Interplay of Monetary Policy, Mortgage Lending, and Wholesale Funding

Abstract

I study the impact of banking market concentration and wholesale funding reliance on the transmission of monetary policy shocks to mortgage rates. I analyze this imperfect transmission through the lens of a New Keynesian model with monopolistically competitive banks and costly access to wholesale funding. I find that high market power banks with greater reliance on wholesale funding transmit monetary policy less to deposit rates, generating lower liability. This leads to lower mortgage lending, house prices, and borrower consumption. If monetary policy shocks become persistent, this negative effect amplifies as banks increasingly pivot from deposits to wholesale funding.

JEL Codes: E44, E52, G21

Keywords: mortgages, wholesale funding, monetary policy

1 Introduction

Most homeowners consider their homes as their primary assets, with mortgages being their predominant form of credit. Changes in the policy interest rate by the central banks significantly impact the economy, primarily affecting the funding costs for commercial banks. Banks, in turn, determine mortgage rates, and the effectiveness of monetary policy hinges on how borrowers react to changes in these rates, transmitted through the banking system. To comprehend the transmission of monetary policy, we must examine the impact of monetary policy shifts on households' financial decision-making, particularly in relation to the effect on banks' cost of mortgage credit. Banks generally depend on two main sources of funding: retail deposits from households and wholesale funding from financial institutions. The ratio of wholesale funding to retail deposits, which depicts the reliance on wholesale funding, varies based on market concentration. The interplay between these aspects is a key factor in determining the approval of new mortgage loans.

In this paper, I examine how market concentration and wholesale funding reliance affect the transmission of monetary policy shocks to mortgage rates, housing prices, output, and consumption. Motivated by empirical evidence on how banks with higher reliance on wholesale funding in concentrated deposit markets transmit monetary policy shocks less to mortgage rates (Drechsler et al., 2017; Choi and Choi, 2019; Scharfstein and Sunderam, 2016), I build a New Keynesian model that generates imperfect pass-through of monetary policy shocks to mortgage rates. In my model, banks are monopolistically competitive and have costly access to wholesale funding. Banks engage in maturity mismatch by lending long-term mortgages and borrowing short-term funding, which consists of wholesale funding and deposits to finance long-term mortgages. However, this leaves banks vulnerable to not having enough short-term funds to cover mortgages. When they need to access more short-term funds, they face quadratic adjustment costs that can be expensive when deposits are scarce. Wholesale funding can either dampen or amplify the transmission of monetary policy, depending on how banks balance it with deposits. When the policy rate decreases, banks often substitute retail deposits for wholesale funding. When they do not meet their desired profit targets, they pay higher deposit rates to attract more deposits. In my model, banks with greater market power and costly access to wholesale funding partially respond to policy interest rate changes, which dampens the transmission of monetary policy to the aggregate economy.

I calibrate the steady state of the model to match moments from US data. I pay close attention to bank portfolio moments, such as wholesale funding cost and elasticity of substitutions in mortgages and deposits. The model-generated business cycle moments closely replicate observed mortgage and deposit rate volatilities, the correlation between mortgage rates and housing prices, and consumption and output volatilities. To assess the model's ability to generate plausible dynamics, I conduct a comparative analysis of the responses of bank variables to a monetary policy shock in both the model and the data. The impulse responses obtained from the model closely correspond to those observed in the data.

The mechanism that generates imperfect pass-through of changes in the policy rate to mortgage rates relies on two sets of features: (1) banks have market power in both deposit and mortgage markets; (2) banks face quadratic costs both in terms of wholesale funding and dividend adjustments. When the Federal Reserve increases the policy rate, the cost of short-term funding increases. The rate on wholesale funding increases fully, however, banks exercise their market power in deposits by partially raising their deposit rates. However, since banks must increase deposit rates for all of their deposit holdings, they end up shifting toward wholesale funding to offset the increased cost of funds. This shift increases banks' marginal cost of funds, which is then passed on to new mortgage rates. This leads to a fall in new mortgage loans, as borrowers are discouraged by higher borrowing costs. Furthermore, higher borrowing costs and lower mortgage loan issuance discourage households from purchasing housing, leading to a decline in housing prices.

I extend my research to investigate the effects of persistent monetary shocks on mortgage rates and economic activity. This is important because the economy has been facing challenges since the Great Recession, and the Federal Open Market Committee's (FOMC) decisions have had lasting impacts on mortgage rates. I explore both transitory and persistent monetary shocks; the former has a greater effect on economic activity through the sticky price channel and the latter has a greater effect on economic activity through the mortgage credit channel. Under an inflation targeting rule (Garriga, Kydland, and Šustek (2017), Garriga, Kydland, and Šustek (2019)), banks tend to rely heavily on wholesale funding because inflation target shocks raise deposit rates more, leading to fewer mortgage loans and persistently higher mortgage rates. This causes a decline in housing prices and a fall in borrowers' consumption, amplifying the negative effects of the monetary shock.

Related Literature First, I contribute to the literature by studying how the interaction between banking market concentration and reliance on wholesale funding affects the transmission of monetary policy to mortgage rates. While recent studies focus on bank market power and reliance on wholesale funding (Drechsler, Savov, and Schnabl (2017), Choi and Choi (2019), Scharfstein and Sunderam (2016), Wang, Whited, Wu, and Xiao (2020)), the interplay between market concentration and reliance on wholesale funding in the mortgage market has been missing. Following a tightening in monetary policy, banks with market power over deposits optimally contract their deposit supply in order to earn a higher deposit spread (Drechsler, Savov, and Schnabl, 2017). As a result, banks may need to borrow more wholesale funding to meet their lending requirements. Choi and Choi (2019) study how loans contract when replacing retail deposits with wholesale funding becomes costly. I highlight the mortgage credit channel via the banking sector and capture the effects of a monetary policy transmission mechanism in a New Keynesian model.

Second, I contribute to the literature by extending the New Keynesian model with a monopolistically competitive banking sector that has costly access to wholesale funding. My model closely follows Greenwald (2018), which explores the impact of mortgage market structure on macroeconomic dynamics, and Polo (2018), which integrates a banking sector into a traditional New Keynesian model. While Polo (2018) examines deposit pass-through, I focus on mortgage pass-through to assess the effects of monetary policy shocks. I allow banks to have market power in deposits and mortgage loans (Piazzesi, Rogers, and Schneider, 2019) rather than relegate the banking sector to a passive role. I complement papers that have developed models of banking frictions in a general equilibrium context (Gertler and Karadi (2011), Gertler and Kiyotaki (2010), Meh and Moran (2010), Dib (2010), Angeloni and Faia (2013), Gerali et al. (2010)). In particular, Gerali et al. (2010) constructs a New Keynesian model with a banking sector that experiences slow adjustment of retail rates due to Calvo frictions in the rate setting. I incorporate a quadratic adjustment cost to account for imperfect pass-through to mortgage rates. Unlike the standard New Keynesian literature, which assumes frictionless household capital markets with one-period borrowing, my model features collateral requirements and long-term fixed nominal payments that can be refinanced at some cost (Garriga, Kydland, and Šustek, 2017). Garriga, Kydland, and Šustek (2019) investigate how monetary policy affects the economy through the cost of new mortgage borrowing and real payments on outstanding debt. My paper incorporates maturity mismatch, market power in mortgages and deposits, and a bank's choice between deposit and wholesale funding into the traditional New Keynesian model.

Third, I contribute to the literature by focusing on how banks' balance sheets can affect the transmission of monetary policy. While my paper mainly focuses on banks, it connects to recent work on monetary policy in incomplete markets that studies differences in household balance sheets (Kaplan, Moll, and Violante (2018), Auclert (2019)). Several papers highlight the importance of mortgage rates in the transmission of monetary policy. For instance, Di Maggio et al. (2017) examine the relationship among household balance sheets, mortgage contract rigidity, and monetary policy pass-through. They find that areas with a higher share of adjustable-rate mortgages are more responsive to lower interest rates, which leads to a substantial increase in car purchases. Berger et al. (2018) argue that fixed-rate prepayable mortgage contracts result in path-dependent consequences of monetary policy. Beraja et al. (2019) demonstrate that the time-varying regional distribution of housing equity influences the aggregate consequences of monetary policy through its effects on mortgage refinancing. Hedlund et al. (2017) quantify the joint role of housing and mortgage debt in the transmission of monetary policy. They find that the transmission of monetary policy depends on the distribution of mortgage debt, and monetary policy is more effective in a high loan-to-value (LTV) environment. Guren et al. (2018) analyze how mortgage design interacts with monetary policy and find that mortgage designs that raise mortgage payments during booms and lower them during recessions perform better than fixed-rate mortgage payments. I contribute to this literature by examining how differences in banks' market concentration and reliance on wholesale funding affect the transmission of monetary policy through the mortgage credit channel. Overall, understanding the role of banks in transmitting monetary policy can provide insights into how changes in interest rates impact households and the broader economy.

Outline

The paper is organized as follows. Section 2 describes the New Keynesian framework with a monopolistic banking sector. I calibrate and assess the model in Section 3. Section 4 presents quantitative results, followed by counterfactuals in Section 5. Section 6 concludes.

2 Model

I analyze the impact of imperfect monetary policy transmission to mortgage rates on economic activities. I present a New Keynesian model with monopolistically competitive banks that have access to costly wholesale funding. Time is discrete and infinite. There are four types of agents in the economy shown in Figure 1: savers, borrowers, banks, and the production sector. Households come in two types that differ in their rate of time preference. The more patient household is a saver with measure χ, and the more impatient household is a borrower with measure $1-\chi$. Savers save in short-term deposits, while borrowers take long-term mortgage loans.

Banks intermediate funds between savers and borrowers. On the asset side, banks finance long-term, fixed-rate mortgage loans to borrowers, while on the liability side, they raise short-term retail deposits from savers and wholesale funding from the central bank. Banks have market power on newly issued mortgage loans and deposits. The central bank sets the nominal interest rate on wholesale funding according to the Taylor rule, while the rates on mortgage loans and deposits adjust endogenously. Monopolistically competitive firms hire labor from households to produce intermediate goods into the final good.

Assets

There are three nominal assets in the economy: mortgages, deposits, and wholesale funding; there is one real asset in the economy: housing. I consider a fixed-rate mortgage contract, which is the predominant contract in the US. The mortgage is a nominal perpetuity with geometrically declining payments (Chatterjee and Eyigungor, 2015). The bank lends one dollar to the borrower in exchange for $(1-\nu)^k(i_{jt}^{M*}+\nu)$ dollars in each future period $t+k$ until the mortgage is prepaid, where ν is the fraction of principal paid in each period and i_{jt}^{M*} is the equilibrium mortgage rate at origination. The borrower faces an *iid* transaction cost when refinancing. A new loan for borrower b must satisfy an LTV constraint defined by $m_{bt}^* \leq \theta^{LTV} p_t^h h_{bt}^*$, where m_{bt}^* is the balance on the new loan, θ^{LTV} is the maximum LTV ratio, p_t^h is the housing price, and h_{bt}^* is the quantity of new housing purchased.

To finance their assets, banks collect short-term nominal deposits from savers and wholesale funding from the central bank. The rate on wholesale funding is the policy rate set by the central bank. Wholesale funding is perfectly substitutable and pays the same rate $1+i_t$ in period $t+1$ per dollar invested in t. Deposits are imperfectly substituted by banks because of their market concentration. One dollar of deposit pays a rate $1+i_{jt}^D$ in period $t+1$ per dollar saved in t.

