Housing Prices and Consumer Spending: The Bank Balance Sheet Channel *

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September 11, 2018

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Abstract

I quantify the extent to which deterioration of bank balance sheets explains the large contraction in housing prices and consumption experienced by the U.S. during the last recession. I introduce a Banking Sector with balance sheet frictions into a model of long-term collateralized debt with risk of default. Credit supply is endogenously determined and depends on the capitalization of the entire banking sector. Mortgage spreads and endogenous down payments increase in periods when banks are poorly capitalized. I simulate an increase in the stock of housing and a negative income shock to match the decline in house prices between 2006-2009. The model generates changes in consumption, foreclosures and refinance rates similar to those observed in the U.S. between 2006 and 2009. Changes in financial intermediaries' cost of funding explain, respectively, 13, 9 and 22 percent of the changes in housing prices, foreclosures and consumption generated by the model. These results show that the endogenous response of banks' credit supply can partially explain how changes in housing prices affect consumption decisions. I also present empirical evidence that balance sheet mechanism in the model was operational during this period. In other words, I show that during the great recession, changes in the real estate prices impacted the balance sheet of the banks that reacted by contracting their mortgage credit supply.

Keywords: Housing Prices, Consumption, Long-Term Mortgages, Leverage, Bank's Capitalization, Bank's Cost of Funding, Credit Conditions, Refinance, Foreclosures
JEL Classification: E21, E30, E50, G01, G11, G21

*I want to thank Veronica Guerrieri, Harald Uhlig and Erik Hurst for their guidance and support throughout this project. I would also like to thank Chanont Banterngansa, Bonggeun Choi, David Martinez-Miera, Elisa Giannone, Joao Granja, Kerstin Holzheu, Cesaire Meh, Sara Moreira, Aaron Pancost, Joseph Vavra and Thomas Winberry and other seminar participants at Bank of Portugal, Bank of Canada, LubraMacro, SED, EFA, EEA and the University of Chicago Capital Theory, Economic Dynamics and Applied Macroeconomics working groups. Contact information: manu@bankofcanada.ca

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1 Introduction

Between 2006 and 2009, housing prices in the United States fell by 18 percent in real terms, followed by an increase in foreclosures and a severe and persistent drop in consumption. Simultaneously, the balance sheets of the principal financial intermediaries deteriorated, credit flows dropped and credit spreads increased. This period is therefore characterized by balance sheet contractions for both households and banks.

Motivated by these facts, I analyze the connections between the housing and credit markets and their impact on macroeconomic activity. I find, both empirically and theoretically, that the contraction of bank balance sheets is an important mechanism for transmitting and amplifying shocks originated in the housing market. Moreover, during this period, several policies were implemented to increase credit access and mitigate the drop in housing prices and consumption. Although the existing literature has estimated positive impacts for such policies, the mechanisms driving these results are still an open question. The framework developed in this paper suitable to compare different policies and guide policy interventions.

A growing empirical literature has shown that consumption responds strongly to housing price shocks. Mian et al. (2013) estimate an elasticity of non-durable consumption to changes in the housing share of household net worth of between 0.34 and 0.38. Although in traditional macroeconomic models, fluctuations in housing prices have only a modest effect on household consumption, the empirical literature has shown evidence that housing wealth is an important factor in consumption dynamics. To account for this evidence, recent theoretical literature such as Iacoviello (2005) and Berger et al. (2015) have developed incomplete markets models with income uncertainty and housing as collateral. In these models, collateral and wealth effects are the main mechanisms in play and consumption response depends crucially on the initial joint distribution of housing and debt. However, in this class of models, credit conditions are exogenous and households are forced to deleverage to satisfy the collateral constraint after a drop in house prices.

This paper, instead, looks at how the endogenous response of the banking sector can be an important source of amplification of shocks originated in the housing market. A decline in house prices and subsequent increase in foreclosure impact bank's profitability and equity. This negative effect on banks' balance sheets induces banks to contract the credit supply, amplifying further the drop in consumption and borrowing. Then, this paper analyzes, both empirically and theoretically, the extent to which the contraction in the bank's balance sheet impact the consumption response to changes in house prices. I call this endogenous response of the banking sector to shocks originated in the housing market the *bank balance sheet channel*.

First I present empirical evidence that the credit supply is responsive to negative shocks originated in the housing market that impact the bank balance sheets. By implementing an empirical strategy that allows to disentangle change of the credit supply from the credit demand, I show that that banks located in areas with larger exogenous decreases in house prices faced larger drops in their capital to assets ratio and contracted the credit supply by more. I then build a novel structural macroeconomic model to analyze and quantify the role of the bank balance sheet channel in transmitting and amplifying shocks that originate in the housing market. I introduce a banking sector with balance sheet frictions into a model of long-term collateralized debt with risk of default. In contrast to most of the literature that looks at the impact of changes in house prices, the credit supply depends on the aggregate capitalization of the banking sector and not solely on the creditworthiness of the households. Therefore, the credit supply react endogenously to changes in households risk and changes in banking system health.

Graphs 1 and 2 shows a large decline in the number and amount of credit originated between after 2006. Although such drop could be driven solely by a decline in demand, I show that this drop is also driven by a contraction in the credit supply. Moreover, I also show that the decline in the credit supply is driven by the contraction in the bank's capital ratio. Graph 3 shows that the aggregate capital decreased almost 1.5 percentage points between 2006 and 2009. Although it's clear the correlation between changes in house prices, banking capitalization and loans' originations, several endogeneity challenges arises when trying to identify banks reduction of the mortgage supply in response to real estate shocks and that the banks' balance sheets play a role in this process. My empirical strategy exploits variation in banks' exposure to different local housing markets and implements an instrumental variable approach.

Figure 1: Number of Loans originated

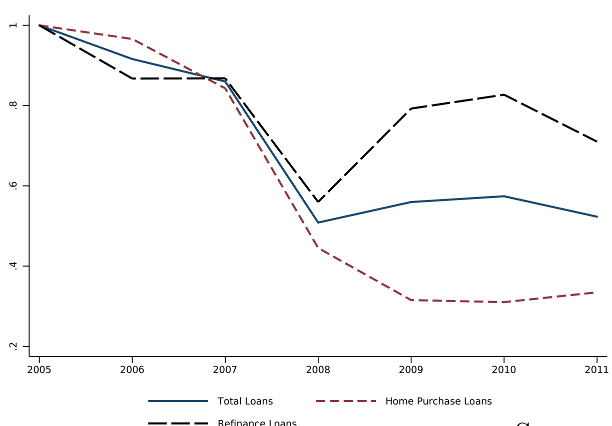
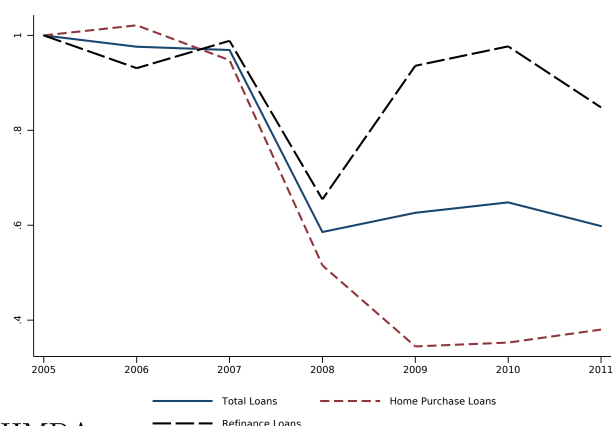
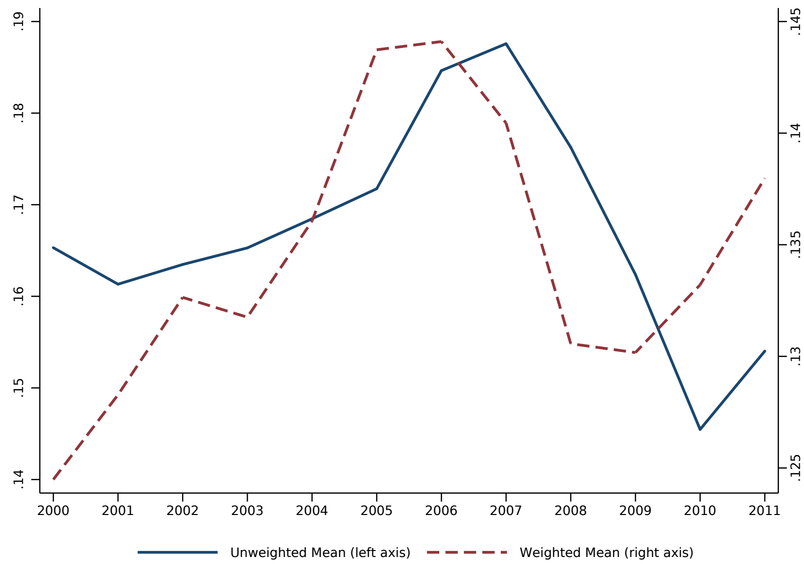


Figure 2: Loan's amount originated



Source: HMDA

Figure 3: Capital to Assets Ratio



Source: Call Reports. Capital to Assets Ratio is weighted by total assets.

I find that banks that operate in areas that experienced a larger drop in housing prices suffered a larger contraction in their equity capital to assets ratio (capital ratio). In order to isolate the balance sheet losses that result from an exogenous change in housing prices, I apply an instrumental variable approaching following Charles, Hurst and Notowidigdo (2017) to correct for potential biases. This instrument consistent of estimated structural breaks in the house price evolution between 2000 and 2006. This approach relies on the emerging consensus that much of the variation in housing prices during the boom and bust derived from a speculative "bubble" and not from changes in standard determinants of housing values. Given that the size of the boom is very strongly correlated with the size of its later housing bust, this structural breaks are strongly correlated with house demand in the bust period. Although I interpret these estimates as bank losses resulting from exogenous real estate shocks, they are not a pure partial equilibrium response, since they reflect direct housing price effects through foreclosures in addition to any general equilibrium response, including losses from other loans, such as commercial loans, that are not secured by real estate. Although 70 percent of the mortgages were government-guaranteed, and there was rapid increase in private label mortgage backed securities leading up to 2006, the results show that bank losses are still highly dependent on local conditions where banks are present. That is, banks were not able to diversify away their own idiosyncratic geographic risk.

After establishing that real estate shocks impact bank balance sheets, I show that the extent to which banks contracted the credit supply depends on their exposure to such shocks. I find that mortgage origination decreased more in counties with a higher presence of distressed banks, i.e., banks that faced greater losses. In order to identify the contraction in mortgage lending resulting from weaker bank balance sheets rather than from the deterioration of borrower creditworthiness, I restrict my attention to counties with a high concentration of large banks with a geographically diverse U.S. presence. This restriction allows me to identify how these banks' balance sheets transmit shocks from a highly affected county to counties that were less affected by local housing price shocks.

Since I use the predicted change in bank capital ratios in response to exogenous changes in housing prices from the previous regression as my independent variable, I interpret the resulting estimates as changes in the credit supply induced by exogenous variation in house prices. Therefore, I am able to find a causal relationship between housing prices and the credit supply, while simultaneously identifying bank balance sheets as the most important transmission mechanism. I estimate that a decrease of 1p.p. in the capital ratio resulting from housing price decreases leads to an approximately 10.5 percent of house purchase loans and 15.2 percent of refinances.

Although the literature has established that a contraction in bank balance sheets leads to a contraction of credit (Chodorow-Reich (2014), Santos (2010), among others), to the best of my knowledge this is the first paper that looks at mortgage credit rather than firms' financing. Moreover, unlike the current literature, I isolate the changes in bank balance sheets that result from variation in housing prices. These results highlight that despite government guarantees on conventional loans and the growth of private MBS prior to the crisis, banks' losses are still correlated with changes in local housing prices.

Building on the empirical evidence, I introduce a banking sector with balance sheet frictions in a model of long-term collateralized debt with risk of default. By doing so, the credit supply reacts to changes in the banks net worth, which allows to analyze and quantify the relevance of the endogenous response of the banking sector in propagating and amplifying shocks originated in the housing market. Households live infinitely and face uninsurable idiosyncratic income risk. Long-term mortgages are modeled as a sequence of payments that follow a geometrically declining path, which implies accumulation of equity over time. Borrowers can default and extract equity through refinancing.

The financial sector is composed of a continuum of heterogeneous banks that behave competitively. They engage in maturity transformation as they issue and hold long-term mortgages funded by short-term liabilities that exceed their own net worth. Banks face two main frictions. Net worth is accumulated solely through retained earnings, following a predetermined dividend policy. Moreover, banks face a quadratic cost function when their capital goes below an exogenously determined leverage target. This can be seen as a flexible leverage constraint that allows banks to trade-off higher leverage at a higher cost. In the case of a negative shock to their net worth, banks are not forced to deleverage immediately, as occurred during the Great Recession and shown in graph 3.

Banks have also access to a secondary market where they can trade mortgages among themselves. This market allows banks to diversify their idiosyncratic risk and adjust their balance sheet every period. More importantly, this market breaks the link between loan origination and bank balance sheets such that the distribution of banks' net worth is irrelevant in equilibrium. However, the capitalization of the entire banking system is crucial in determining the credit supply and mortgage spreads at each point in time. Individual mortgages are priced taking into account the individual household creditworthiness, house price evolution as well as the capitalization of the financial system at the time of origination. Shocks originated in the housing market that lead to an increase in the mortgage default rate cause a decrease banks' net worth. As the leverage ratio increases, banks' financing costs rise, leading to a contraction in the credit supply and an increase in mortgage spreads. The model is calibrated to match certain important moments of the housing and credit markets in the U.S. before the bust. The model is successful in replicating some non-targeted features of the housing and mortgage markets, such as the share of homeowners with mortgages, equity distribution and the average income ratio between homeowners and renters. In order to replicate the decrease in housing prices that occurred between 2006 and 2009, I use a combination of housing and labor market shocks. There is no exogenous financial shock. All responses of the financial sector are endogenous, and the quantification of such responses and their amplification is the core element of this exercise. I analyze a negative housing demand shock. Moreover, to match the observed increase in foreclosure processing times during the crisis, agents who default are able to remain in the foreclosable property with a certain probability. Finally, to account for the deterioration in the labor market, aggregate income drops. These shocks imply that housing prices drop by 18 percent, matching the observed decrease in the U.S. between 2006 and 2009. The model also generates an increase in foreclosure of 11.2p.p. and a decrease in consumption of 10.6 percent. This compares with a change in foreclosures and consumption in the data of 13p.p. and 11.5 percent, respectively. The capital ratio of the financial system decreases 1.15 p.p. in the model, implying an increase of 109 basis points in banks' cost of funding. Between 2006 and 2009, bank capital decreased 1.4 p.p. and spreads increased approximately 133 basis points. The unanticipated shocks described above imply an immediate drop in housing prices. As a result, household leverage increased automatically, since mortgages are long-term and lenders cannot force borrowers to put up additional collateral. Highly leveraged households may end up with negative home equity, and default becomes the optimal choice. Foreclosures add to the excess housing supply, exacerbating the price drop and leading to further foreclosures. The increase in foreclosures also has a negative impact on banks' net worth and their leverage increase, implying a higher funding cost. Banks would like to sell some of their loans in the secondary market in order to avoid an excessive increase in leverage. However, the lack of liquidity in the secondary market generates a decrease in the value of the outstanding loans, depressing the banks' net worth even further. Therefore, banks require higher expected returns on the mortgages they hold in their portfolio to compensate for higher funding costs. Thus, credit supply decreases and mortgage spreads increase, making it harder for households to obtain new loans or refinance. Housing prices, in turn, decrease even further, and the magnitude of the original shock is amplified. Consumption decreases due to wealth effects, as well as households' inability to smooth their income shocks with home equity loans.

Quantitatively, the endogenous response of the banking sector amplifies the drop in house prices by 13 percent, the increase in foreclosures by 9 percent and the decrease in consumption by 22 percent. If the cost of funding had not increased, housing prices would only have dropped by 16.6 percent and consumption by only 10.2 percent. Renters would have had a higher incentive to take opportunity of the low housing prices by purchasing a home. A greater percentage of homeowners would have refinanced to smooth their consumption.

