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

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Abstract

This paper studies how banking market concentration and its reliance on wholesale funding can affect the transmission of monetary policy shocks to mortgage rates. First, I document heterogeneous mortgage rate responses to monetary policy shocks. I find differential responses from banks with varying reliance on wholesale funding in concentrated markets. Second, I build a quantitative New Keynesian model with monopolistically competitive banks that have costly access to wholesale funding. In contrast to assuming a perfectly competitive banking sector, my model exhibits a dampened transmission of monetary policy on mortgage rates, consumption, and housing prices. I then study monetary policy transmission under the Basel III Liquidity Coverage Ratio rule that limits excessive reliance on wholesale funding. I find that higher market power banks with greater reliance on wholesale funding respond strongly to monetary tightening on mortgage rates. My findings provide new insights into how monetary policy affects mortgage rates through the interaction between bank competition and the cost of providing mortgage loans.

JEL Codes: E44, E52, G21

Keywords: Monetary policy transmission, market power, wholesale funding reliance

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1 Introduction

Housing is the largest asset on most homeowners' balance sheets and mortgages tend to be their dominant source of credit. While the central bank can influence the state of the economy by changing the policy interest rate, and while this influences commercial banks' cost of funding, it is ultimately the banks that set mortgage rates. As a result, the efficacy of monetary policy depends on borrowers' exposure to changes in mortgage rates that have been passed through banking. The banking sector's market concentration and reliance on wholesale funding are important features for examining the effects of policy rate changes on economic activities. Reliance on wholesale funding – defined as the ratio of wholesale funding to retail deposits, where households supply retail deposits and institutional investors provide wholesale funding – varies by market concentration, and their interaction is a crucial factor in 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 micro data. The interaction between market concentration and wholesale funding reliance has been understudied in this literature. 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 by lowering their markups, 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 (measured by the Herfindahl-Hirschman Index (HHI) of a local deposit market) and its wholesale funding reliance. 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 distribution transmit 61 bps, whereas banks in competitive markets with the most reliance on wholesale funding transmit 116 bps.

Market concentration has a larger impact on mortgage rates than wholesale funding reliance, but the interaction between the two changes the direction of the transmission to mortgage rates. While banks' transmission of monetary policy increases with reliance on wholesale funding in competitive markets, transmission decreases with wholesale funding reliance in concentrated markets. These findings suggest that wholesale funding is an expensive form of funding in competitive markets on account of sufficient deposits, but it partially mitigates deposit shortfalls in concentrated markets and smooths the pass-through onto mortgage rates.

To explain these empirical findings, I extend the Greenwald (2018) model by incorporating banking details into a general equilibrium model. Greenwald (2018) presents a New Keynesian model with a mortgage refinancing option, and the size of new loans is limited by the value of the underlying collateral and by the ratio of the mortgage payment to income. In the Greenwald (2018) model, savers and borrowers intermediate funds among themselves. I extend this framework by including a monopolistically competitive banking sector that faces financial frictions. Banks engage in maturity mismatch by lending long-term mortgages and borrowing short-term funding which consists of costly access to wholesale funding and limited supply of deposits. Banks have dividend-smoothing motives where they incur convex costs if they deviate from the target level. In my model, the size of new loans is limited only by the value of the underlying collateral.

I calibrate the steady state of the model to match moments from US microeconomic data. Given the importance of banking in the mechanisms, the model calibration pays particularly close attention to matching bank-portfolio moments, including wholesale funding cost, dividend adjustment costs, and elasticity of substitutions in mortgages and deposits. The model generates key business cycle moments that closely match mortgage and deposit rate volatilities, the correlation between mortgage rates and housing prices, and consumption and output volatilities. I run an empirical specification on simulated data from the calibrated model and find that model-implied regressions are qualitatively consistent with the data. Monetary policy transmission is higher for banks with greater reliance on wholesale funding in competitive markets relative to banks in concentrated markets.

I examine the ability of my model to analyze how market power and wholesale funding reliance replicate the empirical features of the data. Following a contractionary monetary policy, banks with market power reduce their markups to mitigate the effects of falling loan demand, which dampens the monetary policy transmission on mortgage rates. Consistent with the data, the model's mortgage rates are less responsive for banks with greater market power. Monetary tightening increases the cost of short-term funding and banks face a decrease in their profits from intermediation. Given that banks have dividend-smoothing motives, they have to adjust their dividends by raising deposits and cutting wholesale funding.

Contractionary monetary policy raises the opportunity cost of relying on wholesale funding and changes the composition of short-term funding. I use the model to examine how costlier access to wholesale funding affects the response of mortgage rates to a tightening of monetary policy. Quantitatively, I find that banks with costlier access to wholesale funding charge higher mortgage rates and issue fewer loans as they stop borrowing from wholesale funding but partially increase deposit rates to attract deposits. Overall, a rise in short-term funding rates lowers bank funding and banks facing higher wholesale funding costs issue fewer loans and charge higher mortgage rates.

I quantify the role of the banking sector in the transmission of monetary policy through the mortgage market. In a basic New Keynesian model (Iacoviello, 2015), banks costlessly transform savings into loans. Under my model, I find that a policy rate shock of +100 bps causes mortgage rates to rise by 22 bps, compared to a pass-through of 100% in a basic New Keynesian model. I show that the imperfect pass-through on mortgage rates dampens the fall in borrower consumption by 1.5 percentage points (pps) and the fall in housing prices by 1.2 pps relative to the basic New Keynesian model. The mechanism that generates imperfect pass-through of changes in the policy rate to mortgage rates relies on: i) banks having market power in deposit and mortgage markets, ii) banks engaging in maturity-mismatch, and iii) banks facing wholesale funding and dividend adjustment costs. When the Federal Reserve increases the policy rate, the cost of short-term funding increases. Banks partially raise deposit rates while the rate on wholesale funding increases fully. As a result, wholesale funding falls relative to deposits because the opportunity cost of relying on wholesale funding is higher than the opportunity cost of borrowing from deposits. Due to the rise in deposit rates and the policy rate, bank funding falls and the policy rate shock is partially transmitted to mortgage rates.

Reliance on wholesale funding increases liquidity risks during times of market disruption because wholesale funding is susceptible to bank runs. Bank assets including mortgages are illiquid and long term and the maturity mismatch between assets and short-term funding leaves banks vulnerable. Basel III Liquidity Coverage Ratio (LCR) rule restricts excessive reliance on wholesale funding and I use the model to understand how monetary policy transmission works under the new liquidity regulation. I find that banks with high market power that rely excessively on wholesale funding are affected the most by this regulation. During a monetary tightening, banks with high market power cannot borrow from wholesale funding. As a result, banks increase deposits by increasing their deposit rates. Lower funding reduces their new issuances of mortgages and amplifies the increase in mortgage rates relative to banks with low market power. Although Basel III LCR rule stabilizes the financial system, it hurts borrowers by letting them pay higher mortgage rates.

I extend the analysis to unconventional monetary policy by raising the inflation target in order to provide policymakers with more room to cut rates before reaching the zero lower bound. The inflation target shock has a persistent effect on mortgage and deposit rates, while the Taylor rule has a transitory effect. The nominal rate rises more under the Taylor rule than under the inflation targeting. As a result, deposit rates rise more and banks rely heavily on wholesale funding. Banks issue fewer mortgage loans and cause a persistent increase in mortgage rates, amplifying the decline in housing prices by 0.4 pps and the fall in borrowers' consumption by 0.5 pps.

Related Literature

The first contribution of the paper is to study how the interaction between banking market concentration and wholesale funding reliance affects the transmission of monetary policy to mortgage rates. Recent studies have focused on bank market power and wholesale funding reliance (Drechsler, Savov, and Schnabl (2017), Choi and Choi (2019), Scharfstein and Sunderam (2016), Wang, Whited, Wu, and Xiao (2020)), however, the interaction between market concentration and wholesale funding reliance 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). When retail deposit supply falls, banks borrow from wholesale funding. Choi and Choi (2019) studies how loans contract when it is costly to replace retail deposits with wholesale funding. I follow the lead of Drechsler, Savov, and Schnabl (2017) and Choi and Choi (2019) in putting deposit concentration and wholesale funding, respectively, at center stage, but highlight a complementary mechanism: banks with a greater reliance on wholesale funding in concentrated markets transmit monetary shocks less often relative to banks in competitive markets.

The second focus of the paper is extending of the New Keynesian model with a monopolistically competitive banking sector with costly access to wholesale funding. My model closely follows Greenwald (2018), which studies how the structure of the mortgage market influences macroeconomic dynamics, and Polo (2018), which embeds a banking sector into a standard New Keynesian model. While Polo (2018) focuses on deposit pass-through, whereas I study mortgage pass-through in order to evaluate 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)). Gerali et al. (2010) build a New Keynesian model that has a banking sector with sluggish adjustment of retail rates due to Calvo frictions in the rate setting. I confirm the sluggishness empirically and use a quadratic adjustment cost in order to have an imperfect pass-through to mortgage rates. Unlike the standard New Keynesian literature, which typically 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) study 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 choice between deposit and wholesale funding into the basic New Keynesian model.

Seminal papers on the bank lending channel of monetary policy, such as Bernanke and Blinder (1988, 1992) and Kashyap and Stein (1995b), rely on reserve requirements. Kashyap and Stein (1995b) study whether the impact of Federal Reserve policy on lending behavior is stronger for banks with less liquid balance sheets. Their main mechanism relies on the idea that by drawing on their stock of liquid assets, banks with larger reserves should be better able to buffer their lending activity against shocks in the availability of external finance. They find strong evidence of an effect for small banks. I conduct an analogous exercise but analyze market concentration and the composition of funding rather than bank size and looking at the effect on mortgage rates. Lastly, my empirical results on the state-dependence of interest rate pass-through connect to work investigating the time-varying effects of monetary policy (Boivin and Giannoni (2006), Galí and Gambetti (2009), Boivin, Kiley, and Mishkin (2010)). The results of this literature using aggregate data and vector autoregression are ambiguous, partly because of the high level of aggregation. I use micro-data on bank rates instead to highlight a mortgage credit channel via the banking sector to capture the effect of a monetary policy transmission mechanism.

The third focus of the paper analyzes the transmission of monetary policy through banks' balance sheets. While my paper mainly focuses on banks, it connects to recent work on monetary policy in incomplete markets that studies heterogeneity in household balance sheets (Kaplan, Moll, and Violante (2018), Auclert (2019)). The following papers argue for mortgage rates importance in the transmission of monetary policy. Di Maggio et al. (2017) study household balance sheets and mortgage contract rigidity for monetary policy pass-through. They find that areas with a larger share of adjustable-rate mortgages are more responsive to lower interest rates, which induces a significant increase in car purchases. Berger et al. (2018) argue that fixed-rate prepayable mortgage contracts lead to 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-LTV environment. Guren et al. (2018) analyze how mortgage design interacts with monetary policy and finds that designs that raise mortgage payments in booms and lower them in recessions do better than fixed-rate mortgage payments. I contribute to the monetary policy transmission literature by analyzing the mortgage credit channel through the heterogeneity in banks' market concentration and wholesale funding reliance.

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 introduces the basic model in which the banking sector is perfectly competitive. Section 4 describes the New Keynesian framework with a monopolistic banking sector, followed by discussion on the qualitative insights of the model in Section 5. I calibrate and assess the model in Section 6. Section 7 presents quantitative results, followed by counterfactuals in Section 8. Section 9 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 fewer 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 fewer 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 score, 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.

Definition of Key Variables

Local market concentration: I use variation in deposit 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 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 also measure market concentration using the Home Mortgage Disclosure Act (HMDA) for mortgage market and the Summary of Deposits (SOD) for the deposit market. Figure 14 in Appendix A.1.1 shows the distribution of HHI in the mortgage and deposit markets. Mortgage market concentration in HMDA has mean of 0.17 and standard deviation of 0.15. Deposit market concentration in SOD has mean of 0.28 and standard deviation of 0.22. I do not use these datasets as they are annual surveys and elect to instead use the Statistics on Depository Institutions and Fannie Mae and Freddie Mac, which are at the quarterly level.

Wholesale funding reliance: $\text{WFR}_{bmt} = \frac{\text{wholesale funding}}{\text{retail deposits}}$ 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, and federal funds. Retail deposits consist of checking, savings, and small-time deposits. Wholesale funding is easier to access given its infinite supply, 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.

Summary statistics My working sample includes micro data 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 9 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% is 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.

2.2 Heterogeneity in Monetary Policy Transmission

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

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

where 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; 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 control 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 a concentrated market. 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.

Table 1 shows that banks in a concentrated market reduce their mortgage rates by 56 bps in response to a 100 bps increase in the policy rate. One explanation is that banks reduce their markups to mitigate the effects of a fall in loan demand. Banks with a greater reliance on wholesale funding increase their mortgage rates by 0.1 bps in response to a 100 bps increase in the policy rate because wholesale funding is an expensive form of funding. The triple interaction term shows a negative effect on the mortgage rate of 0.2 bps. When monetary policy tightens, banks in concentrated markets experience deposit outflows and rely more heavily on wholesale funding. Wholesale funding smooths lending, and thus banks are able to transmit monetary policy at a lower rate.

Columns (1) and (3) of Table 1 show that market concentration does not play a statistically significant role. Geographic variation mutes the impact of monetary shocks through market concentration on mortgage rates. However, the interaction between wholesale funding and monetary policy shocks and the triple interaction are statistically significant throughout different specifications.

Table 1: Heterogeneity in 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)
HHI^D_{mt}	0.0535	0.178***	0.0501	0.0699
	(0.0325)	(0.0618)	(0.0494)	(0.0528)
$\Delta i_t \times HHI^D_{mt}$	-0.439	-0.728**	-0.499	-0.566*
	(0.286)	(0.301)	(0.319)	(0.334)
WFR_{bmt}	-0.00001	0.00001	-0.0002	-0.0002
	(0.0002)	(0.00002)	(0.00002)	(0.00002)
$\Delta i_t \times WFR_{bmt}$	0.009***	0.001***	0.001***	0.001***
	(0.002)	(0.002)	(0.003)	(0.003)
$HHI^D_{mt} \times WFR_{bmt}$	0.0007***	-0.000003	0.0006*	0.0005
	(0.0002)	(0.0002)	(0.0001)	(0.0001)
$\Delta i_t \times HHI^D_{mt} \times WFR_{bmt}$	-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 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. $***p < 0.01, **p < 0.05, *p < 0.1$.

Even though the coefficient magnitudes of wholesale funding (β_5) and the triple interaction term (β_7) are smaller than that of market concentration (β_6), I show that the interaction effect between market concentration and wholesale funding as well as the direct effect of market concentration play economically significant roles in table 2. Reading table 2 from left to right, we see that the direction of monetary policy transmission switches. Monetary policy transmission rises as banks rely more heavily on wholesale funding in a competitive market, whereas it falls as banks rely more heavily on wholesale funding in a concentrated market. I plug in different percentiles of market concentration and wholesale funding reliance to interpret Table 1. Table 2 shows that holding market concentration constant at the 10th percentile HHI value, monetary policy transmission rises as wholesale funding reliance increases. This is because wholesale funding is an expensive form of funding. Holding market concentration constant at the 90th percentile, we see that the transmission falls as wholesale funding reliance rises. Wholesale funding mitigates the impact of deposit outflow and results in less loan contraction. The transmission falls as the market becomes more concentrated because banks are reducing markups to mitigate the effect of loan demand.