The final asset in the economy is housing, which produces a service flow each period. Both types own housing; however, only the borrower takes a mortgage to purchase a house. A constant fraction δ of the house value must be paid as a maintenance cost at the start of each period. The borrower's and saver's housing are denoted by $h_{b,t}$ and $\bar{H}_s$, respectively. The saver's demand for housing is fixed so that borrowers do not rent from savers at equilibrium.

Also, Landvoigt, Piazzesi, and Schneider (2015) find that overall house price movements over the boom-bust period are primarily driven by the lower end of the price distribution, where borrowers tend to be more credit-constrained. There is a total housing stock $\bar{H}$ where the price of housing fully characterizes the state of the housing market. Both households are subject to proportional taxation of labor income at rate τ_y. All taxes are returned in lump-sum transfers. Interest payments on the mortgage are tax deductible.

2.1 Preferences

Saver s is endowed with n_s units of labor in each period and supplies labor elastically. Savers have a discount factor β_s, have separable preferences over consumption of the final good c_{st} and stock of housing $\bar{H}_s$, and have disutility from labor n_{st} based on the period-utility function,

$$U\left(c_{st}, n_{st}\right) = \log\left(\frac{c_{st}}{\chi}\right) + \psi \log\left(\frac{\bar{H}_s}{\chi}\right) - \xi_s \frac{\left(\frac{n_{st}}{\chi}\right)^{1+\eta}}{1+\eta}.$$

Borrower b derives utility from consumption of the final good c_{bt} and housing h_{bt-1}, and disutility from labor n_{bt} based on the period-utility function, separable in all arguments,

$$U\left(c_{bt}, h_{bt-1}, n_{bt}\right) = \log\left(\frac{c_{bt}}{1-\chi}\right) + \psi \log\left(\frac{h_{bt-1}}{1-\chi}\right) - \xi_b \frac{\left(\frac{n_{bt}}{1-\chi}\right)^{1+\eta}}{1+\eta}.$$

The parameter ψ governs the weight on housing services, $\xi_s(\xi_b)$ is the weight on disutility from labor supply for the saver (borrower), and η is the inverse Frisch elasticity of labor supply. Weights on disutility from labor supply are allowed to differ so that the two types supply the same amount of labor in a steady state.

2.2 Representative Saver's problem

Each saver chooses consumption c_{st}, labor supply n_{st}, and deposits d_{st} to maximize the expected present discounted value of utility:

$$\max_{c_{st},n_{st},d_{st}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta_s^t U\left(c_{st}, n_{st}\right) \right], \tag{1}$$

subject to the budget constraint

$$c_{st} + d_{st} \leq \underbrace{(1-\tau_y)\, w_t n_{st}}_{\text{labor income}} - \underbrace{\delta p_t^h \bar{H}_s}_{\text{maintenance}} + \frac{(1+i_{t-1}^D)d_{st-1}}{\pi_t} + \underbrace{\Pi_t}_{\text{profits}} + T_{st}, \tag{2}$$

where w_t is the real wage, τ_y is a linear tax on labor income rebated at the end of the period T_{st}, and Π_t are profits from banks and the intermediate firm. The saver pays a maintenance cost at a constant fraction δ of house value at price p_t^h. They get a return i_{t-1}^D on deposits from period $t-1$ to t. The expression $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross rate of inflation between $t-1$ and t.

2.3 Representative Borrower's Problem

The representative borrower's problem follows Greenwald (2018) where payment-to-income (PTI) constraints are abstracted in my paper. Each borrower chooses consumption c_{bt}, labor supply n_{bt}, new housing h_{bt}^*, new mortgage loans m_{bt}^*, and refinancing ρ_t to maximize the expected present discounted value of utility,

$$\max_{c_{bt},h_{bt},n_{bt},m_{bt}^*,\rho_t} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta_b^t U\left(c_{bt}, h_{bt-1}, n_{bt}\right) \right], \tag{3}$$

subject to the budget constraint

$$
\begin{aligned}
c_{bt} \leq \underbrace{(1-\tau_y)\, w_t n_{bt}}_{\text{labor income}} - \underbrace{\frac{((1-\tau_y)x_{bt-1} + \tau_y \nu m_{bt-1})}{\pi_t}}_{\text{payment net of deduction}} + \underbrace{\rho_t \left(m^*_{bt} - (1-\nu)\frac{m_{bt-1}}{\pi_t} \right)}_{\text{new issuance}} \\
- \underbrace{\delta p^h_t h_{bt-1}}_{\text{maintenance}} - \underbrace{\rho_t p^h_t \left(h^*_{bt} - h_{bt-1} \right)}_{\text{housing purchases}} + T_{b,t}.
\end{aligned}
\tag{4}
$$

The borrower's labor income $w_t n_{bt}$ is taxed at rate τ_y, which they get in a tax rebate as T_{bt}. The interest payments on the mortgage are tax deductible, but principal payments are not. When a borrower refinances, they need to pay all of their non-repaid loans in order to receive newly issued mortgages. They pay the maintenance cost of housing and the difference in the price of an old and new house if they choose to refinance.

Their new borrowing is subject to the LTV constraint:

$$
m^*_{b,t} \leq \theta^{LTV} p^h_t h^*_{b,t}, \tag{5}
$$

where m^*_{bt} is the balance on the new loan for borrower b in period t, θ^{LTV} is the maximum LTV ratio, p^h_t is the housing price, and h^*_{bt} is the quantity of new housing purchased for borrower b in period t.

The mortgage principal consists of new loans m^*_{bt} if borrowers refinance and non-repaid loans if borrowers do not refinance:

$$
m_{bt} = \rho_t m^*_{bt} + (1-\rho_t)(1-\nu)\frac{m_{bt-1}}{\pi_t}. \tag{6}
$$

The mortgage payment x_{bt} they make in each period t consists of

$$
x_{bt} = \rho_t (i^{M*}_t + \nu) m^*_{bt} + (1-\rho_t)(1-\nu)\frac{x_{bt-1}}{\pi_t}. \tag{7}
$$

If a borrower chooses to refinance, they pay new loan rate i^{M*}_t and principal ν toward their new loan m^*_{bt}. If they do not refinance, then they pay toward a non-repaid loan.

The law of motion for housing is

$$h_{bt} = \rho_t h^*_{bt} + (1 - \rho_t)\, h_{bt-1}. \tag{8}$$

2.4 Bank's Problem

My banking problem has a new margin of imperfect competition in the mortgage loan market, building on Polo (2018)'s angle on deposit market competition. Banks are owned by savers. Each bank $j \in [0, 1]$ enters period t with total payments to be collected from borrowers on outstanding mortgages x_{jt-1}, total principal on outstanding mortgages m_{jt-1}, and payments on short-term funding $(1 + i^D_{jt-1})d_{jt-1}$ and $(1 + i_{t-1})b_{jt-1}$. New mortgages and loans that are not repaid are funded by retail deposit d_{jt} and wholesale funding b_{jt}.

$$m_{jt} = d_{jt} + b_{jt} \tag{9}$$

Banks engage in maturity transformation by issuing long-term mortgages to borrowers and borrowing short-term retail deposits from savers and wholesale funding from the central bank. Banks issue new mortgages m^*_{jt}. Banks' cash flow in period $t + 1$ is

$$x_{jt} + d_{jt+1} + b_{jt+1} - m^*_{jt} - (1 + i^D_{jt})d_{jt} - (1 + i_t)b_{jt} \geq 0. \tag{10}$$

The endogenous state variables for the bank's problem are total payments to be collected from borrowers on outstanding mortgages x_{jt-1} and total principal on outstanding mortgages m_{jt-1}. The laws of motion for these state variables are given by

$$m_{jt} = m^*_{jt} + (1 - \nu)\frac{m_{jt-1}}{\pi_t} \tag{11}$$

$$x_{jt} = (i_{jt}^{M*} + \nu)m_{jt}^* + (1-\nu)\frac{x_{jt-1}}{\pi_t} \tag{12}$$

Banks have market power over newly issued mortgages and deposits:

$$m_{jt}^* = \Big(\frac{1+i_{jt}^{M*}}{1+i_t^{M*}}\Big)^{-\theta^M} m_t^*, \tag{13}$$

$$d_{jt} = \Big(\frac{1+i_{jt}^{D}}{1+i_t^{D}}\Big)^{-\theta^D} d_t, \tag{14}$$

where θ^M is the elasticity of substitution for mortgages between banks, m_t^* is the aggregate mortgage in the economy, and i_t^{M*} is the aggregate mortgage rate index. The term θ^D is the elasticity of substitution for deposits between banks, d_t is the aggregate deposit in the economy, and i_t^D is the aggregate deposit rate index. The CES aggregator may be an inaccurate representation of reality where households borrow from all banks. Ulate (2019) shows that a heterogeneous borrower with stochastic utility and extreme value shocks works as a microfoundation for the CES aggregator in the case of a homogeneous borrower. I show this in Appendix B.3.

The bank's objective is to maximize the expected present discounted value of net real dividends paid to savers. Each period the bank chooses deposit rate i_{jt}^D and new mortgage rate i_{jt}^{M*},

$$\max_{i_{jt}^D, i_{jt}^{M*}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \Lambda_{t+1}^s div_{jt+1}\right], \tag{15}$$

where

$$div_{jt+1} = \frac{1}{\pi_{t+1}}\left[x_{jt} - \nu m_{jt} - i_{jt}^D d_{jt} - (i_t + \frac{\phi^B}{2}\frac{b_{jt}}{d_{jt}})b_{jt}\right] - \frac{\kappa^{div}}{2}(div_{jt} - \overline{div})^2 \tag{16}$$

subject to the balance sheet constraint (9), laws of motions (11), (12), mortgage (13), and deposit demand (14). Banks incur a quadratic financing cost ϕ^B when accessing wholesale funding to compensate for any deposit shortfalls. The cost is higher than the current federal funds rate. Banks also pay a quadratic dividend adjustment cost κ^{div} when deviating from a target level. When dividends are below the target level, banks have a motive to bring profits closer to the target. Otherwise, banks pay a higher rate on short-term deposits and build a bigger deposit base.

2.4.1 Pricing Equations

I now explain how the composition of bank funding costs is a critical determinant of optimal bank innovations. To generate imperfect monetary policy pass-through to mortgage rates and deposit rates, my model is comprised of two adjustment costs that are associated with dividends and access to wholesale funding.

Monopolistic competition and quadratic adjustment costs lead to imperfect monetary policy pass-through to mortgage rates and deposit rates. Specifically, the presence of quadratic adjustment costs in wholesale funding and monopolistic competition gives rise to imperfect pass-through in the mortgage market. Similarly, the combination of quadratic adjustment costs in dividends and monopolistic competition in the deposit market leads to incomplete pass-through in the deposit market. These adjustment costs could be interpreted as the speed with which banks can change the source of funds when the financial conditions change.

The optimality condition for deposit rate is

$$1 + i_{jt}^{D} = \frac{\theta^{D}}{\theta^{D} - 1}\left[1 + i_t + \frac{\phi^{B}}{2}\right]. \tag{17}$$

The deposit rate depends on the adjustment cost of accessing wholesale funding amplified by deposit markup [1] where higher wholesale funding costs increase deposit rates.

The optimality condition for mortgage rate is

$$1 + i_{jt}^{M*} = \frac{\theta^{M}}{\theta^{M} - 1}\left(1 - \nu + \frac{\Omega_{jt}^{M}}{\Omega_{jt}^{X}}\right). \tag{18}$$

[1] It is simpler to get imperfect pass-through with CES and adjustment costs than generating variable markups with Kimball. Under the CES aggregator, there is no need to impose a leverage constraint on banks due to the presence of curvature in loan demand and deposit supply.

