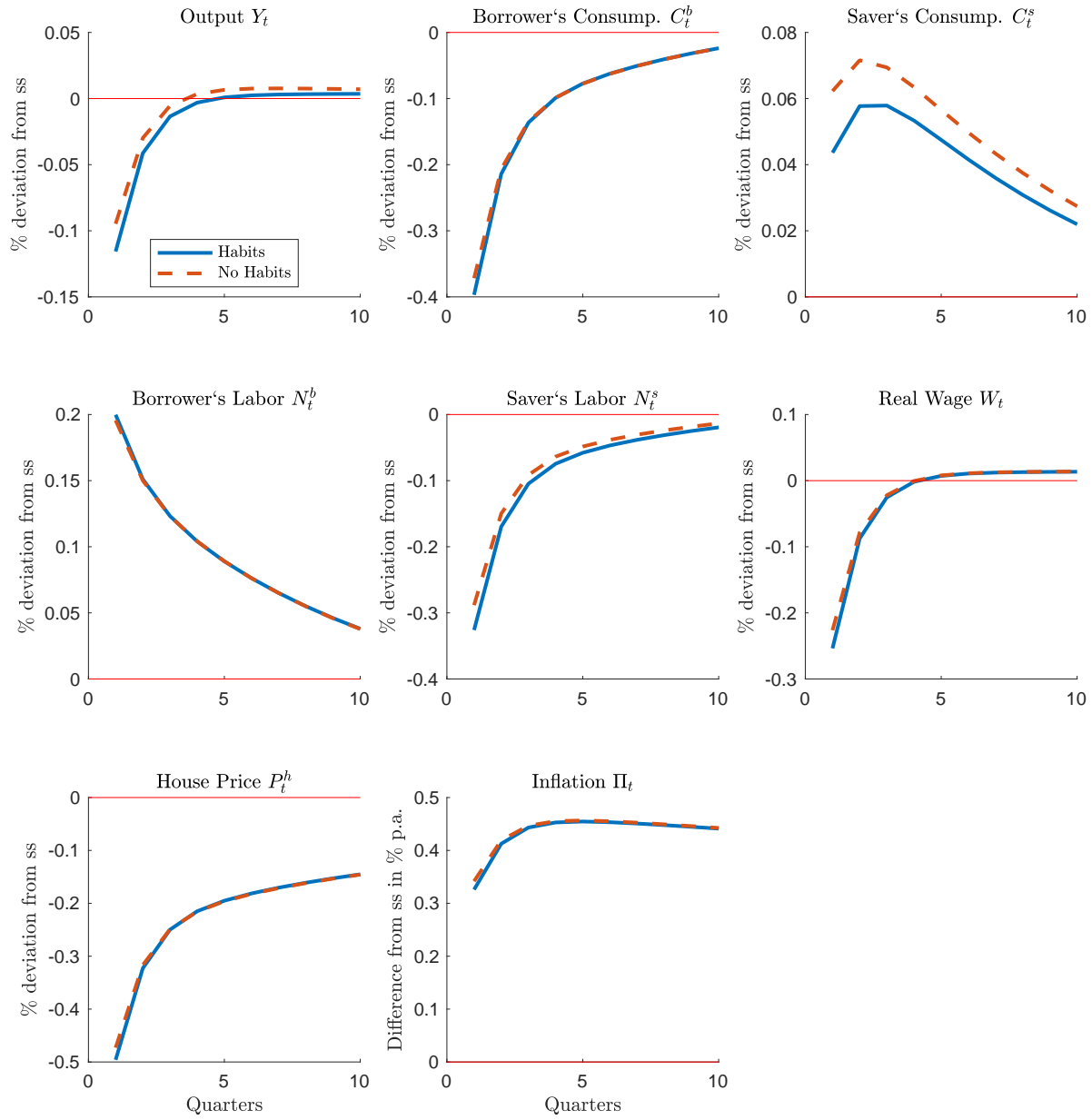


Figure B.8: IRFs to a 50 bp Inflation Target Shock - Non-separable Preferences
Real Variables

C Representation of CES deposit demands as aggregate choices of individuals

CES with Habits from Discrete Choice Model (Anderson et al., 1987)

Consider N banks offering deposits. Each saver household consists of a continuum of members of mass 1. Each period, each member has to decide 1) what *single* bank to deposit at and 2) how much to deposit. The saver household is willing to forgo Y to hold deposits at banks. Since at the beginning of each period all members are identical, each of them will have the same interest income Y to forgo on deposits.