Table 2: Heterogeneity in monetary policy transmission

	Wholesale funding reliance					
Market Concentration	P10	P25	P50	P75	P90	P90-P10
P10	1.084	1.084	1.085	1.085	1.159	0.075
P25	1.039	1.039	1.039	1.039	1.093	0.054
P50	0.9702	0.9703	0.9703	0.9705	0.9942	0.024
P75	0.8391	0.839	0.8389	0.8387	0.8049	-0.0342
P90	0.7022	0.7021	0.7018	0.7012	0.6075	-0.0947
P90-P10	-0.3818	-0.3819	-0.3832	-0.3838	-0.5515	

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

Empirical Analysis Takeaway The interaction between market concentration and wholesale funding reliance plays an important role when driving the heterogeneities in monetary policy transmission. Banks in competitive markets with greater reliance on wholesale funding transmit more, whereas banks in concentrated markets transmit less to mitigate the effects of a fall in loan demand. Although wholesale funding is an expensive form of funding, it mitigates the loan supply shock in a concentrated market and smooths the pass-through on mortgage rates.

These results demonstrate that access to non-deposit funding in a concentrated market is influential in the transmission of mortgage rates; existing literature has attributed market-wide pricing power as the key driver of deposit 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 wholesale funding reliance. Wholesale funding reliance is an endogenous choice; therefore, a model that interlinks market concentration and wholesale funding reliance is needed to quantify the importance of imperfect monetary policy transmission on the aggregate economy. In my model, banks optimally choose between deposits and wholesale funding and have market power in the mortgage and deposit market.

3 The Basic Model

This section contains a standard New Keynesian model with a competitive banking sector to explain how monetary policy is transmitted into the mortgage market and aggregate economy. Consider a discrete time and infinite horizon economy populated by borrowers and savers. Savers work and consume. Borrowers consume, work, and demand housing, and because of their high level of impatience, they accumulate only the required net worth to finance a down payment on their home. I allow housing investment by borrowers and assume that housing is fixed in the aggregate. There is a production sector and a central bank. The production sector works under nominal rigidity, and the central bank adjusts its policy rate according to the Taylor rule. I discuss problems of the production sector and the central bank in Section 4.

Saver Each saver chooses consumption c_{st}, deposits d_t, and labor supply n_{st} to solve the following intertemporal problem:

$$\max_{c_{st},d_t,n_{st}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_s^t \left[\log\left(\frac{c_{st}}{\chi}\right) - \frac{\left(\frac{n_{st}}{\chi}\right)^{1+\eta}}{1+\eta} \right], \tag{2}$$

where β_s^t is the discount factor, subject to the budget constraint

$$c_{st} + d_t = w_t n_{st} + \frac{(1+i_{t-1}^D)}{\pi_t} d_{t-1} + \Pi_t, \tag{3}$$

where d_t denotes bank deposits earning a predetermined, gross return $1+i_t^D$ on deposits, w_t is the real wage rate, and Π_t are profits from the intermediate firm. The expression $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross rate of inflation.

Borrower Each borrower chooses consumption c_{bt}, housing h_t, mortgage loan m_t, and labor n_{bt},

$$\max_{c_{bt},h_t,n_{bt}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_b^t \left[\log(\frac{c_{bt}}{1-\chi}) + \psi \log\left(\frac{h_{t-1}}{1-\chi}\right) - \frac{(\frac{n_{bt}}{1-\chi})^{1+\eta}}{1+\eta} \right], \tag{4}$$

subject to the budget constraint and borrowing constraint, respectively,

$$c_{bt} + p_t^h(h_t - h_{t-1}) + \frac{(1+i_{t-1}^M)}{\pi_t} m_{t-1} = w_t n_{bt} + m_t, \tag{5}$$

$$m_t \leq \theta^{LTV} p_t^h h_t \tag{6}$$

where θ^{LTV} is the maximum LTV ratio and p_t^h is the housing price.

Bank The representative bank solves the following problem:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_f^t \log c_{ft}, \tag{7}$$

subject to

$$c_{ft} + \frac{(1+i^D_{t-1})}{\pi_t}d_{t-1} + m_t = d_t + \frac{(1+i^M_{t-1})}{\pi_t}m_{t-1} + \frac{(1+i_{t-1})}{\pi_t}b_{t-1}, \tag{8}$$

where c_{ft} is the banker's private consumption after deposits have been repaid and loans have been issued. Banks borrow wholesale funding b_t in central bank at the policy rate i_t. Banks also face borrowing and balance sheet constraints, respectively:

$$d_t \leq \gamma m_t. \tag{9}$$

Bank liabilities d_t are bounded by the fraction of bank assets that can be used as collateral,

$$d_t = m_t + b_t, \tag{10}$$

where short-term funding is used to finance loans,

$$c_{ft} - \frac{(i_{t-1} - i^D_{t-1})}{\pi_t}d_{t-1} + m_t = d_t + \frac{(i^M_{t-1} - i_{t-1})}{\pi_t}m_{t-1}. \tag{11}$$

Market clearing conditions The market clearing conditions for labor, housing and goods are respectively:

$$n_{bt} + n_{st} = n_t$$
$$h_{bt} = \overline{h}$$
$$c_{bt} + c_{st} + c_{ft} = y_t.$$

3.1 The Role of Banking

The implicit assumption in this basic model is that borrowers will always pay their debts, even during declines in housing value. As a consequence, banks are insulated from movements in housing wealth. However, reductions in housing prices led to smaller repayments, and some borrowers defaulted when the market value of their house dropped below the face value of their debt. Smaller repayments affect banks' net worth. If banks are able to absorb these losses by raising capital or by borrowing alternative funding, a fall in repayments could be absorbed. If banks face credit constraints, however, a negative repayment shock would cause a loss for banks. Therefore, it is vital that the model incorporates a banking sector that engages in maturity mismatch by lending long-term mortgages and borrowing short-term funding with costly access to wholesale funding is needed.

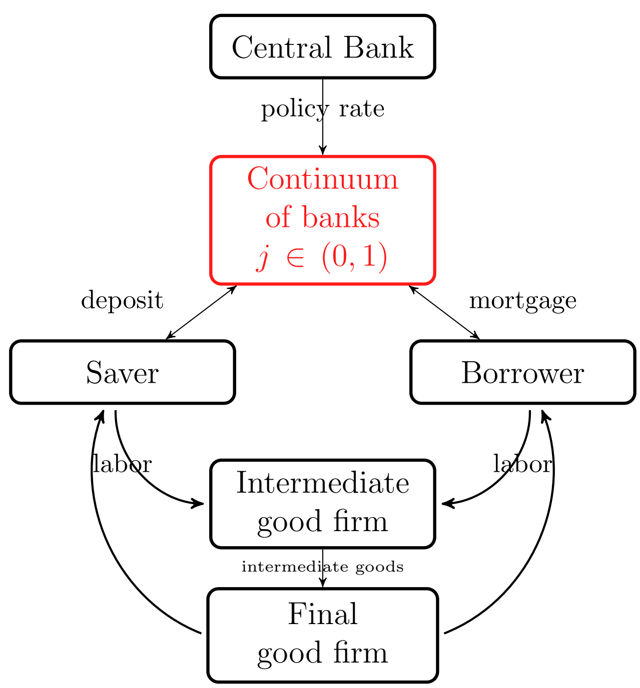
Section 4 discusses the agent problem in detail. For model completeness, I add a fixed housing stock for savers for model completeness. I incorporate a refinancing decision and a long-term mortgage structure with evolution of mortgage payments and outstanding mortgage debt. Most importantly, I allow the banking sector to have market power in deposit and mortgage markets with costly access to wholesale funding and have a dividend-smoothing motive. I need both monopolistic competition and quadratic adjustment costs to generate imperfect pass-through. A perfectly competitive banking sector would yield perfect pass-through. Extending the monopolistic competition into oligopolistic competition is possible; however, the former lends simplicity and captures imperfect transmission. Costly access to wholesale funding is needed so that wholesale funding does not comprise the entirety of bank borrowing.

4 Extended Model

I present a New Keynesian model with monopolistically competitive banks. 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 endogeneously. 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, and 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 $(1-\nu)^k(i^{M*}_{jt}+\nu)$ 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^{M*}_{jt} 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 $m^*_{bt} \leq \theta^{LTV} p^h_t h^*_{bt}$, where m^*_{bt} is the balance on the new loan, θ^{LTV} is the maximum LTV ratio, p^h_t 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. The rate on wholesale funding is the policy rate set by the central bank. Deposits are imperfectly substituted by banks because of their market concentration. One dollar of deposits pays a rate $1 + i^D_{jt}$ 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 were 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.

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 and have separable preferences over consumption of the final good c_{st} and stock of housing $\bar{H}_s$ and 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 steady state.

4.1 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:

$$\max_{c_{st},n_{st},d_{st}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta_s^t U\left(c_{st}, n_{st}\right) \right], \tag{12}$$

subject to the budget constraint

$$c_{st} + d_{st} \leq \underbrace{\left(1-\tau_y\right) w_t n_{st}}_{\text{labor income}} - \underbrace{\delta p_t^h \bar{H}_s}_{\text{maintenance}} + \frac{(1+i_{t-1}^D) d_{st-1}}{\pi_t} + \underbrace{\Pi_t}_{\text{profits}} + T_{st}, \tag{13}$$

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. She gets 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.

4.2 Representative Borrower's Problem

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,

$$\max_{c_{bt},h_{bt},n_{bt},m_{bt}^*,\rho_t} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta_b^t U\left(c_{bt}, h_{bt-1}, n_{bt}\right) \right], \tag{14}$$

subject to the budget constraint

$$\begin{aligned} c_{bt} \leq \underbrace{\left(1-\tau_y\right) w_t n_{bt}}_{\text{labor income}} &- \underbrace{\frac{((1-\tau_y) x_{bt-1} + \tau_y \nu m_{bt-1})}{\pi_t}}_{\text{payment net of deduction}} + \underbrace{\rho_t \left(m_{bt}^* - (1-\nu) \frac{m_{bt-1}}{\pi_t} \right)}_{\text{new issuance}} \\ &- \underbrace{\delta p_t^h h_{bt-1}}_{\text{maintenance}} - \underbrace{\rho_t p_t^h \left(h_{bt}^* - h_{bt-1}\right)}_{\text{housing purchases}} + T_{b,t} - \underbrace{\iota(\rho_t, m_{b,t}^*)}_{\text{transaction cost}}. \end{aligned} \tag{15}$$

The borrower's labor income $w_t n_{bt}$ is taxed at rate τ_y which she gets 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, she needs to pay all of her non-repaid loans in order to receive newly issued mortgages and a transaction cost $\iota(\rho_t, m_{b,t}^*)$. She pays the maintenance cost of housing and the difference between the new house and old house if she chooses to refinance.

Her new borrowing is subject to the LTV constraint:

$$m_{b,t}^* \leq \theta^{LTV} p_t^h h_{b,t}^*, \tag{16}$$

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

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

$$m_{bt} = \rho_t m^*_{bt} + (1-\rho_t)(1-\nu)\frac{m_{bt-1}}{\pi_t}. \tag{17}$$

The mortgage payment she makes in each period t consists of

$$x_{bt} = \rho_t (i^{M*}_t + \nu) m^*_{bt} + (1-\rho_t)(1-\nu)\frac{x_{bt-1}}{\pi_t}. \tag{18}$$

If a borrower chooses to refinance, she pays new loan rate i^{M*}_t and principal ν toward her new loan m^*_{bt}. If she does not refinance, then she pays toward a non-repaid loan.

The law of motion for housing is

$$h_{bt} = \rho_t h^*_{bt} + (1-\rho_t)\, h_{bt-1}. \tag{19}$$

4.3 Bank's Problem

Banks are owned by savers. Each bank $j \in [0,1]$ enters period t with total payments to be collected from borrowers on outstanding mortgages x_{jt-1}, total principal on outstanding mortgages m_{jt-1}, and payments on short-term funding $(1+i^D_{jt-1})d_{jt-1}$ and $(1+i_{t-1})b_{jt-1}$. New mortgages and loans that are not repaid are funded by retail deposit d_{jt} and wholesale funding b_{jt}.

$$m_{jt} = d_{jt} + b_{jt} \tag{20}$$

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

Table 3: 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

$$x_{jt} + d_{jt+1} + b_{jt+1} - m^*_{jt} - (1+i^D_{jt})d_{jt} - (1+i_t)b_{jt} \geq 0 \tag{21}$$

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 4: 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

$$m_{jt} = m^*_{jt} + (1-\nu)\frac{m_{jt-1}}{\pi_t} \tag{22}$$

$$x_{jt} = (i^{M*}_{jt} + \nu)m^*_{jt} + (1-\nu)\frac{x_{jt-1}}{\pi_t} \tag{23}$$

Banks have market power over newly issued mortgages and deposits:

$$m^*_{jt} = \Big(\frac{1+i^{M*}_{jt}}{1+i^{M*}_t}\Big)^{-\theta^M} m^*_t, \tag{24}$$

$$d_{jt} = \Big(\frac{1+i^{D}_{jt}}{1+i^{D}_t}\Big)^{-\theta^D} d_t, \tag{25}$$

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.6.

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},

$$\max_{i^D_{jt}, i^{M*}_{jt}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \Lambda^s_{t+1} div_{jt+1}\right], \tag{26}$$

where

$$div_{jt+1} = \frac{1}{\pi_{t+1}}\left[x_{jt} - m^*_{jt} - i^D_{jt}d_{jt} - (i_t + \frac{\phi^B}{2}\frac{b_{jt}}{d_{jt}})b_{jt}\right] - \frac{\kappa^{div}}{2}(div_{jt} - \overline{div})^2 \tag{27}$$

subject to the balance sheet constraint (20), laws of motions (22), (23), mortgage (24), and deposit demand (25). 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.

4.4 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

$$y_t = \Big(\int_0^1 y_t(\omega)^{\frac{\theta-1}{\theta}} \Big)^{\frac{\theta}{\theta-1}}. \tag{28}$$

CES demands for each intermediate good ω are

$$y_t(\omega) = \Big(\frac{p_t(\omega)}{p_t} \Big)^{\theta} y_t, \tag{29}$$

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 good 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 $\epsilon_{A,t+1}$ is a TFP shock. Intermediate good producers are subject to price stickiness of the 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.

4.5 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):

$$\log(1+i_t) = \phi_r \log(1+i_{t-1}) + (1-\phi_r)\left[(\psi_y(\log y_t - \log y) + \psi_\pi(\log \pi_t - \log \pi)\right] + \epsilon_t, \tag{30}$$

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

4.6 Equilibrium

A 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:

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

$$h_{bt} + \bar{H}_s = \bar{H}$$
$$c_{bt} + c_{st} + \delta p_t^h \bar{H} + f(div_t) = y_t$$
$$(1-\chi)m_{bt}^* = m_t^* = \left[\int_0^1 (m_{jt}^*)^{\frac{\theta^{M*}-1}{\theta^{M*}}} dj\right]^{\frac{\theta^{M*}}{\theta^{M*}-1}}$$
$$\chi d_{st} = d_t = \left[\int_0^1 (d_{jt})^{\frac{\theta^D-1}{\theta^D}} dj\right]^{\frac{\theta^D}{\theta^D-1}}$$
$$\int_0^1 b_{jt} = 0.$$

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.