The mortgage rate depends on the fraction of non-paid principals $1-\nu$, and the ratio of marginal benefits to the bank of giving an additional dollar of face value debt (Ω_{jt}^{M}) and marginal benefits to the bank of giving an additional dollar of promised initial payments (Ω_{jt}^{X}). The mortgage rate is amplified by mortgage markup.

The marginal benefit to the bank of giving an additional dollar of promised initial payments, Ω_{jt}^{X}, is the fraction of non-paid principals and the marginal value of profits to the bank, Ω_{jt+1},

$$\Omega_{jt}^{X} = \mathbb{E}_t \left[\frac{\Lambda_{t+1}^{s}}{\pi_{t+1}} \{ (1-\nu)\Omega_{jt+1}^{X} + \Omega_{jt+1} \} \right]. \tag{19}$$

Finally, the marginal benefit to the bank of giving an additional dollar of face value debt, Ω_{jt}^{M}, includes the marginal value of profits to the bank, Ω_{jt+1}, and wholesale funding ratio multiplied by the wholesale funding cost

$$\Omega_{jt}^{M} = \mathbb{E}_t \left[\frac{\Lambda_{t+1}^{s}}{\pi_{t+1}} \{ (1-\nu)\Omega_{jt+1}^{M} - \Omega_{jt+1}(\nu + i_t + \phi^{B}\frac{b_{jt}}{d_{jt}}) \} \right]. \tag{20}$$

The marginal value of profits to the bank, Ω_{jt+1}, is decreasing in dividends

$$\Omega_{jt+1} = \frac{1}{1 + \kappa^{div}(div_{jt+1} - \bar{div})}. \tag{21}$$

Under no-arbitrage conditions, the marginal benefit of the real value of debt and initial payments is equal to the marginal cost of borrowing wholesale funding

$$\mathbb{E}_t \left[\frac{\Lambda_{t+1}}{\pi_{t+1}} \right] (i_t + \phi^{B}\frac{b_{jt}}{d_{jt}}) = \mathbb{E}_t \Lambda_{t+1} \left[\Omega_{t+1}^{M} + i_{jt}^{M*}\Omega_{t+1}^{X} - 1 \right]. \tag{22}$$

Under no-arbitrage conditions, the wedge between the policy rate and the deposit rate is half of the adjustment cost of accessing wholesale funding

$$i_{jt}^{D} = i_t - \frac{\phi^{B}}{2}. \tag{23}$$

The imperfect pass-through of an increase in the policy rate to mortgage rates can be influenced by a combination of rigidity in banks' interest income earned on long-duration assets and two adjustment costs involved in accessing wholesale funding and dividend smoothing. The direction of monetary policy transmission to mortgage rates is ambiguous and depends on the interplay of these factors. First, we can see that when the marginal benefit of giving an additional dollar of face value debt (Ω^M) shrinks, monetary policy is transmitted less to mortgage rates shown in equation (18). Second, higher policy rates, higher wholesale funding costs, or higher reliance on wholesale funding in equation (20) are attenuated by lower dividends, leading to lower Ω^M. Lower dividends increase the marginal value of profits to the bank, Ω, in equation (21). However, higher Ω decreases Ω^M leading to lower mortgage rate pass-through.

2.5 Productive Technology

The production side of the economy is populated by a competitive final good producer and a continuum of intermediate good producers owned by the saver. 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

$$y_t = \Big(\int_0^1 y_t(\omega)^{\frac{\theta-1}{\theta}} \Big)^{\frac{\theta}{\theta-1}}. \tag{24}$$

CES demands for each intermediate good ω are

$$y_t(\omega) = \Big(\frac{p_t(\omega)}{p_t} \Big)^{\theta} y_t, \tag{25}$$

and $p_t = (\int_0^1 p_t(\omega)^{1-\theta} d\omega)^{\frac{1}{1-\theta}}$ is the price of the final good.

Intermediate goods producers operate a linear production function,

$$y_t(\omega) = a_t n_t(\omega),$$

to meet the final good producer's demand, where n_t is labor hours and a_t is total factor productivity, which evolves according to

$$\log a_{t+1} = (1-\phi_A)\mu_A + \phi_A \log a_t + \epsilon_{A,t+1},$$

where μ_A is productivity mean, ϕ_A is productivity persistence, and $\epsilon_{A,t+1}$ is a TFP shock. Intermediate goods producers are subject to the price stickiness of Calvo. A fraction $1-\phi$ of firms are able to adjust their price each period, while the remaining fraction ϕ update their existing price by the rate of steady state inflation.

2.6 Monetary Authority

The monetary authority adjusts the policy rate $1+i_t$ in response to deviations of inflation and output from the steady-state level (π and y):

$$\log(1+i_t) = \phi_r \log(1+i_{t-1}) + (1-\phi_r)\left[(\psi_y(\log y_t - \log y) + \psi_\pi(\log \pi_t - \log \pi)\right] + \epsilon_t, \tag{26}$$

where $\epsilon_t \sim N(0, \sigma_R)$ represents a zero-mean normally distributed monetary policy shock with standard deviation $\sigma_R = 0.0025$.

2.7 Equilibrium

I focus on a symmetric equilibrium, where banks and intermediate goods producers choose the same deposit and mortgage rates, and prices. Competitive equilibrium is a sequence of allocations $(c_{st}, c_{bt}, n_{st}, n_{bt})$, endogenous states $(m_{t-1}, x_{t-1}, h_{t-1})$, mortgage origination and funding decisions (m_t^*, b_t, d_t), and housing refinancing decisions (h_{bt}^*, ρ_t) and prices $(w_t, \pi_t, p_t^h, i_t, i_t^D, i_t^{M*})$ that satisfy borrower, saver, bank, and firm optimality, and the following market clearing conditions:

$$n_{bt} + n_{st} = n_t$$

$$h_{bt} + \bar{H}_s = \bar{H}$$

$$c_{bt} + c_{st} + \delta p_t^h \bar{H} = y_t$$

$$(1-\chi) m_{bt}^* = m_t^* = \left[\int_0^1 (m_{jt}^*)^{\frac{\theta^{M*}-1}{\theta^{M*}}} dj \right]^{\frac{\theta^{M*}}{\theta^{M*}-1}}$$

$$\chi d_{st} = d_t = \left[\int_0^1 (d_{jt})^{\frac{\theta^{D}-1}{\theta^{D}}} dj \right]^{\frac{\theta^{D}}{\theta^{D}-1}}$$

Due to Walras's law, once the market for deposit and mortgage has cleared, the market for wholesale funding will be cleared automatically. This completes the description of the model.

3 Calibration

This section describes the calibration procedure. Time is quarterly. The calibrated parameter values are presented in Table 3. While some parameters are set to standard values, a number of others are calibrated to match a set of moments computed for the period from 2000Q1 to 2014Q1. Two parameters (κ^{div}, ϕ^B) are specific to my model.

Borrower and Saver I set a number of parameters to standard values in the macroeconomics literature. The IES is set to 1 (log-utility), and I choose an inverse Frisch elasticity of labor supply of 1. The weights on labor disutility, ξ_b and ξ_s, are set such that households supply the same labor equal to 1/3 in steady state. The saver discount factor β_s is calibrated to match the 2000 to 2014 average of 10-year Treasury yield.

I calibrate the fraction of borrowers χ to match the Survey of Consumer Finances. I classify borrower households in the data to be homeowners with a mortgage and mortgage yielding $\chi = 0.319$. I calibrate the log of housing stock $\log \bar{H}$ and the log of saver housing demand $\log \bar{H}_s$ so that the price of housing is unity at a steady state and the ratio of saver house value to income is the same as in the 2004 SCF.

I calibrate the housing preference weight ψ to 0.2 to target a housing expenditure share of 20% (Davis and Ortalo-Magné, 2011). I set $\theta^{LTV} = 0.85$ as a compromise between the mass bunching at 80% and the masses constrained at 90%. The housing maintenance cost is set to $\delta = 0.004$ to match an annual depreciation rate of 1.5% (Kaplan, Mitman, and Violante, 2017). The linear labor tax is set to the average marginal individual income tax rate estimated by Mertens and Montiel Olea (2018) over the period 1946 to 2012.

Banks I take half of the average non-interest expenditures excluding expenditures on-premises or rent per dollar of assets of banks in the Call Report over the period 2000 to 2014. I set $\nu = 0.435\%$ to match the average share of principal paid on existing loans.

The scale of the dividend adjustment cost κ^{div} affects the degree of pass-through. I set it to 0.147 to match the average pass-through of the policy rate to mortgage rates. The values θ^M and θ^D are calibrated from the mortgage and deposit pricing equations $\theta^M = \frac{1+i^{M*}}{i^{M*}-i}$, and $\theta^D = \frac{1+i^D}{i^D-i}$. The elasticity of substitution for mortgages, θ^M, is set to match mortgage rates of 5.7%, while the elasticity of substitution for deposits, θ^D, is set to match deposit rates of 0.28% for annual policy rate of 3%. A loan-level mortgage rate is taken from Fannie Mae and Freddie Mac's 30-year single-family conventional fixed-rate mortgages that are fully amortizing with full documentation. I pool data from both datasets because the combination of these two datasets covers the majority of conforming loans issued in the US. In the literature, Ulate (2019) uses θ^M of 203 for annual lending rate of 6% and θ^D of -268 for annual policy rate of 3%. Mark-up is measured by $\frac{\theta^M}{\theta^M-1}$. The cross-section of deposit markups ranges from 1.4 to 1.8, while credit markups range from 1.15 to 1.55 in Bellifemine, Jamilov, and Monacelli (2022). The wholesale funding adjustment cost ϕ_b is calculated from the no-arbitrage condition for deposits.

Other Parameters The remaining parameters are taken from the literature. In the Taylor rule, interest rate smoothing $\phi_r = 0.89$ (Campbell, Pflueger, and Viceira, 2014), inflation reaction $\psi_\pi = 1.5$, output reaction $\psi_y = 0$, and trend inflation π is set to 1.008. The steady state of productivity is set to $\mu_A = 1.099$ to have a steady-state output equal to 1. The persistence of productivity ϕ_A is set to 0.964 (Garriga, Kydland, and Šustek, 2017).

3.1 Model Assessment

Before presenting the main results of the paper, I show that the model also performs well along dimensions that were not targeted in the calibration. Table 4 shows the volatilities in mortgage and deposit rates, the correlation between mortgage rates and housing prices, output volatility, the relative volatility of consumption, and the relative volatility of aggregate consumption. Table 4 suggests that the model has a relatively good fit in terms of business cycles. While it exhibits smaller output volatility and volatility of aggregate consumption than seen in the data, the model precisely matches the data in terms of the relative volatility of consumption. Additionally, the model replicates a relevant set of bank pricing moments. While the correlation between mortgage rate and housing price falls below the empirical counterpart due to fixed housing, the model successfully delivers a deposit rate volatility that precisely matches the data.

