Staff Working Paper/Document de travail du personnel—2023-35

Last updated: June 12, 2023

Monetary Policy Transmission, Bank Market Power, and Wholesale Funding Reliance

by Amina Enkhbold

Financial Stability Department
Bank of Canada
AEnkhbold@bankofcanada.ca

DOI: https://doi.org/10.34989/swp-2023-35 | **ISSN** 1701-9397

Acknowledgements

I am grateful to Serdar Ozkan, Margarida Duarte, and Michelle Alexopoulos for guidance, advice, and encouragement. This paper has benefited from discussions with Stephen Ayerst, Murat Celik, Alexandre Corhay, Pablo D'Erasmo, Jim Goldman, Katya Kartashova, Burhan Kuruscu, Cory Langlais, Jiaqi Li, Josef Schroth, Baxter Robinson, Tamon Takamura, and Xu Tian, as well as seminar participants at the Bank of Canada, Bank of Latvia, Central Bank of Chile, Ghent University, Toronto Metropolitan University, University of Manitoba, University of Oklahoma, University of Oxford, University of Toronto, Vanguard, and the World Bank. All errors are my own.

Abstract

I study the impact of banking market concentration and wholesale funding reliance on the transmission of monetary policy shocks to mortgage rates. I empirically demonstrate that in the United States, banks with higher reliance on wholesale funding in concentrated (competitive) deposit markets transmit monetary policy shocks less (more) to mortgage rates. I study 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 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 is amplified with banks shifting away from deposits more towards wholesale funding.

Topics: Monetary policy transmission, Financial institutions, Inflation targets, Wholesale funding
JEL codes: E44, E52, G21

Résumé

J'étudie les effets de la concentration du marché bancaire et de la dépendance au financement de gros sur la transmission des chocs de politique monétaire aux taux hypothécaires. Je démontre empiriquement que, aux États-Unis, les banques qui dépendent davantage du financement de gros dans les marchés des dépôts concentrés (concurrentiels) transmettent moins (plus) les chocs de politique monétaire aux taux hypothécaires. J'examine cette transmission imparfaite au moyen d'un modèle de type nouveau keynésien comportant des banques en situation de concurrence monopolistique et un accès coûteux au financement de gros. Je constate que les banques qui ont un grand pouvoir de marché et dépendent davantage du financement de gros transmettent moins la politique monétaire aux taux de rémunération des dépôts, ce qui se traduit par des passifs réduits. Cela entraîne une baisse des prêts hypothécaires, des prix des logements et de la consommation des emprunteurs. Si les chocs de politique monétaire deviennent persistants, ces effets négatifs sont amplifiés étant donné que les banques délaissent les dépôts en faveur du financement de gros.

Sujets : Transmission de la politique monétaire, Institutions financières, Cibles en matière d'inflation, Financement de gros

Codes JEL : E44, E52, G21

1 Introduction

Housing is the largest asset on most homeowners' balance sheets, and mortgages tend to be their dominant source of credit. Central banks influence the state of the economy by changing the policy interest rate, which affects commercial banks' cost of funding. In fact, banks set mortgage rates and the efficacy of monetary policy depends on borrowers' exposure to changes in mortgage rates that have been passed through banking. To understand the transmission of monetary policy, it is crucial to analyze how changes in monetary policy shocks affect households' balance sheet decisions through the effect on banks' cost of mortgage credit. Banks typically rely on two primary sources of funding: retail deposits from households and wholesale funding from institutional investors. The degree of reliance on wholesale funding, which is measured as the ratio of wholesale funding to retail deposits, varies by market concentration. The interaction between these factors is a critical determinant of the issuance 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. I make two main contributions to the literature on monetary policy transmission. First, I empirically show how the banking sector's market concentration and reliance on wholesale funding affect the transmission of monetary policy to mortgage rates. To do so, I document new panel regression results using bank- and loan-level microdata. I am the first to show that the interaction between bank market concentration and reliance on wholesale funding are important features for examining the effects of policy rate changes on economic activities. Second, I develop a model that accounts for the empirical patterns to quantify the imperfect pass-through of monetary policy shocks to mortgage rates on the aggregate economy. In my model, banks with greater market power and less costly access to wholesale funding partially respond to policy interest rate changes, which dampens the transmission of monetary policy.

I estimate how the transmission of monetary policy shocks to mortgage rates is affected by both a bank's local market concentration in deposits, measured by the Herfindahl-Hirschman Index (HHI), and its reliance on wholesale funding. I define a market as concentrated if its HHI is in the top 10%, and define a market as competitive if its HHI is in the bottom 10%. My empirical identification comes from variation both across banks within each metropolitan statistical area (MSA) and over time. I document that, in response to an increase in the policy interest rate of 100 basis points (bps), banks in concentrated markets with the greatest reliance on wholesale funding transmit 61 bps, whereas banks in competitive markets with the most reliance on wholesale funding transmit 116 bps.

The analysis shows that market concentration has a more significant effect on mortgage rates than wholesale funding reliance. However, the direction of the transmission to mortgage rates is altered by the interaction between these two factors. Specifically, the transmission of monetary policy shocks to mortgage rates increases for banks with greater reliance on wholesale funding in competitive markets, but it decreases for banks with greater reliance on wholesale funding in concentrated markets. These results suggest that wholesale funding is more costly for banks in competitive markets with enough deposit funding, but it partially alleviates deposit shortfalls in concentrated markets and smooths the transmission of monetary policy shocks to mortgage rates. Banks in concentrated markets borrow wholesale funding at higher rates than they offer on deposits because raising deposit rates on a larger pool of deposits is costlier than borrowing wholesale funding in smaller quantities.

To understand how imperfect transmission of monetary policy to mortgage rates affects economic activity, I develop a New Keynesian model where 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. When they do not meet their desired profit targets, they pay higher deposit rates to attract more deposits.

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 test the validity of the model, I run an empirical specification on simulated data from the calibrated model. The model-implied regressions are found to be qualitatively consistent with the data, indicating that the model accurately captures the observed economic relationships. I also investigate the effect of monetary policy transmission to mortgage rates and find that it is higher for banks that rely more on wholesale funding in competitive markets compared to banks in concentrated markets.

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. As a result, banks exercise their market power in deposits by partially raising deposit rates, while the rate on wholesale funding increases fully. 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 results in an increase in 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.

I quantify the role of the banking sector in transmitting monetary policy shocks through the mortgage market. I investigate the impact of a 100 bps policy rate shock on mortgage rates. My model shows an imperfect pass-through of the policy rate shock on mortgage rates, resulting in a 20 bps increase in mortgage rates. The primary contributor to this increase in mortgage rates is market power, which outweighs both wholesale funding cost and dividend adjustment cost. Banks transmit monetary policy to deposit rates at a significantly lower rate, leading to deposit outflows and increased borrowing from wholesale funding sources. As a result, there is a decrease in liability and fewer mortgage issuances, leading to lower borrower consumption due to 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 move nominal rates where deposit rates rise 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 The first contribution of the paper to the literature is that it studies 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 follow the lead of Drechsler, Savov, and Schnabl (2017) and Choi and Choi (2019) in putting deposit concentration and wholesale funding, respectively, at the center stage, but I highlight a complementary mechanism: banks with a greater reliance on wholesale funding in concentrated markets transmit monetary shocks less relative to banks in more competitive markets.

The second focus of the paper is an extension of 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. My paper complements 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) construct a New Keynesian model with a banking sector that experiences slow adjustment of retail rates due to Calvo frictions in the rate setting. I confirm the sluggishness empirically and 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.

Seminal papers such as Bernanke and Blinder (1988, 1992) and Kashyap and Stein (1995b) study the impact of reserve requirements on bank-lending behavior. Kashyap and Stein (1995b) study whether the impact of Federal Reserve policy on lending behavior is stronger for banks with less liquid balance sheets. They propose that banks with larger reserves can buffer their lending activity against external finance shocks by drawing on their stock of liquid assets. Their study finds strong evidence of such an effect for small banks. In this paper, I conduct an analogous exercise but focus on analyzing market concentration and the composition of funding rather than bank size, and assess the impact on mortgage rates. Additionally, my empirical results on the state-dependence of interest rate pass-through connect to prior research on the time-varying effects of monetary policy, as studied by Boivin and Giannoni (2006), Galí and Gambetti (2009), Boivin, Kiley, and Mishkin (2010). These studies, which rely on aggregate data and vector autoregression, have produced ambiguous results partly due to a high level of aggregation. To overcome this limitation, I utilize micro-data on bank rates, which allows me to highlight the mortgage credit channel via the banking sector and to capture the effects of a monetary policy transmission mechanism.

The third focus of the paper is 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. In Section 2, I use loan- and bank-level data to document heterogeneous mortgage rate responses to monetary policy shocks. Section 3 describes the New Keynesian framework with a monopolistic banking sector. I calibrate and assess the model in Section 4. Section 5 presents quantitative results, followed by counterfactuals in Section 6. Section 7 concludes.