5 Mortgage Credit Channel of Monetary Policy

Before performing the quantitative analysis, I theoretically characterize the mortgage credit channel through which monetary policy affects the mortgage rate via the banking sector in my model. This section illustrates the mechanism that generates imperfect pass-through of the policy rate to the mortgage rate.

A contractionary monetary policy shock is transmitted to the aggregate economy via (i) intertemporal substitution effects, (ii) general equilibrium effects where a contractionary shock lowers aggregate demand and labor income, and (iii) the interaction of higher cost of issuing loans and bank competition. In this section, I focus on the latter where monetary tightening raises banks' funding costs and the steepness depends on bank's market power.

Figure 2 plots the marginal benefit (MB) and marginal cost (MC) of issuing loans as a function of mortgages. The marginal benefit of issuing mortgages is derived from the optimality condition of the mortgage:

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

where $\Omega_{jt+1} = \frac{1}{1+\kappa^{div}(div_{jt+1}-\bar{div})}$ and $div_{jt+1} = \frac{1}{\pi_{t+1}}\left[x_{jt} - \nu m_{jt} - i_{jt}^D d_{jt} - i_t b_{jt}\right]$. After rearranging equations in steady state,

$$i^{M*} = a - \frac{\Gamma}{\kappa \Omega^M}\phi^B \frac{m}{d},$$

where $a = \bar{div} - \frac{1}{\kappa^{div}} + (i^D d + ib)\frac{\nu}{m^*} - (\nu + i - \phi^B)\frac{\Gamma}{\kappa^{div}\Omega^M}$ and $\Gamma = \frac{\beta}{1-\beta(1-\nu)}$. The mortgage rate is related negatively to mortgage loans, so MB is downward sloping.

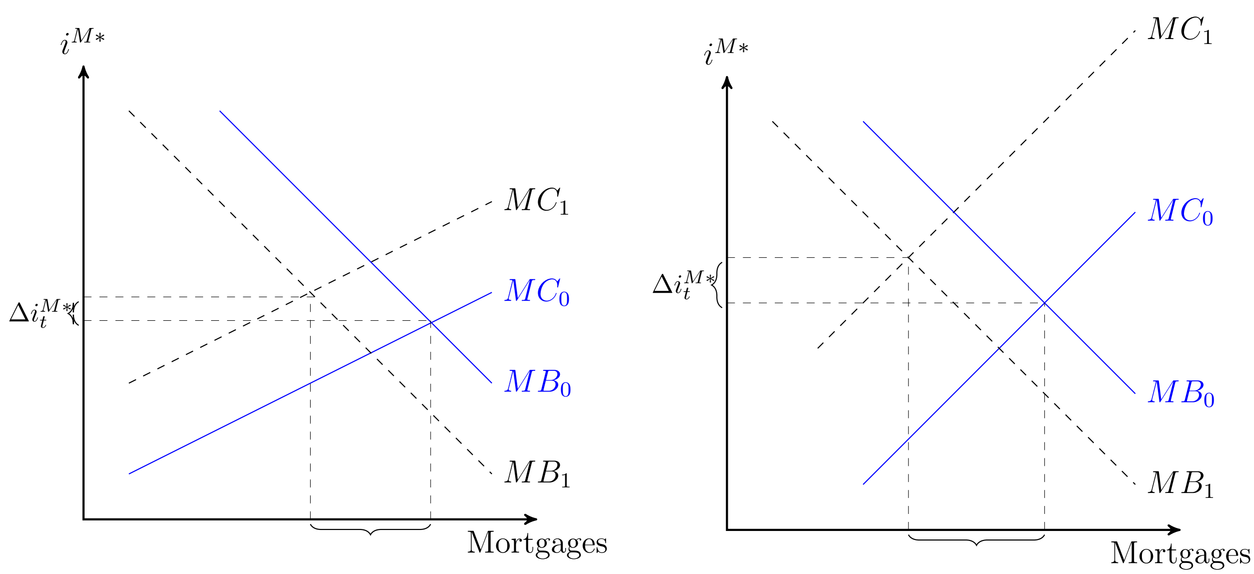
The marginal cost of issuing new mortgages is derived from the optimality condition of new mortgage loans:

$$1 + i^{M*} = \underbrace{\frac{\theta^M}{\theta^M - 1}}_{\text{markup}}\Big(1 + i - \phi^B + \phi^B \frac{m}{d}\Big).$$

The mortgage rate is correlated positively to mortgage loans, and MC is upward sloping.

To illustrate the key economic mechanisms, I compare how these curves shift following a contractionary monetary policy shock for two examples of banks. Panels (a) and (b) of figure 2 show banks with high and low levels of market power, respectively. Banks' market power determines the steepness of the curve, while access to wholesale funding and monetary policy shocks determine the magnitude of the shift.

A contractionary monetary policy shock lowers aggregate demand, which decreases income and shifts MB downward. Now, borrowers can only afford loans of the same amount at a lower rate. As a result, banks receive lower payments on mortgages. The contractionary monetary shock increases banks' funding cost and shifts MC upward. Banks with a high level of market power have a flatter MC curve and a lower cost in accessing wholesale funding. Monetary tightening squeezes the profit margin, which constrains banks in making new loans and requires them to obtain outside funding to finance. Falls in mortgage loans are lower for banks with a high level of market power. Monetary policy is dampened by market power, but amplified by reliance on wholesale funding.



(a) High Market Power

(b) Low Market Power

Figure 2: Mortgage Credit Channel of Monetary Policy

6 Calibration

This section describes the calibration procedure. Times is quarterly. The calibrated parameter values are presented in Table 5. 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 2000-2014 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 log of saver housing demand $\log \bar{H}_s$ so that the price of housing is unity at 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 1946-2012.

Banks I take the 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. Market power in mortgages and deposits is targeted for periods 2000 to 2006, 2007 to 2009, and 2010 to 2014. 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%, 3.45%, and 2.56%, while θ^D is set to match deposit rates of 0.0182%, 0.0184%, and 0.006%. The federal funds rates are 3.21%, 2.45%, and 0.12%, respectively. 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 steady state output equal to 1. The persistence of productivity ϕ_A is set to 0.964 (Garriga, Kydland, and Šustek, 2017).

Table 5: 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	42/61/18	Mortgage rate of 5.7%/4.15%/5.88%	
EOS for deposit	θ^D	-34/-42	Deposit rate of 0.028%/0.007%	
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 subset of parameters that are calibrated to match targeted moments.

6.1 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 6 shows volatilities in mortgage and deposit rates, the correlation between mortgage rate and housing price, output volatility, relative volatility of consumption, and relative volatility of aggregate consumption. It shows the difference between the basic model in which banking is perfectly competitive and the extended model in which banking is monopolistically competitive with quadratic adjustment costs.

Table 6 suggests that the extended 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 extended model delivers a relative volatility of consumption that exactly matches the data. Additionally, the extended model replicates a relevant set of bank pricing moments. While its correlation between mortgage rate and housing price is below the empirical counterpart due to fixed housing, the model delivers a deposit rate volatility that precisely matches the data.

Table 6: Unconditional Business Cycle Statistics

Moments	Description	Basic	Extended	Data
sd(i^M)	Mortgage rate volatility	1.69	0.63	1.18
sd(i^D)	Deposit rate volatility	0.09	0.02	0.02
corr(i^M,p^H)	Correlation mortgage rate and house price	-0.99	-0.95	-0.48
sd(Output)	Output volatility	0.05	0.03	0.07
sd(C_b)/sd(C_s)	Relative volatility consumption	0.57	0.98	0.98
sd(C)/sd(Y)	Relative volatility agg. consumption	1.15	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 2000-2014 using Bureau of Economic Analysis (BEA), Federal Housing Finance Administration (FHFA), Consumer Expenditure Survey (CEX), Fannie Mae, Freddie Mac and Call Reports.

6.1.1 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

$$y_{bt+h} = \alpha_{bh} + \alpha_{mh} + \beta_h \Delta i_t + \Gamma_h^{'} X_{bt-1} + u_{bt+h}, \qquad (31)$$

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 3 shows model and data impulse responses of the mortgage rate along with their 90% confidence bands to a monetary policy shock of +100 bps. The graph describes the response of the increase in the monetary policy shock by 100 bps. Overall, despite the model's relative parsimony, the model and data responses match up well, generating paths in the same direction and of similar magnitudes. The model abstracts from habit persistence and labor market frictions. If these features were added, the model would replicate a hump-shaped curve.

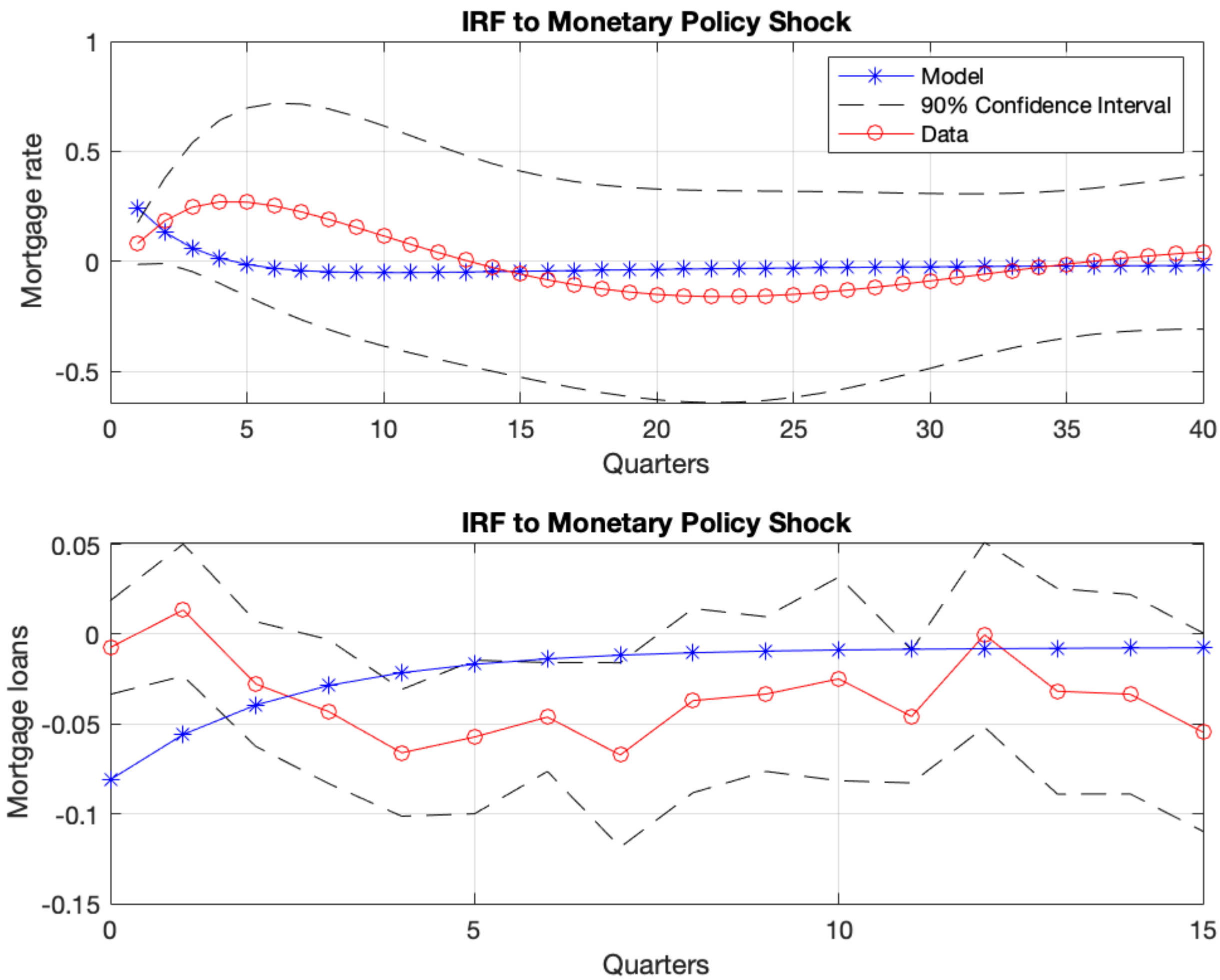


Figure 3: Response to +100 bps Monetary Policy Shock, Model vs. Data Projections

Notes: The relative contribution of each force to the response of bank variables following increase in a monetary policy shock of +100 bps.

6.1.2 Model-Implied Regression Coefficients

To directly compare our model to the data, I simulate the model in response to a contractionary monetary policy shock and estimate my empirical specification on the simulated data:

$$\Delta i^M_{jt} = \alpha_j + \beta WFR_{jt}\Delta i_t + \Gamma' Z_{jt-1} + \varepsilon_{jt}.$$

I assume that the high-frequency monetary policy shocks Δi_t are the innovations to the Taylor rule in the model. I estimate the empirical specification using wholesale funding reliance WFR_{jt} in cases where banks have high or low levels of market power.

Columns (1) and (2) of Table 7 show that banks with high market power and greater reliance on wholesale funding are less responsive to monetary policy in the model, as in the data. That is, banks in concentrated markets with greater wholesale funding reliance 0.02 bps in the model versus 0.02 bps in the data transmit 0.3 bps. Columns (3) and (4) estimate the same regression for banks with low market power and find that banks in competitive markets with greater wholesale funding reliance respond more to monetary policy shocks. The R^2 is lower for the regression with data than with the model, indicating that the data contain more unexplained variations than the model. Regression coefficients from the model are qualitatively aligned with the empirical findings.

Transmission is different for low and high market concentration, because the composition of bank funding varies by market concentration. Banks with low market power have higher transmission, with the rise in the policy rate exceeding that of the rise in deposit rates, because they have less deposits and thereby rely more on wholesale funding.

Table 7: Empirical results, model vs. data

	Mortgage rate			
	High market power		Low market power	
	Data	Model	Data	Model
	(1)	(2)	(3)	(4)
Wholesale funding×Monetary Policy	-0.003*	-0.0002	0.2192***	0.0227
	(0.0014)		(0.0623)	
R^2	0.02	0.07	0.02	0.07

Notes: Columns (1) and (3) show the results from running the specification $\Delta i^M_{jt} = \alpha_j + \beta WFR_{jt}\Delta i_t + \Gamma' Z_{jt-1} + \varepsilon_{jt}$ where all variables are defined in the notes for Table 1. Columns (2) and (4) estimate this empirical specification on the simulated data.

7 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 and negative productivity shocks. I compare the response of a New Keynesian model in which banking is perfectly competitive to a model that includes market power and adjustments costs in the banking sector are included. Overall, I find that monopolistic banking with costly access to wholesale funding dampens monetary policy shocks on mortgage rates and the aggregate economy.

7.1 Monetary Policy Shocks

I study the effect of an unexpected one-time increase in an annualized shock to the Taylor rule by +100 bps followed by perfect foresight transition back to steady state. Figures 4 and 5 show the impulse response functions of banks and real variables. A New Keynesian model with perfectly competitive banking corresponds to the line with red asterisks, and the extended model corresponds to the line with blue circles. Impulse response functions (IRFs) are expressed as percentage deviations from steady state for all variables, except for the deposit rate, policy rate, mortgage rate, and inflation rate, whose values are plotted in annualized levels in percentage points.