Suppose that, after stage 1), bank j was determined to be the preferred bank by one of the members - let us call her ι - between periods t and $t + 1$. If bank j offers a net deposit rate i_j^d between these periods, the cost to the member of holding deposits there is the deposit spread $m_j^d = i - i_j^d$. Then the member has to satisfy $Y = d_j(\iota)m_j^d$ ⁶⁴, and accordingly deposit demand will be $d_j(\iota) = Y/m_j^d$.

Let us assume that the indirect utility for a member from deposits at bank j is

$$v_j(d_j) = \log(d_j) + \theta \log(S_j)$$

where S_j is the habit stock of bank j . The habit appears as a preference shifter, increasing the indirect utility from holding deposits at a bank for any household member.

Then, given the deposit demand,

$$v_j(m_j^d) = \log(Y) - \log(m_j^d) + \theta \log(S_j)$$

Going back to stage 1), let us assume the choice of a bank by household member ι follows the stochastic utility approach used in discrete choice theory. Therefore,

$$u_j(\iota) = v_j(m_j^d) + \Xi \epsilon_j(\iota) \text{ for each } j = 1, \dots, N$$

where $u_j(\iota)$ is the stochastic indirect utility associated with bank j by member ι , $\Xi > 0$ and $\epsilon_j(\iota)$ is a random variable with Gumbel distribution.

Assuming that $\epsilon_j(\iota)$ are *iid* across household members and banks, by a law of large numbers, the share of members who choose bank j is

$$p_j = \text{Prob} \left(j = \underset{z=1, \dots, N}{\text{argmax}} u_z(\iota) \right) \text{ for each } j = 1, \dots, N$$

⁶⁴The unique discount factor shared by all members cancels from each side of the equality, since rates are known in advance.

which, using the definition of $v_j(m_j^d)$, becomes

$$p_j = \frac{(S_j^\theta / m_j^d)^{\frac{1}{\Xi}}}{\sum_{z=1}^N (S_z^\theta / m_z^d)^{\frac{1}{\Xi}}} \text{ for each } j = 1, \dots, N$$

Finally, the demand for deposits at bank j by the household is

$$d_j^* \equiv \int_0^1 d_j(\iota) d\iota = \frac{Y}{m_j^d} p_j = \frac{S_j^\theta (m_j^d)^{-\frac{1}{\Xi}-1}}{\sum_{z=1}^N (S_z^\theta / m_z^d)^{\frac{1}{\Xi}}} Y \text{ for each } j = 1, \dots, N \quad (21)$$

Letting $\Xi = \frac{1}{\eta-1}$ and defining

$$\tilde{m}^d \equiv \left[\sum_{z=1}^N (m_z^d S_z^{-\theta})^{1-\eta} \right]^{\frac{1}{1-\eta}}$$

we have

$$d_j^* = \frac{(m_j^d)^{-\eta} S_j^{\theta(\eta-1)}}{(\tilde{m}^d)^{1-\eta}} Y \text{ for each } j = 1, \dots, N$$

Since the interest income given up is $Y = \tilde{m}^d D$ (see Appendix D), then

$$d_j^* = \frac{(m_j^d)^{-\eta} S_j^{\theta(\eta-1)}}{(\tilde{m}^d)^{1-\eta}} \tilde{m}^d D = \left(\frac{m_j^d}{\tilde{m}^d} \right)^{-\eta} S_j^{\theta(\eta-1)} D \text{ for each } j = 1, \dots, N$$

which is the form of deposit demand from the CES function obtained in Appendix D.

CES with Habits from Characteristics Model (Anderson et al., 1989)

Consider N banks offering deposits and M characteristics⁶⁵. As before, each saver household consists of a continuum of members of mass 1. However, now it is assumed that they are distributed over characteristics according to a multinomial logit. Each period, each member has to decide 1) what *single* bank to deposit at and 2) how much to deposit. The saver household is willing to forgo Y to hold deposits at banks. Since the household cannot condition on the characteristics of each member, each of them will have the same interest income Y to forgo on deposits.

Given the interest income that members can forgo, deposit demands are as in the previous model with discrete choice: $d_j = Y / m_j^d$.