2 Empirical Analysis

In this section, I document that banks with greater reliance on wholesale funding in concentrated markets are less responsive to changes in monetary policy relative to banks in competitive markets. I find that banks in concentrated markets transmit 38 to 55 bps less than banks in competitive markets in response to a contractionary monetary policy shock. Banks in competitive markets transmit monetary policy more as they rely on wholesale funding, whereas banks in concentrated markets transmit monetary policy less as they rely on wholesale funding.

2.1 Data Description

My dataset runs from the first quarter of 2000 to the first quarter of 2014. I obtain bank balance sheet data for all US commercial banks from Statistics on Depository Institutions. I use loan-level data about mortgage rates, credit scores, and loan-to-value ratio from Fannie Mae's Single Family Loan Performance Data and Freddie Mac's Single Family Loan-Level Data. I use unanticipated monetary shocks from Nakamura and Steinsson (2018), which employ a high-frequency identification approach. These shocks consist of the first principal component of unanticipated changes in prices of five federal funds and Eurodollar futures over 30-minute windows around Federal Open Market Committee announcements. Nakamura and Steinsson (2018) construct a monetary policy shock consisting of a 100 bps increase in first-year Treasury yields, using data from January 2000 to March 19, 2014, excluding the financial crisis from July 2008 to June 2009.

The population of Fannie Mae and Freddie Mac's datasets includes a subset of the 30-year, fully amortizing, full documentation, single-family, and conventional fixed-rate mortgages. The advantage of Fannie Mae and Freddie Mac datasets is that they identify lenders, thus making it easier to merge with bank balance sheet data. However, datasets provide information for the largest 35 commercial banks and exclude investment banks such as Goldman Sachs or Morgan Stanley. Monetary policy transmission to mortgage rates is for the largest 35 banks, while the measure for market concentration is from the universe of all US banks.

Definition of Key Variables

Local market concentration: I use variation in market concentration, which is measured using a standard Herfindahl-Hirschman Index (HHI). This measure is used by bank regulators and the US Department of Justice to evaluate the effect of bank mergers on competition:

$$\text{HHI}_{mt} = \sum_{b \in \{m\}} \Big(\frac{dep_{bmt}}{\sum_{b \in \{m\}} dep_{bmt}} \Big)^2$$

HHI_{mt} is calculated as the sum of squared deposit market shares of all banks b that operate in a given MSA m in a given quarter t. I use deposit market concentration for my empirical analysis because deposit and mortgage market concentrations are highly correlated and market power is coming from holding deposits. I calculate the HHI from the Statistics on Depository Institutions, which covers 7,176 banks in 380 MSAs from the first quarter of 2000 to the first quarter of 2014. I calculate HHI before merging mortgage rates with bank balance sheet information in order to capture the actual market concentration. A lower HHI indicates a lower level of market concentration and hence a higher level of competition.

For robustness, I measure market concentration using the Home Mortgage Disclosure Act (HMDA) for the mortgage market and the Summary of Deposits (SOD) for the deposit market. Figure 7 in Appendix A.1 shows the distribution of HHI in the mortgage and deposit markets. Mortgage market concentration in HMDA has a mean of 0.17 and a standard deviation of 0.15. Deposit market concentration in SOD has a mean of 0.28 and a standard deviation of 0.22. I do not use these datasets as they are annual surveys; instead, I use the Statistics on Depository Institutions and Fannie Mae and Freddie Mac, which are at the quarterly level.

Wholesale funding reliance is defined as the ratio of wholesale funding over retail deposits $\text{WFR}_{bmt} = \frac{\text{wholesale funding}}{\text{retail deposits}}$ for bank b in MSA m and quarter t. Wholesale funding is a "catch-all" term that refers to repurchase agreements, time deposits, brokered deposits, foreign deposits, federal funds, and other borrowed funds. Retail deposits consist of checking, savings, and small-time deposits. Wholesale funding is easier to access given its unlimited supply of funds (Huang and Ratnovski (2011)), but reliance on wholesale funding increases liquidity risks during market disruption. Retail deposits, in contrast, are guaranteed by the government and are risk-free, but they are limited by savers' supply of deposits.

2.2 Summary Statistics

My working sample includes microdata for the 35 largest banks in the US, with assets over $1 billion USD, located in 65 MSAs with an average population of 7 million given by the Fannie Mae and Freddie Mac datasets. Based on a unique bank-MSA-quarter identifier, I construct panel data for each bank in each MSA and quarter. For example, in a given quarter, the identifier for Bank of America in Philadelphia is different from that of Bank of America in New York, as Philadelphia mortgagors are not taking out their mortgage loans from New York. I construct a panel-level dataset at the bank level by weighting the loan-level interest rates with loan volume. Table 1 presents summary statistics from my working sample. Banks in my sample hold 27% of total deposits, 38.4% of retail deposits, 24% of mortgage loans, and 27% of wholesale funding from the universe of US banks in the Call Reports. My dataset consists of banks with assets greater than $1 billion, with an average mortgage rate of 5.4%, and an average deposit rate of 0.02%. Borrowers have an average credit score of 743 and an average loan-to-value ratio (LTV) of 73%. With respect to liabilities, bank funding is composed of 59% retail deposits and 37% wholesale funding. The average HHI is 0.43 with a standard deviation of 0.26. Mortgage loans are 55% of all loans and 35% of assets.

Table 1: Summary Statistics

Variable	Mean	Std. Dev.	Min	Max	P25	P50	P75
Wholesale funding/retail deposit	.84	1.16	.07	17.12	.35	.58	.96
Wholesale funding/liability	.37	.16	.05	1.06	.25	.35	.46
Retail deposit/liability	.59	.17	.06	.96	.49	.6	.71
Deposit rate	.02	.02	0	.1	0	.01	.02
Mortgage rate	5.4	1.3	2.77	8.47	4.19	5.61	6.26
HHI^D	.43	.26	.04	.99	.23	.35	.6
HHI^M	.42	.24	.04	.99	.24	.37	.56
MBS/Asset	.12	.09	0	.64	.06	.11	.16
Credit score	742.59	23.05	577	790.52	726.65	743.25	762.22
LTV	73.36	6.43	39.06	91.56	71.01	74.73	77.07

Summary statistics are based on the Consolidated Reports of Condition and Income (Call Reports) from 2000Q1 to 2014Q1 for US banks with size greater than $1B. All variables are quarterly. Wholesale funding includes brokered deposits, federal funds purchased, deposits held in foreign offices, time deposits, and other borrowed funds. The deposit rate is an imputed measure by dividing the total interest expense by the total deposit. The number of observations is 1,791.

2.3 Heterogeneity in Monetary Policy Transmission

I estimate whether the composition of bank funding and local market concentration affect the transmission of monetary policy shocks:

$$\begin{aligned} \Delta r_{mbt} = \alpha_b + \alpha_m + \beta_1 \Delta i_t + \beta_2 WFR_{bmt} + \beta_3 HHI_{mt} + \beta_4 WFR_{bmt} \times HHI_{mt} \\ + \beta_5 WFR_{bmt} \times \Delta i_t + \beta_6 \Delta i_t \times HHI_{mt} + \beta_7 WFR_{bmt} \times HHI_{mt} \times \Delta i_t \\ + \Gamma \text{HH Controls}_{bmt} + X \text{Bank Controls}_{bmt} + \epsilon_{mbt} \end{aligned} \quad (1)$$

where Δr_{mbt} is changes in loan-level mortgage rate at MSA m by bank b at quarter t, α_b is bank fixed effects, α_m is MSA fixed effects, and Δr_{mbt} is the change in the mortgage rate for bank b in MSA m at quarter t. The term Δi_t is the monetary shock from Nakamura and Steinsson (2018) normalized to have a +100 bps impact. The term WFR_{bmt} is the wholesale funding reliance for bank b in MSA m at quarter t, and HHI_{mt} is the local deposit concentration in MSA m at quarter t. The term HH Controls_{bmt} includes the FICO score and LTV ratio; $\text{BankControls}_{bmt}$ includes log assets, liquid asset ratio, liability interest rate, real estate loans ratio, commercial and industrial loans ratio, and mortgage-backed securities (MBS) to assets ratio.

Log assets is the log of total assets used to capture bank size. To control for the liquidity of a bank's assets, I include the liquid asset ratio, defined as liquid assets to total bank assets. The capital ratio is the ratio of total equity to total assets, resembling bank soundness. The liability interest rate is the ratio of total interest expenses to average total liability, capturing a difference in funding costs across banks. The real estate loan ratio is the fraction of real estate loans to total loans, and the commercial and industrial loans ratio is the fraction of commercial and industrial loans to total loans, which controls for differences in bank business models. I include the MBS to asset ratio to control for a bank's ability to securitize mortgages. Standard errors are clustered at the bank level for correlation within banks.