Highly leveraged households and those with lower income experienced greater increases in mortgage and refinancing costs. These households, which have a higher marginal propensity to consume, also experienced the most drastic consumption declines, which can explain a significant share of the aggregate decline in consumption. This paper differs from prior literature that looks at the lending channel because it focuses on household borrowing rather than firm financing. While most of the literature studies how the deterioration of the bank balance sheets impacts the accumulation and price of capital, I analyze its impact on consumer borrowing and foreclosures. Moreover, this paper differs from the literature that looks at household financing since mortgage prices and aggregate lending behavior are driven not only by credit demand but also by the capitalization of the banking sector. I highlight the importance of the bank balance sheet channel in propagating and amplifying macroeconomic shocks in a scenario that includes a rich and realistic mortgage structure, as well as heterogeneity of bank assets. Most of the literature that analyzes the role of the bank balance sheet channel abstracts from such heterogeneity.

The paper is structured as follows. Section 2 reviews the related literature. In section 3, I describe the data, outline the empirical strategy and discuss the empirical results. Section 4 sets up the model and section 5 solves it. Section 6 describes the calibration process and analyzes the model fit and steady state. Section 7 discusses the results of an experiment in the model. Section 8 concludes.

2 Related Work

This paper is part of a growing literature that studies the response of economic outcomes to housing price shocks. On the empirical side, Mian et. al. (2013) and Kaplan et. al. (2016) show large elasticities of consumption to the drop in housing prices and housing net worth. Mian and Sufi (2011) and Mian and Sufi (2014) also evaluate the impact of the same shocks on foreclosures and employment, respectively.

The current theoretical literature bases its analysis on a class of models that feature incomplete markets, income uncertainty, heterogeneous agents and housing as collateral. These papers highlight the importance of housing prices, household wealth and debt in explaining the evolution of consumption during the recession. Berger et. al. (2016) show that the individual elasticity of consumption to housing prices can be approximated by a simple sufficient statistic formula that equals the correlation of the marginal propensity to consume with temporary income shocks times housing values. Other examples in a partial equilibrium setting are Carrol and Dunn (1998) and Campbell and Cocco (2007). More recently, some authors have incorporated these features into a general equilibrium framework to study the role of household balance sheets and debt capacity during the Great Recession. Huo and Rios-Rull (2013), Kaplan et al. (2015) and Garriga and Hedlund (2016) are papers in which housing prices, consumption and income are endogenously determined.

Kaplan et al. (2015) allow for different types of shocks: productivity shocks, taste shocks, credit shocks and shocks to beliefs about future prices. They show that this last shock is the most important in explaining movements in the housing prices, while shocks to credit conditions are important in explaining home ownership rates, leverage and foreclosures.

Garriga and Hedlund (2016) introduce housing market search frictions, which creates an endogenous and asymmetric amplification mechanism. The need to pay off outstanding debt imposes a lower bound on list price, causing long delays in housing sales and forcing households to either default or cut consumption. But the authors show that an increase in the downside labor market risk and the tightening of down payment constraints have the largest contribution to the steep drop in housing prices and consumption. Endogenous housing illiquidity and default-induced illiquidity reinforce each other and prove essential to replicating the severity of the recession and the slow recovery.

Although these papers consider that credit conditions are important in explaining the evolution of consumption, foreclosures and housing prices, they employ models in which these are exogenous, neglecting the connections and feedback effects between the housing market and the banking sector.

My paper shares several features with the models mentioned above, including incomplete markets, heterogeneity, uncertain income and collateral constraints, but I focus my attention on the lending channel, namely shocks to banks that affect their balance sheets and ability to extend credit. Important papers on the empirical literature include Stein (1998), Kashyap and Stein (2000) and Jimenez et al. (2012). These papers explore cross-sectional variation in bank balance sheets to estimate the effect of contractive monetary policy and adverse economic conditions on the credit supply. My paper focuses on real estate shocks instead. In this line, Chakraborty et al. (2016) and Flannery and Lin (2015) look at the boom period before 2006 and study the impact of positive shocks to banks' lending opportunities, using individual bank data. The former concludes that the boom in housing prices led to an increase in mortgage lending and a decrease in commercial lending, while the latter reports an increase in both types of loans. Huang and Stephens (2011) and Cunat et al. (2013) look at the impact of the housing market on the credit supply, but their focus is on the financial crisis period and the credit crunch caused by housing bust. Grenstone and Alexandre (2012) and Chodow-Reich (2014) look at the transmission of housing shocks to firm employment through bank balance sheets. Santos (2013) concludes that firms paid higher loan spreads during the crisis, and this increase was higher for firms that borrowed from banks that incurred larger losses. Ivashina and Scharfstein (2008) provide support for the existence of significant supply constraints in terms of quantity. I differ from these papers by focusing on the loan supply to households, specifically mortgage loans.

The emphasis on the transmission of financial shocks through banks connects this paper to the large theoretical literature on financial frictions and the credit channel, which includes Bernanke and Gertler (1989) and Kiyotaki and Moore (1997). Gertler and Keradi (2011) and Gertler and Kiyotaki (2009) model the way financial intermediaries and lending channels work, through the impact of shocks to capital quality, on banks' external finance premium, which is determined by their perceived balance sheet strength. The deterioration of financial intermediaries' balance sheets is key to the transmission and amplification of shocks.

More generally, this paper relates to the credit crunch literature that highlights the impact of deleveraging on the economy as in Eggerstsson and Krugman (2012), Guerrieri and Lorenzoni (2015) and Jermann and Quadrini (2012). However, these papers are different from mine in that they abstract from the housing market and financial intermediaries, modeling a credit shock as an unexpected tightening of borrowing limits.

This paper also connects with the literature that looks at household balance sheet frictions. Iacoviello (2005) embeds nominal household debt and collateral constraints tied to real estate values, as in Kiyotaki and Moore (1997), into a new-Keynesian model. The paper shows that demand shocks move housing and consumer prices in the same direction and thus amplify their variation. When demand rises due to an exogenous shock, consumer and asset prices increase. The rise in asset prices increases the borrowing capacity of debtors, allowing them to spend and invest more. The rise in consumer prices reduces the real value of outstanding debt obligations, positively affecting debtors' net worth. Given that borrowers have a higher propensity to spend than lenders, the net effect on demand is positive and the demand shock is amplified. The model presented in my paper differs in several dimensions from Iacoviello, mainly because in my model households face an endogenous, rather than exogenous, borrowing constraint that is determined by the strength of both household and bank balance sheets.

Incomplete market models with heterogeneous agents have also been used to study housing markets along other dimensions. For example, Favilukis et al. (2015) use this type of model to ask whether financial innovation and the relaxation of financial constraints were at the root of the recent U.S. housing boom-bust cycle. Campbell and Cocco (2015) and Corbae and Quintin (2015)) study how the boom and bust affected default risk and incentives in the financial system. My paper focuses on the on role of the bank lending channel in amplifying the consumption drop after the negative housing price shock, so I leave these important issues aside.

3 Empirical Analysis

In this section, I empirically demonstrate that the bank balance sheet channel was relevant during the 2006-2010 period. I present evidence that changes in real estate prices impacted financial institutions' balance sheets and that banks reacted by adjusting their lending policies.

First, I show that banks operating in counties that experienced a greater decrease in housing prices faced a larger contraction in their capital ratio[1]. Second, I find that banks changed their mortgage loan supply as the volume of new mortgages and refinance loans decreased more in counties with a larger presence of affected banks. The identification strategy relies on exogenous regional variation in house prices and an instrumental approach to disentangle changes in credit supply from changes in demand. This allows my results to be interpreted as shocks to bank balance sheets, which impact mortgage loans exclusively through the credit channel.

3.1 Data

The analysis in this section focuses on the 2006-2010 period, the period with the sharpest housing price declines, the largest changes in bank balance sheets and contraction in credit. Information on the bank balance sheets and income statements comes from Reports of Condition and Income, usually known as Call Reports. Data on the banks' exposure to changes in housing prices comes from information on each bank's deposits (at the county level) and from changes in housing values. These data are obtained from the Summary of Deposits and the Zillow Median Home Value Index for All Homes, respectively.

To assess the supply of credit at the local level, I use data on individual mortgage loan applications. The data is obtained from the Home Mortgage Disclosure Act (HMDA) which covers about 90 percent of U.S. mortgage applications. The analysis is conducted with loans originated for Home Purchase or Refinance of 1-to-4 family houses, owner-occupied as principal dwelling, first lien and not insured by Federal Housing Administration (FHA), Veterans Administration (VA) or Farmers Home Administration(FmHA). All loans originated and later purchased or securatized are included in the sample[2]. To relate the supply of credit to banks' condition and exposure to the housing market, I benefit from the fact I can match each bank's respondent ID in the HMDA data set with the same bank's ID code in the Call Reports and SOD.

My analysis relies on variation across counties, and I account for heterogeneity in economic conditions by using measures of unemployment rate and income obtained from the Bureau of Labor Statistics and IRS Statistics of Income, respectively.

[1]In this paper I focus on the capital ratio, given its direct link to the model presented in this paper. However, exogenous changes in housing prices impacted several balance sheet variables, including net charge-offs, provisions, and late loans, among others.

[2]The mortgage application sample is restricted to applications that were either denied or approved and excludes observations with ambiguous status, such as incomplete files and withdrawn applications. I focus on new loans, excluding purchases of existing loans from the sample.

This section explains how the behavior of county-level housing prices affect the household borrowing through the bank lending channel. I divide this analysis into two parts. First, I look at how changes in housing prices affect banks' performance and the balance sheets. Second, I analyze how such changes induce modifications to the banks' mortgage supply.

3.2 Change in Housing Prices and Bank Balance Sheets

In order to test whether changes in housing prices affect the bank balance sheets, I estimate the following equation:

$$\Delta Y_{k,t} = \beta_1 + \beta_2 \Delta RES^p_{k.t} + \beta_3 X_{k,05} + \epsilon_{k,t} \tag{1}$$

where $\Delta Y_{k,t}$ denotes the change between $t-1$ and t of the capital to assets ratio of bank k, $\Delta RES^p_{k.t}$ is the real state shock faced by bank k and $X_{i,05}$ a set of bank controls to account for differences across banks before being hit by the shock.

A bank's capital ratio is defined as its total equity plus retained earnings divided by total assets. Since I use book value of equity, and assets are not risk adjusted, this measure is equivalent to a pure leverage ratio. This definition of bank capital has a direct link to the definition of bank equity capital in the model. As shown in figure 1, the average capital ratio decreased from 14.4 percent in 2006 to 13 percent in 2009. In 2009 it started increasing again, mainly due to forced recapitalizations. In 2006, banks in the 10th and 90th percentiles of the capital ratio distribution had capital ratios of 10 percent and 18.9 percent, respectively.

Table 1: Variation in Capital to Assets Ratio

	Mean	SD	Median	Perc10	Perc90
Capital Ratio - Weighted					
2006	14.4102	6.8702	12.523	10.6074	18.9267
2009	13.0172	5.5591	12.4066	9.2284	17.8725
Changes Capital Ratio - Unweighted					
2006-2009	-1.1767	7.1829	-.1076	-3.6732	1.4572
Δ2006-2009	-1.481	8.6879	-.3291	-5.4247	1.3389
Changes Capital Ratio - Weighted					
2006-2009	-.5429	3.9144	-.3101	-2.1024	1.8451
Δ2006-2009	-.1361	4.4029	.3226	-2.2392	1.8627

Source: Call Reports. Capital to Assets Ratio weighted by total assets in 2005

The real estate shock to bank k at time t, ΔRES^p_{kt}, is defined as the weighted average of housing price changes, ΔP_{jt}, in the counties (indexed by j) where a bank has depository branches. The weights are the share of the bank's total deposits that are located in a given county in the base year, 2005.

$$\Delta RES^{p}_{kt} = \sum_{j} \omega_{kj05} \Delta P_{jt} \tag{2}$$

The cross-sectional weights ω_{kj05} are static in order to consider the bank's portfolio before prices started to drop and to avoid introducing endogeneity through the weighting procedure. We can think of this measure as the change in house prices relevant to each bank, and I interpret it as a real estate shock to a given bank in a given period. Two major concerns may arise with this measure. First, weights are based on deposits rather than loans. But Aguirregabiria et. al. (2016) show evidence of a strong home bias in the U.S. banking industry for the period 1998-2010, meaning that local deposits are largely used to fund local loans, which makes deposits a good proxy for loans. Second, the rise of mortgage-backed securities may have allowed banks to diversify away from their physical locations. Chakraborty et. al. (2016) argue that this concern is not important because even when loans are sold after origination, the originating bank is likely to remain the servicer of the mortgage, maintaining exposure to the local market. When banks create the mortgage-backed securities, as opposed to simply selling the mortgages to another unrelated sponsor, they often retain a certain amount of the security as a signal of its quality.

Table 2 shows summary statistics for nationwide housing price growth and for the real estate shocks faced by each bank (RES). Between 2006 and 2010, the median home price in real terms in the Zillow data set decreased, on average, 6.4 percent per year, and -22.2 percent over the entire period. When weighted by bank assets, the average RES for each bank was -4.6 percent per year and -15.7 percent over 2006-2010 period. House price changes are very heterogeneous across counties. The 90th-10th percentile differential is 0.17p.p. The index of exposure for each bank, while it averages across locations, it is still very heterogeneous. The 90-10th percentile difference is 0.11p.p.

Table 2: RES and House Prices

	Mean	SD	Median	Perc10	Perc90
RES					
2006-2009	-.0468	.0547	-.0445	-.1085	.0203
2006-2010	-.0458	.0502	-.0454	-.0999	.0049
Δ2006-2009	-.1267	.1007	-.1352	-.2197	.0019
Δ2006-2010	-.1573	.1024	-.1487	-.2708	-.0437
Δ House Prices - Unweighted					
2006-2009	-.0426	.0702	-.0468	-.1078	.0293
2006-2010	-.0482	.0704	-.0513	-.1239	.0222
Δ2006-2009	-.1182	.144	-.1142	-.2786	.0518
Δ2006-2010	-.173	.1557	-.1815	-.3554	.0003
Δ House Prices - Weighted					
2006-2009	-.0674	.0756	-.0603	-.1743	.0117
2006-2010	-.064	.0731	-.0554	-.1634	.0109
Δ_2006-2009	-.182	.1564	-.1751	-.396	-.0082
Δ_2006-2010	-.2228	.1684	-.2171	-.4865	-.0208

Source: Call Reports, SOD and Zillow. House Prices are weighted by county population in 2005

The set of controls is summarized in Table 11 in appendix A. They consist of indicators of a bank's performance in 2005, before the national decline in housing prices. They capture variation in lending standards among banks.

The specification in (1) may not isolate balance sheet changes due to housing price exposure from those due to unobserved economic shocks that may simultaneously drive bank performance and housing prices. Moreover, lending policies may also affect housing prices. To address these concerns, I use an instrumental variable approach. The instrument corresponds to the size of the estimated structural breaks in the evolution of house prices at county level between 2000 and 2006, following the approach in Charles, Hurst and Notowidigdo (2017). This approach relies on the emerging consensus that much of the variation in housing prices during the boom and bust derived from a speculative "bubble" and not from changes in standard determinants of housing values such as income, population, or construction costs. The implicit assumption is that these "sharp breaks" are exogenous to local latent confounds, such as labor supply shocks or unobserved changes in credit changes, which are likely smoothly incorporated into price changes. The authors show in fact that the estimated breaks are not, in fact, systematically related to pre-period levels and changes in many observable local characteristics, and provide evidence consistent with them being the result of speculative activity. Moreover, the structural breaks also strongly predict the housing demand change during the 2006-2012 bust period, a result that follows from the fact that the size of the boom is very strongly correlated with the size of its later housing bust.

The resulting instrumental variable is the weighted average break relevant to each bank. The weights are defined by the deposits of each bank at the county level. Table 3 shows that the House Price break measure can explain a large portion of the real estate shocks faced by the banks. Since areas with the largest structural break in house prices prior to 2005 also suffered the biggest drop in housing prices and household net worth (Mian et al. (2013)), banks with a larger presence in counties with higher breaks saw a larger decline in their housing price index. The first stage presented in table 3 removes concerns about the weakness of the instrument since the F-statistics are always lager than 20.