Figure 4 shows that a 100 bps increase in the policy rate is dampened on mortgage rates, where mortgage rates rise by only 22 bps in the extended model, due to market power and costly access to wholesale funding. This value is consistent with the results in Polo (2018), which finds that mortgage rates rise by 40 bps. Note that Polo (2018) banks only have market power in deposits and do not have access to wholesale funding. The response of mortgage rates is lower than the empirical result because the model abstracts from other channels of housing finance, such as HELOC, household default, with fixed saver's housing demand, and housing stock.

Following a contractionary shock, deposit rates increase by 60 bps and banks attract deposits by 0.15%. Since the rate on wholesale funding rises fully while deposit rates rise partially, banks cut wholesale funding by 0.6%. Because of dividend adjustment costs, banks want to internalize their profit margin so that the rise in the policy rate leads to a fall in wholesale funding. A policy shock affects the composition of wholesale funding reliance and a fall in new mortgage loans is attenuated by 1 pps in the extended model.

The intuition behind these results is that a rise in the policy rate partially increases deposit rates. The opportunity cost of holding wholesale funding relative to the deposit rate is higher. As the policy rate increases, the bank passes through part of the additional increase in its marginal cost of funds to the rate on new mortgages, which leads to a decrease in new mortgage origination. Changes in bank funding lower the issuance of new mortgage loans, and thus banks loan at higher rates.

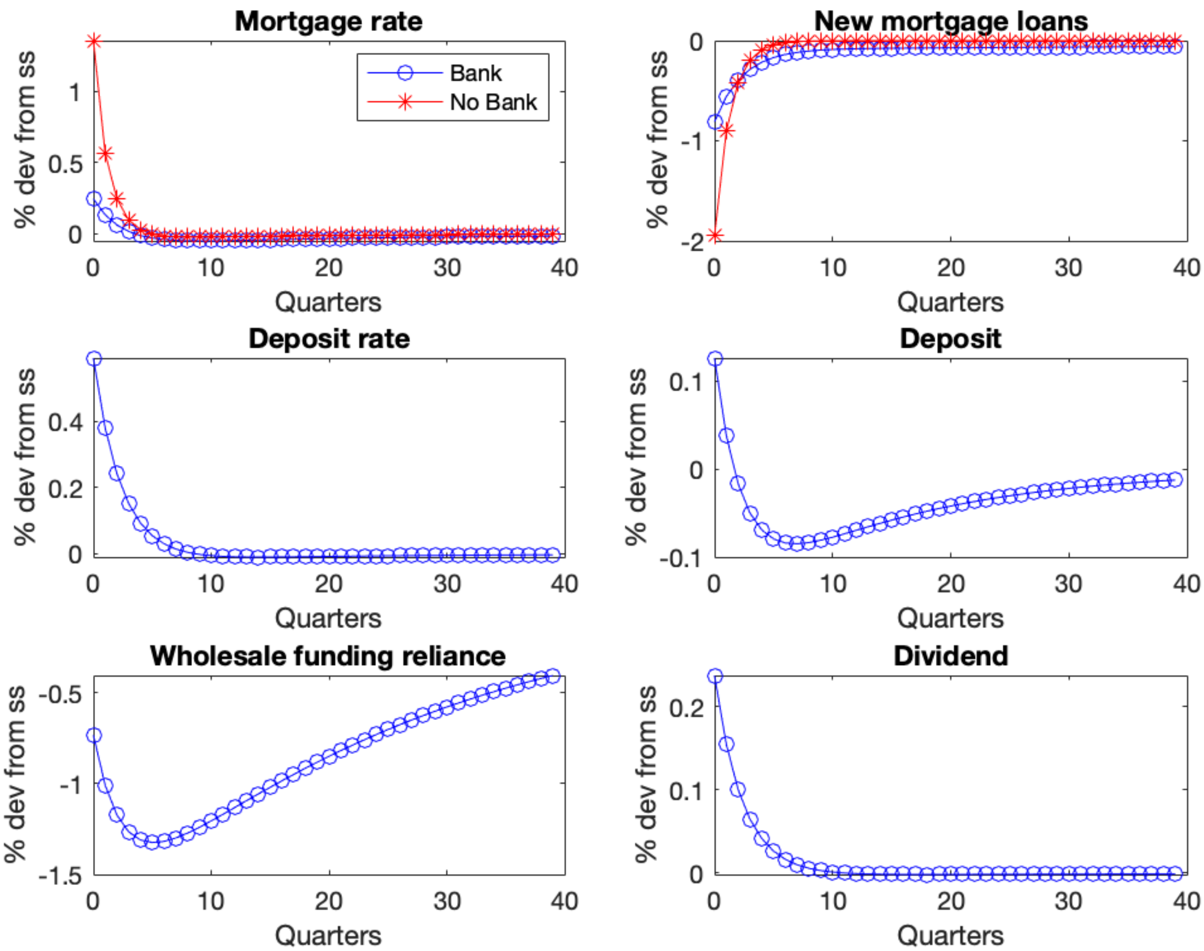


Figure 4: Response to a +100 bps monetary policy shock

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 number of quarters since the shock, and the y axis is given in percent deviation from steady state of the mortgage rate, new mortgage loans, deposit rate, deposits, wholesale funding reliance, and bank dividends. Mortgage and deposit rates are in annualized percentage points.

Figure 5 shows the response of key aggregate variables to a contractionary monetary policy shock. The shock increases the nominal rate and real interest rate because prices are sticky. An increase in the deposit rate stimulates saver consumption, whereas an increase in the mortgage rate amplifies a fall in borrower consumption by 1.5 pps. Fall in output is dampened by 1 pps, and the decline in housing prices is attenuated by 1.2 pps in the banking model.

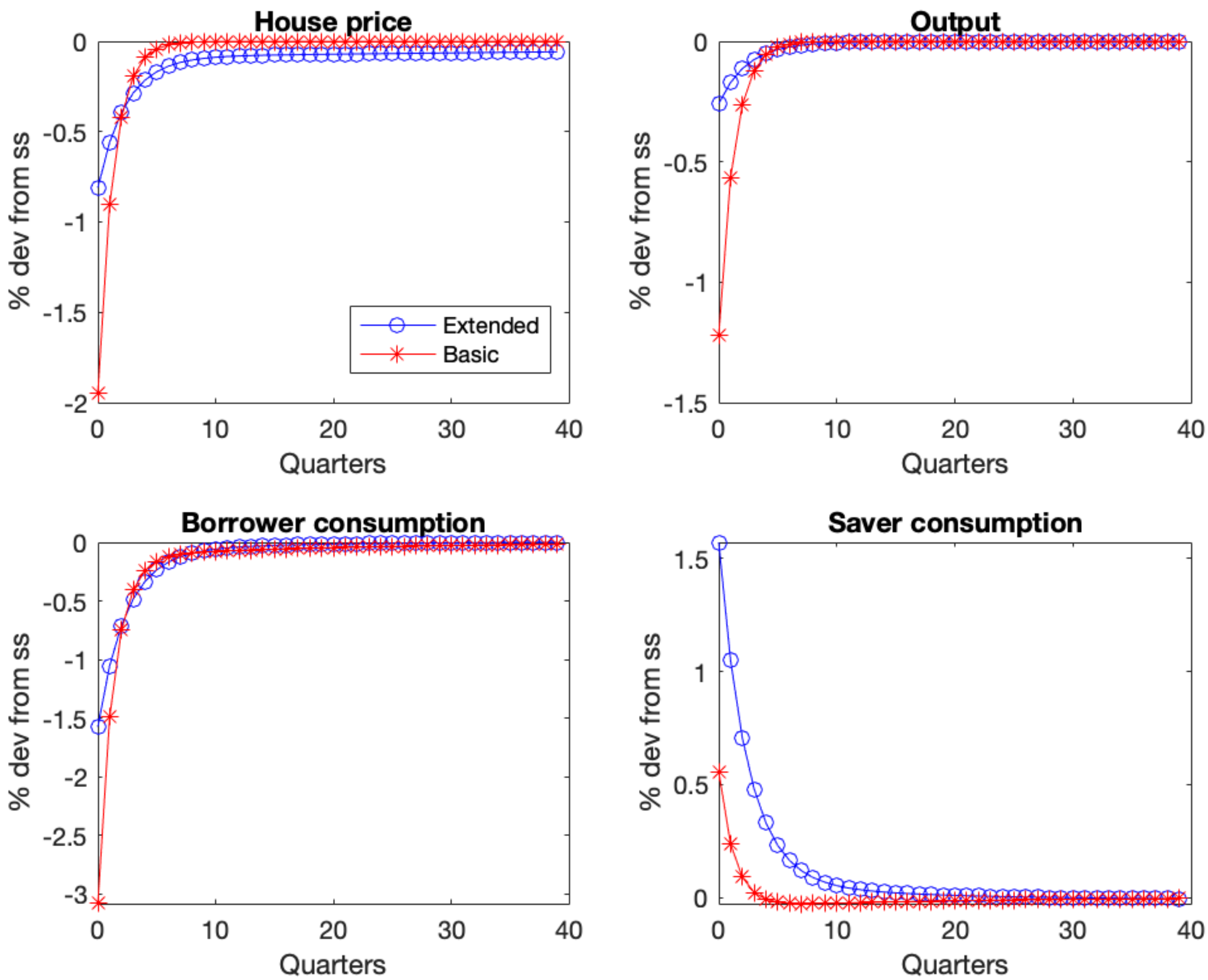


Figure 5: Response to a +100 bps monetary policy shock

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 number of quarters since the shock, and the y axis is given in percent deviation from steady state for house price, output, labor, and consumption.

7.2 Sensitivity analysis

7.2.1 Dividend adjustment cost

Figure 6 shows that deposit rates rise slightly more for banks facing high adjustment costs relative to those with no adjustment costs. The mortgage rate rises the most by 50 bps and new mortgage loans fall by 0.8% for banks with high adjustment costs. Banks with higher adjustment costs borrow from deposits and their reliance on wholesale funding remains constant indicating that they increase wholesale funding as much as rise in deposits. As a result, banks with higher adjustment costs charge more mortgage rates. Banks with no adjustment costs increase deposits and shrink wholesale funding. Given that the rise in the price of wholesale funding is greater than the rise in the deposit rate, banks shrink wholesale funding. Banks with no adjustment costs observe a rise in dividends because they are paying an extra cost to build a bigger deposit base.

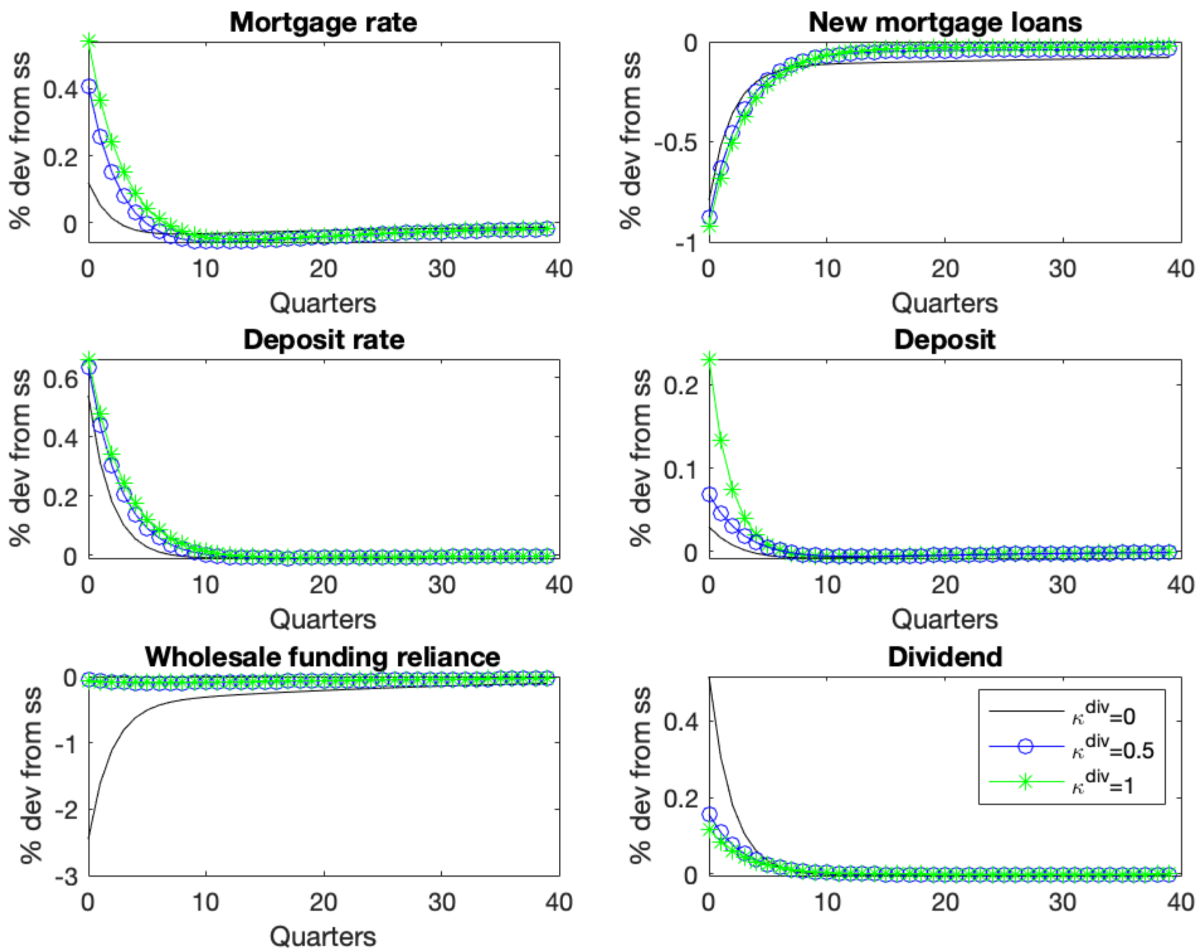


Figure 6: Response to a +100 bps monetary policy shock: Sensitivity analysis in dividend adjustment cost

Figure 7 shows that housing prices fall by 0.9% for banks with a high adjustment cost. Housing prices fall the most for banks with a high adjustment cost because the cost of bank funding increased. Output and borrowers' consumption fall the most for banks with no adjustment cost. Savers' consumption rises slightly more for banks with an adjustment costs because of the rise in the deposit rate.