The main variable of interest is the response of changes in mortgage rates to changes in monetary policy shocks:

$$\frac{\partial \Delta r_{mbt}}{\partial \Delta i_t} = (\beta_1 + \beta_5 WFR_{bmt} + \beta_6 HHI^D_{mt} + \beta_7 WFR_{bmt} \times HHI^D_{mt}),$$

which is the sum of the coefficients that interact with Δi_t from (1). This empirical design allows us to test how the transmission of monetary shocks to mortgage rates changes for banks with a greater reliance on wholesale funding in concentrated markets. Empirical identification comes from the variation across banks after controlling for the MSA fixed effects. Deposits can be transferred across MSAs within a bank, whereas mortgage loans are location specific.

I define a market as concentrated if its HHI is in the top 10%, and define a market as competitive if its HHI is in the bottom 10% in Table 2. We can see that banks operating in concentrated markets tend to reduce their mortgage rates by 56 bps less than those in competitive markets when the policy rate increases by 100 bps. This is because banks in concentrated markets are trying to offset the negative impact of a fall in loan demand (Scharfstein and Sunderam (2016), Wang, Whited, Wu, and Xiao (2020)). On the other hand, banks that rely more heavily on wholesale funding tend to increase their mortgage rates by only 0.1 bps in response to the same increase in the policy rate. Even though wholesale funding is more expensive (Choi and Choi (2019)), it helps stabilize loan supply shocks in concentrated markets. Interestingly, the triple interaction term reveals a negative effect of 0.2 bps on the mortgage rate. This means that the interplay between market concentration and wholesale funding reliance has an impact on mortgage rates. Specifically, when monetary policy tightens, banks in concentrated markets face deposit outflows and become more dependent on wholesale funding. However, reliance on wholesale funding enables these banks to maintain lending stability, which results in a lower transmission rate compared to banks in competitive markets that do not observe deposit outflow due to perfect transmission of monetary policy to deposit rates (Drechsler, Savov, and Schnabl (2017)).

Table 2: Heterogeneous Monetary Policy Transmission

	Δr_{mbt}			
	(1)	(2)	(3)	(4)
Δi_t	1.297***	1.338***	1.152***	1.164***
	(0.135)	(0.147)	(0.154)	(0.162)
WFR_{bmt}	-0.00001	0.00001	-0.0002	-0.0002
	(0.0002)	(0.00002)	(0.00002)	(0.00002)
HHI^D_{mt}	0.0535	0.178***	0.0501	0.0699
	(0.0325)	(0.0618)	(0.0494)	(0.0528)
$HHI^D_{mt} \times WFR_{bmt}$	0.0007***	-0.000003	0.0006*	0.0005
	(0.0002)	(0.0002)	(0.0001)	(0.0001)
$\Delta i_t \times HHI^D_{mt}$	-0.439	-0.728**	-0.499	-0.566*
	(0.286)	(0.301)	(0.319)	(0.334)
$\Delta i_t \times WFR_{bmt}$	0.009***	0.001***	0.001***	0.001***
	(0.002)	(0.002)	(0.003)	(0.003)
$\Delta i_t \times HHI^D_{mt} \times WFR_{bmt}$	-0.002***	-0.002***	-0.002***	-0.002***
	(0.0006)	(0.0005)	(0.0005)	(0.0005)
Bank FE	No	No	Yes	Yes
MSA FE	No	Yes	No	Yes
R^2	0.155	0.195	0.225	0.226
F	87.54	52.89	47.76	29.49
N	878	873	868	867

Notes: Results from estimating

$$\begin{aligned}\Delta r_{mbt} = \alpha_b + \alpha_m + \beta_1 \Delta i_t + \beta_2 WFR_{bmt} + \beta_3 HHI_{mt} + \beta_4 WFR_{bmt} \times HHI_{mt} \\ + \beta_5 WFR_{bmt} \times \Delta i_t + \beta_6 \Delta i_t \times HHI_{mt} + \beta_7 WFR_{bmt} \times HHI_{mt} \times \Delta i_t \\ + \Gamma \text{HH Controls}_{bmt} + X \text{Bank Controls}_{bmt} + \epsilon_{mbt}\end{aligned}$$

where Δr_{mbt} is changes in loan-level mortgage rate at MSA m by bank b at quarter t, α_b is bank fixed effects, α_m is MSA fixed effects, WFR_{bmt} is wholesale funding reliance, HHI_{mt} is the HHI in the deposit market, Δi_t is a +100 bps monetary policy shock, HH controls include borrower's credit score and LTV, and bank controls include log assets, liquidity asset ratio, liability interest rate, real estate loans ratio, commercial and industrial loans ratio, and MBS-to-asset ratio. Standard errors are clustered at the bank level. $*p < 0.1, **p < 0.05, ***p < 0.01$.

To interpret Table 2, I plug in different percentiles of market concentration and wholesale funding reliance. The coefficient magnitudes of market concentration (β_6) are bigger than the coefficient magnitudes of wholesale funding (β_5) and the triple interaction term (β_7). Reading Table 3 from top to bottom, monetary policy transmission to mortgage rates falls as the market becomes more concentrated because banks are reducing markups to mitigate the impact of contractionary monetary policy transmission on loan demand. Even though market concentration has a larger effect than wholesale funding and the triple interaction term, the direction of monetary policy transmission switches when we read Table 3 from left to right. Starting from the 75th percentile of market concentration, the triple interaction term starts to change the direction of monetary policy transmission changes to mortgage rates. Monetary policy transmission rises as banks rely more heavily on wholesale funding in competitive markets because wholesale funding is an expensive form of funding. Banks in competitive markets have enough deposits to issue loans and they transmit additional costs of borrowing wholesale funding to mortgage rates. However, monetary policy transmission to mortgage rates falls for banks in concentrated markets as they rely more on wholesale funding. Banks in concentrated markets observe deposit outflow because they charge constant deposit spread. Borrowing wholesale funding mitigates the impact of a deposit outflow, resulting in less loan contraction.

It is important to note that although market concentration has a larger effect than wholesale funding and the triple interaction term, the direction of monetary policy transmission changes depending on the market structure. Banks in concentrated markets observe deposit outflows when monetary policy tightens, and rely more heavily on wholesale funding. This reliance on wholesale funding helps to smooth lending, and thus banks are able to transmit monetary policy at a lower rate than banks in competitive markets. Overall, the findings suggest that policymakers need to consider the interaction between market concentration and wholesale funding reliance when designing and implementing monetary policy tools to stimulate the economy.

Table 3: Heterogeneous Monetary Policy Transmission in Percentiles

	Wholesale funding reliance			
Market Concentration	P10	P50	P90	P90-P10
P10	1.084	1.085	1.159	0.075
P50	0.9702	0.9703	0.9942	0.024
P90	0.7022	0.7018	0.6075	-0.0947
P90-P10	-0.3818	-0.3832	-0.3838	-0.5515

Notes: To understand the transmission of increase of a +100 bps shock in monetary policy on mortgage rates, I plug in different percentiles of market concentration and wholesale funding reliance into $\beta_1 + \beta_5 WFR_{bmt} + \beta_6 HHI_{mt} + \beta_7 WFR_{bmt} \times HHI_{mt}$.

2.4 Empirical Analysis Takeaway

After monetary policy tightening, there is a shortfall of deposits in concentrated markets (Drechsler, Savov, and Schnabl (2017)). It is costlier for banks in concentrated markets to raise deposit rates for all deposit holdings than to access wholesale funding to mitigate the shortfall in liabilities. Although the policy rate, which is the rate where banks borrow wholesale funding, is higher than deposit rates, banks are constrained in raising deposits due to a limited supply of deposits from households. When banks in concentrated markets observe deposit outflow, they can access wholesale funding.

The interaction between market concentration and reliance on wholesale funding plays an important role when driving the heterogeneities in monetary policy transmission. Banks operating in competitive markets and relying more heavily on wholesale funding exhibit greater transmission, while those operating in concentrated markets exhibit lower transmission to mitigate the negative impact on loan demand. Despite being a relatively expensive source of funding, wholesale funding effectively mitigates loan supply shocks in concentrated markets and facilitates smooth pass-through to mortgage rates. This empirical analysis informs policymakers that the effectiveness of monetary policy tools to stimulate the economy depends on the interaction effect between market concentration and reliance on wholesale funding.