Table 3: RES and and House Price break

	(1)	(2)	(3)	(4)
RES (HP break)	-0.307***	-0.308***	-0.254***	-0.254***
	(0.012)	(0.011)	(0.012)	(0.011)
Observations	7554	7554	7515	7515
Adjusted R^2	0.144	0.227	0.198	0.281
F	630.2	716.7	68.40	81.11
SD	robust	robust	robust	robust
Year FE	No	Yes	No	Yes

Notes. Dependent variable: Real estate shock (RES). The unit of observation is a bank. Variables are normalized by total assets. ***,**,* Coefficients significant at the 1%, 5% ad 10% levels, respectively. The complete regression table is available in appendix A, table 12.

3.3 Bank Balance Sheets and Lending Practices

Next we must isolate the impact of real estate shocks on loan availability through the bank balance sheet channel. In other words, I test whether banks that became more constrained due to real estate shocks reduced their credit supply more. The main challenge is to disentangle credit supply from credit demand, since changes in housing prices may simultaneously affect both. Moreover, households that are more affected by the drop in housing prices and economic conditions may borrow more from affected banks.

To address these concerns, I look at changes in mortgage origination at the county level between 2007 and 2010. More specifically, I regress the changes the balance sheets of the banks operating in a certain county on the changes in mortgages originated in the same county, as expressed in the following equation:

$$\Delta \text{MortgageOriginated}_{j,t} = \beta_1 + \beta_2 \Delta \Upsilon_{j,t} + \beta_3 \Delta H_{j,t} + \beta_3 W_{j,05} + \epsilon_{j,t} \tag{3}$$

In order to capture the change in a bank's balance sheet induced by an exogenous variation in housing prices, I use the predicted values of regression (1) as the independent variable in this specification. Then $\Delta\Upsilon_{j,t}$ is defined as the weighted average of the predicted values of the variable of interest

$$\Delta\Upsilon_{j,t} = \sum_k \alpha_{k,j} \Delta\widehat{Y_{k,t,-j}}$$

To guarantee that the variation is exogenous, I use the predicted values of the IV regression. α_{kj} is the share of deposits of bank k over the total deposits in county j. Note that $\Delta\widehat{Y_{i,t,-j}}$ is the change in capital of the bank as a whole, not the change in capital attributed to that specific county[3]. In fact, I remove from the predicted value the contribution of that specific county to the decline in the bank balance sheet. So, this specification allows me to identify how shocks to a bank's balance sheet in a certain county affects its lending policies in a different county. In other words, how the credit supply in a given county is influenced by shocks that affect the bank as whole, which are potentially unrelated to local shocks. Therefore, I restrict the sample to counties only served by banks that operate in multiple counties.

Moreover, to control for changes in the creditworthiness of potential borrowers, I control for changes in housing prices, changes in unemployment rate and changes in income at the county level, $\Delta H_{j,t}$. $W_{j,06}$ are bank controls at the county level, using a_{kj} as weights.

Although my dataset covers information at the individual level, there are two important reasons to focus on the county level instead. The first relates to selection in the application process. Households choose which banks to apply to. If they suspect that some bank is having difficulties and guess that it will be harder to obtain a loan from that bank, individuals in a certain county may concentrate their loan applications at healthy banks. If this happens, we might find that the acceptance rate decreases at the healthy bank but not at the most constrained banks. Moreover, the HMDA data set, though it covers almost all mortgage applications in the U.S., has very little information on household characteristics, especially about how the creditworthiness of the applicant pool changes over this period. Specifically, there is no information about credit score or employment status. Therefore, by conducting my analysis at the county level, I can use changes in housing prices, changes in the unemployment rate and changes in income as proxies for the creditworthiness of potential borrowers.

[3] In Cunat et al.(2015) banks are considered to be conglomerates of local branches, and therefore they construct a measure of the bank's balance sheet at the branch level. In their formulation Y_{it} would measure the change in capital of bank i attributed to county j. However, my goal is to identify how shocks to a bank in a certain county affect lending in other counties due the impact on that bank's balance sheet

3.4 Results

Change in Housing Prices and Bank Balance Sheets

Table 4 reports the coefficients of the regression (1). The first column shows the raw correlation between the real estate shock faced by each bank and the change in its capital ratio. The correlation is strong and significant at the 99 percent level.

Table 4: RES and Capital Ratio

	OLS	IV	OLS	IV
RES(t)	0.088***	0.091***	0.061***	0.082**
	(0.009)	(0.022)	(0.009)	(0.026)
Observations	4908	4908	4888	4888
Adjusted R^2	0.031	0.031	0.117	0.116
SD	robust	robust	robust	robust
Bank controls	No	No	Yes	Yes
Year FE	No	No	Yes	Yes

Notes. Dependent variable: Variation of Capital to Assets Ratio. The unit of observation is a bank. Variables are normalized by total assets. ***,**,* Coefficients significant at the 1%, 5% ad 10% levels, respectively. The complete regression table is available in appendix A, table 13.

In column (3), I control for bank characteristics, such as size (log of assets), measures related to liquidity and asset composition. I include additional bank characteristics that control for the bank's standard practices. These controls are Late Loans, Income Loss, Provisions and Allowances in 2005, before the shock hit most of the banks. In this specification, the correlation coefficients decrease but are still strong and statistically significant, which indicates that bank lending standards cannot explain the observed changes in bank performance and balance sheets during the crisis.

Column (4) shows the same specification but with the real estate shock instrumentalized with the house prices breaks faced by each bank. Here, the coefficients increase and become closer to the raw correlation. I conclude that a bank that faces a real estate shock of 10 percent (that is, an average price decrease of 10% price in the counties where the bank operates), sees its capital-to-assets ratio decrease 0.82p.p.. If we consider the average shock (-4.6 p.p. per year), the same ratios change by -0.38p.p.. Alternatively, we can interpret the same results in the following way: going from the 90th to the 10th percentile of the real estate shock distribution (-10.48 p.p.) implies that the capital ratio decreases 0.85p.p..

These results lead us to conclude that the the change in housing prices in the locations where banks operate are statistically and economically relevant to the changes in these banks' balance sheets during this period. These results also show that although a large part of the mortgage market is guaranteed by the government and there was an active private MBS market before 2006, banks' losses are still very correlated with economic conditions, especially with changes in local housing prices.

Bank Balance Sheets and the Credit Supply

I have established a causal relationship between real estate shocks and changes in bank balance sheets. In this section, I proceed to test whether banks that became more constrained due to the real estate shock contracted the credit supply more than their counterparts with healthier balance sheets. I attempt to isolate the impact of real estate shocks on loan granting through the bank balance sheet channel. Therefore, I use the predicted change in bank balance sheets from the model presented in Column (3), excluding the predicted changes associated with that county, where the real estate shock is instrumentalized. This variable captures the exogenous change in bank balance sheets induced by the real estate shock. Only banks presented in multiple counties are included in the sample to avoid confounding factors with demand forces.

The dependent variable is the the percentage change in mortgage loan amount origination in each county. I look separately for the Home Purchase mortgages and Refinancing. As in Mian et al. (2013), all standard errors are clustered at the state level to allow for spatial correlation across counties within a state, and to allow for correlation within a state due to state-specific factors, such as foreclosure and bankruptcy laws.

Table 5: Home Purchase Loans

	Origations by banks in sample		All Originations	
	(1a)	(2a)	(1b)	(2a)
Predicted Δ Capital Ratio	141.031***	47.090**	37.701***	10.489*
	(21.241)	(17.293)	(4.514)	(4.352)
Δ real house prices	-0.866	-1.283	0.306*	0.463***
	(0.616)	(1.237)	(0.114)	(0.108)
Δ wages	-0.915	0.649	0.633	0.586**
	(0.568)	(1.222)	(0.517)	(0.205)
Δ income	0.043	0.005	0.603	0.161***
	(0.152)	(0.130)	(0.300)	(0.039)
Δ unemployment rate	-0.009	-0.018	-0.011	-0.006
	(0.023)	(0.033)	(0.006)	(0.010)
Observations	2850	2850	3010	3010
Adjusted R^2	0.036	0.079	0.396	0.497
SD	robust	robust	robust	robust
cluster	State	State	State	State
Year FE	No	Yes	No	Yes
State FE	No	Yes	No	Yes

Notes. Dependent variable: Change in Home Purchase loans. The unit of observation is a county. ***,**,* Coefficients significant at the 1%, 5% and 10% levels, respectively.

From table 5, I conclude that counties served by banks with a larger decrease in capital ratio due to the real estate shock faced a larger decrease in the total amount of mortgages originated for Home Purchase. In the first two columns I aggregate the loan originations for the banks presented in Call Reports. The last two columns, corresponds to all the loans originated in the county[4]

Columns (2) repeats the specification of Columns (1) but adds state fixed effects and Year Fixed Effects. A decrease in capital ratio by 1.p.p. induced by a change in housing prices leads banks to cut the total mortgage supply by 47 percent. Alternatively, going from the 90th to the 10th percentile of the change in capital ratio in the cross-section distribution (-0.57p.p.) in the cross-section implies a decrease in the supply of home purchase mortgages of 26.8 percent.

Not surprisingly, when considering also loans coming from other financial institutions that are usually subjected to less strict regulatory constraints, the effects are attenuated. This result also shows that there is in fact substitution effect as less affected institutions step in and fill part of the credit supply contraction imposed by more affected banks. Nevertheless, we can still conclude that credit supply contracted more in areas with more affected banks.

[4]HMDA reports loans originated by all financial institutions. However, in Call reports I only have information about commercial banks, which are in fact the main source of mortgages originations.

Table 6: Refinance Loans

	Origations by banks in sample		All Originations	
	(1a)	(2a)	(1b)	(2a)
Predicted Δ Capital Ratio	60.902***	78.385***	24.908***	15.184*
	(13.507)	(12.809)	(6.453)	(6.038)
Δ real house prices	0.914*	1.102*	1.568***	1.608***
	(0.346)	(0.449)	(0.165)	(0.131)
Δ wages	0.878	1.362	0.144	0.894*
	(1.127)	(1.192)	(0.457)	(0.389)
Δ income	0.303	0.084	0.753*	-0.201
	(0.861)	(0.959)	(0.307)	(0.332)
Δ unemployment rate	-0.009	0.003	-0.064***	-0.036
	(0.040)	(0.044)	(0.018)	(0.021)
Observations	1464	1463	1509	1508
Adjusted R^2	0.142	0.156	0.581	0.651
SD	robust	robust	robust	robust
cluster	State	State	State	State
Year FE	No	Yes	No	Yes
State FE	No	Yes	No	Yes

Notes. Change in Refinance loans. The unit of observation is a county. ***,**,* Coefficients significant at the 1%, 5% and 10% levels, respectively.

In Table 6, I present the results for refinance loans, which corresponded approximately to 53 percent of the total loans originated during the study period. Going from the 90th to the 10th percentile of the change in capital ratio in the cross-section distribution implies a decrease in the supply of refinancing loans of approximately 44.4 percent when the sample is restricted to loans originated to banks presented in Call Reports. If we look at all loans in the county, we still observed a contraction of 8.55 percent higher in the counties with more constrained banks.

These results soundly support the hypothesis that changes in bank balance sheets induced by a real estate shock can explain the change in the mortgage credit supply. More-constrained banks reduced mortgage loans by a greater amount after the housing price shock. The impact appears to be considerably larger for refinance loans. Given the government guarantees on new conventional loans, these results are not surprising. Changes in income and housing prices are also very important contributors to changes in mortgage at the county level, suggesting that demand for mortgages was also a factor during this period.

4 The Model

4.1 Households

4.1.1 Preferences and Endowments

There is a continuum of heterogeneous, infinitely lived households indexed by i. Households discount the future at rate β and have time-separable preferences over a homogeneous numeraire nondurable consumption good c and housing services s. The per-period utility is given by

$$u(c_{it}, s_{it}) = \frac{\left((1-\alpha){c_{it}}^{1-\gamma} + \alpha {s_{it}}^{1-\gamma}\right)^{\frac{1-\gamma}{1-\sigma}} - 1}{1-\sigma}$$

Housing services can be obtained by owning or renting. Households can rent $h \in \mathcal{H}^r$ units of housing per period and homeowners own a house $h \in \mathcal{H}^h$. Both sets of houses are discrete. Each rental unit generates one unit of housing service, i.e., $s = h$ while each owned house generates $s = \upsilon h$. Agents are not allowed to simultaneously own and rent a house. There are three advantages of owning over renting. First, the amount of housing space rented is limited compared to the housing owned, $\mathcal{H}^r \subset \mathcal{H}^h$. Second, mortgage interest is tax-deductible, which gives it a tax advantage to owning over renting. Third, owning house gives access to the credit market where the house is used as collateral.

Households face an idiosyncratic exogenous income process given by

$$y_{it} = w.exp\left(\bar{w} + z_{it}\right)$$

where z_{it} is a transitory shock that follows an AR(1) process

$$z_{it} = \rho z_{it-1} + \epsilon_{it},\ \epsilon_{it} \sim N\left(0, \sigma_\epsilon^2\right)$$

and w is the equilibrium wage.

In the initial period, individuals are endowed with some non-negative level of financial wealth a. Some, called homeowners, are also endowed with an owner-occupied house, while those with an owner-occupied housing level of zero are called renters. Homeowners may have a mortgage against their house. Each period, agents decide the amount of non-durable consumption and housing services they consume, how to obtain the housing services (renting or owning), holdings of assets, and whether to refinance an existing mortgage. The formalization of these decisions are described in more detail below.

4.2 Assets

There are three assets that households can hold: houses, long-term mortgages and risk-free bank deposits.

Risk-free deposits

Households can save through risk-free deposits that pay a constant and exogenous risk-free real interest rate r. Uninsurable idiosyncratic income shocks generate precautionary savings, such that in equilibrium homeowners may borrow against their housing and save through risk-free deposits.

Housing

Owner-occupied houses can be purchased at the equilibrium price p_t, denominated in terms of the period t numeraire good. Houses are subject to random maintenance expenses $\delta_h \in \{0, \delta\}$. At any point in time, a homeowner that owns a house of size h faces a maintenance cost of $\delta p_t h_t$ with probability p_δ and zero expenses with probability $1 - p_\delta$. Owned houses are, therefore, a risky asset. On top of the maintenance costs, homeowners must pay property taxes τ_h.

Purchasing a new house or changing one's housing stock is subject to non-convex transaction costs, making owner-occupied houses an illiquid asset. In particular, homeowners who wish to sell face a fixed cost proportional to the sale price, $\chi_s p_t h_{it-1}$, and a purchasing cost of $\chi_b p_t h_{it}$.

Rental housing can be purchased at the equilibrium rental rate p_t^r, also denominated in terms of the numeraire good. It can be adjusted costlessly but cannot be used as collateral.

Mortgages

Mortgages are long-term collateralized debt contracts with geometrically declining coupon payments in the spirit of Chatterjee and Eyigungor (2012, 2015) and Hatchondo and Martinez (2009). A mortgage contract signed at time τ with face value $m_\tau = m'$ corresponds to a sequence of payments starting at time $\tau + 1$. Note that m' corresponds to the principal balance one period ahead, i.e., in case the contract terminates at $\tau + 1$ without default, the borrower promises to pay m'.

Every period, the mortgage holder must decide if keeps paying the mortgage, defaults or terminates the current mortgage contract if sells the current house or refinances. The ability to default and prepay mortgages implies that the lender prices mortgages based on the individual probability of default. If at time τ the household i with a choice of savings a', housing stock h' used as collateral and current income y takes a mortgage with face value m' and coupon rate r_τ^m, the bank delivers $q_(y_i, a_i', h_i', m_i', r_\tau^m) m_i'$ units of the consumption good at origination. The mortgage price function decreases with the probability of default and prepayment. For simplicity, I use $q_{i\tau} m'$ and $q(y_i, a_i', h_i', m_i', r_\tau^m) m_i'$ interchangeably.

If at time t the borrower sells the property used as collateral or wants refinance the current mortgage, the borrower must terminate the contract and pay the outstanding principal given by m'[5]. Borrowers can refinance by signing a new mortgage that uses the same house as collateral but faces a fixed refinancing cost χ_m.[6]

Mortgages are non-recourse, so in the case of default, the lender receives the ownership of the house used as collateral and the borrower's obligations to the lender are extinguished. Besides paying property taxes, the lender faces a liquidation cost of χ_d. If the value of the house net of the liquidation cost is lower than the outstanding principal, the bank absorbs the loss, but it can never receive more than the remaining value of the mortgage. Therefore, the lender recover in case of default $x_t^d m'$, where x_t^d denotes the faction of the outstanding principal m' recovered and defined by:

$$x_t^d = \frac{min\left\{(1-\chi_d-\tau_h)\, p_t h, m'\right\}}{m'}$$

Default is costly for the borrower. The household becomes a renter in the period of default and is not allowed to access the mortgage market for a random length of time. Every period, the household is able to obtain a new mortgage with probability $0 < \theta < 1$.