3.1.1 Response to Monetary Policy Shocks

To check that the model generates reasonable dynamics, I compare the responses of bank variables to a monetary policy shock in the model and the data. For the model version, I compute impulse responses from the linearized solution around the deterministic steady state. For the data version, I apply the local projection method of Jorda (2005). I estimate quarterly local projection regressions to understand the role of wholesale funding on mortgage volumes following a contractionary monetary policy shock:

$$y_{bt+h} - y_{bt-1} = \alpha_{bh} + \alpha_{mh} + \beta_h \Delta_t + +\Gamma'_h X_{bt-1} + \epsilon_{bt+h}. \tag{27}$$

Dependent variable y_b is the mortgage rate and mortgage loans, Δ_t is monetary policy shock, and X_{bt-1} includes bank and household controls. Other regressors include bank fixed effects α_{bh} for each horizon and metropolitan statistical area (MSA) fixed effects α_{mh}. I use lagged terms to mitigate concerns about reverse causality. Standard errors are clustered at the bank level to adjust for serial correlation and potential heteroscedasticity.

My dataset runs from the first quarter of 2000 to the fourth quarter of 2014. The unit of observation is at the quarter-MSA-bank level. Mortgage loan origination comes from the Home Mortgage Disclosure Act (HMDA) which covers about 90 percent of the mortgage applications and approved loans in the US. Loan-level mortgage rates are obtained from Fannie Mae's Single-Family Loan Performance Data and Freddie Mac's Single-Family Loan-Level Dataset. I pool data from Fannie Mae and Freddie Mac data sets because the combination of these two datasets covers the majority of conforming loans issued in the US. The population of both data sets includes a subset of the 30-year, fully amortizing, full documentation, single-family, conventional fixed-rate mortgages acquired by the government-sponsored enterprises. It provides information for the largest 27 commercial banks and excludes investment banks such as Goldman Sachs or Morgan Stanley. Household controls include the borrower's credit (FICO) score, the debt-to-income ratio, and the loan size relative to the house value (LTV ratio).

I use unanticipated monetary shocks from Nakamura and Steinsson (2018). This dataset contains the changes in financial variables in a 30-minute window around FOMC announcements (from 10 minutes before to 20 minutes after the announcement). Monetary policy surprises focus on interest rate changes in a narrow window of time around FOMC announcements to rule out reverse causality and other endogeneity problems including the FOMC could not have been reacting to changes in financial markets in a sufficiently narrow window of time around the announcement. I obtain bank-level characteristics including liquid assets, repricing maturity, real estate loans, commercial and industrial loans, and number of branches from the Federal Reserve Board's Report on Condition and Income (Call Reports).

Figure 2 shows the model and data impulse responses of the mortgage rate along with their 90% confidence bands to a 100 bps increase in the monetary policy shock. Despite the model's relative parsimony, the responses from the model and data are closely aligned, generating paths in the same direction and of similar magnitudes. The model qualitatively supports the mechanism, abstracting from features like habit persistence and labor market frictions, which, if incorporated, could generate a hump-shaped curve.

4 Quantitative Analysis

This section illustrates how the features of the model transmit nominal interest rates to mortgage rates, which further affect the aggregate economy. These quantitative results are obtained by linearizing the model around the deterministic steady state and computing impulse responses to positive monetary policy shock.

I study the effect of an unanticipated one-time increase of 100 bps in an annualized shock to the Taylor rule, followed by a perfect foresight transition back to the steady state. Figures 3 and 4 show the impulse response functions of banks and macroeconomic variables. The figure presented in this analysis depicts the impulse response functions (IRFs) of three different models in response to a monetary policy shock. The blue line shows the IRFs for a New Keynesian model that incorporates market power and adjustment costs. The dashed red line represents the IRFs for a model that does not account for dividend adjustment costs, and the dashed purple line shows the IRFs for a model that ignores wholesale funding costs. The IRFs of all variables, except for the deposit rate and mortgage rate, are presented as percentage deviations from their steady-state values. Meanwhile, the deposit rate and mortgage rate are expressed in annualized levels in percentage points.

Figure 3 illustrates the impact of a 100 bps increase in the policy rate on mortgage rates. The model accounts for market power and adjustment costs in wholesale funding and dividends. Interestingly, the effect on mortgage rates is relatively small, with an increase of only 20 bps. The breakdown of the factors that influence the mortgage rate increase reveals that market power is the largest contributor, accounting for 17 bps. Wholesale funding cost only captures 2 bps, while dividend adjustment cost captures 1 bp. In Polo (2018), where banks have market power only in deposit and no option to borrow wholesale funding, mortgage rates rise by 40 bps. It is important to note that my model does not account for other channels that can impact housing finance, such as home equity line of credit, household default, fixed saver's housing demand, and housing stock, which could influence the empirical result.

Figure 3 provides insights into how a 100 bps increase in the policy rate affects deposit rates and banks' deposits. Deposit rates increase by 0.9 bps, while banks' deposits decline by 1.5%. This suggests that banks are hesitant to pass on the full increase in policy rates to their depositors, but they do so to a minimal extent. It also suggests that the impact of adjustment costs on deposit rates is relatively small compared to the impact of adjustment costs on changes in deposit volumes. However, when there is no dividend adjustment cost, banks lose the option of raising deposits by increasing dividends. This can make it more challenging for banks to attract new deposits, leading to a further decline in deposit volumes. On the other hand, when there is no wholesale funding cost, banks have cheaper access to wholesale funding, leading to a decline in deposits. As banks observe deposit outflows, they tend to shift toward wholesale funding, which increases by 1.5%.

Banks pass on the additional increase in their marginal cost of funds to new mortgage rates, resulting in a decline in new mortgage loans of 1.2%. This decline can have a significant impact on the broader economy, as mortgage loans are an essential source of financing for homebuyers. When there are no costs associated with accessing wholesale funding, banks would borrow wholesale funding more. As a result, banks would observe fewer declines in mortgage issuance. Furthermore, the changes in the composition of bank funding lead to a decline in dividends by 0.2%. This decline can be attributed to the lower issuance of new mortgage loans, which subsequently leads to banks lending at higher rates. These findings highlight the importance of understanding the implications of policy rate hikes on bank funding and market concentration when seeking to stimulate the economy. Policymakers must be aware of the impact of monetary policy on bank lending and mortgage rates to ensure that their policy decisions do not have unintended consequences on the broader economy.

Figure 4 provides a detailed analysis of how various macroeconomic variables respond to a contractionary monetary policy shock. We observe that a higher rise in deposit rates has a minimal effect on saver consumption, increasing it by only 0.002%. However, a rise in mortgage rates has a more significant impact, leading to a fall in borrower consumption by 0.08%. This decline can be attributed to higher borrowing costs, which may discourage households from making significant purchases. Additionally, the housing market is also adversely affected, with housing prices falling by 1.25%. The decline in housing prices could be due to a combination of lower mortgage loan issuance and increased cost of borrowing. Furthermore, the contraction in borrower consumption leads to a 1% fall in output, which can cause a ripple effect on the broader economy. It is noteworthy that the imperfect transmission of monetary policy to mortgage rates exacerbates the negative impact on output, housing prices, and borrower consumption. On the other hand, the same factor increases saver consumption by offering higher interest rates, providing some relief to savers in the economy.

5 Counterfactuals

Central banks have started to persistently tighten the economy post-COVID lockdowns. In this section, I analyze the impact of persistent monetary shocks on mortgage rates and economic activities. Persistent monetary shocks have a larger effect on economic activities through the mortgage credit channel, whereas transitory monetary shocks have a larger effect on economic activities through the sticky price channel because firms cannot adjust their prices due to menu costs.

5.1 Inflation Target Shock

In this section, I examine the impact of the inflation target shock, which represents a persistent change in monetary policy that can affect long-term nominal rates, in addition to current short-term rates. By analyzing this shock, we can better understand how changes in nominal rates can impact the economy in isolation. The inflation target shock is particularly interesting because it has a longer horizon and affects the term structure of mortgage rates, as opposed to a Taylor rule shock that primarily affects the short-term structure. Furthermore, this shock moves nominal rates while having a minimal impact on real rates, which makes it an ideal scenario to examine the effects of changes in nominal rates. The inflation target shock is a perturbation to the Taylor rule and it is a label for a standard but very persistent policy shock. By examining the effects of this shock on economic activities and mortgage rates, we can gain valuable insights into how changes in monetary policy can affect the economy over the long term. The monetary authority follows a Taylor rule, similar to that of Smets and Wouters (2007), of the form

$$\begin{aligned} \log(1+i_t) &= \log\bar{\pi}_t + \phi_r\left(\log(1+i_{t-1}) - \log\bar{\pi}_{t-1}\right) \\ &+ (1-\phi_r)\left[\left(\log(1+i_{ss}) - \log\pi_{ss}\right) + \psi_\pi\left(\log\pi_t - \log\bar{\pi}_t\right)\right], \end{aligned} \tag{28}$$

where the subscript ss refers to steady-state values, and $\bar{\pi}_t$ is a time-varying inflation target defined by

$$\log\bar{\pi}_t = (1-\psi_{\bar{\pi}})\log\pi_{ss} + \psi_{\bar{\pi}}\log\bar{\pi}_{t-1} + \varepsilon_{\bar{\pi},t}, \tag{29}$$

where $\varepsilon_{\bar{\pi},t}$ is a white noise process that is referred to as an inflation target shock.

Figure 5 presents a comparison of the impact of inflation target shock and Taylor rule on bank funding, mortgage rates, and deposit rates. The inflation target shock has a persistent effect, while the Taylor rule has a transitory effect on mortgage and deposit rates. In response to an inflation target shock, banks experience larger deposit outflows as deposit rates rise more compared to the Taylor rule scenario. To make up for the shortage in deposits, banks increase their reliance on wholesale funding, resulting in a decline in their dividends due to a rise in interest expenses. Furthermore, the persistent rise in mortgage rates under an inflation target shock leads to a reduction in the issuance of new mortgage loans compared to the Taylor rule scenario. Conversely, under the Taylor rule, banks do not rely as much on wholesale funding since deposit rates do not rise as much as under the inflation target shock. This leads to an increase in banks' dividends since they pay a lower cost to build a larger deposit base under the Taylor rule.

In Figure 6, the impact of the inflation target shock and Taylor rule on output, house price, saver consumption, and borrower consumption are compared. The results show that the impact of the inflation target shock is more severe than that of the Taylor rule. This is because the persistent increase in mortgage rates makes housing more expensive, leading to a fall in borrower consumption. On the other hand, the persistent increase in deposit rates makes savers richer, leading to an increase in their consumption. The decrease in house prices is amplified by 0.5 pps under the inflation target shock compared to the Taylor rule, resulting in an attenuated decrease in output of 0.15 pps. The inflation target shock has a persistent effect on real variables and amplifies the response more than the Taylor rule. In this model, the transmission of monetary policy to mortgage and deposit rates is crucial in determining how borrowers and savers consume, which in turn affects output and housing in the economy.

6 Conclusion

I study the quantitative importance of bank market power and wholesale funding reliance for monetary policy transmission to mortgage rates and economic activities. I build a New Keynesian model with monopolistically competitive banks that have costly access to wholesale funding. My model provides insight into the aggregate effects of imperfect pass-through to mortgage rates on economic activities.

I calibrate my model to match cross-sectional bank portfolio moments. I then validate the model by showing that the model can generate a number of untargeted patterns in the data and assess the model against data projections that are qualitatively consistent with the data. I find that imperfect monetary policy transmission to mortgage rates decreases the response of consumption, output, and housing prices.

My paper adds value to policymakers' decisions by increasing awareness about the fact that the transmission of monetary policy shocks to mortgage rates is imperfect and that the degree of this imperfect pass-through varies across banks by their composition of funding and market power. I focus on the mortgage market due to its significant share of household debt, but future research could extend the analysis to other credit markets.