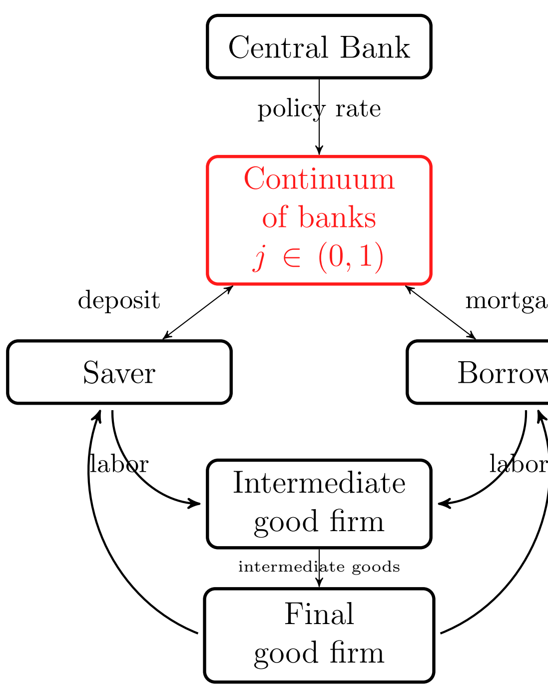
Reliance on wholesale funding is an endogenous choice; therefore, a model that interlinks market concentration and reliance on wholesale funding is needed to quantify the importance of imperfect monetary policy transmission to mortgage rates on economic activities. In my model, banks optimally choose between deposits and wholesale funding and exercise market power in both the mortgage and deposit markets.

3 Model

I now describe my model to 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.

Figure 1: Outline of the Model



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.

3.1 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.

3.2 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:

$$\max_{c_{st},n_{st},d_{st}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta_s^t U\left(c_{st}, n_{st}\right) \right], \tag{2}$$

subject to the budget constraint

$$c_{st} + d_{st} \leq \underbrace{(1-\tau_y)\, w_t n_{st}}_{\text{labor income}} - \underbrace{\delta p_t^h \bar{H}_s}_{\text{maintenance}} + \frac{(1+i_{t-1}^D) d_{st-1}}{\pi_t} + \underbrace{\Pi_t}_{\text{profits}} + T_{st}, \tag{3}$$

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.

3.3 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,

$$\max_{c_{bt},h_{bt},n_{bt},m_{bt}^*,\rho_t} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta_b^t U\left(c_{bt}, h_{bt-1}, n_{bt}\right) \right], \tag{4}$$

subject to the budget constraint

$$\begin{aligned} c_{bt} \leq\; & \underbrace{(1-\tau_y)\, w_t n_{bt}}_{\text{labor income}} - \underbrace{\frac{((1-\tau_y) x_{bt-1} + \tau_y \nu m_{bt-1})}{\pi_t}}_{\text{payment net of deduction}} + \underbrace{\rho_t \left(m_{bt}^* - (1-\nu)\frac{m_{bt-1}}{\pi_t} \right)}_{\text{new issuance}} \\ & - \underbrace{\delta p_t^h h_{bt-1}}_{\text{maintenance}} - \underbrace{\rho_t p_t^h \left(h_{bt}^* - h_{bt-1}\right)}_{\text{housing purchases}} + T_{b,t}. \end{aligned} \tag{5}$$

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:

$$m_{b,t}^{*} \leq \theta^{LTV} p_t^h h_{b,t}^{*}, \tag{6}$$

where m_{bt}^* is the balance on the new loan for borrower b in period t, θ^{LTV} is the maximum LTV ratio, p_t^h 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:

$$m_{bt} = \rho_t m_{bt}^* + (1-\rho_t)(1-\nu)\frac{m_{bt-1}}{\pi_t}. \tag{7}$$

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

$$x_{bt} = \rho_t (i_t^{M*} + \nu) m_{bt}^* + (1-\rho_t)(1-\nu)\frac{x_{bt-1}}{\pi_t}. \tag{8}$$

If a borrower chooses to refinance, they pay new loan rate i_t^{M*} 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

$$h_{bt} = \rho_t h_{bt}^* + (1-\rho_t)\, h_{bt-1}. \tag{9}$$

3.4 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 $(1+i_{jt-1}^D)d_{jt-1}$ 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}.

$$m_{jt} = d_{jt} + b_{jt} \tag{10}$$

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

Table 4: Balance sheet

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

$$x_{jt} + d_{jt+1} + b_{jt+1} - m_{jt}^* - (1+i_{jt}^D)d_{jt} - (1+i_t)b_{jt} \geq 0. \tag{11}$$

Inflow	Outflow
Nominal mortgage payment (x_{jt})	Short-term deposit payment $(1+i^D_{jt})d_{jt}$, $(1+i_t)b_{jt}$
Short-term deposit (d_{jt+1}, b_{jt+1})	New issuance (m^*_{jt})

Table 5: Cash flow in $t+1$

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

$$m_{jt} = m^*_{jt} + (1-\nu)\frac{m_{jt-1}}{\pi_t} \tag{12}$$

$$x_{jt} = (i^{M*}_{jt} + \nu)m^*_{jt} + (1-\nu)\frac{x_{jt-1}}{\pi_t} \tag{13}$$

Banks have market power over newly issued mortgages and deposits:

$$m^*_{jt} = \Big(\frac{1+i^{M*}_{jt}}{1+i^{M*}_t}\Big)^{-\theta^M} m^*_t, \tag{14}$$

$$d_{jt} = \Big(\frac{1+i^D_{jt}}{1+i^D_t}\Big)^{-\theta^D} d_t, \tag{15}$$

where θ^M is the elasticity of substitution for mortgages between banks, m^*_t is the aggregate mortgage in the economy, and i^{M*}_t 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^D_t 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 A.4.

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^D_{jt} and new mortgage rate i^{M*}_{jt},

$$\max_{i^D_{jt}, i^{M*}_{jt}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \Lambda^s_{t+1} div_{jt+1}\right], \tag{16}$$

where

$$div_{jt+1} = \frac{1}{\pi_{t+1}}\left[x_{jt} - \nu m_{jt} - i^D_{jt}d_{jt} - (i_t + \frac{\phi^B}{2}\frac{b_{jt}}{d_{jt}})b_{jt}\right] - \frac{\kappa^{div}}{2}(div_{jt} - \overline{div})^2 \tag{17}$$

subject to the balance sheet constraint (10), laws of motions (12), (13), mortgage (14), and deposit demand (15). 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.

3.5 Pricing Equations

I now explain the optimal conditions for bank innovations. The composition of bank funding costs is a critical determinant of optimal bank innovations. It is comprised of adjustment costs associated with dividends and accessing wholesale funding to generate imperfect monetary policy pass-through to mortgage rates and deposit rates.

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. Adjustment cost 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

$$1 + i_{jt}^{D} = \frac{\theta^{D}}{\theta^{D} - 1}\left[1 + i_t + \frac{\phi^{B}}{2}\right]. \tag{18}$$

The deposit rate depends on the adjustment cost of accessing wholesale funding amplified by deposit markup. Higher wholesale funding cost increases deposit rates.

The optimality condition for mortgage rate is

$$1 + i_{jt}^{M*} = \frac{\theta^{M}}{\theta^{M} - 1}\Big(1 - \nu + \frac{\Omega_{jt}^{M}}{\Omega_{jt}^{X}}\Big), \tag{19}$$

where marginal benefits 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},

$$\Omega_{jt}^{X} = \mathbb{E}_t\left[\frac{\Lambda_{t+1}^{s}}{\pi_{t+1}}\{(1-\nu)\Omega_{jt+1}^{X} + \Omega_{jt+1}\}\right], \tag{20}$$

marginal benefits 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 with wholesale funding cost

$$\Omega_{jt}^{M} = \mathbb{E}_t\left[\frac{\Lambda_{t+1}^{s}}{\pi_{t+1}}\{(1-\nu)\Omega_{jt+1}^{M} - \Omega_{jt+1}(\nu + i_t + \phi^{B}\frac{b_{jt}}{d_{jt}})\}\right], \tag{21}$$

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

$$\Omega_{jt+1} = \frac{1}{1 + \kappa^{div}(div_{jt+1} - \bar{div})}. \tag{22}$$

The imperfect pass-through of an increase in the policy rate to mortgage rates stems from rigidity in banks' interest income earned on long-duration assets in comparison to the interest paid on short-term debt, adjustment costs involved in accessing wholesale funding, and dividend smoothing. When the marginal benefits of giving an additional dollar of face value debt,

Ω^M, shrinks, monetary policy is transmitted less to mortgage rates. Higher policy rates, higher wholesale funding costs, or higher reliance on wholesale funding are attenuated by lower dividends, leading to lower Ω^M. Lower dividends increase the marginal value of profits to the bank, Ω, but decrease mortgage rate pass-through. On the contrary, banks could increase dividends to attract deposits where they do not need to access wholesale funding as much. Lower reliance on wholesale funding could counteract the effect of high wholesale funding cost, which increases deposit rates, and monetary policy transmits higher to mortgage rates. In summary, the imperfect pass-through of an increase in the policy rate to mortgage rates can be influenced by a combination of rigidity in interest income, 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.