In case the mortgage holder decides to keep the current the mortgage contract, the borrower must pay a constant fraction x_τ of the outstanding principal. x is fixed in the period of origination τ and defined as

$$x_\tau = \frac{\mu + r_\tau^m}{1 + r_\tau^m} \tag{4}$$

The payment has two components: the amortization rate, μ, and the coupon or mortgage interest r_τ^m. The amortization rate μ is assumed to be common to all households, for simplicity. The outstanding principal evolves according to $m' = (1-\mu)m$. Therefore, homeowners accumulate home equity over time and the average maturity of the mortgage contract is $\frac{1}{\mu}$ periods. This flexible structure accommodates several mortgage structures. $\mu = 1$ corresponds to one-period mortgages and $\mu = 0$ a perpetual, or interest-only mortgage. In this paper, I assume $\mu \in (0, 1)$ representing a mortgage contract with positive payments for a fixed number of periods and zero thereafter.

r_τ^m is determined at the origination date and fixed throughout all the contract. r^m is determined in equilibrium and is a function of capitalization of the banking sector, as it will become clear in section 5. Although r^m may vary over time, for simplicity is assumed to be common to all the borrowers that take a new mortgage in a given period. Then, all the heterogeneity is loaded into the

[5]Although this mortgage structure shares some features of the one presented in Chatterjee and Eyigungor (2015), it differs in several dimensions. In specific, they assume that in case of prepayment, the borrower is required to pay the stream of payments on the existing loan discounted at the risk-free rate. Therefore, as long as the risk-free rate does not fall, the option to refinance the mortgage is not valuable. This feature is not present in structure used here, and therefore, refinances occurs in equilibrium

[6]χ_m is lower than the transaction costs associated with selling and buying a new house, so it's optimal to refinance instead of selling and buying a new house when the optimal size of housing services is unchanged

price $q_{i\tau}m'$. We can then define an implicit mortgage interest rate, $r^*_{i\tau}$, that reflects the idiosyncratic risk of each borrower.

$$r^*_{i\tau} = \frac{1}{q_{i\tau}} - 1 \tag{5}$$

that corresponds to the solution to $q_{i\tau}m' = \frac{x^*_\tau m'}{1+r^*_{i\tau}} \sum_{j\geq 0} \left(\frac{1-\mu}{1+r^*_{it}}\right)^j$ with $x^*_\tau = \frac{\mu + r^*_{i\tau}}{1+r^*_{i\tau}}$.

4.3 Tax System

Households pay income tax, as well as property tax if they own a house. Mortgage interest payments are tax deductible. For a homeowner, taxable income is given by

$$Y^\tau_t(y, h, m, r^m_\tau) = max\left\{y - \tau_h p_t h - r^m_\tau m, 0\right\}$$

and total tax payment is

$$T_t(y, h, m, r^m_\tau) = \tau_y Y^\tau_t(y_t, h_t, m_{t-1}) + \tau_h p_t h$$

Tax payments for renters and borrowers who default is given by $T_t(y, 0, 0, 0)$.

4.4 Financial Sector

The financial sector is composed of a continuum of banks indexed by k, which are owned by risk-neutral agents outside this economy. The financial sector plays a central role in my model since it intermediates all financial transactions between agents. The only saving instrument available to households is bank deposits and households can only borrow from the banks.

Banks engage in maturity transformation as they issue and hold long-term mortgages funded by short term liabilities beyond their own net worth.

The total amount of short-term liabilities at time t, B_{kt}, necessary to finance lending includes both household's deposits and borrowing in the international credit market. Banks have access to a world credit market where they can lend or borrow at the risk-free interest rate r. By non-arbitrage, households deposits are remunerated at the same interest rate r[7].

The asset side of each bank is a portfolio of differentiated mortgages. Each mortgage is originated by a unique bank in a competitive environment. However, there is a secondary market where banks can trade loans among themselves. An originating bank can keep the mortgages in its portfolio or sell any fraction of its mortgages to other banks in the system, even in the period of

[7]Deposits are risk-free because the government guarantees all bank deposits, even those obtained in the international market. If a bank is hit by a large shock that renders it unable to pay back all its debt, the government intervenes. Therefore, all deposits are risk free and remunerated at interest rate r

origination. Information about the characteristics of the mortgages and the respective borrowers is observable by all banks. Mortgages are traded in a centralized market at p_t^m per unit of mortgage value. In other words, when a bank acquires a fraction ι of a given mortgage with face value m_{it}, it pays $\iota p_t^m q_{it} m_{it}$ in exchange for a fraction ι of all future payments on that mortgage.

Given that the secondary market is frictionless, I will define the loan portfolio of a given bank at each point in time as a fraction of the outstanding loans in the economy. $\iota_{kt} = [\iota_{kit}]_{i\in\Omega_i}$ is a vector that denotes the fraction of each mortgage in the economy hold by bank k in its balance sheet at time t. The book and market value of bank k portfolio is defined, respectively, by

$$M(\iota_{kt}) = \int \iota_{kit} m_{it} di$$

$$Q_t(\iota_{kt})M(\iota_{it}) = \int \iota_{kit} q_{it}(m_{it}) m_{it} di$$

For notation simplicity, I use $M_{kt} = M(\iota_{kt})$ and $Q_t(M_{kt})M_{kt} = Q_t(\iota_{kt})M(\iota_{kt})$.

Although the bank can re-adjust their portfolio in every period, we can define the evolution of the outstanding principal of the mortgage portfolio prior to the adjustment as

$$\tilde{M}_{k,t+1} = (1 - \mathbf{d}_{k,t+1} - \mathbf{s}_{k,t+1})(1-\mu) M_{kt}$$

$\mathbf{d}_{k,t+1}$ is the fraction of principal defaulted given by $\mathbf{d}_{k,t+1} = \int \mathbf{1}_{\{\mathbf{d_{it+1}=1}\}} \iota_{kit} \frac{m_{it}}{M_{kt}} di$ and $\mathbf{s}_{k,t+1}$ the share of principal prepaid, $\mathbf{s}_{t+1} = \int \mathbf{1}_{\{\mathbf{s_{it+1}=1}\}} \iota_{kit} \frac{m_{it}}{M_{kt}} di$. $\mathbf{1}_{\{\mathbf{d_{it+1}=1}\}}$ and $\mathbf{1}_{\{\mathbf{s_{it+1}=1}\}}$ are two indicator functions that equals 1 if household i defaults or prepays, respectively, in period $t+1$ and zero otherwise. Note that $\mathbf{d}_{k,t+1}$ is not the fraction of borrowers that default, but instead the fraction of principal not repaid in case of default.

In every period, each bank must satisfy the following balance sheet constraint:

$$Q_t(M_{kt})M_{kt} = B_{kt} + N_{kt} \tag{6}$$

Frictions

There are two main frictions. First, net worth is accumulated solely through retained earnings. All banks follow a common exogenous dividend policy, ω, such that each period bankers receive $\omega\left[N_{kt-1} + \Pi_{kt}\right]$ from each bank. Π_{kt} denotes the profits of bank k in period t and N_{kt-1} denotes net worth at the end of period $t-1$, after dividends are paid. Therefore, bank k's net worth evolves according to

$$N_{kt} = (1-\omega)\left[N_{kt-1} + \Pi_{kt}\right] \tag{7}$$

Since net worth is accumulated solely through retained earnings, N_{kt} can be thought of as equity capital.

Second, as in Gertler and Karadi (2011) and Gertler and Kiyotaki (2011), I introduce frictions into the banks' balance sheets. Banks pay a quadratic cost, $\Phi(.)$, whenever the capital ratio, $K = \frac{N}{QM}$, is below $\tilde{K}$. Similarly to Gerali et al. (2010), $\Phi(.)$ is assumed to have the functional form:

$$\Phi\left(\frac{N}{QM}\right) = \begin{cases} \kappa\left(\frac{N}{QM} - \tilde{K}\right)^2 & if\ \frac{N}{QM} < \tilde{K} \\ 0 & otherwise \end{cases} \tag{8}$$

This constitutes an alternative way of imposing an endogenous and flexible capital constraint[8]. This cost can be interpreted as the cost paid by banks to FDIC in order to obtain deposit insurance. As in here, FDIC charges a insurance premium that is inversely related to banks capital position. Alternatively, we can suppose that the regulator finds it optimal for banks to keep their capital ratio above $\tilde{K}$. Given resource limitations and the cost of supervision, regulators tend to not intervene when bank's capital is slightly below that value. However, when the capital ratio deviates substantially from the regulator's target, the regulator imposes fines and forces the bank to deleverage. This quadratic cost function, in contrast to a rigid leverage constraint, allows banks to slowly adjust their leverage after a large shock to their balance sheet, as seen in the data. We can also think of Φ as a reduced form of the cost of equity injections when the banking sector is poorly capitalized. In sum, this assumption captures the trade-offs that, in a more structural model, would arise in banks' decisions of how much of their resources to hold in reserve, or, alternatively, as a shortcut for studying the implications and costs of regulatory capital requirements. This friction will be crucial in determining the cost of funding the banking system at each point in time. This aspect of the model is consistent with evidence that banks' cost of funding increases when the banking sector is poorly capitalized.

Risk-neutral bankers maximize the present discounted value of future dividends:

$$\sum_{t=1}^{\infty} \beta_b^t \omega \left[N_{kt-1} + \Pi_{kt}\right]$$

Bankers that are agents outside of this economy discount the future dividends at the risk free rate r, so $\beta_b = \frac{1}{1+r}$.

[8]In this paper, I abstract from the question why there is need for government regulation of banks' risk taking.

4.5 Technology

Composite Consumption

A representative competitive firm hires labor N at competitive wage w to produce the consumption good using a linear production function

$$Y_c = AN$$

The labor supply is inelastic and in equilibrium $w = A$.

Construction Sector

There is a competitive construction sector that builds new houses using a constant return to scale production function with two inputs: consumption good Y_c and housing permits, L, issued by the government at the equilibrium price, p_t^l:

$$Y_h = Y_c^{\alpha_h} L^{1-\alpha_h}$$

The aggregate supply of housing is then given by

$$S_t^h = (\alpha_h p_t)^{\frac{\alpha_h}{1-\alpha_h}} L_t$$

and the equilibrium permit price is $p_t^l = (1-\alpha_h) p_t \left(\frac{Y_{c,t}}{L_t}\right)^{\alpha_h}$. When a house is sold, the government issues the requisite permit to the homeowner in perpetuity at no charge. The assumption is that the buyer of the home is the effective owner, even though (by eminent domain) the government retains the legal right to the permit.

Rental Sector

There is a competitive rental market owned by agents outside this economy who have access to credit in the international market at the constant interest rate r. The rental sector owns the stock of rental properties. Landlords have access to a costless reversible technology that converts one unit of housing into one rental unit. The reverse is also possible; landlords can convert rental housing into houses and sell them at the equilibrium price p_t. It is implicitly assumed that the rental sector can change the size of owner-occupied houses into rental units and vice-versa. Although the rental sector does not face transaction costs, they face a marginal a maintenance cost of δ_r per period. The maintenance cost faced by the rental sector is higher than the highest possible cost for owner-occupied units, $\delta_r > \delta$. This difference is motivated by a moral hazard problem that occurs in the rental market as renters decide how intensively to utilize the units rented. Since the sector is competitive and the technology is costless, landlords can rent each housing unit at the rental rate p_t^r that satisfies the following non-arbitrage condition

$$p_t^r = p_t\left(1 + \delta_r + \tau_h\right) - E_t\left[\frac{p_{t+1}}{1+r}\right]$$

4.6 Government

The government collect revenue by taxing household income and property and by selling housing permits. This revenue is used to finance (wasteful) government spending G_t.

5 Decision Problems

5.1 Household Decisions

Households can be either homeowners or renters. The individual state of a homeowner, $\Lambda_h = (y, a, h, \delta_h, m, r_\tau^m)$, corresponds to current income y, holdings of liquid assets a in form of bank deposits, housing units h, maintenance cost δ_h, outstanding mortgage principal m and coupon rate r_τ^m. Due to transaction costs and long mortgage terms, bank deposits and net housing cannot be consolidated into a single variable. The separation of the balance sheets breaks the link between wealth and home equity and separates the default decision from income and wealth. The individual state space for renters is represented by $\Lambda_r = (y, a)$. The aggregate state space in period t includes current and future housing prices, rents and interest rates and it is denoted by Λ_t^a.

A homeowner must decide between keeping his current housing stock, selling it and become a renter, selling his current house and buying a new one or defaulting on his current mortgage. If the homeowner has a mortgage and decides to keep his current house, he can refinance. If the homeowner defaults, the household becomes a renter and regains access to the mortgage market in the next period with with probability θ. All renters must decide whether to continue renting or become a homeowner. Finally, all individuals decide their consumption of non-durable goods and savings.

The household problem is solved recursively. $V^H\left(\Lambda_h, \Lambda_{at}\right), V^{GR}\left(\Lambda_h, \Lambda_{at}\right)$ and $V^{BR}\left(\Lambda_h, \Lambda_{at}\right)$ denote, respectively, the value functions of a homeowner, renter with access to the mortgage market (M) and a renter with no access to mortgage market (NM).

Homeowner who does not default

A homeowner that decides to not default may choose among:

1. Not adjusting their housing stock $[h' = h]$ or mortgage $[m' = (1-\mu)m]$
2. Keeping their current housing stock $[h' = h]$ but refinancing $[m' \neq (1-\mu)m]$
3. Selling their house and purchasing a new one $[h' \neq h,\ m' \neq (1-\mu)m]$

The value function of a homeowner that does not default and keeps being a homeowner in period t is given by

$$V^{HH}(\Lambda_h, \Lambda_{at}) = max_{\{c,a',h',m'\}} U(c,h') + \beta \mathbf{E}_{(y',\delta_h')|y}\left[V^H(\Lambda_h', \Lambda_{at+1})\right]$$

$$\begin{aligned} c + a' + \delta_h p_t h = {} & w.y + a(1+r) + \left[q_t(y,a',m',h',\Lambda_{at})m' - m - \chi_m\right]_{m'\neq(1-\mu)m, h'=h} \\ & + \left[(1-\chi_s)\, p_t h - (1+\chi_b)\, p_t h' + q_t(y,a',m',h',\Lambda_{at})m' - m\right]_{h'\neq h} \\ & - \left[x_\tau m\right]_{m'=(1-\mu)m, h'=h} - T(y,h',m,r_\tau^m) \end{aligned}$$

Note that the state space tomorrow of a homeowner that keeps the same mortgage is $\Lambda_h' = \left(y', a', h, \delta_h', (1-\mu)m, r_\tau^m\right)$. In case the homeowner changes the current mortgage it pays the current outstanding principal m and obtain a new mortgage with face value m' at price $q_t(y,a',h',m',r_t^m)$. The state space for tomorrow becomes $\Lambda_h' = \left(y', a', h', \delta_h', m', r_t^m\right)$.

Homeowner who defaults

A household that defaults loses its house but does not pay a maintenance cost. His obligations to the lender are extinguished but he is forced to rent for at least one period and is excluded from the mortgage market for some random length of time. The value function for a homeowner that defaults is

$$V^D(\Lambda_h, \Lambda_{at}) = max_{\{c,h',a'\}} U(c,h') + \beta E_{y'|y}\left[(1-\theta)\, V^M(\Lambda_r', \Lambda_{at+1}) + \theta V^{NM}(\Lambda_r', \Lambda_{at+1})\right]$$

$$s.t.\ c + p_t^r h' + a' = y + a(1+r) + max\left\{(1-\chi_d-\tau_h)\, p_t h - m, 0\right\} - T(y,0,0,0)$$

The state space next period is $\Lambda_r' = (y', a')$

Homeowner who sells and becomes a renter

If a homeowner decides to sell his house, he must pay the sale cost, and terminate the current mortgage contract. The value function is given by

$$V^{HS}\left(\Lambda_h,\Lambda_{at}\right)=max_{\{c,h',a'\}}U(c,h')+\beta E_{y'|y}V^{GR}(\Lambda_r^{'},\Lambda_{at+1})$$

$$s.t.\ c+p_t^r h'+a'=y+a(1+r)+\left(1-\delta_h-\chi_s\right)p_t h-m$$

The state space in the following period is $\Lambda_r^{'}=(y',a')$.