The main difference relative to the discrete choice model example is the form of the indirect utility. For a household member whose ideal characteristics are \underline{z} , the indirect utility from deposits at bank j is

$$v_j(\underline{z}; d_j) = \log(d_j) - c \sum_{k=1}^M (z^k - z_j^k)^2 + \theta \log(S_j)$$

⁶⁵ $M = N - 1$, if it is greater, then the density is non-unique (Anderson et al., 1989).

The interpretation is that the habit reduces the cost of deviating from the ideal variety uniformly across depositors, with scale θ .

Using this indirect utility with habits and following the approach in [Anderson et al. \(1989\)](#), it is possible to derive the demand function in Equation (21) under the discrete choice model, and then derive the CES demand following the same steps.

D Derivation of CES deposit demands

Considering two banks i and z , their relative deposit demand is

$$\frac{d_{it}^s}{d_{zt}^s} = \left(\frac{m_{it}^d}{m_{zt}^d} \right)^{-\eta} \left(\frac{S_{i,t-1}}{S_{z,t-1}} \right)^{\theta(\eta-1)}$$

Multiplying by m_{it}^d and integrating with respect to i we have

$$\int_i m_{it}^d d_{it}^s di = d_{zt}^s \left(m_{zt}^d \right)^\eta S_{z,t-1}^{-\theta(\eta-1)} \int_i \left(m_{it}^d S_{i,t-1}^{-\theta} \right)^{1-\eta} di$$

which implies that, for a generic bank i ,

$$d_{it}^s = \frac{\left(m_{it}^d \right)^{-\eta} S_{i,t-1}^{\theta(\eta-1)}}{\int_i \left(m_{it}^d S_{i,t-1}^{-\theta} \right)^{1-\eta} di} \int_i m_{it}^d d_{it}^s di$$

Let us define the average deposit spread

$$\tilde{m}_t^d \equiv \left[\int_i \left(m_{it}^d S_{i,t-1}^{-\theta} \right)^{1-\eta} di \right]^{\frac{1}{1-\eta}}$$

Then

$$d_{it}^s = \left(\frac{m_{it}^d}{\tilde{m}_t^d} \right)^{-\eta} S_{i,t-1}^{\theta(\eta-1)} \frac{\int_i m_{it}^d d_{it}^s}{\tilde{m}_t^d}$$

Finally, plugging into the definition of D_t^s we have

$$\begin{aligned}
D_t^s &= \left[\int_i \left(\frac{(m_{it}^d)^{-\eta} S_{i,t-1}^{\theta(\eta-1)}}{S_{i,t-1}^{-\theta}} \right)^{1-\frac{1}{\eta}} \mathrm{d}i \right]^{\frac{\eta}{\eta-1}} \frac{\int_i m_{it}^d d_{it}^s \mathrm{d}i}{(\tilde{m}_t^d)^{1-\eta}} \\
&= \left[\int_i (m_{it}^d S_{i,t-1}^{-\theta})^{1-\eta} \mathrm{d}i \right]^{\frac{\eta}{\eta-1}} \frac{\int_i m_{it}^d d_{it}^s \mathrm{d}i}{(\tilde{m}_t^d)^{1-\eta}} \\
&= (\tilde{m}_t^d)^{-\eta} \frac{\int_i m_{it}^d d_{it}^s \mathrm{d}i}{(\tilde{m}_t^d)^{1-\eta}} \\
&= \frac{\int_i m_{it}^d d_{it}^s \mathrm{d}i}{\tilde{m}_t^d}
\end{aligned}$$

i.e.

$$\tilde{m}_t^d D_t^s = \int_i m_{it}^d d_{it}^s \mathrm{d}i$$

so the demand for deposits at bank i becomes

$$d_{it}^s = \left(\frac{m_{it}^d}{\tilde{m}_t^d} \right)^{-\eta} S_{i,t-1}^{\theta(\eta-1)} D_t^s$$

The budget constraint can be rewritten as

$$\begin{aligned}
C_t^s + \int_0^1 d_{jt}^s \mathrm{d}j + B_t &= (1 - \tau^y) W_t N_t^s + \frac{1 + i_{t-1}}{\Pi_t} \left(\int_0^1 d_{j,t-1}^s \mathrm{d}j + B_{t-1} \right) - \int_0^1 \frac{i_{t-1} - i_{j,t-1}^d}{\Pi_t} d_{j,t-1}^s \mathrm{d}j + T_t^s + \Xi_t^s \\
C_t^s + \int_0^1 d_{jt}^s \mathrm{d}j + B_t &= (1 - \tau^y) W_t N_t^s + \frac{1 + i_{t-1}}{\Pi_t} \left(\int_0^1 d_{j,t-1}^s \mathrm{d}j + B_{t-1} \right) - \frac{\tilde{m}_{t-1}^d}{\Pi_t} D_{t-1}^s + T_t^s + \Xi_t^s
\end{aligned}$$