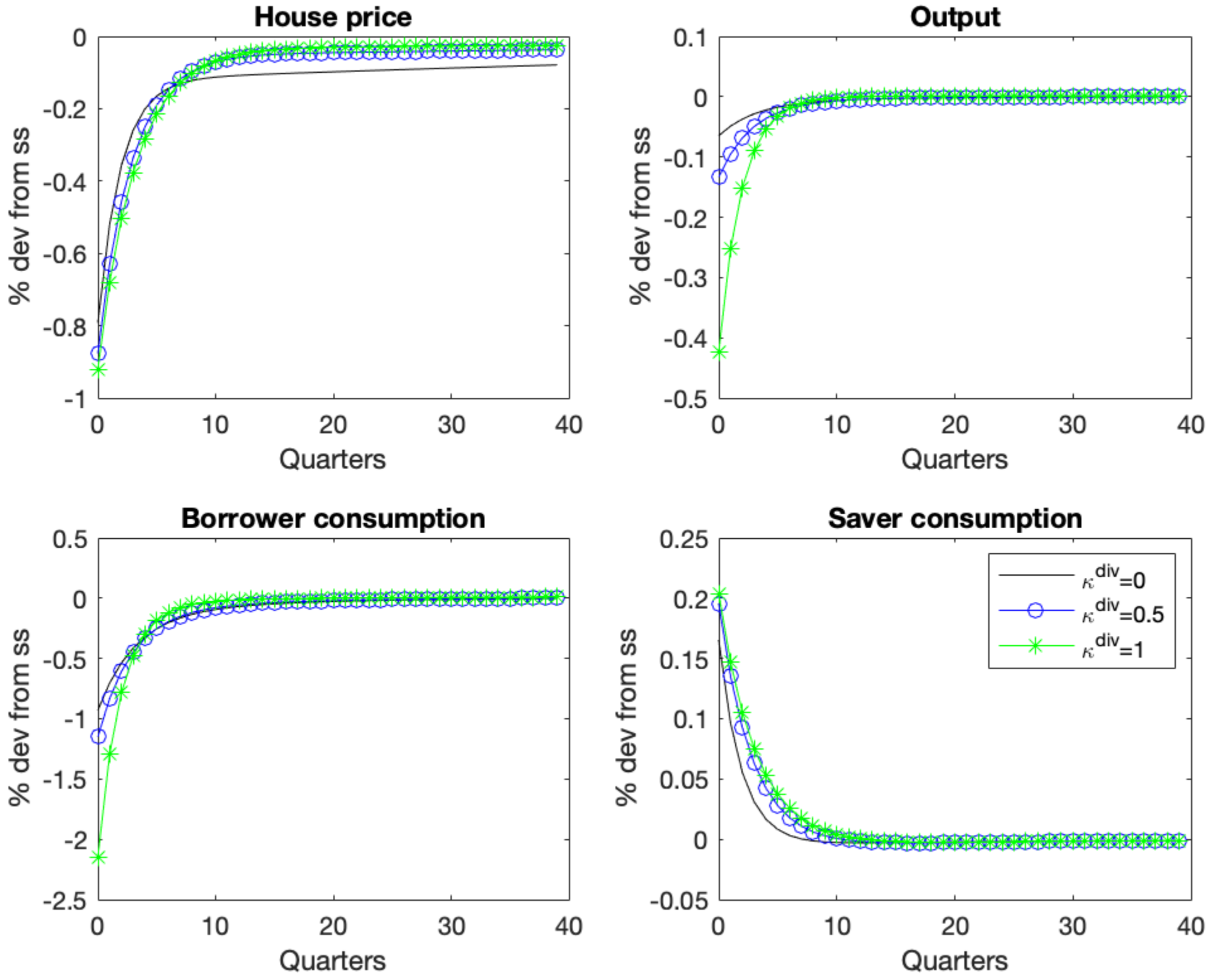


Figure 7: Response to a +100 bps monetary policy shock: Sensitivity analysis in dividend adjustment cost

7.3 Productivity Shocks

In this section, I evaluate the model to Polo (2018)'s quantitative results by shocking the economy with a negative 1% productivity shock. Figures 8 and 9 show impulse response functions of real and bank variables to a negative 1% productivity shock. The decrease in productivity increases firms' marginal costs and through the nominal rigidity leads to an increase in inflation. The central bank increases the nominal rate, and mortgage and deposit rates rise. The rise in the mortgage rate increases by 15 bps in the banking model. This value is in line with the evidence presented by Polo (2018). He finds that the mortgage rate increases by 20 bps after a negative 1% productivity shock. Because of the rise in mortgage rate, newly issued mortgages fall by 0.03% and housing prices fall by 0.02%. Borrower's consumption falls by 0.2% because of the rise in the mortgage rate, and savers' consumption rises by 0.4% from the increase in deposit rates. Although the fall in borrower's consumption is consistent with

Polo (2018)'s result, saver's consumption is in the opposite direction. Saver's consumption falls by 0.6% and deposits fall by 0.8% when deposit rates increase by 0.1% because savers shift their deposits into bonds. As a result, banks in Polo (2018)'s model originate fewer mortgage loans and housing prices fall by 0.2%. Overall, these results imply that market power and costly access to wholesale funding matter for understanding the responses of mortgage rates and economic activities to changes in monetary policy.

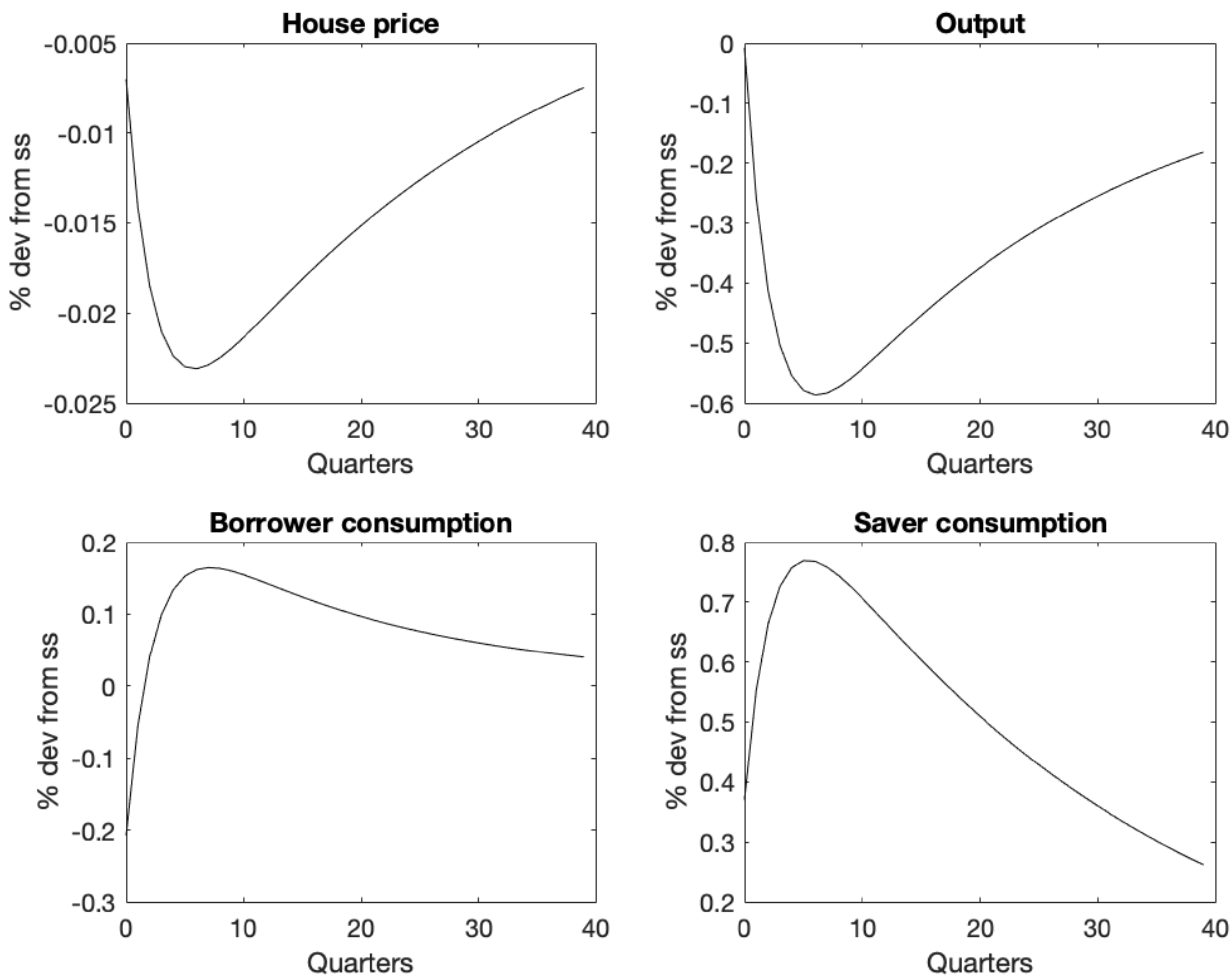


Figure 8: Response to a -1% TFP shock

Notes: This figure depicts the impulse response functions of some of the main variables to a -1% TFP shock under perfect and imperfect transmission. The x axis is given in quarters and the y axis is given in percent deviation from steady state for house price, output, labor and consumption. Inflation rate, real rate and nominal rate are in annualized percentage points.

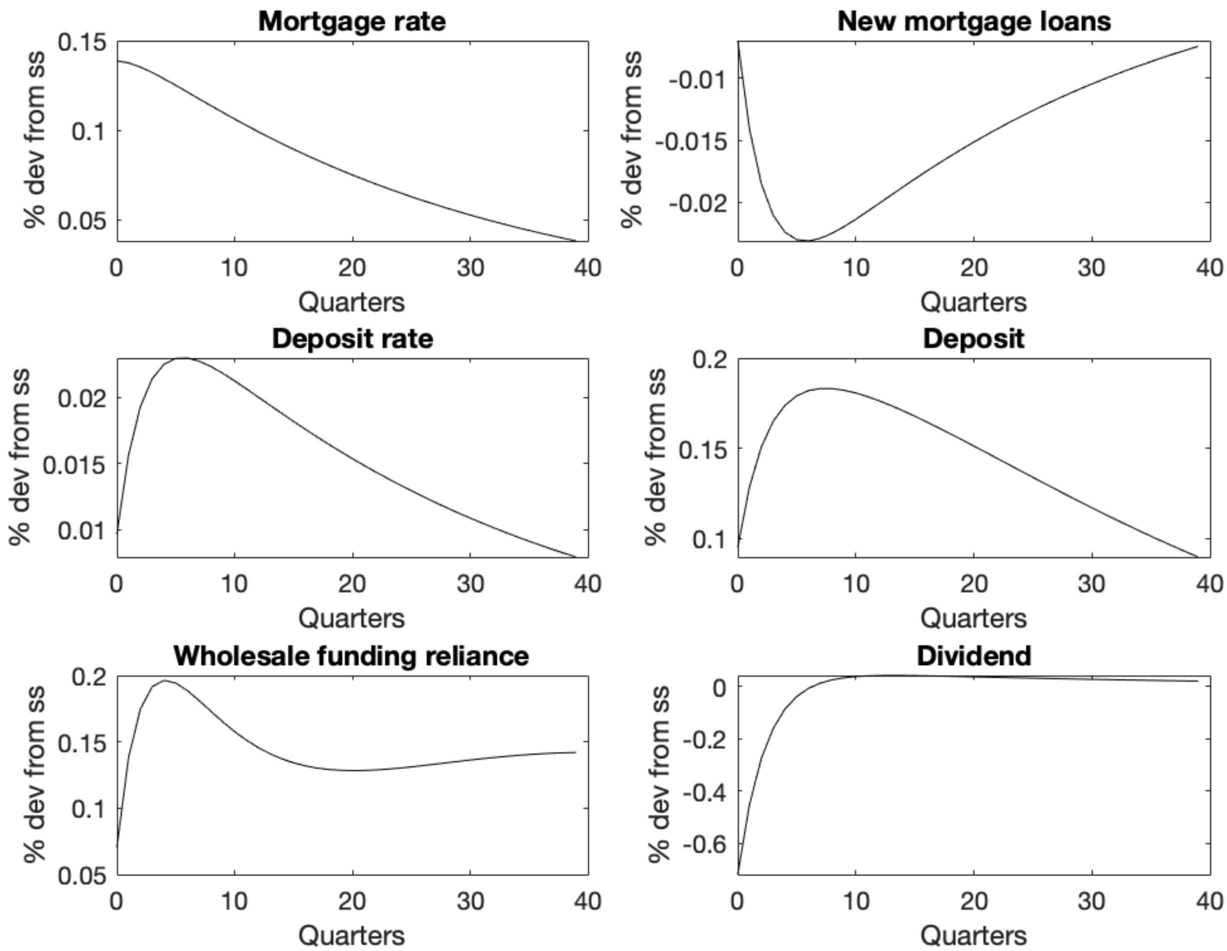


Figure 9: Response to a -1% TFP shock

Notes: This figure depicts the impulse response functions of some of the main variables to a -1% TFP shock under perfect and imperfect transmission. The x axis is given in quarters and the y axis is given in percent deviation from steady state for mortgage rate, deposit rate, new mortgage loans, deposit, wholesale funding reliance and bank dividend. Mortgage rate and deposit rate are in annualized percentage points.

8 Counterfactuals

8.1 Inflation Target Shock

I analyze an inflation target shock with the recent proposal in Blanco (2015) to raise the inflation target in order to provide policymakers with more room to cut rates before reaching the zero lower bound. The inflation target shock captures very persistent changes in monetary policy that are able to affect long-term nominal rates by changing short-term rates far into the future, in addition to current short-term rates. The mortgage rate has a longer horizon and inflation targeting is highly persistent and affects the term structure, whereas a Taylor rule shock affects the transitory structure. An inflation target shock moves nominal rates while influencing real rates very little, making it convenient for analyzing the effect of changing nominal rates in isolation. The monetary authority follows a Taylor rule, similar to that of Smets and Wouters (2007), of the form

$$\begin{aligned} \log(1+i_t) &= \log \bar{\pi}_t + \phi_r \left(\log(1+i_{t-1}) - \log \bar{\pi}_{t-1} \right) \\ &+ (1-\phi_r) \left[\left(\log(1+i_{ss}) - \log \pi_{ss} \right) + \psi_\pi \left(\log \pi_t - \log \bar{\pi}_t \right) \right], \end{aligned} \tag{32}$$

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

$$\log \bar{\pi}_t = (1-\psi_{\bar{\pi}}) \log \pi_{ss} + \psi_{\bar{\pi}} \log \bar{\pi}_{t-1} + \varepsilon_{\bar{\pi},t}, \tag{33}$$

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

Figure 10 shows that reliance on wholesale funding increases and banks' dividends fall under an inflation target shock. Interest expenses have risen, whereas deposit rates rise more than under the Taylor rule. Banks experience larger deposit outflows and thus they rely more on wholesale funding. As a result, reliance on wholesale funding increases more, and dividends fall. However, under the Taylor rule, banks do not increase their reliance on wholesale funding. Banks' dividends rise because they are paying a cost to build larger deposit bases.

Figure 11 shows that inflation falls under the Taylor rule but rises under an inflation target shock. This is a result of the nature of the shock: an inflation target shock raises the inflation rate, whereas the Taylor rule increases the nominal rate, which then decreases the inflation rate. The inflation target shock has a persistent effect on real variables and amplifies the response more than the Taylor rule.