Renter who purchases a house

Renters may decide to buy a house or continue being a renter. If they buy a house, both types of renters ($w\in\{M,NM\}$) face the following problem:

$$V^{RHw}\left(\Lambda_r,\Lambda_{at}\right)=max_{\{c,a',h',m'\}}U(c,h')+\beta E_{y'|y}\left[V^{HH}(\Lambda_h^{'},\Lambda_{at+1})\right]$$

$$s.t.\ c+a'+\left(1+\chi_b\right)p_t h'=y+a(1+r)+q(y,a',h',m',r_t^m)m'-T(y,0,h',0)$$

$$m'=0\ \ if\ w=NM$$

A renter excluded from the mortgage market cannot acquire a mortgage, so he must pay 100 percent of the purchase price. His state space next period is $\Lambda_h^{'}=\left(y',a',h',\delta_h^{'},0,0\right)$. The future state space of a renter with good credit is given by $\Lambda_h^{'}=\left(y',a',h',\delta_h^{'},m',r_t^m\right)$.

Renting

If a current renter decide to continue renting, the value function for $w\in\{M,NM\}$ is

$$V^{RRw}\left(\Lambda_r,\Lambda_{at}\right)=max_{\{c,h',a'\}}U(c,h')+\beta E_{y'|y}\left[V^{Rw}(\Lambda_r^{'},\Lambda_{at+1})\right]$$

$$c+p_t^r h'+a'=y+a(1+r)$$

with $\Lambda_r^{'}=(y',a')$.

The value function of a Homeowner is then given by

$$V^{H}\left(\Lambda_h,\Lambda_{at}\right)=max\left\{V^{HH}\left(\Lambda_h,\Lambda_{at}\right),V^{D}\left(\Lambda_h,\Lambda_{at}\right),V^{S}\left(\Lambda_h,\Lambda_{at}\right)\right\}$$

Let's also define $\mathbf{d}(\Lambda_h, \Lambda_{at})$ as an indicator function that equals one in case of default and $\mathbf{s}(\Lambda_h, \Lambda_{at})$ equals one when the house is sold or the mortgage is refinanced. Note that from the bank's perspective, selling a house and refinancing are equivalent, since both processes result in the termination of the current contract.

A renter not excluded from the mortgage market solves

$$V^{RM}(\Lambda_r, \Lambda_{at}) = max\left\{V^{RHM}(\Lambda_r, \Lambda_{at}), V^{RRM}(\Lambda_r, \Lambda_{at})\right\}$$

and a renter excluded from the mortgage markets solves

$$V^{RNM}(\Lambda_r, \Lambda_{at}) = max\left\{V^{RHNM}(\Lambda_r, \Lambda_{at}), V^{RRNM}(\Lambda_r, \Lambda_{at})\right\}$$

5.2 Financial Intermediaries

Every period, each bank given its net worth, decides the size of its mortgage portfolio and the price of each individual mortgage that issues. Given the existence of a secondary market, the banks can adjust the size of their balance sheet freely. They can expand its assets by issuing new mortgages or acquiring old mortgages in the secondary market. In the same way, banks may decide to downsize by selling fraction of their portfolio. As stated above, mortgages are traded in the secondary market at p_t^m per unit of mortgage value, $q_{it}(m)m$.

Although terms of the mortgage are fixed at the time of the origination τ, the value of the mortgage varies over time as the mortgage holder accumulates equity or changes in the aggregate space impact the probability of default and prepayment over time. Therefore, $q_t(y, a, h, m, r_\tau^m)m$ corresponds to the value at time t of a mortgage originated at time τ with remaining outstanding value m.

Equilibrium in the secondary market

As shown below, q_t is an endogenous object that depends on the borrower's characteristics as well as on the capitalization of the financial system at a given point in time. Given that q_t incorporates all relevant information, and it is costless to trade mortgages in the secondary market, all mortgages are traded at fair value, i.e., $p^m = 1$.

Claim: The equilibrium price per unit of mortgage value in the secondary market is constant and $p_t^m = p^m = 1$ for any t.

Proof: Suppose that a bank owns a mortgage a mortgage whose value at time t is given by $q_t m_t$. As will see in section 5.2.1, $q_t m_t$ corresponds to the expected discount value of all future payments. Therefore, the bank is willing to sell this mortgage for any $p_t^m : p_t^m q_t m_t \geq q_t m_t \Leftrightarrow p_t^m \geq 1$. Instead, suppose that a bank wants to have in its portfolio a mortgage whose value is given by $q_t m_t$. This bank can originate this mortgage at zero cost or buy an existing mortgage. The bank is willing to buy the mortgage at any $p_t^m : p_t^m q_t m_t \leq q_t m_t \Leftrightarrow p_t^m \leq 1$. Therefore, all mortgages are traded in the secondary market at $p_t^m = 1$.

The existence of a secondary market makes long-term mortgages liquid in the sense that a bank that originates a mortgage can sell it and thereby adjust its asset composition. However, mortgages are not fully liquid. They can only be traded among banks in the system, thus the value of mortgages depends on how liquid the secondary market is. In other words, the price of a mortgage depends on the demand and supply of mortgages in this market, which in turn depends on the aggregate capitalization of the financial system. The liquidity available in the secondary market is reflected in the mortgage price, q_t, and not in p^m, which is constant and equal to the marginal cost of trading such mortgages.

Bank Profits

The profits associated with a mortgage portfolio $Q_{kt}(M_{kt})M_{kt}$ are given by

$$\Pi_{k,t+1} = r_{k,t+1}^m Q_t(M_{kt})M_{kt} - rB_{kt} - \Phi\left(\frac{N_{kt}}{Q_t(M_{kt})M_{kt}}\right) \tag{9}$$

where $r_{k,t+1}^m$ is the net rate of return at time $t+1$ on bank k's portfolio:

$$r_{k,t+1}^m = \frac{Z_{k,t+1} + Q_{t+1}\left((1 - \mathbf{d}_{k,t+1} - \mathbf{s}_{k,t+1})(1-\mu)M_{kt}\right)(1 - \mathbf{d}_{t+1} - \mathbf{s}_{t+1})(1-\mu)}{Q_t(M_{kt})} - 1 \tag{10}$$

The rate of return, $r_{k,t+1}^m$, is indexed by k since banks may have different risks profiles. $Z_{k,t+1}$ corresponds to the flow of payments associated with M_{kt}. It depends on the amount paid by borrowers and the value obtained in case of foreclosure.

The outstanding principal associated with M_{kt} becomes $(1 - \mathbf{d}_{t+1} - \mathbf{s}_{t+1})(1-\mu)M_{kt}$ at time $t+1$, reflecting the decline in principal for loans that do not default and the amount of debt that is fully repaid or defaulted upon. $Q_{t+1}\left((1 - \mathbf{d}_{t+1} - \mathbf{s}_{t+1})(1-\mu)M_{kt}\right)(1 - \mathbf{d}_{t+1} - \mathbf{s}_{t+1})(1-\mu)$ corresponds to the market value of the portfolio at $t+1$, i.e., how the amount for which the bank could sell its entire portfolio in the secondary market.

Bank's Problem

The risk neutrality assumption for bankers implies that they are indifferent between two portfolios with different risk profiles if they have the same expected return. Thus, the choice of risk profile is indeterminate. The secondary market allows banks to fully adjust their assets every period independently of the mortgages they issued or previously held. Therefore, bank k's value at the end of $t-1$ is the expected present value of future dividends and satisfies the Bellman equation

$$\begin{aligned} V_{t-1}\left(M_{k,t-1}, N_{k,t-1}\right) &= max_{\left\{M_{k,t+\tau}, B_{k,t+\tau}\right\}} E_{t-1} \sum_{\tau=0}^{\infty} \beta_b^{\tau+1} \omega \left[N_{k,t-1+\tau} + \Pi_{k,t+\tau}\right] \\ &= max_{\left\{M_{kt}, B_{k,t}\right\}} E_{t-1} \beta_b \left[\omega \left[N_{k,t-1} + \Pi_{kt}\right] + V_t\left(M_{kt}, N_{kt}\right)\right] \\ s.t. \quad & Q_{kt}(M_{kt}) M_{kt} = B_{kt} + N_{kt} \\ & N_{kt} = (1-\omega)\left[N_{k,t-1} + \Pi_{kt}\right] \end{aligned}$$

where Π_{kt} satisfies equation (9).

In the presence of aggregate uncertainty, the solution to the problem of bank k is given by

$$E_t \Omega_{k,t+1} \left[r_{k,t+1}^m - r - \Phi\left(K_{kt}\right) - \Phi'\left(K_{kt}\right) K_{kt}\right] = 0, \qquad K_{kt} = \frac{N_{kt}}{Q_t(M_{kt}) M_{kt}} \tag{11}$$

$$\Omega_{k,t+1} = \beta_b \left[\omega + (1-\omega) \frac{\partial V_{t+1}}{\partial N_{t+1}}\right] \tag{12}$$

$$\frac{\partial V_t}{\partial N_t} = E_t \Omega_{t+1} \left[1 + r + \Phi'\left(K_t\right) K_t^2\right]$$

Ω_{t+1} can de defined as an augmented discount factor and reflects the discounted shadow value of a unit of net worth to the bank at time $t+1$. The fraction ω of one additional unit of net worth is used to pay dividends, while the fraction $1-\omega$ is used to replace short term liabilities and decrease leverage ratio, reducing the cost of expanding assets by $r + \Phi'\left(K_t\right) K_t^2$.

Note that the FOC for a given bank k at time t is independent of its net worth $N_{k,t-1}$ and outstanding principal $M_{k,t-1}$. This is a direct implication of the existence of the secondary market. Therefore, all banks choose the same leverage ratio, regardless of their net worth.

Result: In equilibrium, all banks hold the same capital ratio, $K_{kt} = K_t$, regardless of their net worth N_{kt-1} and the face value of the current mortgages in their balance sheet M_{kt-1}.

$$E_t \Omega_{t+1} \left[r_{t+1}^m - r - \Phi\left(K_t\right) - \Phi'\left(K_t\right) K_t\right] = 0, \qquad L_t = \frac{N_t}{Q_t(M_t) M_t} \tag{13}$$

where K_t denotes the capital ratio of the entire financial system with net worth $N_t = \int N_{kt} dk$ and total debt $M_t = \int M_{kt} dk$. Moreover, the net worth distribution across banks is irrelevant and the equilibrium depends only on the aggregate capitalization of the banking system.

This result demonstrates that in equilibrium all banks choose the same leverage ratio, and therefore, all banks keep in their balance sheet a set of mortgages with the same expected net return.

$$E_t \Omega_{k,t+1} \left[r^m_{k,t+1} - r \right] = E_t \Omega_{t+1} \left[r^m_{t+1} - r \right] \qquad , \forall k$$

In a frictionless world where banks do not face a cost for high leverage, banks would expand their balance sheet until the adjusted risk premium is zero:

$$E_t \left[r^m_{t+1} - r \right] = 0$$

This is the standard asset pricing equation, which states that in equilibrium the expected net return must be zero. Note that in this case, the marginal value of net worth equals the unit. When banks face a leveraging cost, limits to arbitrage may emerge leading to an equilibrium with positive excess returns over the risk-free rate. Alternatively, we can define the funding cost at time t as

$$r^c_{t+1} = r + \Phi (K_t) + \Phi' (K_t) K_t \tag{14}$$

which corresponds to the payments on short-term liabilities plus the marginal cost of deviating from the leverage target $\tilde{K}$. This measures the marginal cost of increasing assets by one unit, keeping net worth constant. Therefore, the FOC boils down to the standard asset price equation, which states the the bank must expand its assets until the point where excess returns over the bank's funding cost equal zero, with the relevant discount factor being Ω_{t+1}

$$E_t \Omega_{t+1} \left(r^m_{t+1} - r^c_{t+1} \right) = 0 \tag{15}$$

When the banking system is undercapitalized, the leverage ratio is high, which implies a higher funding cost. Net worth becomes more valuable and banks care more about the future, $\frac{\partial V}{\partial N} > 1$ and $\Omega_{t+1} > \beta_b$. The same principle applies: banks expand their balance sheet until excess returns are zero, but given that funding costs are now higher, the expected portfolio return must also increase. Therefore, a spread between the return on mortgages and risk-free rate emerges and increases with the leverage ratio, or equivalently, decreases with the capital to assets ratio. In other words, the required risk premium increases with the leverage ratio:

$$E_t \Omega_{t+1} \left[r^m_{t+1} - r \right] = E_t \Omega_{t+1} \left[\Phi (K_t) + \Phi' (K_t) K_t \right] \geq 0$$

Equation (13) highlights the role of capital in determining loan supply conditions. On the one hand - insofar as there is a spread between the return on mortgages and the risk-free rate - the bank would like to extend as many loans as possible, increasing its leverage and thus its profit per unit of net worth. On the other hand, when goes below $\tilde{K}$, financing costs start increasing. The optimal choice for banks is to choose a level of capital ratio such that the marginal cost of increasing leverage exactly equals the expected excess return over the riskless rate.

The equilibrium condition (13) determines the value of a mortgage portfolio in each period. To clarify, let us replace (10) into (13):

$$Q_t(M_t)M_t = \frac{1}{E_t\Omega_{t+1}\left(1+r^c_{t+1}\right)} E_t\Omega_{t+1}\left[Z_{t+1}M_t + \tilde{Q}_{t+1}\left(1-\mathbf{d}_{t+1}-\mathbf{s}_{t+1}\right)(1-\mu)M_t\right] \tag{17}$$

where $\tilde{Q}_{t+1} = Q_{t+1}\left(\left(1-\mathbf{d}_{t+1}-\mathbf{s}_{t+1}\right)(1-\mu)M_t\right)$. This equation states that the value at time t of a mortgage with principal M_t must be equal to the discounted value of future payments. This differs from the standard formulation that assumes a frictionlesss banking system since Q_t is a function of the capital ratio of the banking system, through the impact of aggregate capitalization on the cost of funding r^c_t and the discount factor Ω_{t+1}. In the absence of the cost associated with low capital levels, funding cost is constant and equal to the risk-free rate r, $r^c_t = r$ and $\Omega_{t+1} = \beta_b$. In this case, the price of the mortgages depends only on the risk profile of the borrowers. Instead, in this framework, when the financial system is poorly capitalized, the cost of funding increases, $r^c > r$ and banks discount the future less $\Omega_{t+1} > \beta_b$. Therefore, mortgage values decrease. Moreover, as banks' net worth decreases, their willingness to buy loans in the secondary market decreases. As the demand for loans in this market drops, the value of such mortgages decrease even more. This is true even if the risk profile of the borrowers is unchanged. Thus, mortgage values depend not only on borrower characteristics but also on how healthy the financial system.

Moreover, the fact that mortgages are long-term may exacerbate their loss in value when banks are very leveraged. The evolution of outstanding principal of all mortgages in the system is given by

$$\tilde{M}_t = \left(1-\mathbf{d}_t-\mathbf{s}_t\right)(1-\mu)M_{t-1} \tag{18}$$

Thus, even if new mortgages are not issued, the face value of debt cannot decrease below $\tilde{M}_t$. This imposes a upper bound on the capital ratio for a given level of net worth N_t

$$\overline{K_t} = \frac{Q_t(\tilde{M}_t)\tilde{M}_t}{N_t} \leq \frac{N_t}{Q_t\left(\left(1-\mathbf{d}_t-\mathbf{s}_t\right)(1-\mu)M_{t-1}\right)\left(1-\mathbf{d}_t-\mathbf{s}_t\right)(1-\mu)M_{t-1}}$$

5.2.1 Price of Individual Mortgages

Equation (17) expresses the price of a set of mortgages as a function of the capitalization of the financial system. However, the banks' balance sheets are composed by heterogeneous mortgages, with different amounts of collateral and propensities to default. In this section I look at the optimal price of a given individual mortgage that is consistent with the aggregate price level defined above. As stated in the following claim, equation (17) prices any mortgage set, including any individual mortgage.