A Tables and Figures

Table 1: Balance sheet

Asset	Liability
Outstanding debt (m_{jt})	Short-term deposit (d_{jt}, b_{jt})

Table 2: Cash flow in $t+1$

Inflow	Outflow
Nominal mortgage payment (x_{jt})	Short-term deposit payment $(1+i_{jt}^D)d_{jt}$, $(1+i_t)b_{jt}$
Short-term deposit (d_{jt+1}, b_{jt+1})	New issuance (m_{jt}^*)

Table 3: Parameter Values

Parameter	Name	Value	Internal	Source
Household				
Frisch elasticity	η	1.0	N	Standard
Borrower discount factor	β_b	0.965	N	Greenwald (2018)
Saver discount factor	β_s	0.987	N	Avg. 10Y rate, 2000-2014
Fraction of borrowers	χ	0.4	N	SCF 2004
Housing preference	ψ	0.2	N	Davis and Ortalo-Magné (2011)
Borrower's labor disutility	ξ_b	7.809	Y	Borrower's labor supply 1/3
Saver's labor disutility	ξ_s	5.683	Y	Saver's labor supply 1/3
Housing maintenance cost	δ	0.004	N	Depreciation of housing 1.5% pa
Max LTV	θ^{LTV}	0.85	N	Greenwald (2018)
Income tax rate	τ^y	0.24	N	
Log housing stock	$\log \bar{H}$	4.230	Y	$p_{ss}^h = 1$ SCF 2004
Log saver housing stock	$\log \bar{H}_s$	1.914	Y	SCF 2004
Bank				
Mortgage amortization	ν	0.435%	N	Greenwald (2018)
EOS for mortgage	θ^M	35	N	Mortgage rate of 5.7%
EOS for deposit	θ^D	-34	N	Deposit rate of 0.28%
Div. adjustment cost	κ^{div}	0.1468	Y	Average mortgage rate
Wholesale funding cost	ϕ^B	0.00852	Y	No arbitrage condition for deposits
New-Keynesian block				
Variety elasticity	θ	6.0	N	Standard
Calvo pricing	ϕ	0.75	N	Standard
Productivity (mean)	μ_A	1.099	Y	$y_{ss} = 1$
Productivity (pers.)	ϕ_A	0.964	N	Garriga et al. (2017)
Monetary policy: Taylor rule				
Steady-state inflation	π_{ss}	1.008	N	Standard
Taylor weight inflation	ψ_π	1.5	N	Standard
Taylor weight output	ψ_y	0.964	N	Standard
Interest rate smoothing	ϕ_r	0.89	N	Campbell et al. (2014)
Inflation target (pers.)	$\phi_{\bar{\pi}}$	0.994	N	Garriga et al. (2017)

Notes: This table shows the subset of parameters that are fixed in the calibration and the subset of parameters that are calibrated to match targeted moments.

Table 4: Unconditional Business Cycle Statistics

Moments	Description	Model	Data
sd(i^M)	Mortgage rate volatility	0.63	1.18
sd(i^D)	Deposit rate volatility	0.02	0.02
corr(i^M,p^H)	Correlation mortgage rate and house price	-0.95	-0.48
sd(Output)	Output volatility	0.03	0.07
sd(C_b)/sd(C_s)	Relative volatility consumption	0.98	0.98
sd(C)/sd(Y)	Relative volatility agg. consumption	1.02	1.05

Notes: This table shows a set of untargeted moments related to business cycles. Data moments are computed from quarterly frequency for the period 2000 to 2014 using the Bureau of Economic Analysis (BEA), Federal Housing Finance Administration (FHFA), Consumer Expenditure Survey (CEX), Fannie Mae, Freddie Mac, and Call Reports.

Figure 1: Outline of the Model

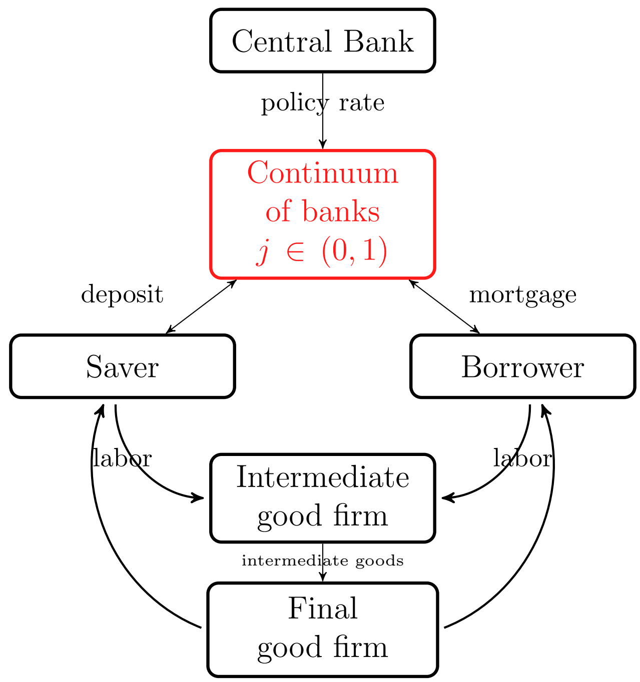
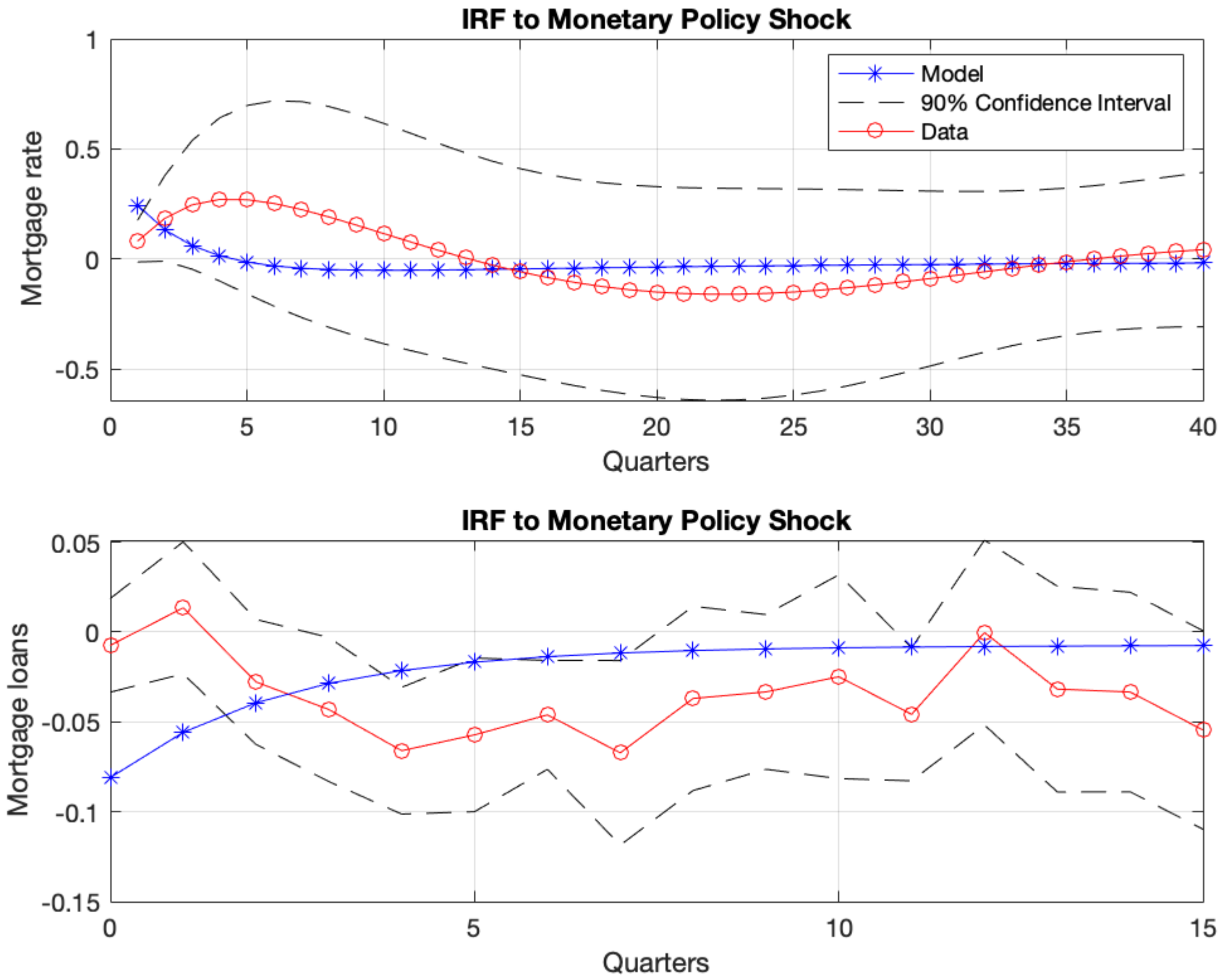
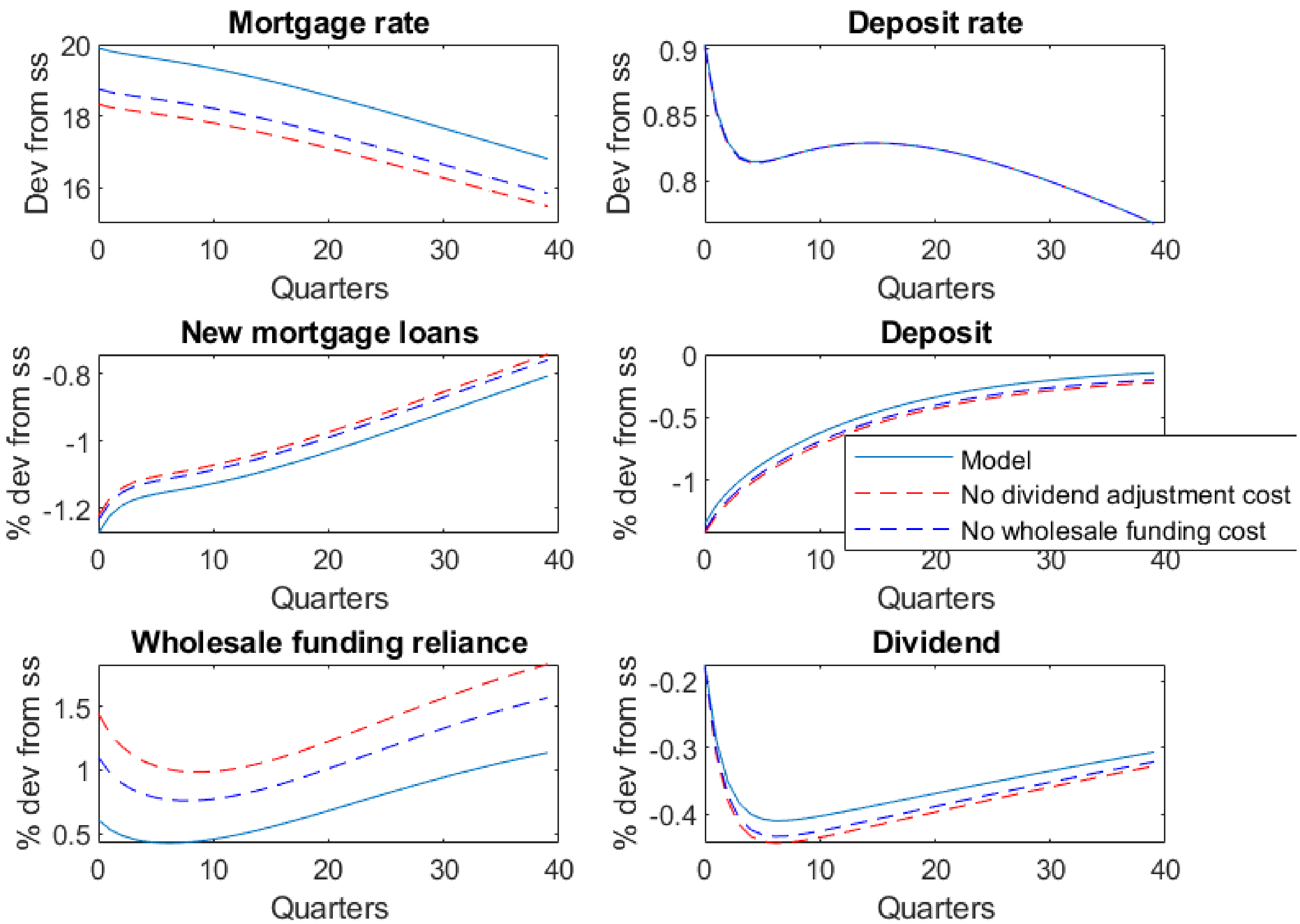