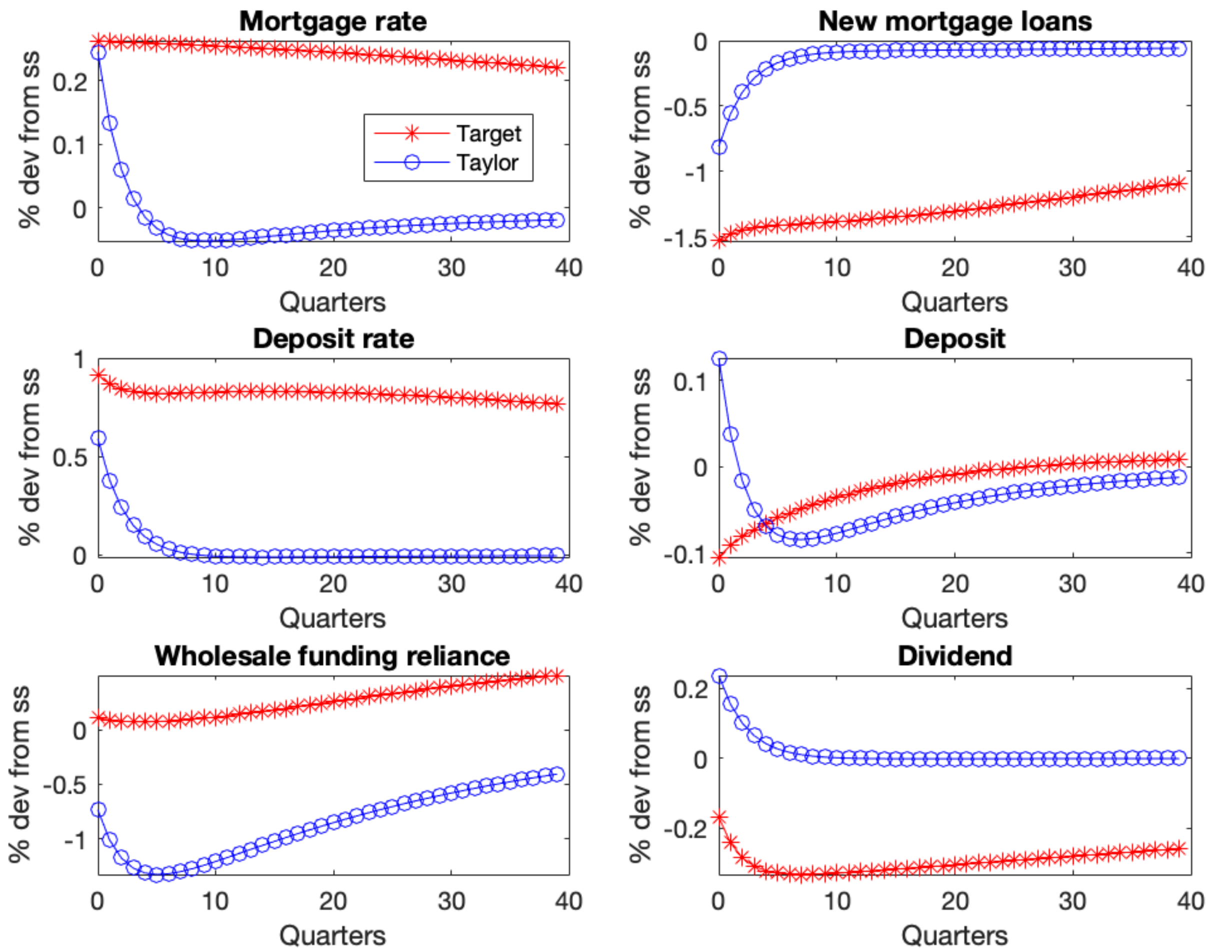


Figure 10: Response to a +100 bps monetary policy shock: Taylor rule vs Target

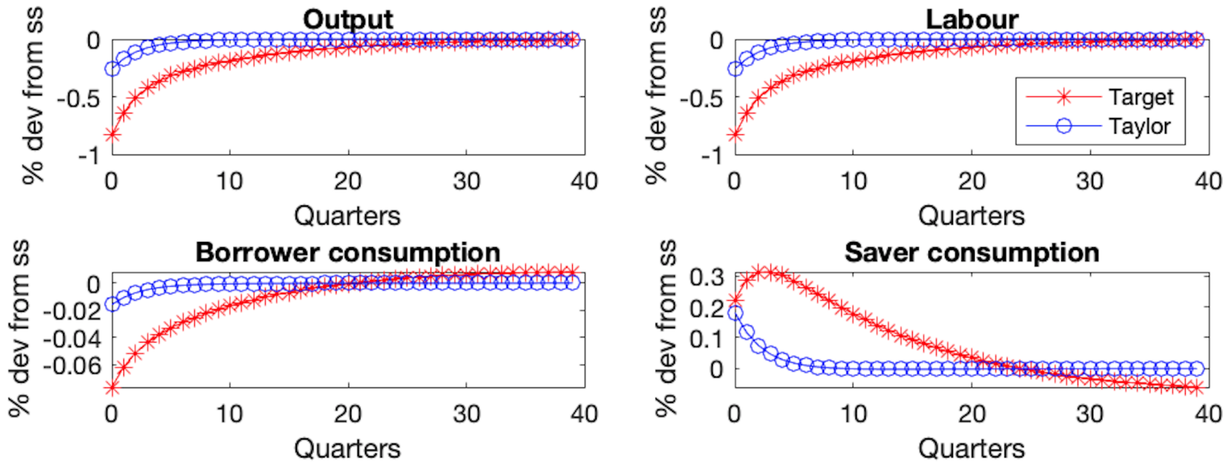


Figure 11: Response to a +100 bps monetary policy shock: Taylor rule vs Target

8.2 Basel III Liquidity Coverage Ratio (LCR)

Reliance on wholesale funding increases liquidity risks during times of market disruptions. Basel III LCR introduced a new liquidity regulation to contain excessive reliance on wholesale funding in the banking sector. It is defined as:

$$LCR = \frac{\text{High Quality Liquid Assets}}{\text{Cash Outflow}} \geq \kappa$$

where high quality liquid assets (HQLA) $= \sum_k$ Liquidity weight$_k \times$Asset$_k$ and

cash outflows $= \sum_k$ Runoff rate$_k \times \frac{\text{Liability}_k}{\text{Maturity}_k}$. Level 1 HQLAs include cash, central bank reserves and government securities with liquidity weight of 100%, level 2a HQLAs include GSE securities with liquidity weight of 85% and level 2b HQLAs include investment corporate and municipal bonds with liquidity weight of 50%.

Starting January 1, 2015 κ was 60% and it raises by 10% each year until it reaches 100% by January 1, 2019. Banks with assets between \$50B and \$250B are subject to 70% of Basel III LCR rule and banks with assets greater than \$250B and foreign exchange greater than \$10B face 100% of the rule. In my model, I only have GSE securities with weight of 85% and runoff rate for deposit is 0 while runoff rate for wholesale funding is 1 which gives equation $\frac{0.85m}{b} \geq \kappa$ giving the Basel III LCR requirement of $p' = 0.85m' - \kappa b'$.

Bank chooses deposit rate i^D_{jt} and new mortgage rate i^{M*}_{jt}

$$\max_{i^{M*}_{jt}, i^D_{jt}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \frac{\Lambda^s_{t+1}}{\pi_{t+1}} \{x_{jt} - \nu m_{jt} - i^D_{jt} d_{jt} - (i_t + \frac{\phi^B}{2} \frac{b_{jt}}{d_{jt}}) b_{jt}\} - \frac{\kappa^{div}}{2} (div_{jt+1} - \overline{div})^2 \right] \tag{34}$$

subject to the balance sheet constraint (20), laws of motions (22), (23), mortgage (24), deposit demand (25) and the Basel III LCR rule

$$m_{jt} \geq \frac{\kappa}{\omega} b_{jt} \tag{35}$$

where $\omega = 0.85$ is the liquidity weight and $\kappa = \{0.7, 1\}$ is the target. Banks with assets greater than \$250B can borrow wholesale funding up to $b \in [0, \underline{b}]$, whereas banks with assets between \$50B and \$250B can borrow wholesale funding up to $b \in [0, \bar{b}]$ where $\bar{b} > \underline{b}$.

Banks with a high level of market power rely heavily on wholesale funding and are more affected by the Basel III Liquidity Coverage Ratio rule. Banks with higher market power engage in wholesale funding substitution more during monetary tightening, but because of the Basel III regulation, they would need to rely more on retail deposits. Their lending is more affected by monetary tightening, and thus mortgage rates are amplified by the new regulatory constraint.

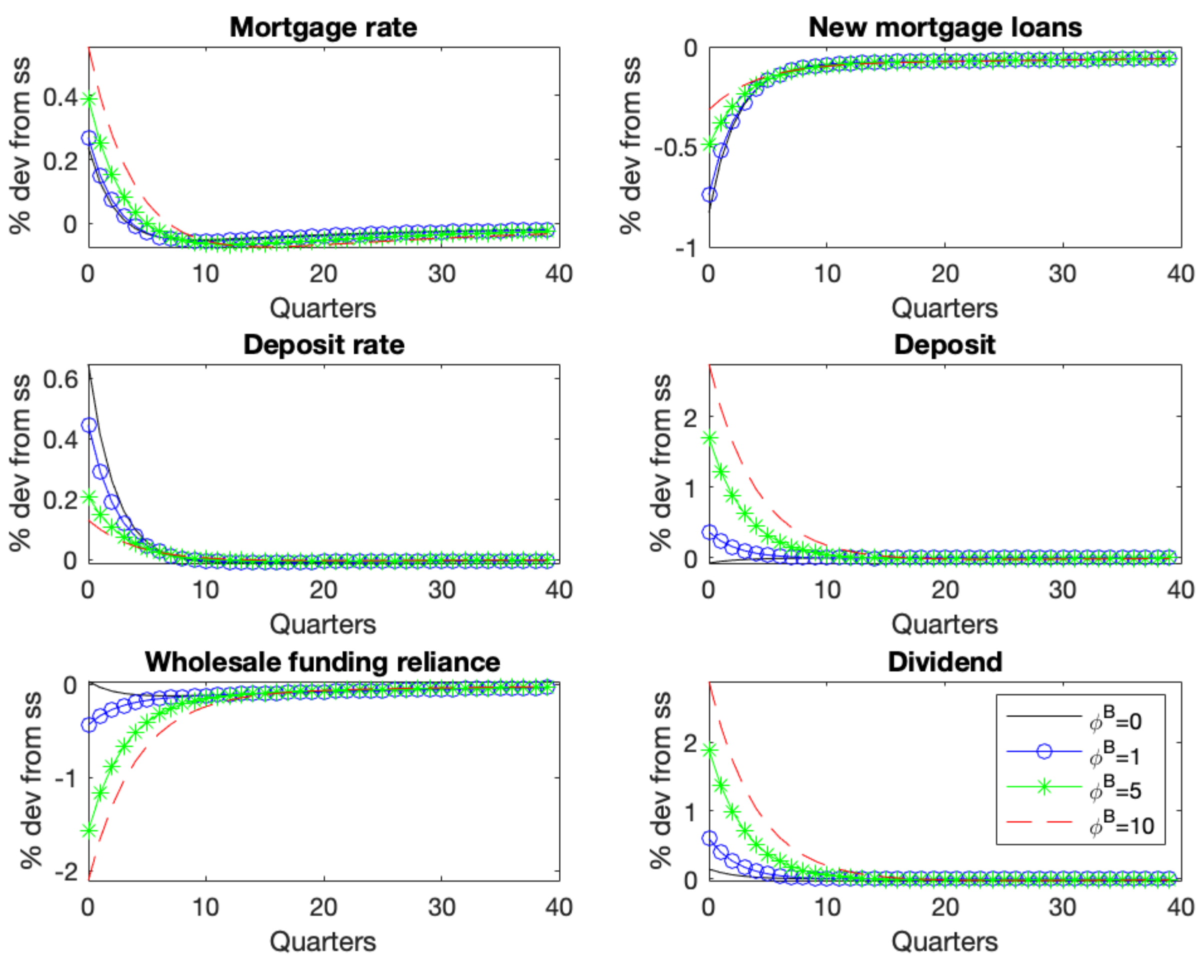


Figure 12: Response to a +100 bps monetary policy shock: Basel III Liquidity Coverage Ratio

9 Conclusion

My paper studies the quantitative importance of bank market power and wholesale funding reliance for transmitting monetary policy shocks to mortgage rates and economic activities. I contribute to the literature on monetary policy transmission by allocating an active role to banking by linking bank funding with loan originations and capturing the aggregate effects of imperfect pass-through to mortgage rates. I find that imperfect monetary policy transmission on mortgage rates dampens the response of consumption, output, and housing prices.

Using a 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. Motivated by these facts, I build a New Keynesian model with a monopolistically competitive banking sector that has a costly access to wholesale funding. I calibrate the 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.

My paper is of independent interest to policymakers who are concerned about the transmission of monetary policy to mortgage rates and the aggregate economy. It adds value to policymakers' decisions by increasing awareness about the fact that transmission of monetary policy shocks to mortgage rates is partial and that the degree of this partial pass-through varies across banks by their funding composition and market power.

Furthermore, the Federal Reserve has been heavily involved in purchasing assets and liabilities, such as mortgage securities from banks during the Great Recession and Treasury securities during the COVID-19 lockdown, to limit economic damages as a result of reaching the effective zero lower bound. Therefore, understanding how monetary policy transmission works via the banking sector under unconventional monetary policy is pertinent for the future.

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A Appendix

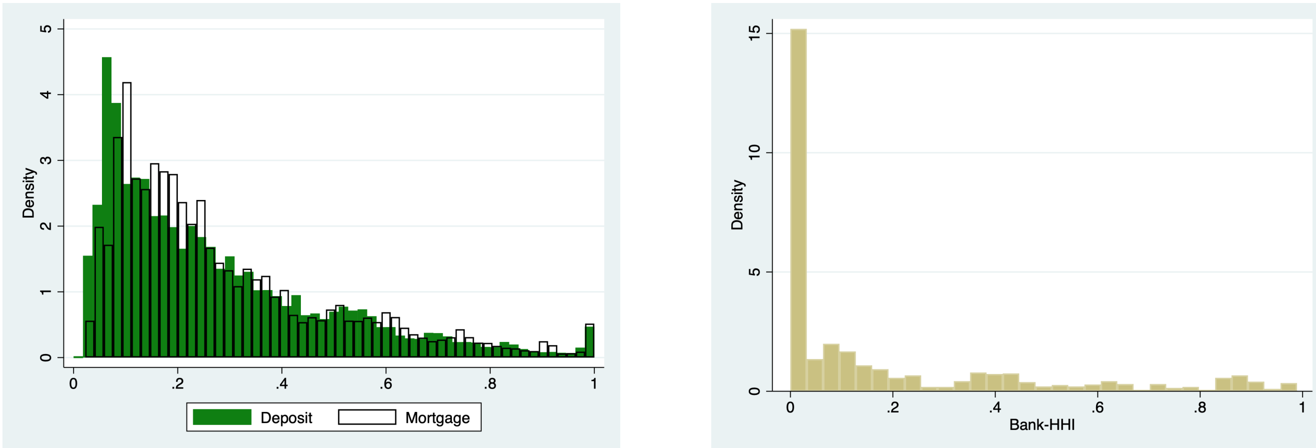
A.1 Empirics

A.1.1 Tables

Table 8: Banks

Ally Bank
Amtrust Bank
Associated Bank, National Association
Bank of America, National Association
Branch Banking and Trust Company
Capital One, National Association
Citizens Bank, National Association
Colorado Federal Savings Bank
Downey Savings and Loan Association
Everbank
Indymac Federal Bank
Fifth Third Bank
First Tennessee Bank National Association
Firstarbank, National Association
Flagstar Bank, Federal Savings Bank
Fremont Bank
HSBC Bank USA, National Association
JPMorgan Chase Bank, National Association
New York Community Bank
PNC Bank, National Association
Regions Bank
Santander Bank, National Association
Sovereign Bank
The Huntington National Bank
Third Federal Savings and Loan
UnionSavingsBank
USAA Federal Savings Bank
US Bank, National Association
Wachovia Mortgage, Federal Savings Bank
Washington Mutual Bank
Wells Fargo Bank, National Association