Claim: For a given cost of funding r^c_{t+1} and bank's augmented discounted factor Ω_{t+1}, the price of an individual mortgage with principal m' originated in period t for a household with current income y, and h' units of housing as collateral and a' savings must satisfy the following relationship

$$\begin{aligned} q_t(y, a', h', m', r^m_t)m' = & \frac{1}{E_t\Omega_{t+1}\left(1 + r^c_{t+1}\right)} E^i_t \Omega_{t+1} \left\{ s_{it+1}m' \right. \\ & + d_{it+1} min \left\{ \left(1 - \chi_d - \tau_h\right) p_{t+1}h', m' \right\} \\ & \left. + \left(1 - d_{it+1} - s_{it+1}\right) \left[x_t m' + q_{t+1}(y', a'', h', (1-\mu)m', r^m_t)(1-\mu)m' \right] \right\} \end{aligned} \tag{19}$$

where E^i_t is the expectation operator over the evolution of household individual state space and aggregate state space.

Proof: Note that condition (19) implies that the discounted expected profit of the mortgage issued to household i must be zero, i.e., $E_t\Lambda_{t,t+1}\Omega_{t+1}\Upsilon_{ikt} = 0$, with

$$\begin{aligned} \Upsilon_{ikt} = & s_{it+1}m' + d_{it+1} min \left\{ \left(1 - \chi_d - \tau_h\right) p_{t+1}h', m' \right\} \\ & + \left(1 - d_{it+1} - s_{it+1}\right) \left[x_t m' + q_{t+1}(y', a'', h', (1-\mu)m', r^m_t)(1-\mu)m' \right. \end{aligned}$$

Suppose that bank k sets price $q_{kt}(y, a', h', m', r^m_t)$ such that $E_t\Omega_{t+1}\Upsilon_{ikt} > 0$. Bank k' could increase the price slightly, issue the mortgage and still make a positive expected profit. Therefore, by competition in the mortgage market, mortgages are priced efficiently such that banks make zero expected profits on each mortgage.

The optimal mortgage price equation (19) implies that banks must price each differentiated mortgage such that in equilibrium it generates zero expected profits. Cross-subsidization among mortgages is not an optimal strategy. The price of each mortgage is then equal to the present discounted value of the expected payments on the mortgage. In the next period, if the homeowner defaults, the intermediary receives $d_{it+1} min \left\{ \left(1 - \chi_d - \tau_h\right) p_{t+1}h', m' \right\}$. If the borrower sells her house or wants to refinance, the bank receives m'. And if neither happens, the intermediary receives $x_t m'$ and the value of continuing holding the mortgage, or equivalently, the value received if the mortgage is sold in the secondary market, $q_{t+1}(y', a'', h', (1-x)m', r^m_t)(1-x)m'$. Note that the continuation value depends on the outstanding principal after the first period, $(1-\mu)m'$, which decays at rate μ. However, the individual mortgage price depends not only on the characteristics of the borrower, but also on the health of financial sector at the moment of origination and in the future. This is reflected through the cost of funding r_t^c and discount factor Ω_{t+1}, which depends on the leverage ratio of the financial system. Expectations about financial system constraints are reflected through the continuation value $q_{t+1}(y', a'', h', (1-x)m', r_t^m)$.

Thus, in moments when the banking system is undercapitalized, mortgage prices are lower for a given level of borrower default risk. This relation is clearer if we look at the mortgage spread, S_{it}, defined as the difference between an implicit constant interest rate (r^*) defined in (5) and the riskless interest rate:

$$S_{it} = r_{it}^* - r = \frac{1}{q_t(y, a', h', m', r_t^m)} - r \tag{20}$$

The spread is inversely related to mortgage price, and, therefore, positively related with the overall leverage of the banking system. Therefore, mortgage spreads not depend solely on the riskiness of the borrower but also on the health of the entire banking system.

5.3 Equilibrium

Given an initial distribution of homeowners $\Gamma_H(\Lambda_h, 0)$, initial distributions of renters not excluded from the mortgage markets $\Gamma_M(\Lambda_r, 0)$ and renters excluded from the mortgage markets $\Gamma_{NM}(\Lambda_r, 0)$ over the individual states $\Lambda_h = (y, a, h, \delta_h, m, r^m)$ and $\Lambda_r = (y, a)$; initial aggregate net worth N_0 and asset composition $Q_0 M_0$ of the banking sector; initial stock of owner-occupied houses H_0^o, the initial stock of rental housing H_0^R, sequence of housing permits issued by the government, $\{K_t\}$ and an exogenous interest rate r, the equilibrium is defined as

- a strictly positive sequence of housing prices $\{p_t\}$, rents $\{p_t^r\}$, mortgage price function $\{q_t(y, a', h', m', r_t^m)\}$ and bank funding cost $\{r_t^c\}$ for $t \geq 1$
- sequence of decision rules and distributions of homeowners $\Gamma_H(\mathcal{S}_h, t)$ and renters $\Gamma_j(\mathcal{S}_r, t), j \in \{M, NM\}\}$ for $t \geq 1$
- Evolution of aggregate banking net worth N_t and asset composition $Q_t M_t$ for $t \geq 1$

such that:

- Decision rules are optimal given price sequences
- Rents satisfy the zero profit condition
- Cost of funding and individual mortgage prices satisfy the bank's problem
- Demand for owner-occupied housing equals supply

- Labor market clears at $w = A$
- Distributions are implied by the sequence of optimal decision rules and initial distributions

The demand for owner-occupied houses is given by the sum of the demand of renters with access to the mortgage market who decide to buy $\int h_M^o(\Lambda_r, \Lambda_{at})\, d\Gamma_M(d\Lambda_h, t)$, renters restricted from the mortgage market who decide to buy $\int h_{NM}^o(\Lambda_r, \Lambda_{at})\, d\Gamma_{NM}(d\Lambda_r, t)$ and the net demand of homeowners that change their house stock (difference between the total number of houses bought and sold), $\int h_H^o(\Lambda_h, \Lambda_{at})\, d\Gamma_H(d\Lambda_h, t)$. On the supply side we have the influx of new construction, the stock of foreclosed houses and the net supply of rental houses converted into owned occupied houses $H_{t-1}^r - H_t^r$.

6 Model Calibration

The model is calibrated to replicate key features of United States economy during 2003-2005, prior to the Great Recession. The calibration puts heavy emphasis on matching key housing and mortgage parameters. Some parameters are selected exogenously and the remained are calibrated jointly in the model. The model period is annual. Table 8 summarizes the model parametrization.

Households

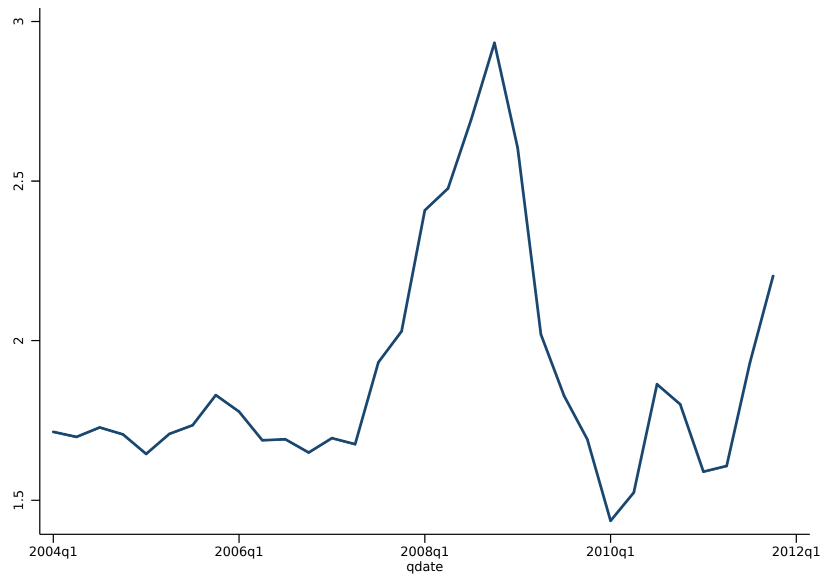
Following Storesletten et al. (2004), I set the autocorrelation parameter of the AR(1) income process to 0.97 and the standard deviation to $\sigma_z = 0.12$. The AR(1) process is approximated with a 9 state Markov chain using Tauchen (1986) procedure. Following standard values in the macro literature, I set σ to 2 togive an intertemporal elasticity of substitution of 0.5, and $\frac{1}{\gamma}$, the elasticity of substituition between non-durable consumption and housing to 1.25. α is set to 0.15 based on the NIPA share of housing expenditure. Discount factor β is determined in the joint calibration to match the fraction of borrowers with LTV above 90 percent of 7.02 and equals 0.945.

Housing market

The additional utility from homeownership is jointly calibrate to match the homeownership rate of 68 percent. Gruber and Martin (2003) using the survey of consumer expenditures a median household reported selling cost of 7.5 percent and buying costs of 2.5 percent of the house value. Given that costs are shared between buyers and sellers, I fix χ_s to 0.04 and χ_b to 0.03. The property tax rate equals 0.0138 as Chatterjee and Eyigungor (2015).

The random maintenance cost takes two values, $\delta_h = 0, \delta$ with probability p_δ. δ is determined in the joint calibration to match the default rate of 1.5 percent and takes the value 0.22. p_δ equals 0.048 to match a depreciation rate of owned-occupied houses of 1.06 percent per year in the

Figure 4: 30 year mortgage Spread



Spread between the 30-year fixed mortgages and the 10 year T-bill rate

tenth year of use (Shilling et al. (1991)). Shilling et al. (1991) also reports a deprecation rate of rental units of 1.66 percent per year in in the tenth year of use. Regarding the foreclosures losses, Pennington-Cross (2009) report a loss in foreclosure of 25% and χ_d is set to 0.25.

In the steady state the supply of housing permits, so the stock of housing is constant (I assume maintenance costs instead of housing depreciation).

Financial Markets

The world risk-free rate is set to 3%. The parameter θ is set to 0.25 which implies an average exclusion period following default of 4 years as in Chatterjee and Eyigungor (2015). The Refinance cost is χ_r calibrated to 0.4 percent of median income in order to match a refinancing fraction of 24 percent as reported by Wong (2015)[9]. The amortization μ, also calibrate, equals 0.018 in order to match an average home equity of 62 percent. This implies an average mortgage duration of 56 years. Although most of the mortgages have a duration of 30 year, the fact that in the model households are long-lived a higher amortization rate would lead to more equity accumulation that the one observed in the data.

Now I focus on the calibration related to the cost of funding of the banks. I assume that the

[9]Wong (2015) use the loan-level panel data from the Freddie Mac Single Family Loan-Level database and to compute the average fraction refinanced loans in a year to the total stock mortgages. These are the new loans in each year which are recorded in the data as refinanced loans (inclusive of both cash-out and non-cash out refinancing).

Table 7: Model Parameters

Parameters	Value
Housing share	$\alpha = 0.15$
Elasticity substituition c and h	$\frac{1}{\gamma} = 1.25$
Intertemporal elasticity	$\sigma = 2$
House sizes	$\mathcal{H}^h = \{1.43, 1.79, 2.3, 2.9, 3.6, 4.2\}$
Rental sizes	$\mathcal{H}^r = \{1.1, 1.43, 1.79\}$
Autocorrelation earning shocks	$\rho_z = 0.97$
S.D. of earning shocks	$\sigma_z = 0.2$
Buying Costs	$\chi_b = 0.01$
Selling Costs	$\chi_s = 0.06$
Liquidation cost	$\chi_d = 0.25$
Rental Maintenance cost	$\delta_r = 0.0165$
World Interest Rate	$r = 0.03$
Probability of reentering credit mkt	$\theta = 0.25$
Dividend	$\omega = 0.115$

cost function takes the functional form

$$\Phi\left(K_t\right) = \kappa_0 + \kappa_1 \left(\tilde{K} - K_t\right)^2$$

when $\tilde{K} - K_t > 0$ and 0 otherwise. There are then three parameters to calibrate: $\tilde{K}$, κ_0 and κ_1. This parameters are chosen to match the the average spread between the 30-year fixed mortgages and the 10 year T-bill rate between 2002 and 2006 and the change in the spread between 2006 and 2009. As we can see in graph 4, the average spread before 2006 was around 165 b.p.. Between 2006 and 2009, the spread between the 30-year fixed mortgages and the 10 year T-bill rate increased from 160 b.p. to its peak in 2009 of 293 b.p. over the same period. As shown in table 1, capital ratio decreased from 14.4 percent in 2006 to 13 percent in 2009. Therefore, $\tilde{K}$ is set to 15 percent, κ_0 to 0.0103 and κ_1 to 3.37. This implies that the cost of funding, r^c, is 1.6 per cent in steady-state. Moreover, r^m is equal to r^c in the origination period.

At last, the dividend policy is given by the equilibrium condition

$$1 = (1 - \omega)\left(1 + r + \Phi'(K)\, K^2\right)$$

which gives a dividend policy of 0.11.

Table 8 presents all the parameter values jointly calibrated.

Table 8: Model's Calibration

Moments	**Data**	**Model**	**Parameters**	**Value**
Homeownership	68%	68.1%	Additional homeownwership utility	$\upsilon = 1.06$
LTV$\geq$ 90%	7.02%	7.51%	Discount Factor	$\beta = 0.945$
Average Equity	62%	63.7%	Mortgage amortization rate	$\mu = 0.018$
Default Rate	1.5%	1.45%	High Depreciation shock	$\delta = 0.22$
Depreciation rate	1.06%	1.06%	Prob High Maintenance	$p_\delta = 0.048$
Refinance Rate	24%	25.7%	Refinance Cost	$\chi_r = 5.1\%$
Mortgage Spread	165b.p.	160b.p.	Capital ratio target	$\tilde{K} = 15\%$
Increase in spread	128b.p.		Leverage Cost Param.	$\kappa_0 = 0.0103$, $\kappa_1 = 3.37$

6.1 Model Fit and and Steady State Analysis

The estimated model fits several non-targeted moments related to the housing and mortgage markets. The average income of homeowners is 2.15 times higher than that of renters in the data. The calibration presented implies that the average income of homeowners is 2.1 times higher than renters.

Figure 5: Homeownership rate

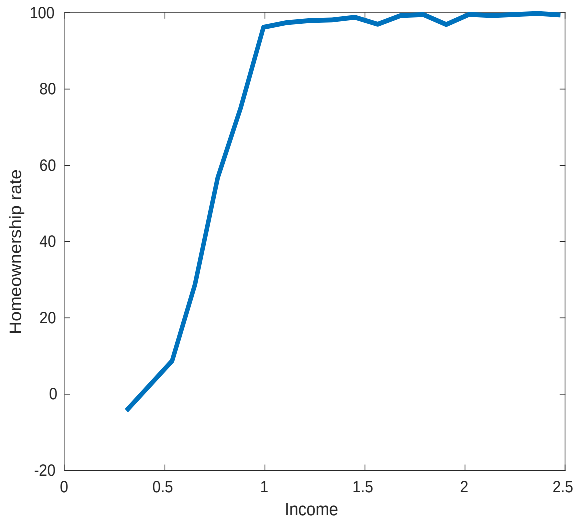


Figure 5 shows that the home ownership is increasing in liquid wealth. Liquid wealth is defined as current income plus liquid assets, $w^l_{it} = y_{it} + (1 + r)a_{it}$. Average housing wealth divided by average income is 1.69 in the data and 1.24 in the model.