Figure 2: Response to +100 bps Monetary Policy Shock, Model vs. Data Projections



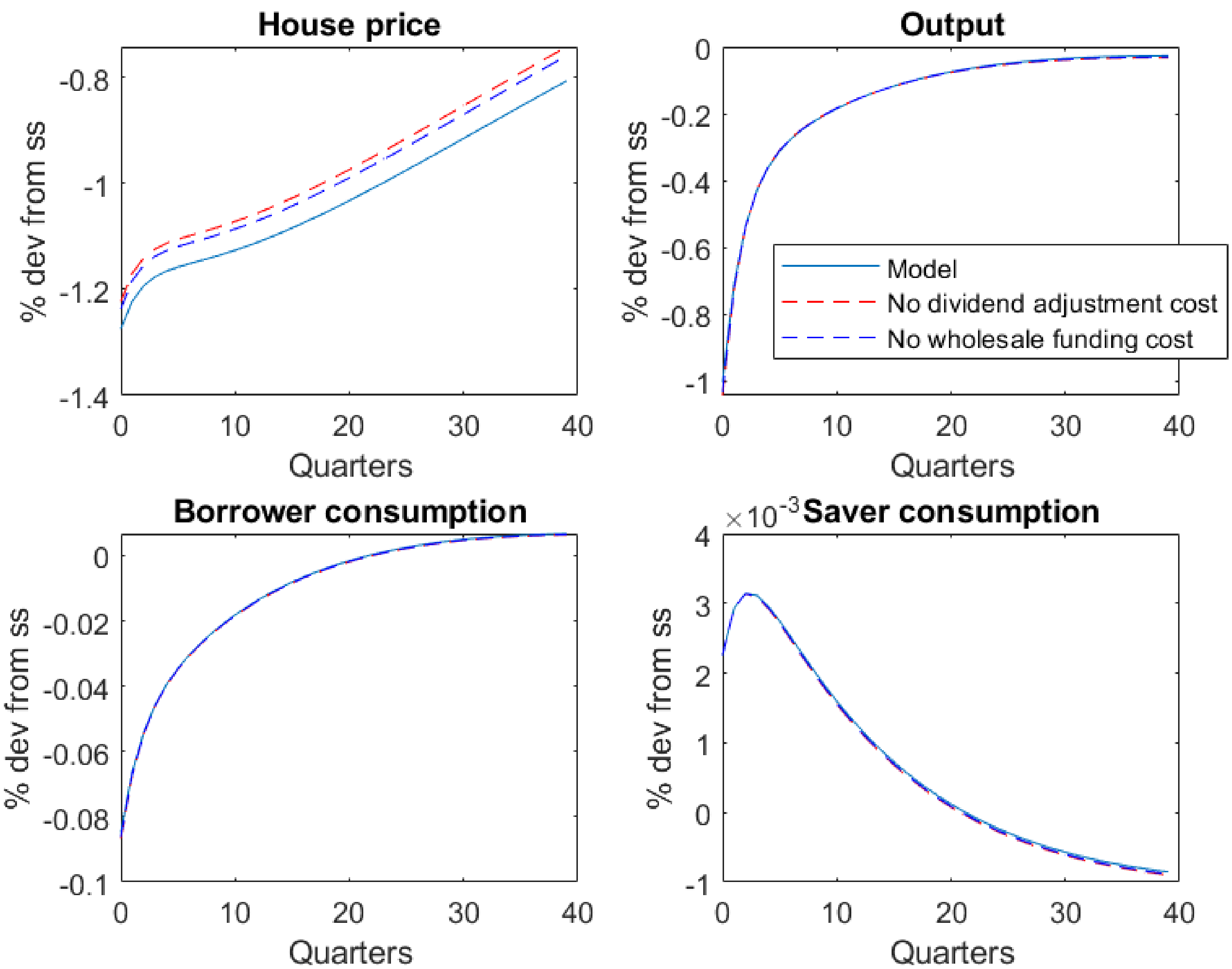
Notes: This figure depicts the impulse response functions of some of the main variables to a monetary policy shock of +100 bps. The x axis is the number of quarters since the shock, and the y axis is given in percent deviation from the steady state for the mortgage rate and loans.

Figure 3: Response to a +100 bps Monetary Policy Shock



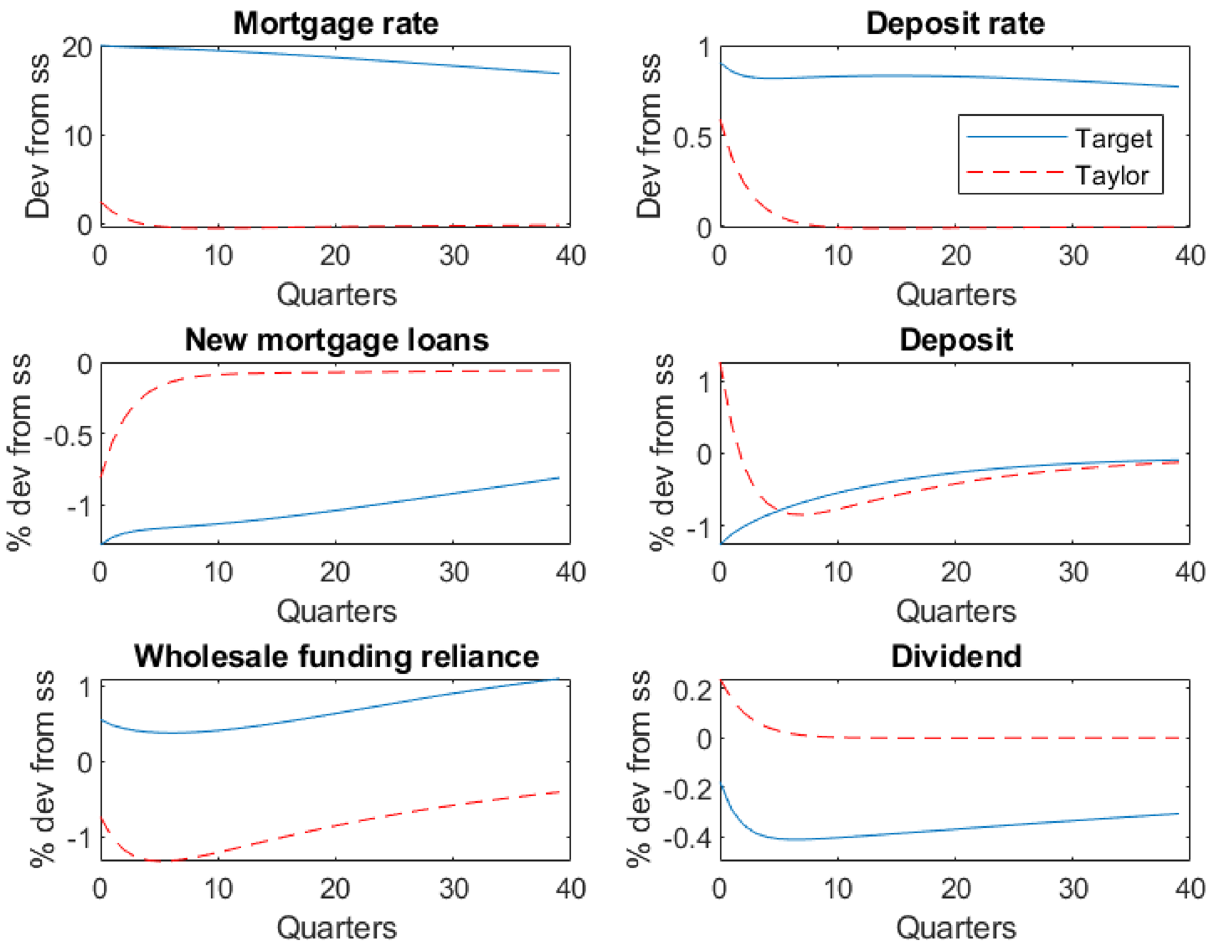
Notes: This figure depicts the impulse response functions of some of the main variables to a monetary policy shock of +100 bps. The x axis is the number of quarters since the shock, and the y axis is given in percent deviation from the steady state of the mortgage rate, new mortgage loans, deposit rate, deposits, wholesale funding reliance, and bank dividends. Mortgage and deposit rates are provided in annualized percentage points.