E Bank's No-Arbitrage Condition with Adjustable-Rate Mortgages

With adjustable-rate mortgages, the no-arbitrage condition of the bank is the same,

$$\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \Omega_{t+1} \right] i_t = \mathbb{E}_t \left[\Lambda_{t,t+1}^s (\Omega_{t+1}^X q_t^* + \Omega_{t+1}^M) \right]$$

However, the marginal values of mortgage principal and payment to the bank become

$$\Omega_t^X = \frac{\Omega_t}{\Pi_t}$$

$$\Omega_t^M = \underbrace{\mathbb{E}_t \left[\Lambda_{t,t+1}^s \left(\Omega_{t+1}^X q_t^* + \Omega_{t+1}^M - \frac{\Omega_{t+1}}{\Pi_{t+1}} i_t \right) \right]}_{=0} \frac{(1-\nu)(1-\mu_t)}{\Pi_t} - \nu \frac{\Omega_t}{\Pi_t}$$

since now the rate on all outstanding mortgage principal is reset each period.

Substituting back into the no-arbitrage condition we get

$$\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \Omega_{t+1} \right] i_t = \mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \Omega_{t+1} \right] (q_t^* - \nu)$$

Hence $q_t^* = i_t + \nu$ for all t .

F No-Arbitrage Condition and Marginal Value of Profits

The no-arbitrage condition of the bank is

$$\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \Omega_{t+1} \right] i_t = \mathbb{E}_t \left[\Lambda_{t,t+1}^s (\Omega_{t+1}^X q_t^* + \Omega_{t+1}^M) \right]$$

which, once expressed in percentage deviations from the deterministic steady-state, becomes

$$-\mathbb{E}_t \hat{\Pi}_{t+1} + \mathbb{E}_t \hat{\Omega}_{t+1} + \hat{i}_t = \frac{\Pi}{i} \left[q^* \Omega^X (\mathbb{E}_t \hat{\Omega}_{t+1}^X + \hat{q}_t^*) + \Omega^M \mathbb{E}_t \hat{\Omega}_{t+1}^M \right]$$

where hatted variables denote percentage deviations from steady state and variables without time subscript denote steady state values. Notice that I used the result that in steady state the marginal value of profits $\Omega = 1$.

Separating the terms that depend on $\hat{\Omega}_t$'s we have

$$\left(\hat{i}_t - \mathbb{E}_t \hat{\Pi}_{t+1} \right) \frac{i}{\Pi q^* \Omega^X} - \hat{q}_t^* = \mathbb{E}_t \hat{\Omega}_{t+1}^X - \mathbb{E}_t \hat{\Omega}_{t+1} \frac{i}{\Pi q^* \Omega^X} + \frac{\Omega^M}{q^* \Omega^X} \mathbb{E}_t \hat{\Omega}_{t+1}^M \quad (22)$$

Expressing the definitions of marginal value of mortgage payments X_t and principal M_t to the bank

$$\begin{aligned} \Omega_t^X &= \mathbb{E}_t \left[\Lambda_{t,t+1}^s \Omega_{t+1}^X \right] \frac{(1-\nu)(1-\mu_t)}{\Pi_t} + \frac{\Omega_t}{\Pi_t} \\ \Omega_t^M &= -\mathbb{E}_t \left[\Lambda_{t,t+1}^s \Omega_{t+1}^X \right] \frac{q_t^*(1-\nu)(1-\mu_t)}{\Pi_t} - \nu \frac{\Omega_t}{\Pi_t} \end{aligned}$$

in percentage deviations from steady state yields

$$\begin{aligned} \Omega^X \hat{\Omega}_t^X &= \frac{\Lambda^s}{\Pi} \Omega^X (1-\nu)(1-\mu) \left[\mathbb{E}_t \hat{\Lambda}_{t,t+1}^s + \mathbb{E}_t \Omega_{t+1}^X - \frac{\mu}{1-\mu} \hat{\mu}_t - \hat{\Pi}_t \right] + \frac{1}{\Pi} (\hat{\Omega}_t - \hat{\Pi}_t) \\ \Omega^M \hat{\Omega}_t^M &= -\frac{\Lambda^s}{\Pi} \Omega^X q^* (1-\nu)(1-\mu) \left[\mathbb{E}_t \hat{\Lambda}_{t,t+1}^s + \mathbb{E}_t \Omega_{t+1}^X + \hat{q}_t^* - \frac{\mu}{1-\mu} \hat{\mu}_t - \hat{\Pi}_t \right] - \frac{\nu}{\Pi} (\hat{\Omega}_t - \hat{\Pi}_t) \end{aligned}$$