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

$$\mathbb{E}_t\left[\frac{\Lambda_{t+1}}{\pi_{t+1}}\right](i_t + \phi^B \frac{b_{jt}}{d_{jt}}) = \mathbb{E}_t\Lambda_{t+1}\left[\Omega^M_{t+1} + i^{M*}_{jt}\Omega^X_{t+1} - 1\right]. \tag{23}$$

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

$$i^D_{jt} = i_t - \frac{\phi^B}{2}. \tag{24}$$

Market power in the model is captured through the degree of imperfect substitution across various financial products offered by banks. There is no variation in markups with the CES aggregator because the markup is homogenous across banks. Extending the monopolistic competition with the CES aggregator into an oligopolistic competition where demand is non-CES as in Kimball (1995) is possible; however, the former lends simplicity and captures imperfect transmission. In addition, due to the presence of curvature in loan demand and deposit supply, there is no need to impose a leverage constraint on banks under the CES aggregator. Kimball (1995)'s method employs a quasi-kinked demand curve where banks find it more optimal to increase mortgage rates than to decrease them. Under Kimball (1995)'s assumption, a drop in banks' relative mortgage rates triggers only a small increase in demand, but a rise in its relative mortgage rates generates a larger fall in demand.

Kimball (1995)'s method engineers variable markups that increase with relative balance sheet size. However, variable markup does not guarantee heterogeneous monetary policy transmission. Instead, adjustment costs in accessing wholesale funding and dividend smoothing, in conjunction with imperfect competition, generate variable monetary policy transmission to mortgage rates and deposit rates. In the appendix, a micro-foundation for the CES aggregator model is proposed, where heterogeneity in borrower preferences is introduced through stochastic utility and extreme value shocks. This approach offers a solution to the homogenous borrower assumption in the CES model.

3.6 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

$$y_t = \Big(\int_0^1 y_t(\omega)^{\frac{\theta-1}{\theta}} \Big)^{\frac{\theta}{\theta-1}}. \tag{25}$$

CES demands for each intermediate good ω are

$$y_t(\omega) = \Big(\frac{p_t(\omega)}{p_t} \Big)^{\theta} y_t, \tag{26}$$

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.

3.7 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):

$$\log(1 + i_t) = \phi_r \log(1 + i_{t-1}) + (1 - \phi_r) \left[(\psi_y (\log y_t - \log y) + \psi_\pi (\log \pi_t - \log \pi) \right] + \epsilon_t, \tag{27}$$

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

3.8 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.

4 Calibration

This section describes the calibration procedure. Time is quarterly. The calibrated parameter values are presented in Table 6. 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 interest rates.

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 2017. 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 $\theta^D = \frac{1+i^D}{i^D-i}$. θ^M is set to to match mortgage rates of 3.6%, while θ^D is set to match deposit rates of 0.0182%. 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).

Table 6: 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	$p^h_{ss} = 1$ 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	Mortgage rate of 5.7%	
EOS for deposit	θ^D	-34	Deposit rate of 0.028%	
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.

4.1 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 7 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 7 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.

Table 7: 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.

4.1.1 Response to Monetary Policy Shocks

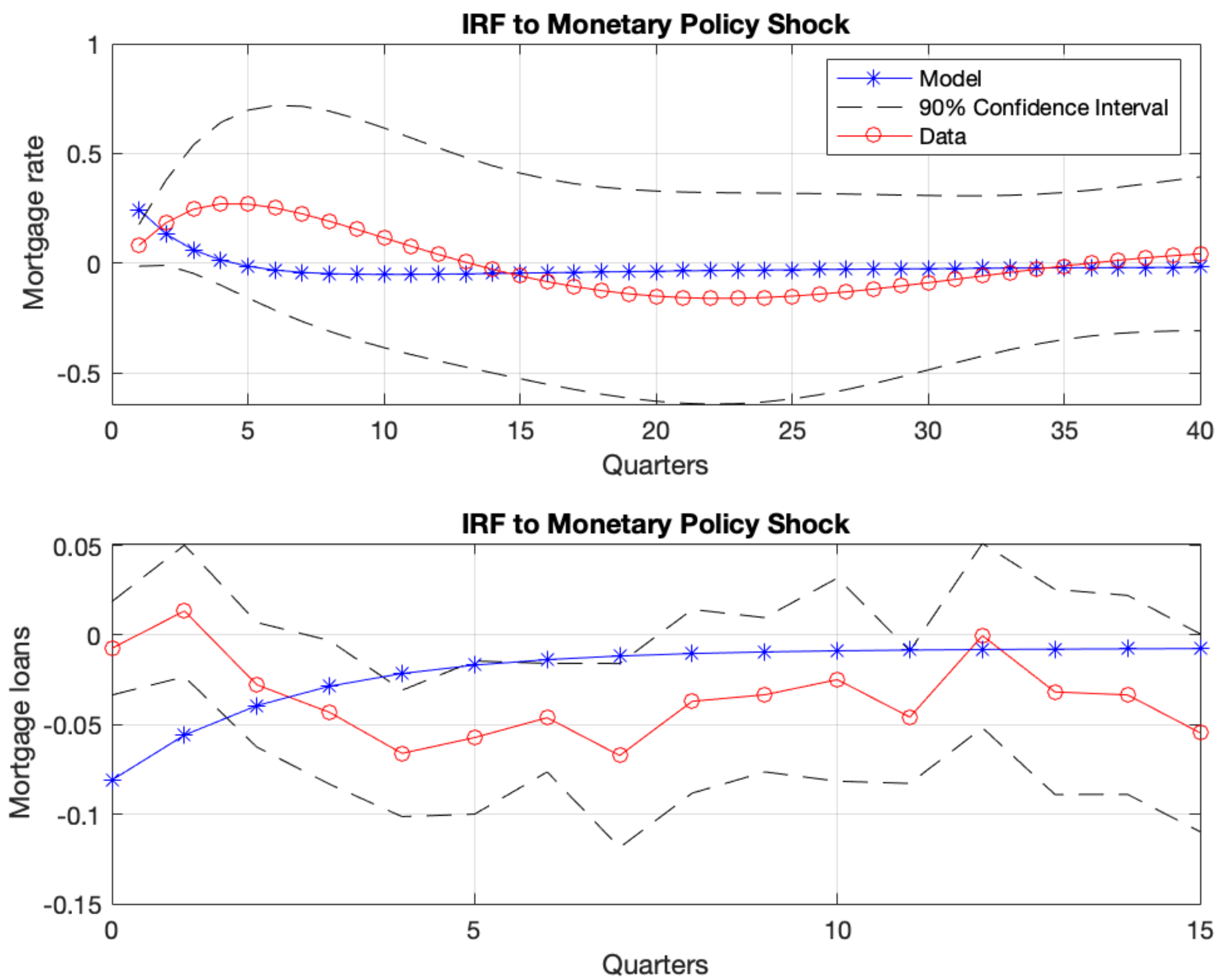
To check that the model generates reasonable dynamics, I compare the responses of bank variables to a monetary policy shock in the model and the data. For the model version, I compute impulse responses from the linearized solution around the deterministic steady state. For the data version, I apply the local projection method of Jorda (2005). Specifically, for each forecast horizon $h \geq 0$ and each variable of interest y, I run the regression

$$y_{bt+h} = \alpha_{bh} + \alpha_{mh} + \beta_h \Delta i_t + \Gamma_h^{'} X_{bt-1} + u_{bt+h}, \tag{28}$$

where the variable of interest y_{bt+h} is the mortgage rate and mortgage loans; Δi_t is the monetary policy shock; and X_{bt-1} includes bank and household controls. In this specification, fitted coefficient $\hat{\beta}_h$ represents the estimated response of the y variable to a monetary policy shock of +100 bps at quarter h after impact.

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. While the extended model improves the fit compared to the basic model, it abstracts from features such as habit persistence and labor market frictions, which, if incorporated, could generate a hump-shaped curve.

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 house price, output, labor, and consumption.

5 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.