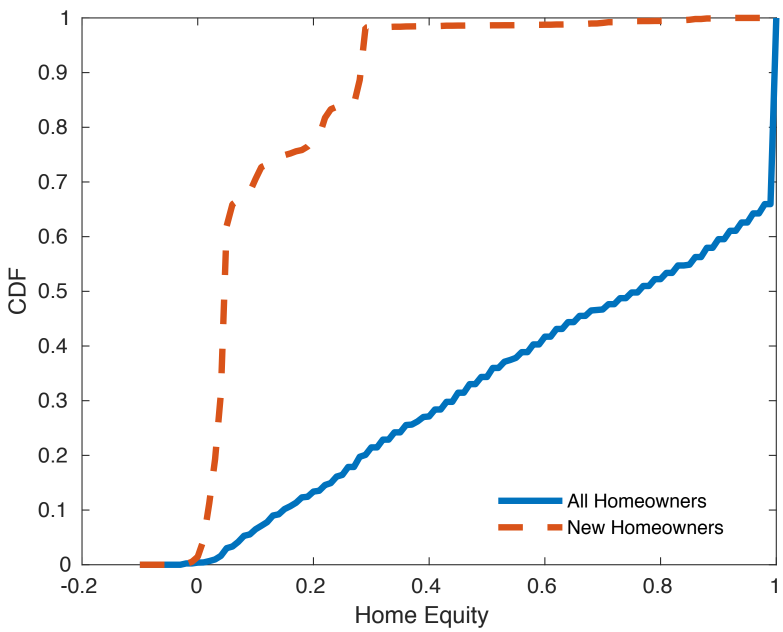
Table 9: Non-target Moments

Moments	Data	Model
Mortgage Holder Rate	66%	67%
Avg. Income Homeowners / renters	2.05	3.34
Avg. Housing Wealth /Avg. Income	1.69	2.54
Cash Buyers	19	19.41
% Homeowners with 0% equity	1.81	0.39
% Homeowners with $\leq$ 10% equity	7.02	6.5
% Homeowners with $\leq$ 20% equity	14.07	13.04
% Homeowners with $\leq$ 30% equity	22.4	21.05
% Homeowners with 100% equity	28.75	34.05

Although not being a target a model, the share of households with mortgages in the model is 19.41 while 19 in the data.

The model also provides a reasonable match with home equity distribution, as seen in graph 6 and table 9. However, it underestimates the share of mortgagors with negative equity. Graph 6 also shows the equity distribution for new home-owners that shows that most of the new homeowners has an LTV above 70 percent. The model was matches closely the share of cash-buyers. The model delivers 19.41 while 19 in the data.

Figure 6: Equity Distribution



7 Bust Episode

During the great recession, we observe a large decline in housing prices and consumption, as well as a significant rise in the foreclosure rate. New mortgage originations and refinancing also fell significantly during the same period.

I analyze a set of unanticipated shocks in order to replicate the decline of 18 percent in real house prices observed in 2006-2009 period. I focus on a demand driven shock (permanent decrease in preferences for owned occupied houses). I also consider an increase in the duration of the foreclosure process that allows defaulters to remain in their foreclosable home and a productivity shock that translates into a drop in wages. However, I do not consider a shock to the financial sector. All changes in the banking system are endogenous and constitute the amplification force that this exercise aims to quantify.

Demand Shock

I consider a permanent decrease in the additional of utility of homeownership. While in the steady state $\upsilon = 1.06$, I assume that υ drops to one permanently.

Productivity Shock

Total factor productivity drops 1.6 percent per year over three periods which results in a total cumulative drop of 4.7 percent. After three periods, productivity reverts to the steady state level. This shock accounts for the deterioration in labor markets during the crisis. It is constructed such that the model matches the 18 percent drop in housing prices between 2006 and 2009. Fernald (2014) have estimated a decline in total productivity of 4 percent peak-to-trough during the downturn.

Delays in the Foreclosure Process

As documented in Chatterjee and Eyigungor (2015), during the great recession the average duration of the foreclosure process increased by 7.5 months. Therefore, a homeowner who defaults can remain in the property with probability 0.63 for three periods.

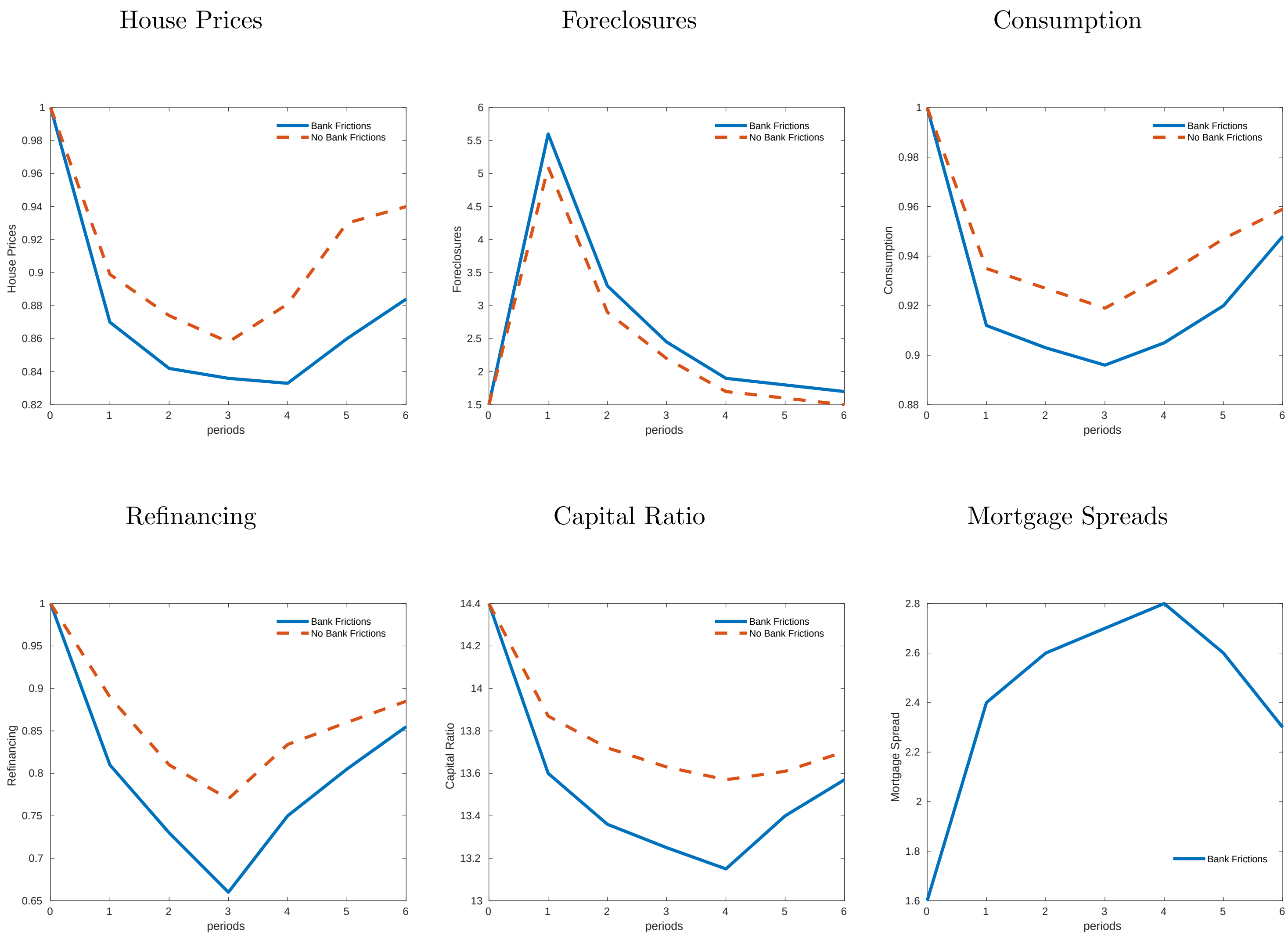
7.1 Baseline Results

The combination of shocks described above replicates the observed 18 percent drop in housing prices between 2006 and 2009, as well as changes in other key variables over the same period, as reported in Table 10. Although housing prices recover over time, the permanent decrease in the demand for house leads to lower prices in the long run and therefore a permanent decrease in the value of a household's collateral. This effect is reinforced in the short run as the negative productivity shock implies that household's consumption of housing is too high. Therefore, given the combination of these two shocks, household have then an incentive to sell its current house and acquire a smaller one or become a renter, leading to a drop in house prices.

The decrease in house prices implies an automatic increase in household leverage due to the assumed long-term mortgage structure. This contrasts with models of one-period debt and models in which lenders force households to put up more collateral to satisfy tighter lending constraints. Therefore, home equity decreases for most homeowners. For very highly leveraged households, a permanent decrease in property value may lead to a situation in which the homeowner's obligation to the lender exceeds the value of the house minus transaction costs. When housing prices decrease, the benefits of selling decrease as well. If a household is highly leveraged, the proceeds of selling its current property may be lower than the mortgage obligation, and therefore default becomes the dominant option. During the crisis, the benefit of default increases due to foreclosure processing delays, which allow homeowners to stay at their property for free. The increase in foreclosures expands the supply of housing and amplifies the initial drop in housing prices and foreclosures.

Moreover, the increase in defaults imposes losses on banks. Income flows from current mortgages decrease since lower prices imply a lower gain from selling the property after taking liquidation costs into account. Such losses negatively impact banks' net worth and lead to an automatic decrease in their capital ratio. The interaction between bank balance sheet friction and the fact that mortgages are long-term leads to an amplification of the banks' initial losses as follows. As housing prices drop, the value of mortgage collateral decreases, as does borrower creditworthiness, since households become more likely to default. Given that mortgages are long-term and lenders are not able to ask borrowers for an equity injection to compensate for the loss in collateral value, the value of banks' mortgage portfolios decreases, and therefore, their net-worth. Moreover, as the cost of funding of banks increases as their capital drops, banks have an incentive to downsize the size of their portfolio to bring their capital closer to the target value. In other words, banks want to sell part of the long-term mortgages on their balance sheets. Given that losses are spread across banks, liquidity in the secondary market dries up, and mortgage values decrease even further. Therefore, bank's capital decreases due to the direct losses imposed by default and by the drop in the market value of their mortgage portfolio as it becomes riskier and as the mortgage values in the secondary markets goes down. So, since mortgages are accounted at market value has an amplification effect on capital's losses. Thus, the cost of funding of the banks increase even more.

Figure 7: Bust Episode



To compensate for these higher leverage costs and increased risk, banks require higher expected returns. This effect is translates to lower credit supply and higher mortgage spreads, as we can see in figure 7. As mortgage loans for new purchases become more expensive, the demand for housing falls even more, exacerbating the initial drop in housing prices, increase in foreclosures, deterioration of bank capitalization and increase in mortgage spreads.

Consumption also falls considerably. The permanent decrease in housing prices triggers a negative wealth effect, reducing consumption across homeowners. Homeowners who have a mortgage but do not default or sell their house see their disposable income decrease because their income decreases but their mortgage payments do not. Since the income drop is temporary and households are forward looking, these households attempt to smooth their consumption. Refinancing allows homeowners to adjust their home equity to smooth income shocks. However, the increase in mortgage spreads as the credit supply declines makes refinancing difficult for many homeowners. Therefore, they must reduce consumption. The effect is less pronounced for renters and households that default, since their disposable income increases as they free themselves of debt payments.

The decrease in housing demand has a direct implication in homeownership and the consumption of rental units increases as rents fall along with housing prices. Moreover, as mortgage spreads increase, households have an incentive to provide higher down payments to attenuate the increase in mortgage spreads. Lower income makes it harder for households to pay transaction costs and higher down payments. Therefore, in order to facilitate homeowner adjustment, housing prices must decrease even further.

Table 10: Model Simulation

△Cumulative	**Data**	**Model (a)**	**No Fric (b)**	**(a-b)/a**
House prices	-18%	-18%	-16.6%	13%
Default Rate	13p.p.	11.2p.p.	10.2p.p.	9%
Consumption	-11.5%	-10.6%	-8.2 %	22%
Refinancing	-43%	-38.5%	-24.9%	35%
Bank Capital	-1.4p.p.	-1.15p.p.	-0.72p.p.	38%
Mortgage spread	133b.p.	109b.p.	0	

7.2 Bank Balance Sheet Channel

The interaction between balance sheet frictions and long-term mortgages is a important amplification force in the model. Column 2 of Table 10 reports the changes induced in the model if banks do not face balance sheet frictions. More specifically, I introduce into the model the same shocks as before but assume that the cost of funding does not increase as bank's capital goes down. In this situation, banks discount future cash flows at the same rate as in the steady state, and any increase in spreads is driven only by an increase in the borrower default risk and not by an increase in banks' funding costs. The fact that the financial accelerator effect is not present reduces the amplification effect of the baseline case. Without frictions in the financial sector, housing prices would only drop 16.6 percent, the default rate would rise 10.2p.p. and consumption would fall by 8.2 percent. By construction, mortgage spreads do not increase (controlling for changes in borrower creditworthiness), banks' capital decreases 1.15p.p. and refinancing decreases by 24.9 percent.

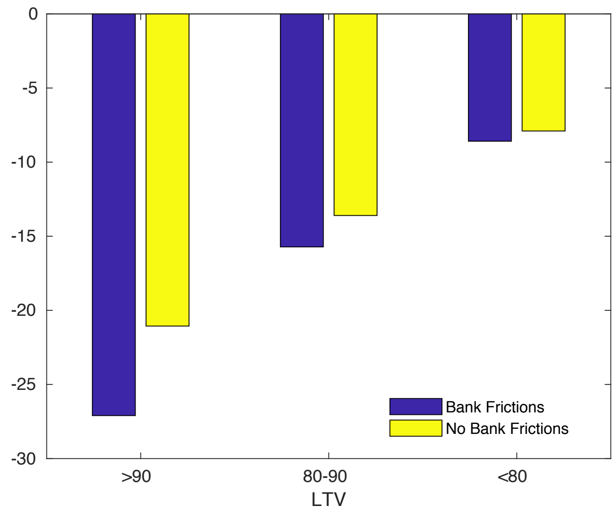
The endogenous change in the credit supply due to the increase in banks' cost of funds banks explains approximately 13 percent of housing price changes in the baseline case. Although prices drop mainly due to the contraction in the credit supply, some households still find optimal to adjust their holding stocks or moving from being renters to homeowners, as their income increases or they have already saved up enough to pay the downpayment. However, as the cost of funding increases, banks demand higher collateral and higher spreads, which reinforces the initial house demand contraction, expands house supply and reinforces the drop in house prices. In the absence of the endogenous increase in bank's funding cost, this effect is no longer present, and households are able to borrow at better terms than they would have otherwise. Therefore, housing market equilibrium is reached at a higher price. Because housing prices fall less, household leverage does not spike as much and therefore the benefits of defaulting are smaller. In fact, the default rate increases by 10.2p.p., compared to 11.2p.p. in the baseline case. The difference is not large due to the fact that homeowners can stay in foreclosable properties for free, which still drives a large fraction of borrowers to default.

Since foreclosures remain high, banks face large losses, leading to a decrease in their capital ratio of 1.15p.p.. However, this increase in leverage does not translate into an increase in the cost of funds. Obviously, in periods during which housing prices fall and the default risk increases, banks modify their lending decisions. However, the adjustment is smaller because the channel which leads banks to discount future cash flows at a higher rate as they become less capitalized is not present.

Because mortgage spreads and down payments increase less than they do in the presence of financial frictions, refinancing rates only decrease by 24.9 percent after the crisis, as opposed to 38.54 percent in the baseline model. Homeowners are able to smooth consumption through refinancing. Moreover, as housing wealth does not contract as much, wealth effects on consumption are also reduced. Better refinancing opportunities also allow financially distressed homeowners to keep their current house, decreasing the foreclosure rate. However, since refinancing is still expensive for these households, their disposable income and non-durable consumption is actually smaller than it would be they had defaulted. Overall, aggregate consumption decreases 1.4p.p. less than in the baseline case, which means that the balance sheet channel accounts for approximately 22 percent of the change in consumption.

In sum, the bank balance sheet channel is an important source of application of shocks coming from the housing market, with a sizable impact mainly on refinance and consumption. This is in fact consistent with the empirical evidence in section 3, where I show that the contraction in the credit supply is stronger for refinance loans than home purchase loans.

Figure 14: Consumption



7.3 Heterogeneity

The response to house price shocks is heterogeneous across households with different levels of home equity. The baseline model generates a drop in aggregate consumption of 10.5 percent, but the consumption change distribution among homeowners exhibits a strong left skew. Consumption drops, on average, 27.1 percent for households with LTV higher than 90 percent and 15.7 percent for those with an LTV between 80 and 90 percent. The average consumption drop for households with an LTV lower than 80 percent is significantly lower, at 8.59 percent. This is consistent with the empirical evidence that consumption fell more for homeowners with low home equity (Mian et al.(2013)). The refinancing option allows homeowners to smooth their consumption. However, as banks become more constrained and their cost of funding increases, financing conditions deteriorate, and aggregate refinancing drops. More specifically, refinancing decreases 59.9 percent for households with an LTV higher than 90 percent, 45.2 percent for those with an LTV between 80 and 90 percent and 21.4 percent for those with an LTV lower than 80 percent. As the risk of default decreases with the level of home equity, the mortgage interest rate increases more for more-leveraged homeowners than for those with higher levels of home equity.