Figure 4: Response to a +100 bps Monetary Policy Shock



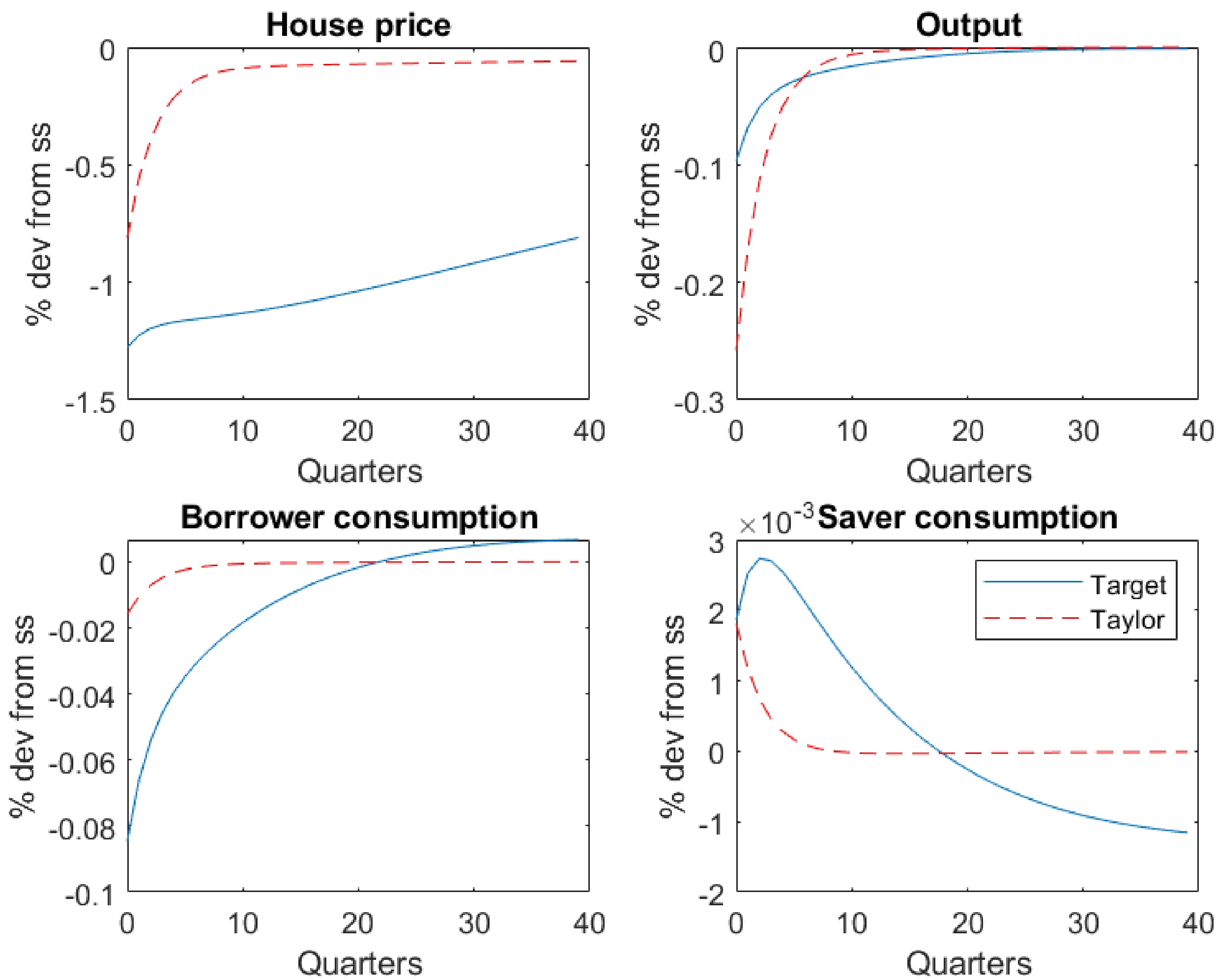
Notes: This figure depicts the impulse response functions of some of the main variables to a monetary policy shock of +100 bps. The x axis is the number of quarters since the shock, and the y axis is given in percent deviation from the steady state for the house price, output, labor, and consumption.

Figure 5: Response to a +100 bps Monetary Policy Shock: Taylor Rule vs Target



Notes: This figure depicts the impulse response functions of some of the banking variables to a monetary policy shock of +100 bps between the Taylor rule vs the inflation targeting rule. The x axis is the number of quarters since the shock, and the y axis is given in percent deviation from the steady state of the mortgage rate, new mortgage loans, deposit rate, deposits, wholesale funding reliance, and bank dividends. Mortgage and deposit rates are provided in annualized percentage points.

Figure 6: Response to a +100 bps Monetary Policy Shock: Taylor Rule vs Target



Notes: This figure depicts the impulse response functions of some of the main variables to a monetary policy shock of +100 bps between the Taylor rule vs inflation targeting rule. The x axis is the number of quarters since the shock, and the y axis is given in percent deviation from the steady state for output, labor, and consumption.

B Appendix

B.1 Model Solution

Saver Optimality

Intratemporal condition

$$-\frac{U_{st}^{n}}{U_{st}^{c}} = (1 - \tau_y)\, w_t \tag{30}$$

Euler equation

$$1 = (1 + i_t^D)\mathbb{E}_t\left[\frac{\Lambda_{st+1}}{\pi_{t+1}}\right] \tag{31}$$

where $\Lambda_{s,t+1} \equiv \beta_s \frac{U_{st+1}^c}{U_{st}^c}$

Tax

$$T_{st} = \tau_y w_t n_{st} \tag{32}$$

Profits

$$\Pi_t = div_t + y_t - w_t n_t \tag{33}$$

Borrower Optimality

$$P_t^h = \frac{U_{b,t}^h}{U_{b,t}^c} + \mathbb{E}_t\left[\Lambda_{b,t+1} P_{t+1}^h(\theta^{LTV} + 1 - \delta)\right] \tag{34}$$

where $\Lambda_{b,t+1} \equiv \beta_b \frac{U_{bt+1}^c}{U_{bt}^c}$

$$-\frac{U_{b,t}^n}{U_{b,t}^c} = (1 - \tau_y)\, w_t \tag{35}$$

The euler equation for new borrowing is

$$1 = \Omega_{bt}^M + \Omega_{bt}^X i_t^{M*} + \lambda_t \tag{36}$$

where λ_t is multiplier on borrowing constraint.

$$\rho_t = \Gamma_\gamma\{\underbrace{(1 - \Omega_{bt}^M - \Omega_{bt}^X i_{t-1}^M)(m_{bt}^* - \frac{(1-\nu)m_{bt-1}}{\pi_t})}_{\text{new debt incentive}} - \underbrace{\Omega_{bt}^X(i_t^{M*} - i_{t-1}^M)}_{\text{interest rate incentive}}\} \tag{37}$$

where

$$\Omega_{bt}^M = \mathbb{E}_t\left[\frac{\Lambda_{bt+1}}{\pi_{t+1}}\{\nu\tau_y + \rho_{t+1}(1-\nu) + (1-\rho_{t+1})(1-\nu)\Omega_{bt+1}^M\}\right] \tag{38}$$

$$\Omega_{bt}^X = \mathbb{E}_t\left[\frac{\Lambda_{bt+1}}{\pi_{t+1}}\{(1-\tau_y) + (1-\rho_{t+1})(1-\nu)\Omega_{bt+1}^X\}\right] \tag{39}$$

Firm Optimality

$$x_{1t} = u'(C_t)mc_t y_t + (\phi\beta)E_t(1+\pi_{t+1})^{\theta}x_{1t+1} \tag{40}$$

$$x_{2t} = u'(C_t)y_t + (\phi\beta)E_t(1+\pi_{t+1})^{\theta-1}x_{2t+1} \tag{41}$$

$$1+\pi_t^{\#} = \frac{\theta}{\theta-1}(1+\pi_t)\frac{x_{1t}}{x_{2t}} \tag{42}$$

$$(1+\pi_t)^{1-\theta} = (1-\phi)(1+\pi_t^{\#})^{1-\theta} + \phi \tag{43}$$

$$\mathcal{D}_t = (1-\phi)(1+\pi_t^{\#})^{-\theta}(1+\pi_t)^{\theta} + \phi(1+\pi_t)^{\theta}\mathcal{D}_{t-1} \tag{44}$$

$$mc_t = \frac{w_t}{a_t} \tag{45}$$

$$y_t = \frac{a_t n_t}{\mathcal{D}_t} \tag{46}$$

B.2 Dixit-Stiglitz Aggregator

Mortgage Market Borrower seeks a total amount of mortgage loans equal to M_t^*, they borrow an amount M_{jt}^* from each bank j and face the following constraint:

$$M_t^* = \left[\int_0^1 M_{jt}^{*\frac{\theta^M-1}{\theta^M}} dj\right]^{\theta^M/(\theta^M-1)} \tag{47}$$

which indicates that the loans they get from individual banks are aggregated via a CES aggregator into the total mortgage loans they obtain. θ^M is the elasticity of substitution between banks and it is assumed to be greater than one. Each bank charges the borrower a net mortgage interest rate i^{M*}_{jt}. Demand for the borrower can be derived from minimizing over M^*_{jt} the total repayment (including principal) due to the continuum of banks j:

$$\min_{M^*_{jt}} \int_0^1 (1 + i^{M*}_{jt}) M^*_{jt} dj \tag{48}$$

subject to the constraint given above.

The FOC wrt M_{jt} yields mortgage demand:

$$M^*_{jt} = \Big(\frac{1 + i^{M*}_{jt}}{1 + i^{M*}_t}\Big)^{-\theta^M} M^*_t \tag{49}$$

where $1 + i^{M*}_t = \Big[\int_0^1 (1 + i^{M*}_{jt})^{1-\theta^M} dj\Big]^{\frac{1}{1-\theta^M}}$.

Deposit Market Savers want to maximize total repayment from deposits subject to total deposits as aggregated through a CES aggregator.

$$\max_{D_{jt}} \int_0^1 (1 + i^D_{jt}) D_{jt} dj \tag{50}$$

subject to

$$D_t = \Big[\int_0^1 D_{jt}^{\frac{\theta^D-1}{\theta^D}} dj\Big]^{\theta^D/(\theta^D-1)} \tag{51}$$

The FOC wrt D_{jt} yields deposit demand:

$$D_{jt} = \Big(\frac{1 + i^D_{jt}}{1 + i^D_t}\Big)^{-\theta^D} D_t \tag{52}$$

where $1+i^D_t = \Big[\int_0^1 (1 + i^D_{jt})^{1-\theta^D} dj\Big]^{\frac{1}{1-\theta^D}}$. $\theta^D < -1$ is the elasticity of deposit substitution across banks $j \in [0, 1]$, which means that savers put more deposits in a particular bank the higher that bank's deposit rate is.

B.3 Microfoundation of Bank CES

It may be an inaccurate representation of reality where households borrow from all banks. Ulate (2019) presents how a model where each consumer chooses to borrow from a single bank and is subject to a stochastic utility of borrowing from each bank can deliver the same demand for loans as the CES approach. The different stochastic utilities across individuals borrowing from specific banks can be due to proximity, switching costs, tastes, or asymmetric information.

Assume there is a borrower that lives for two periods, denoted 1 and 2. The borrower has a total income of $\bar{Y}$ in the second period and consumes in both periods. To consume in period 1, this borrower must borrow against their future income $\bar{Y}$ through one of a continuum of banks between zero and one. The decision process happens in two stages. In the first stage, the borrower decides which bank they want to borrow from and in the second stage, they choose the amount they want to borrow. The direct utility function of the borrower conditional on their choice of bank j is

$$U(C_{0j}, C_1) = ln(C_{0j}) + \beta ln(C_1)$$

The first period, second period, and aggregate budget constraints of the borrower are:

$$C_{0j} = B_j$$

$$C_1 = \bar{Y} - (1 + i_j^m)B_j$$

$$(1 + i_j^m)C_{0j} + C_1 = \bar{Y}$$

where $1 + i_j^m$ is the mortgage rate charged between periods 1 and 2 by bank j. The solution to this problem is:

$$C_{0j} = \frac{\bar{Y}}{(1 + \beta)(1 + i_j^m)}$$

$$C_1 = \frac{\beta \bar{Y}}{1 + \beta}$$

and indirect utility is

$$v(1+i_j^m) = (1+\beta)(ln(\bar{Y}) - ln(1+\beta)) + \beta ln(\beta) - ln(1+i_j^m).$$

As in Anderson and de Palma (1989), assume that the first stage is described by a stochastic utility approach

$$V_i = v(1+i_j^m) + \mu\epsilon_j$$

where μ is a positive constant and ϵ_j is random variable with zero mean and unit variance. ϵ_j is iid with type-1 extreme value distribution, then the probability of a borrower choosing bank j is:

$$Pr(j) = Pr\left(V_j = \max_r V_r\right) = \frac{e^{v\left(1+i_j^m\right)/\mu}}{\int_0^1 e^{v(1+i_r^m)/\mu} dr} = \frac{\left(1+i_j^m\right)^{-\frac{1}{\mu}}}{\int_0^1 \left(1+i_r^m\right)^{-\frac{1}{\mu}} dr}$$

as in McFadden et al. (1973). Substituting $1/\mu$ for $\theta^m - 1$ gives

$$Pr(j) = \frac{\left(1+i_j^m\right)^{1-\theta^m}}{\int_0^1 \left(1+i_r^m\right)^{1-\theta^m dr}} = \left(\frac{1+i_j^m}{1+i^m}\right)^{1-\theta^m}$$

where i^m is the aggregate loan rate. Multiplying C_{0j} by this probability gives:

$$C_{0j}Pr(j) = \frac{\bar{Y}}{(1+\beta)(1+i^m)} \left(\frac{1+i_j^m}{1+i^m}\right)^{-\theta^m}.$$

If we interpret $C_{0j}Pr(j)$ as the amount borrowed from bank j once the whole population of consumers is taken into account and denote this by M_j then

$$M_j = \left(\frac{1+i_j^m}{1+i^m}\right)^{-\theta^m} M$$

which is the same expression we get directly from the CES aggregator. This shows that a heterogeneous borrower approach with stochastic utility and extreme value shocks works as a microfoundation for the CES aggregator in the case of a homogeneous borrower.