5.1 Monetary Policy Shocks

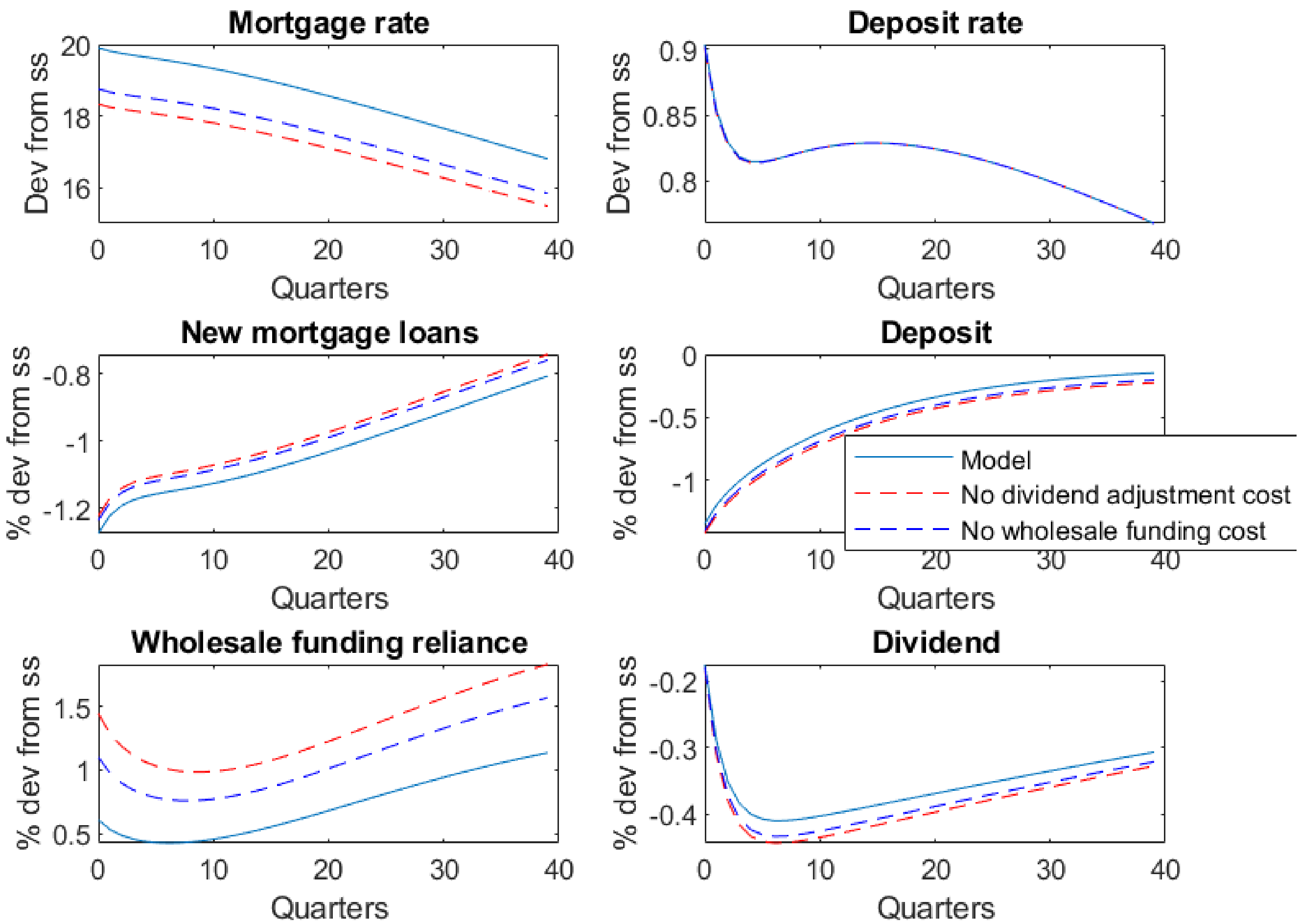
I study the effect of an unanticipated one-time increase of 100 bps in an annualized shock to the Taylor rule, followed by a perfect foresight transition back to the steady state. Figures 3 and 4 show the impulse response functions of banks and macroeconomic variables. The figure presented in this analysis 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 HELOC, 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.

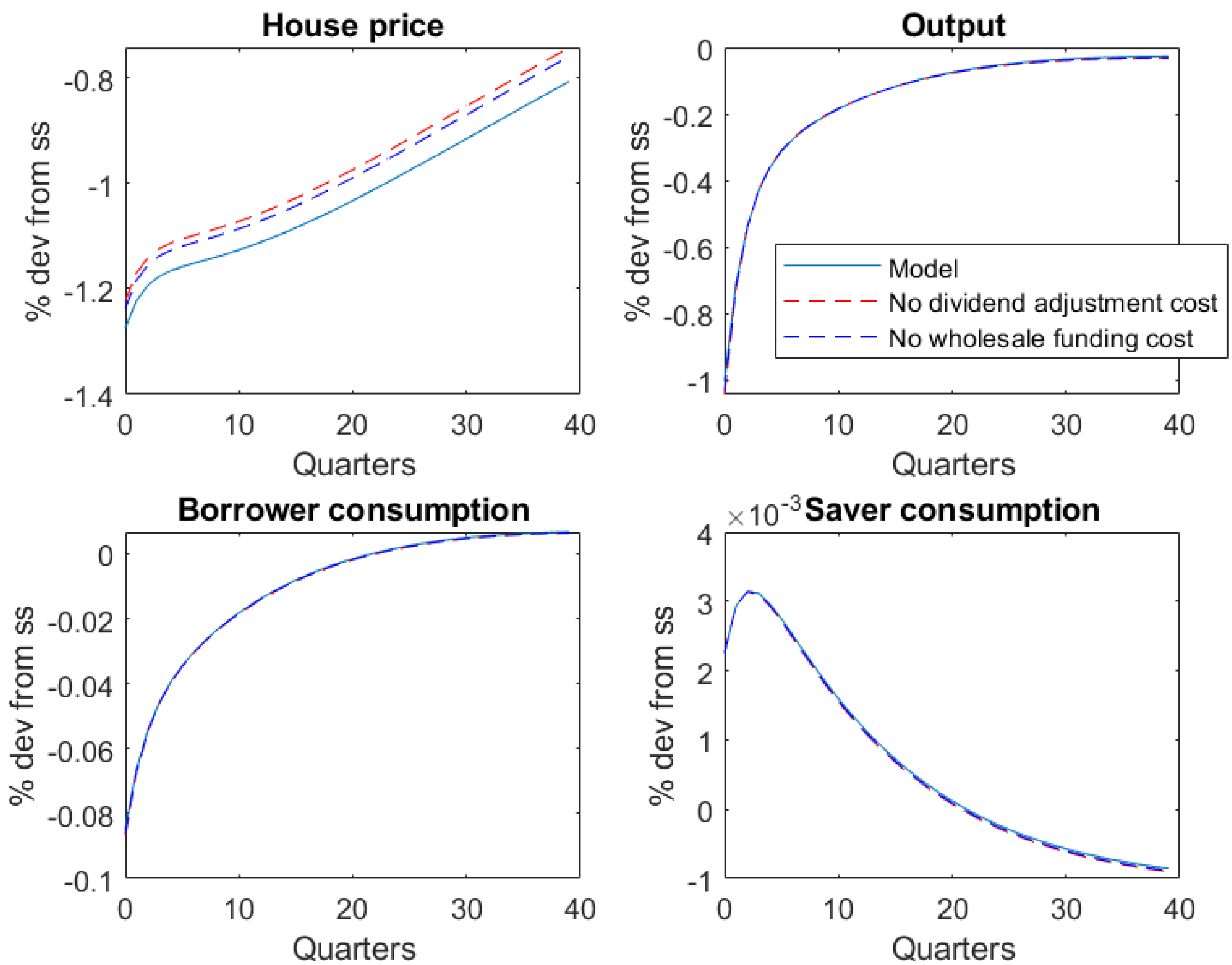
Figure 3: Response to a +100 bps Monetary Policy Shock



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 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.

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.

6 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.

6.1 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

$$\begin{aligned} \log(1+i_t) &= \log\bar{\pi}_t + \phi_r\left(\log(1+i_{t-1}) - \log\bar{\pi}_{t-1}\right) \\ &+ (1-\phi_r)\left[\left(\log(1+i_{ss}) - \log\pi_{ss}\right) + \psi_\pi\left(\log\pi_t - \log\bar{\pi}_t\right)\right], \end{aligned} \tag{29}$$