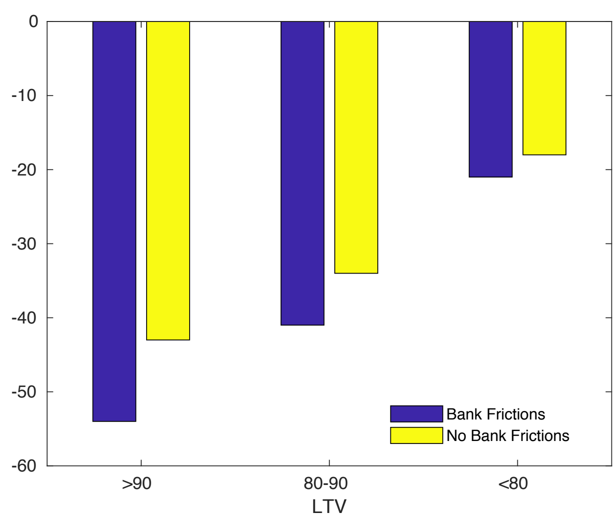
Therefore, it becomes difficult for highly leveraged households to refinance and smooth their consumption, so both refinancing and consumption fall most among this group. Households with a higher stake in their homes cut consumption less for two reasons. First, the impact of the housing prices decrease on their wealth is lower, so wealth effects on their consumption are smaller. Moreover, since the refinancing conditions they face deteriorate less, they are able to extract equity out of their homes to smooth income shocks.

Refinancing is a crucial channel by which housing shocks are transmitted to consumption dynamics in models of long-term debt, as emphasised in Wong(2015) and Garriga and Hedlund(2016).

However, in these papers, the changes in refinancing conditions depend only on borrowers' financial condition. In this model, due to the bank balance sheet channel, refinancing conditions also depend on the capitalization of the financial system. This mechanism amplifies the change in credit spreads for all borrowers, but it is not uniform across households. Credit spreads increase relatively more for more-leveraged households. The increase in banks' cost of funding leads to higher future mortgage payments. This increases the likelihood of default for a highly leveraged household facing a negative income shock or maintenance cost, leading banks to require an even higher return from these borrowers. The probability of default for borrowers with high equity is less sensitive to the rise in future payments, so banks will require a lower interest rate increase for these households.

In figure 14 and 15, we can see the changes in refinancing and consumption across home equity that would occur if banks did not face balance sheet frictions. As expected, consumption and refinancing would fall by less. But the difference is larger for more-leveraged households. This shows that bank balance sheet frictions amplifies not only the aggregate drop in consumption but also the heterogeneous response across agents. More-leveraged households are forced to cut consumption 35.5 percent more in the case bank frictions are present while for those with LTV below 80 percent the relative cut is of 8.7 percent. For the refinancing, the difference is even larger, 50 percent. However, for homeowners with an LTV lower than 80 percent, refinance only follows 5 percent more under the baseline scenario.

Figure 15: Refinance



8 Conclusion

In this paper, I analyze and quantify the extent to which deterioration of bank balance sheets explains the large contraction in housing prices and consumption experienced by the U.S. during the last recession.

I provide empirical evidence that the bank balance sheet channel was present in the data between 2006 and 2009. Using regional variation and an instrumental approach, I show that banks with branches in counties that faced a higher housing price decline experienced a greater decrease capital ratio. Moreover, banks with a largest declined in their capital ratio induced by the exogenous variation in house prices decreased their credit supply by more, mainly affecting refinancing loans. This contraction is not compensated by other banks less impacted or by other banks enter the market to take advantage of lending opportunities. These results also suggest that although the active securitization market during the boom, banks were not able to fully diversify their geographic risk and that the aggregate capitalization of the banking system is relevant for the overall credit supply. Moreover, it also indicates that the credit supply is also a source of shock transmission across space.

These results contribute to the current literature by revealing the impact of bank balance sheet shocks on the mortgage supply rather than corporate financing. Moreover, unlike the current literature, I isolate the changes in bank balance sheets resulting from variation in housing prices instead of monetary policy shocks.

Motivated by these empirical facts, I build a quantitative model where I introduce a banking sector with balance sheet frictions into a framework of long-term collateralized debt with risk of default. Credit supply is endogenously determined and depends on the capitalization of the entire banking sector. Mortgage spreads and endogenous down payments increase in periods when banks are poorly capitalized. Therefore, mortgage prices and aggregate lending behavior is driven not only by credit demand but also by the capitalization of the banking sector.

After simulating a downturn that matches the drop in house prices between 2006 and 2009 in the US, I show that bank balance sheets act as a powerful amplification force for shocks generated by the housing market. More specifically, changes in financial intermediaries' cost of funding explain, respectively, 13 percent, 9 percent and 22 percent of the changes in housing prices, foreclosures and consumption generated by the model. These results show that the endogenous response of the credit supply can partially explain how changes in housing prices affect consumption decisions. The change in the credit conditions also reinforces the heterogeneous response of consumption and refinance across the home equity distribution. More leveraged homeowners cut their consumption relatively more than they would do if the bank balance sheet channel was not present, reinforcing consumption inequality.

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A Appendix

Table 11: Bank Controls

	2005		2006-2009		2006-2010	
	Mean	SD	Mean	SD	Mean	SD
log(assets)	17.72114	2.63953	-.0198028	.2306353	.0489068	.213657
Cash	.0433825	.0484731	.02944	.0715453	.0073514	.0647065
Deposits	.6285732	.1988702	.0350567	.0420396	.0129798	.0476636
Loans	.5467162	.2034257	-.0100137	.0508883	-.0126243	.0562386
Real Estate Loans	.4818417	.2772164	.0264964	.0493967	.0021581	.0293224
ROA	.007759	.0061539	-.0036406	.0901358	.0033857	.1923383
Loss Income	.0003356	.0009964	.0000116	.0006085	-.0000326	.0003459
Net Charge-offs	.0018164	.0044291	.0044356	.0058142	-.0001236	.0057859
Late Loans	.0022434	.0036579	.0081239	.00936	.0033162	.0081757
Late Loans - RE	.0029617	.0039289	.0191449	.0187922	.0080955	.0139373
Provisions	.0017198	.0045511	.0044722	.0072674	-.0045113	.0074495
Allowances	.0075387	.0065248	.0056279	.0065008	.0013776	.0064074
MBS	.1040957	.0941221	.0019536	.0332171	.	.
Deposit Interests	.0103453	.003748	-.006314	.0025744	-.0024565	.0021145
Interest Income	.0284993	.0097444	-.0053235	.0704344	-.0017348	.0051541
Interest Cost	.0107661	.0030243	-.006033	.0109148	-.0019804	.001655

Source: Call Reports. All variables are normalized by total assets.

Table 12: RES and House Price break

	(1) RES(t)	(2) RES(t)	(3) RES(t)	(4) RES(t)
RES (break1)	-0.307***	-0.308***	-0.254***	-0.254***
	(0.012)	(0.011)	(0.012)	(0.011)
log(assets)			-0.004***	-0.004***
			(0.000)	(0.000)
Cash			-0.005	-0.003
			(0.022)	(0.021)
Deposits			0.042***	0.042***
			(0.010)	(0.010)
Loans			-0.022**	-0.022***
			(0.007)	(0.006)
RE Loans			-0.049***	-0.050***
			(0.004)	(0.004)
ROA			0.617***	0.621***
			(0.096)	(0.089)
Loss Income			-1.482***	-1.477***
			(0.425)	(0.405)
Net Charge-offs			1.375***	1.338***
			(0.333)	(0.313)
Late Loans			-0.031	-0.015
			(0.162)	(0.154)
Late Loans - RE			0.397***	0.384***
			(0.080)	(0.075)
Provisions			-0.737*	-0.710*
			(0.329)	(0.303)
Allowances			0.039	0.048
			(0.202)	(0.190)
MBS			-0.029**	-0.029***
			(0.009)	(0.008)
Deposit Interests			-2.171***	-2.175***
			(0.387)	(0.360)
Interest Income			-0.488***	-0.492***
			(0.126)	(0.118)
Ineterst Cost			3.956***	3.985***
			(0.443)	(0.412)
Observations	7554	7554	7515	7515
Adjusted R^2	0.144	0.227	0.198	0.281
F	630.2	716.7	68.40	81.11
SD	robust	robust	robust	robust
Year FE	No	Yes	No	Yes

Notes. Dependent variable: Real estate shock (RES). The unit of observation is a bank. Variables are normalized by total assets. ***,**,* Coefficients significant at the 1%, 5% and 10% levels, respectively.

Table 13: RES and Capital Ratio

	(1) OLS	(2) IV	(3) OLS	(4) IV
RES(t)	0.088***	0.091***	0.061***	0.082**
	(0.009)	(0.022)	(0.009)	(0.026)
log(assets)			-0.001*	-0.001*
			(0.000)	(0.000)
Cash			-0.009	-0.007
			(0.016)	(0.016)
Deposits			0.036**	0.035**
			(0.013)	(0.013)
Loans			-0.016*	-0.015*
			(0.006)	(0.007)
RE Loans			-0.020***	-0.019***
			(0.004)	(0.004)
ROA			0.288	0.277
			(0.157)	(0.161)
Loss Income			0.098	0.130
			(0.200)	(0.204)
Net Charge-offs			0.393	0.331
			(0.372)	(0.382)
Late Loans			-0.104	-0.100
			(0.170)	(0.168)
Late Loans - RE			-0.190*	-0.204*
			(0.090)	(0.092)
Provisions			-0.344	-0.313
			(0.378)	(0.380)
Allowances			0.273	0.276
			(0.204)	(0.205)
MBS			0.006	0.007
			(0.007)	(0.008)
Deposit Interests			-1.722***	-1.675***
			(0.379)	(0.385)
Interest Income			-0.259*	-0.246*
			(0.116)	(0.119)
Interest Cost			1.851***	1.752***
			(0.434)	(0.452)
Observations	4908	4908	4888	4888
Adjusted R^2	0.031	0.031	0.117	0.116
SD	robust	robust	robust	robust
Year FE	No	No	Yes	Yes

Notes. Dependent variable: Change in Capital to Assets Ratio. The unit of observation is a bank. Variables are normalized by total assets. ***,**,* Coefficients significant at the 1%, 5% and 10% levels, respectively.

Table 14: Home Purchase Loans

	Origations by banks in sample		All Originations	
	(1a)	(2a)	(1b)	(2a)
Predicted Δ Capital Ratio	141.031***	47.090**	37.701***	10.489*
	(21.241)	(17.293)	(4.514)	(4.352)
Δ real house prices	-0.866	-1.283	0.306*	0.463***
	(0.616)	(1.237)	(0.114)	(0.108)
Δ wages	-0.915	0.649	0.633	0.586**
	(0.568)	(1.222)	(0.517)	(0.205)
Δ income	0.043	0.005	0.603	0.161***
	(0.152)	(0.130)	(0.300)	(0.039)
Δ unemployment rate	-0.009	-0.018	-0.011	-0.006
	(0.023)	(0.033)	(0.006)	(0.010)
log(assets)	0.213***	0.061	0.035***	0.003
	(0.050)	(0.032)	(0.010)	(0.009)
Cash	-2.354	1.945	0.756*	0.405
	(3.788)	(4.426)	(0.295)	(0.232)
Deposits	-4.813***	-2.283	-1.519***	-0.258
	(1.116)	(1.596)	(0.243)	(0.194)
Loans	-0.051	-0.861	0.893***	0.221
	(1.196)	(0.965)	(0.138)	(0.163)
RE Loans	2.337***	0.636	0.467***	-0.073
	(0.611)	(0.814)	(0.113)	(0.115)
ROA	-15.340	7.260	-10.978***	-1.584
	(9.977)	(9.851)	(2.456)	(2.122)
Loss Income	-21.618	8.873	-18.657*	-2.425
	(23.062)	(22.669)	(8.111)	(5.961)
Net Charge-offs	-75.807	36.576	0.231	-4.597
	(42.960)	(67.840)	(14.934)	(7.750)
Late Loans	-12.350	3.994	0.648	-1.444
	(16.157)	(18.097)	(3.227)	(3.662)
Late Loans - RE	-2.309	10.464	11.065***	6.684*
	(25.517)	(13.410)	(2.709)	(2.512)
Provisions	-29.373	-96.693	-13.701	1.216
	(43.361)	(79.542)	(13.869)	(7.209)
Allowances	-47.522	-24.296	-20.254***	-11.688*
	(27.534)	(24.127)	(4.624)	(4.374)
MBS	-0.345	0.553	-0.079	-0.021
	(0.694)	(0.557)	(0.119)	(0.133)
Deposit Interests	303.907***	169.315*	63.846***	13.535
	(53.972)	(66.666)	(12.405)	(10.474)
Interest Income	81.030**	47.205	10.109**	1.860
	(23.053)	(26.837)	(3.352)	(2.647)
Ineterst Cost	-346.626***	-208.129	-67.590***	-10.762
	(69.877)	(104.336)	(12.956)	(11.187)
Observations	2850	2850	3010	3010
Adjusted R^2	0.036	0.079	0.396	0.497
SD	robust	robust	robust	robust
cluster	State	State	State	State
Year FE	No	Yes	No	Yes
State FE	No	Yes	No	Yes

Table 15: Refinance Loans

	Origations by banks in sample		All Originations	
	(1a)	(2a)	(1b)	(2a)
Predicted Δ Capital Ratio	60.902***	78.385***	24.908***	15.184*
	(13.507)	(12.809)	(6.453)	(6.038)
Δ real house prices	0.914*	1.102*	1.568***	1.608***
	(0.346)	(0.449)	(0.165)	(0.131)
Δ wages	0.878	1.362	0.144	0.894*
	(1.127)	(1.192)	(0.457)	(0.389)
Δ income	0.303	0.084	0.753*	-0.201
	(0.861)	(0.959)	(0.307)	(0.332)
Δ unemployment rate	-0.009	0.003	-0.064***	-0.036
	(0.040)	(0.044)	(0.018)	(0.021)
log(assets)	-0.008	-0.005	0.018	-0.000
	(0.025)	(0.030)	(0.011)	(0.012)
Cash	0.376	-2.880	1.258***	0.752
	(3.993)	(4.557)	(0.346)	(0.390)
Deposits	-1.777*	-2.541**	-0.917*	-0.427
	(0.699)	(0.751)	(0.378)	(0.274)
Loans	0.119	-0.014	0.761***	0.272
	(0.635)	(0.759)	(0.184)	(0.171)
RE Loans	0.313	0.070	0.424*	0.106
	(0.375)	(0.434)	(0.161)	(0.168)
ROA	26.493	15.874	-4.346	-2.102
	(22.553)	(20.395)	(3.669)	(3.308)
Loss Income	-49.531	-24.490	-1.803	18.885*
	(39.518)	(33.482)	(12.438)	(7.891)
Net Charge-offs	-20.765	-25.693	-15.548	-16.398*
	(41.601)	(52.960)	(12.400)	(7.073)
Late Loans	-29.568	-26.907	15.468*	13.063*
	(38.665)	(39.390)	(6.072)	(5.520)
Late Loans - RE	14.939	16.256	-0.582	-1.798
	(16.261)	(15.887)	(3.133)	(2.613)
Provisions	-47.094	-28.841	-3.494	6.655
	(44.603)	(65.721)	(9.195)	(6.100)
Allowances	-22.228	-36.825	1.468	-0.205
	(33.874)	(39.392)	(6.421)	(4.742)
MBS	-0.549	0.386	-0.152	0.210
	(0.778)	(0.797)	(0.224)	(0.130)
Deposit Interests	117.107***	155.778***	50.452*	26.515
	(33.133)	(39.946)	(18.812)	(14.514)
Interest Income	16.769	25.542**	2.676	-0.063
	(9.402)	(8.721)	(3.384)	(2.957)
Ineterst Cost	-121.116**	-186.604***	-37.199	-21.008
	(40.483)	(47.441)	(22.142)	(16.617)
Observations	1464	1463	1509	1508
Adjusted R^2	0.142	0.156	0.581	0.651
SD	robust	robust	robust	robust
cluster	State	State	State	State
Year FE	No	Yes	No	Yes
State FE	No	Yes	No	Yes