Figure 13: Local market concentration and Bank-HHI

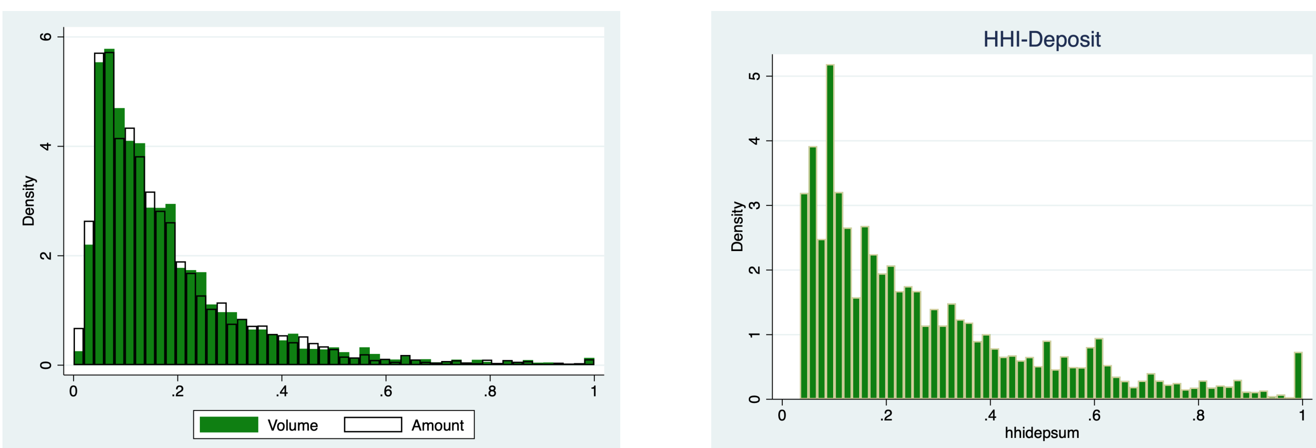


(a) Local market concentration

(b) Bank-HHI

Notes: Bank-HHI is measured by multiplying the local market concentration with the share of deposits: Bank-HHI$_{mt}$ = HHI$_{mt} \times \left(\frac{dep_{bmt}}{\sum_{b \in \{m\}} dep_{bmt}}\right)$. Deposit (mortgage) HHI has a mean of 0.28 (0.27) and standard deviation of 0.21 (0.21). Bank-HHI in deposit (mortgage) has a mean of 0.18 (0.18) and a standard deviation of 0.27 (0.26).

Figure 14: 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 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 standard deviation of 0.22.

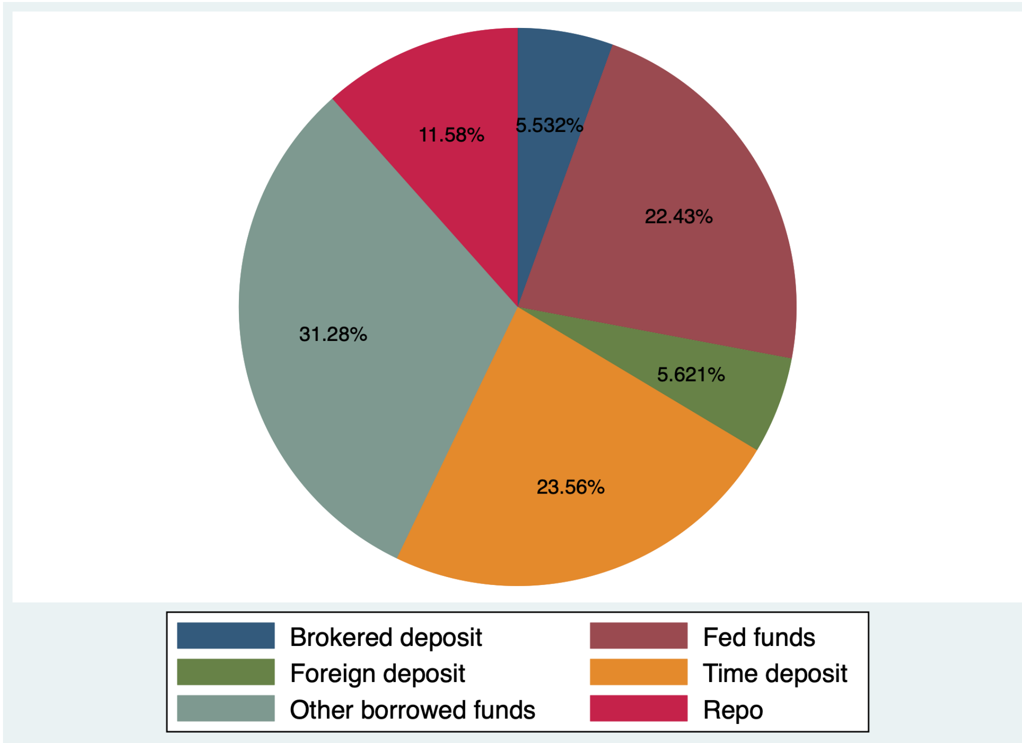


Figure 15: Composition of wholesale funding

Notes: Wholesale funding consists of 5.5% of brokered deposit, 22.4% of federal funds purchased, 5.6% of deposits held in foreign offices, 23.6% of time deposits, 11.6% of repurchase agreements (repos) and 31.3% of other borrowed funds.

Table 9: 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 deposit, federal funds purchased, deposits held in foreign offices, time deposits and other borrowed funds. Deposit rate is an imputed measure by dividing total interest expense over total deposit. Number of observations is 1791.

A.1.2 Robustness checks

In this section, I check for robustness by using bank market power in mortgage and deposit market in response to +100 and -100 bps monetary policy shocks. Overall, market/bank concentration in deposit and mortgage show similar results. My main empirical result shows that banks located in a concentrated market pass-through less. They reduce markups to mitigate the effects of fall in loan demand. Reliance on wholesale funding substitutes deposit outflows for banks located in a concentrated market. Banks in concentrated markets are responsive to +100 bps, but not responsive to -100 bps because there is not enough competition between cash and deposits to experience deposit outflow. However, only banks with market power in mortgage is responsive to both monetary expansion and tightening. One possible explanation is that the mortgage market is concentrated in high levels of deposit while deposits can be transferred within bank.

Table 10 in appendix shows how 1% increase in wholesale funding reliance affects mortgage rate transmission. The triple interaction is statistically significant across bank variation and when there are no fixed effects. 1% increase in wholesale funding reliance in a concentrated market transmits 29 to 36 bps less to mortgage rates. Triple interaction of log of wholesale funding reliance with monetary policy shocks and market concentration has a larger effect on mortgage rates, but its interaction with monetary shocks are not statistically significant. The magnitude of bank concentration stays the same throughout different specifications.

Table 10: Heterogeneity in monetary policy transmission

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 α_b is a bank fixed effect, α_m is a MSA fixed effect, WFR_{bmt} is wholesale funding reliance, HHI_{mt} is the HHI in deposit market, Δi_t is +100 bps monetary policy shock, HH controls include borrower's credit score and LTV and bank controls include log asset, liquidity asset ratio, liability interest rate, real estate and commercial and industrial loans ratio and MBS to asset ratio. Standard errors are clustered at the bank level. $***p < 0.01, **p < 0.05, *p < 0.1$.

	Δr_{mbt}			
	(1)	(2)	(3)	(4)
Δi_t	1.323***	1.365***	1.221***	1.236***
	(0.132)	(0.148)	(0.150)	(0.157)
HHI^D_{mt}	0.0633**	0.257***	0.0763	0.109
	(0.0295)	(0.0903)	(0.0783)	(0.0913)
$\Delta i_t \times HHI^D_{mt}$	-0.576**	-0.858***	-0.653**	-0.726**
	(0.275)	(0.282)	(0.295)	(0.311)
$\log(WFR_{bmt})$	0.0015	0.0132	-0.0057	-0.005
	(0.00402)	(0.00800)	(0.0109)	(0.0120)
$\Delta i_t \times \log(WFR_{bmt})$	0.0863	0.112	0.0685	0.0651
	(0.0698)	(0.0910)	(0.0858)	(0.0915)
$HHI^D_{mt} \times \log(WFR_{bmt})$	0.0120*	-0.0200	0.0002	-0.004
	(0.00675)	(0.0168)	(0.0163)	(0.0190)
$\Delta i_t \times HHI^D_{mt} \times \log(WFR_{bmt})$	-0.296*	-0.358*	-0.265	-0.263
	(0.156)	(0.196)	(0.184)	(0.196)
Bank FE	No	No	Yes	Yes
MSA FE	No	Yes	No	Yes
R^2	0.156	0.196	0.223	0.225
F	45.90	38.67	51.10	44.58
N	871	866	862	861

Table 11: Why is mortgage only responsive? Deposits can be transferred within bank.

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

where Δr_{mbt} is the change in mortgage rate for bank b at MSA m at quarter t. Δi_t is the monetary shock from Nakamura and Steinsson (2018) normalized to have a +100 bps impact. WFR_{bmt} is the wholesale funding reliance for bank b in MSA M at quarter t and Bank-HHI$_{mt}$ is the bank market power in deposit and mortgage. HH Controls$_{bmt}$ includes FICO score and LTV. BankControls$_{bmt}$ include log asset, liquidity asset ratio, liability interest rate, real estate and commercial and industrial loans ratio and MBS to asset ratio. The empirical design allows me to test how elasticities of mortgage rates relative to monetary policy shock changes in competitive vs concentrated markets relative to banks with greater or fewer wholesale funding. $***p < 0.01, **p < 0.05, *p < 0.1$. **Only bank market power in mortgage is statistically significant in response to monetary policy shocks.** The main interested variable is:

$$\frac{\partial \Delta r_{mbt}}{\partial \Delta i_t} = (\beta_1 + \beta_5 WFR_{bmt} + \beta_6 \text{Bank-HHI}_{mt} + \beta_7 WFR_{bmt} \times \text{Bank-HHI}_{mt}).$$

	(1)	(2)	(3)	(4)
	+100 bps		-100 bps	
	$\Delta r_{mbt}(HHI^M_{mt})$	$\Delta r_{mbt}(HHI^D_{mt})$	$\Delta r_{mbt}(HHI^M_{mt})$	$\Delta r_{mbt}(HHI^D_{mt})$
Δi_t	0.952***	0.899***	-1.856***	-1.816***
	(0.125)	(0.126)	(0.427)	(0.432)
WFR$_{bmt} \times \Delta i_t$	0.029	0.031	-0.207	-0.178
	(0.026)	(0.0636)	(0.026)	(0.142)
Bank-HHI$_{mt} \times \Delta i_t$	-0.152	0.069	0.151	0.953
	(0.353)	(2.284)	(0.533)	(1.34)
WFR$_{bmt} \times \Delta i_t \times$ Bank-HHI$_{mt}$	-0.359*	-0.308	1.346**	-0.538
	(0.205)	(0.140)	(0.539)	(1.409)
R^2	0.222	0.202	0.222	0.185
N	867	977	867	919

Table 12: Why is local market concentration unresponsive to -100 bps? Not enough competition between cash and deposits.

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

where Δr_{mbt} is the change in mortgage rate for bank b at MSA m at quarter t. Δi_t is the monetary shock from Nakamura and Steinsson (2018) normalized to have a +100 bps impact. WFR_{bmt} is the natural logarithm of wholesale funding in bank b, MSA M at quarter t and HHI_{mt} is the local market concentration in MSA m at quarter t. HH Controls_{bmt} includes FICO score and LTV. $\text{BankControls}_{bmt}$ include log asset, liquidity asset ratio, liability interest rate, real estate and commercial and industrial loans ratio and MBS to asset ratio. The empirical design allows me to test how elasticities of mortgage rates relative to monetary policy shock changes in competitive vs concentrated markets relative to banks with greater or fewer wholesale funding. The triple interaction is responsive only to +100 bps monetary policy shock. $***p < 0.01, **p < 0.05, *p < 0.1$. The main interested variable is:

$$
\frac{\partial \Delta r_{mbt}}{\partial \Delta i_t} = (\beta_1 + \beta_5 WFR_{bmt} + \beta_6 HHI_{mt} + \beta_7 WFR_{bmt} \times HHI_{mt}).
$$

	(1)	(2)	(3)	(4)
	+100 bps		-100 bps	
	$\Delta r_{mbt}(HHI^M_{mt})$	$\Delta r_{mbt}(HHI^D_{mt})$	$\Delta r_{mbt}(HHI^M_{mt})$	$\Delta r_{mbt}(HHI^D_{mt})$
Δi_t	1.167***	1.164***	-2.32***	-2.271***
	(0.161)	(0.162)	(0.669)	(0.663)
$\text{WFR}_{bmt} \times \Delta i_t$	0.0005**	0.001***	-0.001	-0.001
	(0.0002)	(0.0003)	(0.001)	(0.001)
$\text{HHI}_{mt} \times \Delta i_t$	-0.598*	-0.566*	0.898	0.704
	(0.348)	(0.334)	(1.296)	(1.198)
$\text{WFR}_{bmt} \times \Delta i_t \times \text{HHI}_{mt}$	-0.002**	-0.002***	0.002	0.002
	(0.0005)	(0.0005)	(0.003)	(0.002)
R^2	0.223	0.226	0.181	0.181
N	867	867	919	919

A.1.3 Data Sources and Description

In this section, I begin by describing the different datasets used in this paper. I then detail how the relevant variables were computed.

Consumer Expenditure Survey (CEX). It is an annual rotating panel survey for US households elaborated by the Bureau of Labor Statistics available since 1996. Interviews are conducted on a monthly basis, but each household is interviewed every three months up to five times. On each interview, a household provides information about consumption during the three months prior to the month of the current interview. On the fifth interview, households also provide information on wealth variables, in particular, whether they hold "stocks, bonds, mutual funds, and other such securities". I construct total average annual expenditures by housing tenure: homeowner without mortgage and homeowner with mortgage.

Federal Housing Finance Administration (FHFA). It is an index that measures changes in single-family house prices based on data covering all 50 states and over 400 American cities. It is obtained by reviewing repeat mortgage transactions on single-family properties whose mortgages have been purchased or securitized by Fannie Mae or Freddie Mac since January 1975.I use quarterly purchase-only indexes to construct housing price.

Table 13: Data Definitions

Name	Definition	Source	Code
Output	Real GDP	BEA	GDPC1
House Price	All-Transactions House Price Index	FHFA	USSTHPI
Saver consumption	Homeowner without mortgage	CEX	CXUTOTALEXPLB0804M
Borrower consumption	Homeowner with mortgage	CEX	CXUTOTALEXPLB0803M

Sources for the various macroeconomic data used in the paper are Bureau of Economic Analysis (BEA), Federal Housing Finance Administration (FHFA) and Consumer Expenditure Survey (CEX).

A.1.4 Treasury relation

Table 14: Nakamura and Steinsson 2018 Replication

I document the relationship between Treasury bond and mortgage rates and monetary policy shocks. Monetary policy shocks have almost 1-to-1 relationship for Treasury bonds with maturity less than 10 years. For 10 year Treasury bond and 30 Year mortgage rate, the monetary policy shock passes through half. $***p < 0.01, **p < 0.05, *p < 0.1$.