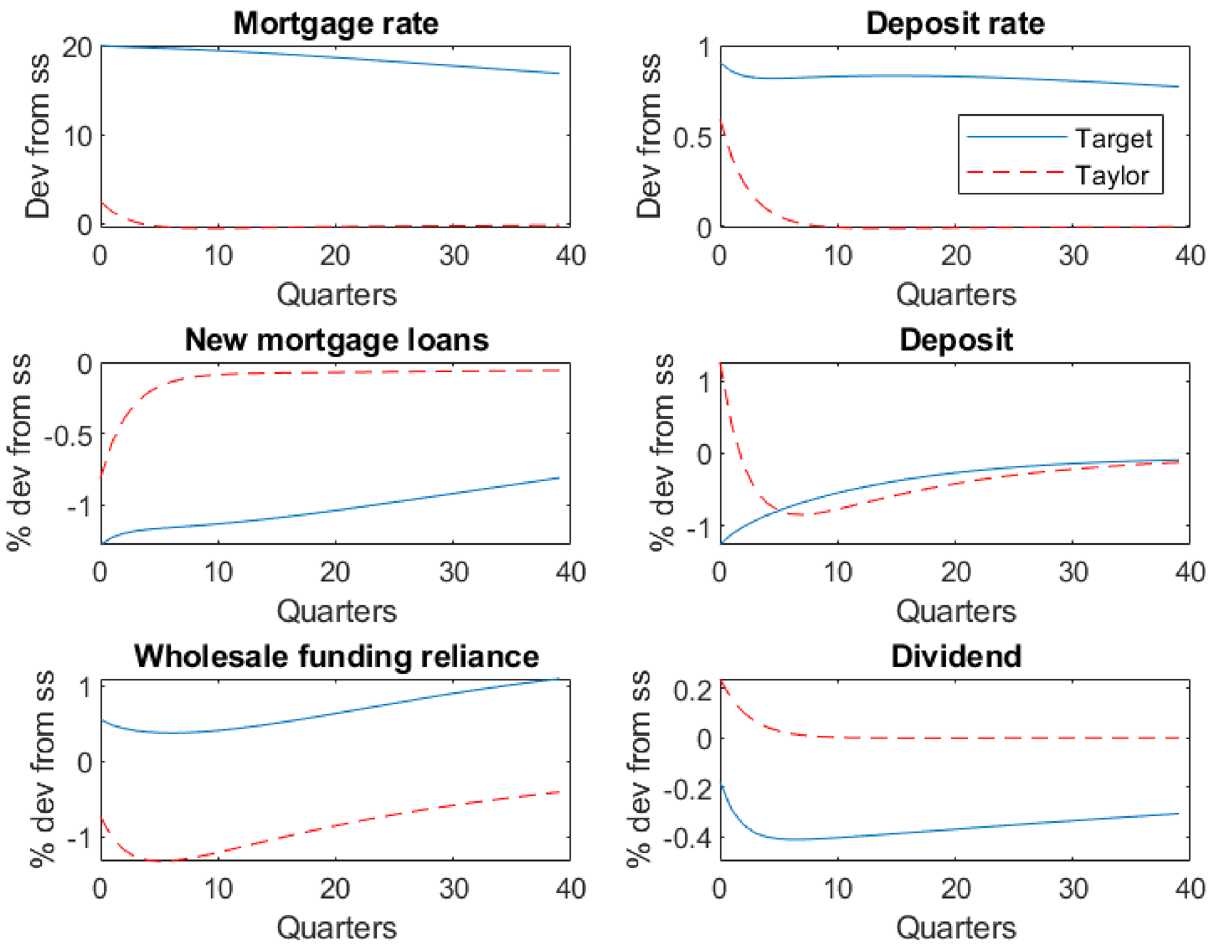
where the subscript ss refers to steady-state values, and $\bar{\pi}_t$ is a time-varying inflation target defined by

$$\log\bar{\pi}_t = (1-\psi_{\bar{\pi}})\log\pi_{ss} + \psi_{\bar{\pi}}\log\bar{\pi}_{t-1} + \varepsilon_{\bar{\pi},t}, \tag{30}$$

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.

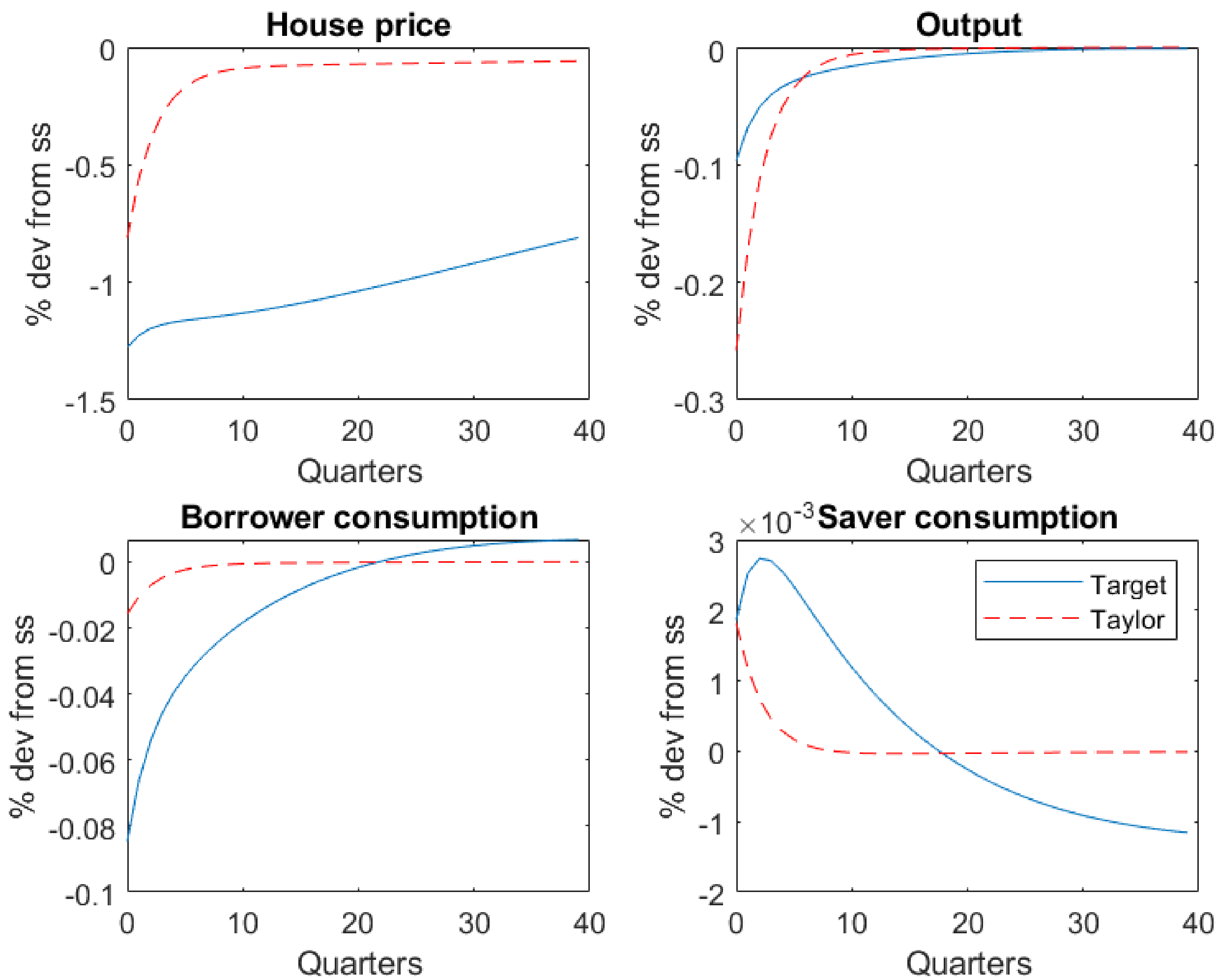
Figure 5: Response to a +100 bps Monetary Policy Shock: Taylor Rule vs Target



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.

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.

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.

7 Conclusion

My paper studies the quantitative importance of bank market power and wholesale funding reliance for monetary policy transmission to mortgage rates and economic activities. I contribute to the literature by empirically documenting that monetary policy transmission to mortgage rates varies across bank market concentration and wholesale funding. To further explore these findings, I build a New Keynesian model with monopolistically competitive banks that have costly access to wholesale funding. This model provides insight into the aggregate effects of imperfect pass-through to mortgage rates on economic activities.

Using bank-level and loan-level datasets, I find that, in response to a 100 bps increase in the policy rate, banks at the 90th percentile of wholesale funding reliance in concentrated markets transmit 61 bps, whereas banks in competitive markets transmit 116 bps. 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, assess the model against data projections, and document that the model-implied regression coefficients 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.

References

Abel, J. and A. Fuster (2018). How do mortgage refinances affect debt, default, and spending. *Evidence from HARP*.

Agarwal, S., G. Amromin, S. Chomsisengphet, T. Landvoigt, T. Piskorski, A. Seru, and V. Yao (2017). Mortgage refinancing. *Consumer Spending, and Competition: Evidence from the Home Affordable Refinancing Program*.

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.

Andrés, J. and O. Arce (2012). Banking competition, housing prices and macroeconomic stability. *The Economic Journal 122*(565), 1346–1372.

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.

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.

Brunnermeier, M. K. and Y. Koby (2016). The reversal interest rate: An effective lower bound on monetary policy. *unpublished paper, Princeton University*.

Buchak, G., G. Matvos, T. Piskorski, and A. Seru (2018). Beyond the balance sheet model of banking: Implications for bank regulation and monetary policy. *Columbia Business School Research Paper* (18-75).

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*.

Corbae, D. and P. D'Erasmo (2019). Capital requirements in a quantitative model of banking industry dynamics. Technical report, National Bureau of Economic Research.

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.

De Nicolo, G., A. Gamba, and M. Lucchetta (2014). Microprudential regulation in a dynamic model of banking. *The Review of Financial Studies 27*(7), 2097–2138.