Substituting for Ω_{t+1}^X and Ω_{t+1}^M in the *rhs* of Equation (22) we have

$$\left(\hat{i}_t - \mathbb{E}_t \hat{\Pi}_{t+1}\right) \frac{i}{\Pi q^* \Omega^X} - \hat{q}_t^* = -\mathbb{E}_t \hat{\Omega}_{t+1} \frac{i}{\Pi q^* \Omega^X} + \frac{\left(\mathbb{E}_t \hat{\Omega}_{t+1} - \mathbb{E}_t \hat{\Pi}_{t+1}\right)}{\Omega^X \Pi} \left(1 - \frac{\nu}{q^*}\right) - \frac{\Lambda^s}{\Pi} (1 - \nu)(1 - \mu) \mathbb{E}_t q_{t+1}^*$$

Since $\Omega = 1$, we have that

$$q^* = i + \nu$$

thus the term

$$\frac{\mathbb{E}_t \hat{\Omega}_{t+1}}{\Pi q^* \Omega^X} (q^* - i - \nu) = 0 \quad \forall t$$

and the dynamics of the marginal value of profits Ω_t are irrelevant for this equation to the first order, near the steady state.

The only other equation where the marginal value of profits appears is the intertemporal equation (16) of the deposit spread m_t^d , and it does affect the deposit spread through that equation. In addition to that equation, the other equations where deposits, habit stock or the deposit spread appear are: the saver's Euler equation for deposits (14), the saver's budget constraint (15), the definition of dividends (17), the balance-sheet constraint (18), and the resource constraint (20)⁶⁶.

It is easy to show that, by Walras' law, the saver's budget constraint is redundant. Then: i) bonds B_t appear only in the balance-sheet constraint and the definition of dividends; ii) dividends div_t appear only in the resource constraint through the cost $f(div_t)$ and the marginal value Ω_t ; iii) the marginal value Ω_t , to the first order, only appears in the Euler equation for the deposit spread (16); iv) the deposit spread/deposit rate only appears in the saver's Euler equation for deposits (14) and dividends.

Hence, except for the dividend adjustment cost, this block of equations is recursive. Since in the numerical solution the dividend adjustment cost is zero to machine precision, the evolution of deposit-related variables is irrelevant for the rest of the economy.

G New First Order Conditions with Portfolio-Adjustment Costs

Euler equation for deposit spread

$$\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \Omega_{t+1} \right] \left(\frac{\eta}{\eta - 1} \left(1 - \frac{i_t^B - i_t}{\kappa} \right) - \frac{m_t^d}{\kappa} \right) =$$

⁶⁶The law of motion of the habit stock (19) does not need to be in the list, since it only involves habit stock and deposits, which are already counted in the other equations listed.

$$= \mathbb{E}_t \left[\frac{\Lambda_{t,t+2}^s}{\Pi_{t+2}} \Omega_{t+2} \left[\rho_s \left(\frac{\eta}{\eta-1} \left(1 - \frac{i_{t+1}^B - i_{t+1}}{\kappa} \right) - \frac{m_{t+1}^d}{\kappa} \right) + (1 - \rho_s) \theta \frac{m_{t+1}^d}{\kappa} \frac{d_{t+1}}{S_t} \right] \right]$$

No-arbitrage condition

$$\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}^s}{\Pi_{t+1}} \Omega_{t+1} \right] i_t^B = \mathbb{E}_t \left[\Lambda_{t,t+1}^s (\Omega_{t+1}^X q_t^* + \Omega_{t+1}^M) \right]$$

Dividends

$$div_t = \frac{1}{\Pi_t} \left[X_{t-1} - \nu M_{t-1} - (i_{t-1}^d + \kappa) d_{t-1} - i_{t-1}^B B_{t-1} \right] - \frac{\kappa^{div}}{2} (div_t - \bar{div})^2$$