References

Altavilla, C., F. Canova, and M. Ciccarelli (2019). Mending the broken link: Heterogeneous bank lending rates and monetary policy pass-through. *Journal of Monetary Economics*.

Anderson, S. P. and A. de Palma (1989). The logit as a model of product differentiation: Further results and extensions. Technical report, Discussion Paper.

Angeloni, I. and E. Faia (2013). Capital regulation and monetary policy with fragile banks. *Journal of Monetary Economics 60*(3), 311–324.

Auclert, A. (2019). Monetary policy and the redistribution channel. *American Economic Review 109*(6), 2333–67.

Bellifemine, M., R. Jamilov, and T. Monacelli (2022). Hbank: Monetary policy with heterogeneous banks.

Beraja, M., A. Fuster, E. Hurst, and J. Vavra (2019). Regional heterogeneity and the refinancing channel of monetary policy. *The Quarterly Journal of Economics 134*(1), 109–183.

Berger, D. W., K. Milbradt, F. Tourre, and J. Vavra (2018). Mortgage prepayment and path-dependent effects of monetary policy. Technical report, National Bureau of Economic Research.

Bernanke, B. and A. S. Blinder (1992). The federal funds rate and the transmission of monetary policy. *American Economic Review 82*(4), 901–21.

Bernanke, B. S. and A. S. Blinder (1988). Credit, money, and aggregate demand. Technical report, National Bureau of Economic Research.

Bianchi, J. and S. Bigio (2022). Banks, liquidity management, and monetary policy. *Econometrica 90*(1), 391–454.

Blanco, J. A. (2015). Optimal inflation target in an economy with menu costs and an occasionally binding zero lower bound. *Unpublished Paper, New York University*.

Boivin, J. and M. P. Giannoni (2006). Has monetary policy become more effective? *The Review of Economics and Statistics 88*(3), 445–462.

Boivin, J., M. T. Kiley, and F. S. Mishkin (2010). How has the monetary transmission mechanism evolved over time? In *Handbook of monetary economics*, Volume 3, pp. 369–422. Elsevier.

Campbell, J. Y., C. E. Pflueger, and L. M. Viceira (2014). *Monetary policy drivers of bond and equity risks*. Number w20070. National Bureau of Economic Research.

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*(2), 165–184.

Choi, D. B. and H.-S. Choi (2019). The effect of monetary policy on bank wholesale funding. *Management Science, forthcoming*.

Cloyne, J., C. Ferreira, and P. Surico (2020). Monetary policy when households have debt: new evidence on the transmission mechanism. *The Review of Economic Studies 87*(1), 102–129.

Corbae, D. and P. D'erasmo (2011). A quantitative model of banking industry dynamics. *manuscript, University of Wisconsin, Madison, and University of Maryland*.

Cuciniello, V. and F. M. Signoretti (2014). Large banks, loan rate markup and monetary policy. *Bank of Italy Temi di Discussione (Working Paper) No 987*.

Cúrdia, V. and M. Woodford (2016). Credit frictions and optimal monetary policy. *Journal of Monetary Economics 84*, 30–65.

Davis, M. A. and F. Ortalo-Magné (2011). Household expenditures, wages, rents. *Review of Economic Dynamics 14*(2), 248–261.

Den Haan, W. J., S. W. Sumner, and G. M. Yamashiro (2007). Bank loan portfolios and the monetary transmission mechanism. *Journal of Monetary Economics 54*(3), 904–924.

Di Maggio, M., A. Kermani, B. J. Keys, T. Piskorski, R. Ramcharan, A. Seru, and V. Yao (2017). Interest rate pass-through: Mortgage rates, household consumption, and voluntary deleveraging. *American Economic Review 107*(11), 3550–88.

Dib, A. (2010). Banks, credit market frictions, and business cycles. Technical report, Bank of Canada Working Paper.

Drechsler, I., A. Savov, and P. Schnabl (2017). The deposits channel of monetary policy. *The Quarterly Journal of Economics 132*(4), 1819–1876.

Drechsler, I., A. Savov, and P. Schnabl (2018). Banking on deposits: Maturity transformation without interest rate risk. Technical report, National Bureau of Economic Research.

Flodén, M., M. Kilström, J. Sigurdsson, and R. Vestman (2019). Household debt and monetary policy: Revealing the cash-flow channel. *Riksbank Research Paper Series* (166), 18–4.

Garriga, C., F. E. Kydland, and R. Šustek (2017). Mortgages and monetary policy. *The Review of Financial Studies 30*(10), 3337–3375.

Garriga, C., F. E. Kydland, and R. Šustek (2019). Monk: Mortgages in a new-keynesian model. Technical report, National Bureau of Economic Research.

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.

Gertler, M. and P. Karadi (2011). A model of unconventional monetary policy. *Journal of monetary Economics 58*(1), 17–34.

Gertler, M. and N. Kiyotaki (2010). Financial intermediation and credit policy in business cycle analysis. In *Handbook of monetary economics*, Volume 3, pp. 547–599. Elsevier.

Gertler, M., N. Kiyotaki, and A. Prestipino (2016). Wholesale banking and bank runs in macroeconomic modeling of financial crises. In *Handbook of macroeconomics*, Volume 2, pp. 1345–1425. Elsevier.

Gödl-Hanisch, I. et al. (2022). Bank concentration and monetary policy pass-through.

Gomez, M., A. Landier, D. Sraer, and D. Thesmar (2020). Banks? exposure to interest rate risk and the transmission of monetary policy. *Journal of Monetary Economics*.

Greenwald, D. (2018). The mortgage credit channel of macroeconomic transmission.

Guren, A. M., A. Krishnamurthy, and T. J. McQuade (2018). Mortgage design in an equilibrium model of the housing market. Technical report, National Bureau of Economic Research.

Hedlund, A., F. Karahan, K. Mitman, and S. Ozkan (2017). Monetary policy, heterogeneity, and the housing channel. *Unpublished manuscript*.

Huang, R. and L. Ratnovski (2011). The dark side of bank wholesale funding. *Journal of Financial Intermediation 20*(2), 248–263.

Hurst, E., B. J. Keys, A. Seru, and J. Vavra (2016). Regional redistribution through the us mortgage market. *American Economic Review 106*(10), 2982–3028.

Iacoviello, M. (2015). Financial business cycles. *Review of Economic Dynamics 18*(1), 140–163.

Jamilov, R. (2021). A macroeconomic model with heterogeneous banks. *Available at SSRN 3732168*.

Jamilov, R. and T. Monacelli (2021). Bewley banks. *Available at SSRN 3732172*.

Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. *American economic review 95*(1), 161–182.

Kaplan, G., K. Mitman, and G. L. Violante (2017). The housing boom and bust: Model meets evidence. Technical report, National Bureau of Economic Research.

Kaplan, G., B. Moll, and G. L. Violante (2018). Monetary policy according to hank. *American Economic Review 108*(3), 697–743.

Kashyap, A. and J. Stein (1995a). The impact of monetary policy on bank balance sheets. *Carnegie-Rochester Conference Series on Public Policy*.

Kashyap, A. K. and J. C. Stein (1995b). The role of banks in the transmission of monetary policy. *NBER Reporter*, 6.

Keys, B. J., T. Piskorski, A. Seru, and V. Yao (2014). Mortgage rates, household balance sheets, and the real economy. Technical report, National Bureau of Economic Research.

Klein, M. A. (1971). A theory of the banking firm. *Journal of money, credit and banking 3*(2), 205–218.

Krishnamurthy, A. and A. Vissing-Jorgensen (2015). The impact of treasury supply on financial sector lending and stability. *Journal of Financial Economics 118*(3), 571–600.

Kwapil, C. and J. Scharler (2010). Interest rate pass-through, monetary policy rules and macroeconomic stability. *Journal of International Money and Finance 29*(2), 236–251.

Landvoigt, T., M. Piazzesi, and M. Schneider (2015). The housing market (s) of san diego. *American Economic Review 105*(4), 1371–1407.

Luetticke, R. (2018). Transmission of monetary policy with heterogeneity in household portfolios.

Mandelman, F. S. (2010). Business cycles and monetary regimes in emerging economies: A role for a monopolistic banking sector. *Journal of International Economics 81*(1), 122–138.

McFadden, D. et al. (1973). Conditional logit analysis of qualitative choice behavior.

Meh, C. A. and K. Moran (2010). The role of bank capital in the propagation of shocks. *Journal of Economic Dynamics and Control 34*(3), 555–576.

Mertens, K. and J. L. Montiel Olea (2018). Marginal tax rates and income: New time series evidence. *The Quarterly Journal of Economics 133*(4), 1803–1884.

Mian, A., K. Rao, and A. Sufi (2013). Household balance sheets, consumption, and the economic slump. *The Quarterly Journal of Economics 128*(4), 1687–1726.

Monti, M. (1972). *Deposit, credit and interest rate determination under alternative bank objective function.* North-Holland/American Elsevier.

Nakamura, E. and J. Steinsson (2018). High-frequency identification of monetary non-neutrality: the information effect. *The Quarterly Journal of Economics 133*(3), 1283–1330.

Olivero, M. P. (2010). Market power in banking, countercyclical margins and the international transmission of business cycles. *Journal of International Economics 80*(2), 292–301.

Piazzesi, M., C. Rogers, and M. Schneider (2019). Money and banking in a new keynesian model. Technical report, Working paper, Stanford University.

Piazzesi, M. and M. Schneider (2018). Payments, credit and asset prices.

Polo, A. (2018). Imperfect pass-through to deposit rates and monetary policy transmission. *manuscript*.

Scharfstein, D. and A. Sunderam (2016). Market power in mortgage lending and the transmission of monetary policy. *Unpublished working paper. Harvard University*.

Smets, F. and R. Wouters (2007). Shocks and frictions in us business cycles: A bayesian dsge approach. *American economic review 97*(3), 586–606.

Sterk, V. and S. Tenreyro (2018). The transmission of monetary policy through redistributions and durable purchases. *Journal of Monetary Economics 99*, 124–137.

Stroebel, J. and J. Vavra (2019). House prices, local demand, and retail prices. *Journal of Political Economy 127*(3), 1391–1436.

Tella, S. D. and P. Kurlat (2017). Why are banks exposed to monetary policy? Technical report, National Bureau of Economic Research.

Ulate, M. (2019). Going negative at the zlb: The effects of negative nominal interest rates. *manuscript*.

Wang, O. (2018). Banks, low interest rates, and monetary policy transmission. *manuscript*.

Wang, Y., T. M. Whited, Y. Wu, and K. Xiao (2020). Bank market power and monetary policy transmission: Evidence from a structural estimation. Technical report, National Bureau of Economic Research.