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.

Di Maggio, M., A. Kermani, and C. J. Palmer (2020). How quantitative easing works: Evidence on the refinancing channel. *The Review of Economic Studies 87*(3), 1498–1528.

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.

Edmond, C., V. Midrigan, and D. Y. Xu (2015). Competition, markups, and the gains from international trade. *American Economic Review 105*(10), 3183–3221.

Egan, M., S. Lewellen, and A. Sunderam (2017). The cross section of bank value. 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.

Galí, J. and L. Gambetti (2009). On the sources of the great moderation. *American Economic Journal: Macroeconomics 1*(1), 26–57.

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 P. Karadi (2015). Monetary policy surprises, credit costs, and economic activity. *American Economic Journal: Macroeconomics 7*(1), 44–76.

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.

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*.

Gornemann, N., K. Kuester, and M. Nakajima (2016). Doves for the rich, hawks for the poor? distributional consequences of monetary policy.

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. (2016). Illiquidity and its discontents: Trading delays and foreclosures in the housing market. *Journal of Monetary Economics 83*, 1–13.

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

Heider, F., F. Saidi, and G. Schepens (2018). Life below zero: Bank lending under negative policy rates.

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.

Jiang, E., G. Matvos, T. Piskorski, and A. Seru (2020). Banking without deposits: Evidence from shadow bank call reports. Technical report, National Bureau of Economic Research.

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.

Kimball, M. S. (1995). The quantitative analytics of the basic neomonetarist model.

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.

Li, W., Y. Ma, and Y. Zhao (2019). The passthrough of treasury supply to bank deposit funding. *Columbia Business School Research Paper, Forthcoming*.

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*.

Rıos-Rull, J.-V., T. Takamura, and Y. Terajima (2014). Financial institution dynamics and capital regulations.

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.

Swanson, E. T. (2021). Measuring the effects of federal reserve forward guidance and asset purchases on financial markets. *Journal of Monetary Economics 118*, 32–53.

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*.

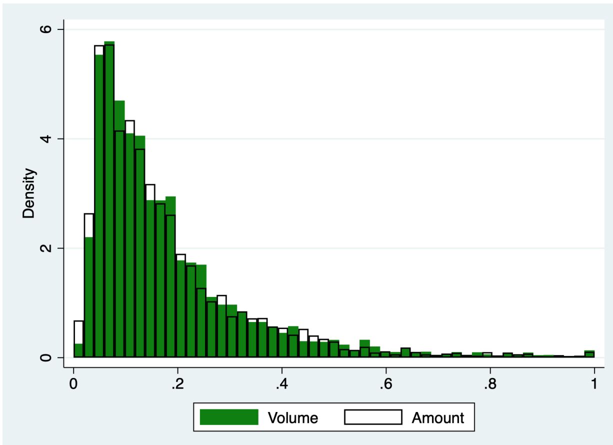
Wang, O. (2018). Banks, low interest rates, and monetary policy transmission. *manuscript*.

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.

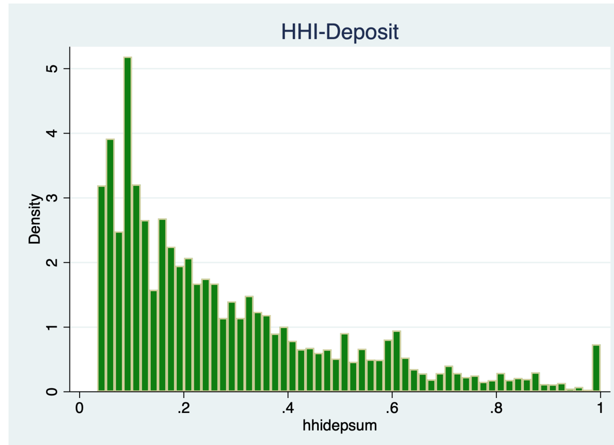
A Appendix

A.1 Empirics

Figure 7: HHI



(a) HHI-Mortgage (HMDA)



(b) HHI-Deposit (SOD)

Notes: Mortgage market concentration is constructed from the Home Mortgage Disclosure Act for loans originated in volume and amount. HHI in the mortgage market has a mean of 0.17 and a standard deviation of 0.15. Deposit HHI is constructed from the Summary of Deposits and has a mean of 0.28 and a standard deviation of 0.22.

A.2 Model Solution

Saver Optimality

Intratemporal condition

$$-\frac{U^n_{st}}{U^c_{st}} = (1-\tau_y)\, w_t \tag{31}$$

Euler equation

$$1 = (1+i^D_t)\mathbb{E}_t\left[\frac{\Lambda_{st+1}}{\pi_{t+1}}\right] \tag{32}$$

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

Tax

$$T_{st} = \tau_y w_t n_{st} \tag{33}$$

Profits

$$\Pi_t = div_t + y_t - w_t n_t \tag{34}$$

Borrower Optimality

$$P^h_t = \frac{U^h_{b,t}}{U^c_{b,t}} + \mathbb{E}_t\left[\Lambda_{b,t+1} P^h_{t+1}(\theta^{LTV} + 1 - \delta)\right] \tag{35}$$

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

$$-\frac{U^n_{b,t}}{U^c_{b,t}} = (1-\tau_y)\, w_t \tag{36}$$

The euler equation for new borrowing is

$$1 = \Omega^M_{bt} + \Omega^X_{bt} i^{M*}_t + \lambda_t \tag{37}$$

where λ_t is multiplier on borrowing constraint.

$$\rho_t = \Gamma_\gamma \{ \underbrace{(1-\Omega^M_{bt} - \Omega^X_{bt} i^M_{t-1})(m^*_{bt} - \frac{(1-\nu)m_{bt-1}}{\pi_t})}_{\text{new debt incentive}} - \underbrace{\Omega^X_{bt}(i^{M*}_t - i^M_{t-1})}_{\text{interest rate incentive}} \} \tag{38}$$

where

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

$$\Omega^X_{bt} = \mathbb{E}_t \left[\frac{\Lambda_{bt+1}}{\pi_{t+1}} \{ (1-\tau_y) + (1-\rho_{t+1})(1-\nu)\Omega^X_{bt+1} \} \right] \tag{40}$$

Firm Optimality

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

$$x_{2t} = u'(C_t) y_t + (\phi\beta) E_t (1+\pi_{t+1})^{\theta-1} x_{2t+1} \tag{42}$$

$$1 + \pi^\#_t = \frac{\theta}{\theta-1}(1+\pi_t)\frac{x_{1t}}{x_{2t}} \tag{43}$$

$$(1+\pi_t)^{1-\theta} = (1-\phi)(1+\pi^\#_t)^{1-\theta} + \phi \tag{44}$$

$$\mathcal{D}_t = (1-\phi)(1+\pi^\#_t)^{-\theta}(1+\pi_t)^\theta + \phi(1+\pi_t)^\theta \mathcal{D}_{t-1} \tag{45}$$

$$mc_t = \frac{w_t}{a_t} \tag{46}$$

$$y_t = \frac{a_t n_t}{\mathcal{D}_t} \tag{47}$$

A.3 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:

$$M_t^* = \left[\int_0^1 M_{jt}^{*\frac{\theta^M-1}{\theta^M}} dj\right]^{\theta^M/(\theta^M-1)} \tag{48}$$

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_{jt}^{M*}. Demand for the borrower can be derived from minimizing over M_{jt}^* the total repayment (including principal) due to the continuum of banks j:

$$\min_{M_{jt}^*} \int_0^1 (1 + i_{jt}^{M*}) M_{jt}^* dj \tag{49}$$

subject to the constraint given above.

The FOC wrt M_{jt} yields mortgage demand:

$$M_{jt}^* = \left(\frac{1 + i_{jt}^{M*}}{1 + i_t^{M*}}\right)^{-\theta^M} M_t^* \tag{50}$$

where $1 + i_t^{M*} = \left[\int_0^1 (1 + i_{jt}^{M*})^{1-\theta^M} dj\right]^{\frac{1}{1-\theta^M}}$.

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

$$\max_{D_{jt}} \int_0^1 (1 + i_{jt}^D) D_{jt} dj \tag{51}$$

subject to

$$D_t = \left[\int_0^1 D_{jt}^{\frac{\theta^D-1}{\theta^D}} dj\right]^{\theta^D/(\theta^D-1)} \tag{52}$$

The FOC wrt D_{jt} yields deposit demand:

$$D_{jt} = \left(\frac{1 + i_{jt}^D}{1 + i_t^D}\right)^{-\theta^D} D_t \tag{53}$$

where $1 + i_t^D = \left[\int_0^1 (1 + i_{jt}^D)^{1-\theta^D} dj\right]^{\frac{1}{1-\theta^D}}$. $\theta^D < -1$ 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.

A.4 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.