Final goods market clearing

$$C_t^b + C_t^s + \delta P_t^h \bar{H} + f(div_t) + \frac{\kappa^B}{2} \left(\max \left\{ \frac{B_t}{M_t} - \frac{\bar{B}}{\bar{M}}, 0 \right\} \right)^2 M_t = Y_t \left[1 - \frac{\kappa^{adj}}{2} \left(\frac{\Pi_t}{\Pi_{ss}} - 1 \right)^2 \right]$$

H Estimation of Deposit Market Share Residuals

Using quarterly US Call Reports data at the bank holding company level, I estimate the following panel regression

$$\log(s_{i,t}) = \alpha_i + \beta i_{i,t}^d + \Gamma X_{i,t} + \delta_t + \epsilon_{i,t}$$

where $s_{i,t}$ is the share of total deposits in the US held by bank i at time t , $i_{i,t}^d$ is the deposit rate it offers, $X_{i,t}$ are other observables of the bank, and α_i and δ_t are bank- and time-fixed effects. This equation can be obtained from a discrete choice model of deposit services. As done by [Egan et al. \(2017b\)](#), I use as controls $X_{i,t}$: the number of employees of the bank, its non-interest expenditure (which includes salaries and costs related to management of bank branches), and the number of bank branches. Deposits are the sum of transaction and savings deposits and the deposit rate is the ratio of interest expense to the total stock of deposits for these two classes of deposits. In order to account for endogeneity of deposit rates, I use as instrument the average characteristics of other products in the market ([Berry et al., 1995](#)). Following [Egan et al. \(2017b\)](#), these are identified with the number of branches, employees, total non-interest expenditures, and service charges on deposits of the competitors of a bank. Information on MSAs where a bank operates through its branches comes from FDIC data. For each bank characteristic, I compute the average value across competitors for each MSA and quarter⁶⁷ where the bank operates. Then these averages are aggregated across MSAs by taking the weighted average based on the share of deposits in the MSA held by a bank. The instruments then are the lagged values of these average characteristics. They

⁶⁷MSAs are another standard level of aggregation in defining deposit markets, see [Dick \(2008\)](#) and [Yankov \(2014\)](#).

will be relevant to the extent that a bank is induced to offer a higher deposit rate if its competitors offer better products. The instruments are valid if, in each period, they are orthogonal to bank i -period t demand shocks⁶⁸.

Table 4 below shows the results of the panel IV estimation. The results are in line with Egan et al. (2017b) and the instruments pass under-identification, weak-identification and over-identification tests. At a market share of 5%, an increase in the deposit rate by 100 bp increases the market share by 1.1 percentage points.

Finally, I compute the residuals

$$\hat{\epsilon}_{i,t} = \log(s_{i,t}) - \hat{\alpha}_i - \hat{\beta}_{i,t}^d - \hat{\Gamma} X_{i,t} - \hat{\delta}_t$$

and find that the autocorrelation of residuals is high, ranging from 0.995 at one quarter to 0.97 at five years.

⁶⁸Since competitors' characteristics used in the instruments adjust slowly relative to rates and are lagged, validity is more likely to hold.

	(1)
	Log-deposit market share
Deposit rate	23.173** (9.4546)
N. employees (1,000s)	0.011*** (0.0037)
Non-interest expense (billions)	-0.109 (0.0684)
N. branches	0.012*** (0.0021)
Bank FE	Y
Time FE	Y
N	212,254
R2	0.932

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Data is from US Call Reports and FDIC, Q1 1994 - Q4 2013. The dependent variable is the natural logarithm of the share of total US deposits in a quarter accounted for by a bank, where deposits are transaction and saving deposits. The deposit rate is the ratio of interest expense to stock of deposits, and its coefficient reported in the table is the IV estimate using the [Berry et al. \(1995\)](#) instruments - as explained in the main text. Independent variables are winsorized at the 1% level. The instruments are relevant and valid. The null hypothesis of an LM underidentification test (instruments are not correlated with the endogenous regressor) is rejected with a value of the Kleibergen-Paap rk LM statistic of 59.6 ($p=0$), the null hypothesis of a 'weak' identification test (instruments are only weakly correlated with the endogenous regressor) is rejected with a value of the robust Kleibergen-Paap Wald rk F statistic of 202.7 ($p=0$), and the null hypothesis of the overidentification test (instruments are uncorrelated with the error term) is not rejected with a value of the Hansen J statistic of 1.1 ($p=0.75$).

Table 4: Deposit Demand IV Estimation