	(1)	(2)	(3)	(4)	(5)	(6)
	Δi_t^M	1Y Treasury	2Y Treasury	3Y Treasury	5Y Treasury	10Y Treasury
Δi_t	0.508**	1.583***	1.216***	1.010***	0.793***	0.535***
	(0.230)	(0.204)	(0.235)	(0.248)	(0.235)	(0.189)
R^2	0.030	0.133	0.080	0.055	0.034	0.018
F	4.871	60.49	26.65	16.55	11.39	7.965
N	157	414	414	414	414	414

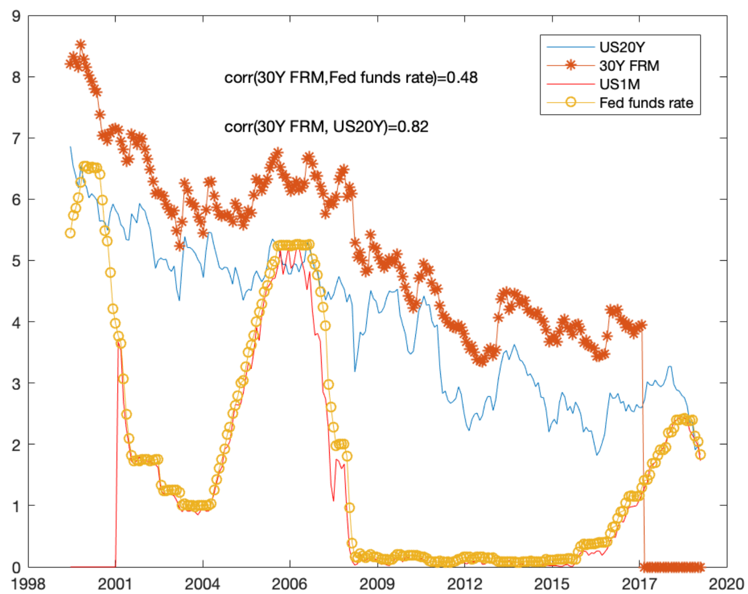
Table 15: Treasury Yields on mortgage rate

I document the relationship between Treasury bond and mortgage rates and monetary policy shocks. The pass-through of treasury bonds on mortgage rates is around 17%. $***p < 0.01, **p < 0.05, *p < 0.1$.

	(1)	(2)	(3)	(4)	(5)
			Δi_t^M		
1Y Treasury	0.149**				
	(0.0599)				
2Y Treasury		0.177***			
		(0.0577)			
3Y Treasury			0.178***		
			(0.0567)		
5Y Treasury				0.173***	
				(0.0583)	
10Y Treasury					0.159**
					(0.0686)
R^2	0.047	0.060	0.059	0.052	0.037
F	6.176	9.445	9.876	8.792	5.338
N	116	116	116	116	116

Figure 16: Federal funds rate, Treasury bonds, 30Year Fixed-Rate Mortgage

20 year Treasury bonds and 30 year fixed rate mortgage are 82% correlated, while policy rate and 1 month Treasury bonds are 62% correlated. The policy rate and 20 year Treasury bonds are 65% correlated.



A.2 Basic Model Solution

Saver Optimality The optimality conditions yield standard first-order conditions for consumption and labor supply:

$$\mathbb{E}_t\Big(\beta_s \frac{\Lambda^s_{t+1}}{\pi_{t+1}}(1+i^D_{jt})\Big) = 1$$

$$\Big(\frac{n_{st}}{\chi}\Big)^\eta = \frac{w_t}{c_{st}}$$

where $\Lambda^s_{t+1} = \frac{u^c_{st+1}}{u^c_{st}}$

Borrower Optimality Denote with λ_{bt} the multiplier associated with the borrowing constraint normalized by the marginal utility of consumption. The optimization conditions for loans, housing and labor are respectively:

$$(1-\lambda_{bt})\frac{1}{c_{bt}} = \beta_b \mathbb{E}_t\Big(\frac{1+i^M_t}{c_{bt+1}}\Big)$$

$$p^h_t(1-\lambda_{bt}\theta^{LTV})\frac{1}{c_{bt}} = \beta_b \mathbb{E}_t\Big(\frac{\psi c_{bt+1}}{h_t(1-\chi)} + p^h_{t+1}\Big)\frac{1}{c_{bt+1}}$$

$$\Big(\frac{n_{bt}}{1-\chi}\Big)^\eta = \frac{w_t}{c_{bt}}$$

Bank Optimality Denote with λ_{ft} the multiplier on the borrowing constraint normalized by the marginal utility of consumption. The optimality conditions for deposits and loans are respectively:

$$1-\lambda_{ft} = \mathbb{E}_t\Big(\beta_f \frac{c_{ft}}{c_{ft+1}}(i_t - i_t^D)\Big)$$

$$1-\gamma\lambda_{ft} = \mathbb{E}_t\Big(\beta_f \frac{c_{ft}}{c_{ft+1}}(i_t^M - i_t)\Big)$$

A.3 Extended Model Solution

Saver Optimality

Intratemporal condition

$$-\frac{U_{st}^n}{U_{st}^c} = (1-\tau_y)\, w_t \tag{36}$$

Euler equation

$$1 = (1+i_t^D)\mathbb{E}_t\left[\frac{\Lambda_{st+1}}{\pi_{t+1}}\right] \tag{37}$$

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

Tax

$$T_{st} = \tau_y w_t n_{st} \tag{38}$$

Profits

$$\Pi_t = div_t + y_t - w_t n_t \tag{39}$$

Borrower Optimality

$$P_t^h = \frac{U_{b,t}^h}{U_{b,t}^c} + \mathbb{E}_t\left[\Lambda_{b,t+1} P_{t+1}^h(\theta^{LTV} + 1 - \delta)\right] \tag{40}$$

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

$$-\frac{U_{b,t}^n}{U_{b,t}^c} = (1-\tau_y)\, w_t \tag{41}$$

Euler equation for new borrowing is

$$1 = \Omega_{bt}^M + \Omega_{bt}^X i_t^{M*} + \lambda_t \tag{42}$$

where λ_t is multiplier on borrowing constraint.

$$\rho_t = \Gamma_\gamma\{\underbrace{(1-\Omega_{bt}^M - \Omega_{bt}^X i_{t-1}^M)(m_{bt}^* - \frac{(1-\nu)m_{bt-1}}{\pi_t})}_{\text{new debt incentive}} - \underbrace{\Omega_{bt}^X(i_t^{M*} - i_{t-1}^M)}_{\text{interest rate incentive}}\} \tag{43}$$

where

$$\Omega_{bt}^{M} = \mathbb{E}_t \left[\frac{\Lambda_{bt+1}}{\pi_{t+1}} \{ \nu\tau_y + \rho_{t+1}(1-\nu) + (1-\rho_{t+1})(1-\nu)\Omega_{bt+1}^{M} \} \right] \tag{44}$$

$$\Omega_{bt}^{X} = \mathbb{E}_t \left[\frac{\Lambda_{bt+1}}{\pi_{t+1}} \{ (1-\tau_y) + (1-\rho_{t+1})(1-\nu)\Omega_{bt+1}^{X} \} \right] \tag{45}$$

Bank Optimality

Perfect pass-through

Deposit rate:

$$1 + i_{jt}^{D} = \frac{\theta^D}{\theta^D - 1}(1 + i_t) \tag{46}$$

Mortgage rate:

$$1 + i_{jt}^{M*} = \frac{\theta^M}{\theta^M - 1}\Big(1 - \nu + \frac{\Omega_{jt}^{M}}{\Omega_{jt}^{X}}\Big) \tag{47}$$

$$\Omega_{jt}^{X} = \mathbb{E}_t \left[\frac{\Lambda_{t+1}^{s}}{\pi_{t+1}} \{ (1-\nu)\Omega_{jt+1}^{X} + 1 \} \right] \tag{48}$$

$$\Omega_{jt}^{M} = \mathbb{E}_t \left[\frac{\Lambda_{t+1}^{s}}{\pi_{t+1}} \{ (1-\nu)\Omega_{jt+1}^{M} - (\nu + i_t) \} \right] \tag{49}$$

No-arbitrage conditions:

$$\mathbb{E}_t \left[\frac{\Lambda_{t+1}^{s}}{\pi_{t+1}} \right] i_t = \mathbb{E}_t \Lambda_{t+1} \left[\Omega_{t+1}^{M} + i_{jt}^{M*}\Omega_{t+1}^{X} - 1 \right] \tag{50}$$

$$i_{jt}^{D} = i_t \tag{51}$$

Imperfect pass-through

Deposit rate:

$$1 + i_{jt}^{D} = \frac{\theta^D}{\theta^D - 1}\left[1 + i_t + \frac{\phi^B}{2} \right] \tag{52}$$

Mortgage rate:

$$1 + i_{jt}^{M*} = \frac{\theta^M}{\theta^M - 1}\Big(1 - \nu + \frac{\Omega_{jt}^{M}}{\Omega_{jt}^{X}}\Big) \tag{53}$$

$$\Omega_{jt}^{X} = \mathbb{E}_t \left[\frac{\Lambda_{t+1}^{s}}{\pi_{t+1}} \{ (1-\nu)\Omega_{jt+1}^{X} + \Omega_{jt+1} \} \right] \tag{54}$$

$$\Omega_{jt}^{M} = \mathbb{E}_t \left[\frac{\Lambda_{t+1}^{s}}{\pi_{t+1}} \{ (1-\nu)\Omega_{jt+1}^{M} - \Omega_{jt+1}(\nu + i_t + \phi^B \frac{b_{jt}}{d_{jt}}) \} \right] \tag{55}$$

$$\Omega_{jt+1} = \frac{1}{1 + \kappa^{div}(div_{jt+1} - \bar{div})} \tag{56}$$

No-arbitrage conditions:

$$i^D_{jt} = i_t - \frac{\phi^B}{2} \tag{57}$$

Firm Optimality

$$x_{1t} = u'(C_t)mc_t y_t + (\phi\beta)E_t(1 + \pi_{t+1})^{\theta} x_{1t+1} \tag{58}$$

$$x_{2t} = u'(C_t)y_t + (\phi\beta)E_t(1 + \pi_{t+1})^{\theta-1} x_{2t+1} \tag{59}$$

$$1 + \pi^{\#}_t = \frac{\theta}{\theta - 1}(1 + \pi_t)\frac{x_{1t}}{x_{2t}} \tag{60}$$

$$(1 + \pi_t)^{1-\theta} = (1 - \phi)(1 + \pi^{\#}_t)^{1-\theta} + \phi \tag{61}$$

$$\mathcal{D}_t = (1 - \phi)(1 + \pi^{\#}_t)^{-\theta}(1 + \pi_t)^{\theta} + \phi(1 + \pi_t)^{\theta}\mathcal{D}_{t-1} \tag{62}$$

$$mc_t = \frac{w_t}{a_t} \tag{63}$$

$$y_t = \frac{a_t n_t}{\mathcal{D}_t} \tag{64}$$

A.4 Basel III Liquidity Coverage Ratio (LCR)

Deposit rate:

$$1 + i^D_{jt} = \frac{\theta^D}{\theta^D - 1}\left[1 + i_t + \lambda\kappa + \frac{\phi^B}{2}\right] \tag{65}$$

where

$$\lambda = \frac{1}{\kappa}(\frac{\phi^B}{2} - i_t + i^D_{jt}) \tag{66}$$

Mortgage rate:

$$1 + i^{M*}_{jt} = \frac{\theta^M}{\theta^M - 1}\Big(1 - \nu + \frac{\Omega^M_{jt}}{\Omega^X_{jt}}\Big) \tag{67}$$

$$\Omega^X_{jt} = \mathbb{E}_t\left[\frac{\Lambda^s_{t+1}}{\pi_{t+1}}\{(1 - \nu)\Omega^X_{jt+1} + \Omega_{jt+1}\}\right] \tag{68}$$

$$\Omega_{jt}^{M}=\mathbb{E}_t\left[\frac{\Lambda_{t+1}^{s}}{\pi_{t+1}}\{(1-\nu)\Omega_{jt+1}^{M}-\Omega_{jt+1}(\nu+i_t+\phi^{B}b_{jt}-\lambda(\omega-\kappa))\}\right] \tag{69}$$

$$\Omega_{jt+1}=\frac{1}{1+\kappa^{div}(div_{jt+1}-\bar{div})} \tag{70}$$

A.5 Dixit-Stiglitz aggregator

Mortgage market Borrower seeks a total amount of mortgage loans equal to M_t^*, he borrows an amount M_{jt}^* from each bank j and faces the following constraint:

$$M_t^*=\left[\int_0^1 {M_{jt}^*}^{\frac{\theta^M-1}{\theta^M}}dj\right]^{\theta^M/(\theta^M-1)} \tag{71}$$

which indicates that the loans he gets from individual banks are aggregated via a CES aggregator into the total mortgage loans he obtains. θ^M is the elasticity of substitution between banks and it is assumed to be greater than one. Each bank charges 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:

$$\min_{M_{jt}^*}\int_0^1(1+i_{jt}^{M*})M_{jt}^*dj \tag{72}$$

subject to the constraint given above.

The FOC wrt M_{jt} yields mortgage demand:

$$M_{jt}^*=\Big(\frac{1+i_{jt}^{M*}}{1+i_t^{M*}}\Big)^{-\theta^M}M_t^* \tag{73}$$

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.

$$\max_{D_{jt}}\int_0^1(1+i_{jt}^{D})D_{jt}dj \tag{74}$$

s.t

$$D_t=\left[\int_0^1 D_{jt}^{\frac{\theta^D-1}{\theta^D}}dj\right]^{\theta^D/(\theta^D-1)} \tag{75}$$

The FOC wrt D_{jt} yields deposit demand:

$$D_{jt}=\Big(\frac{1+i_{jt}^{D}}{1+i_t^{D}}\Big)^{-\theta^D}D_t \tag{76}$$

where $1+i^D_t = \left[\int_0^1 (1+i^D_{jt})^{1-\theta^D} dj\right]^{\frac{1}{1-\theta^D}}$. $\theta^D < -1$ 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.6 Microfoundation of Bank CES

It may be an inaccurate representation of reality where households borrow from all banks. Ulate (2018) presents how a model where each consumer chooses to borrow from a single bank and is subject to an stochastic utility of borrowing from each bank can deliver the same demand for loans as the CES approach. The different stochastic utilities across individuals of 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 consume in both periods. To consume in period 1, this borrower must borrow against her future income $\bar{Y}$ through one of a continuum of banks between zero and one. The decision process happens in two stags. In the first stage, the borrower decides which bank she wants to borrow from and in the second stage she chooses the amount she wants to borrow. The direct utility function of the borrower conditional on her 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:

$$C_{0j} = B_j$$
$$C_1 = \bar{Y} - (1+i^m_j)B_j$$
$$(1+i^m_j)C_{0j} + C_1 = \bar{Y}$$

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

$$C_{0j} = \frac{\bar{Y}}{(1+\beta)(1+i^m_j)}$$
$$C_1 = \frac{\beta\bar{Y}}{1+\beta}$$

and indirect utility is

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

As in Anderson et al.,(1988) assume that the first stage is described by a stochastic utility approach

$$V_i = v(1+i^m_j) + \mu\epsilon_j$$

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:

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

as in McFadden (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 are 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.